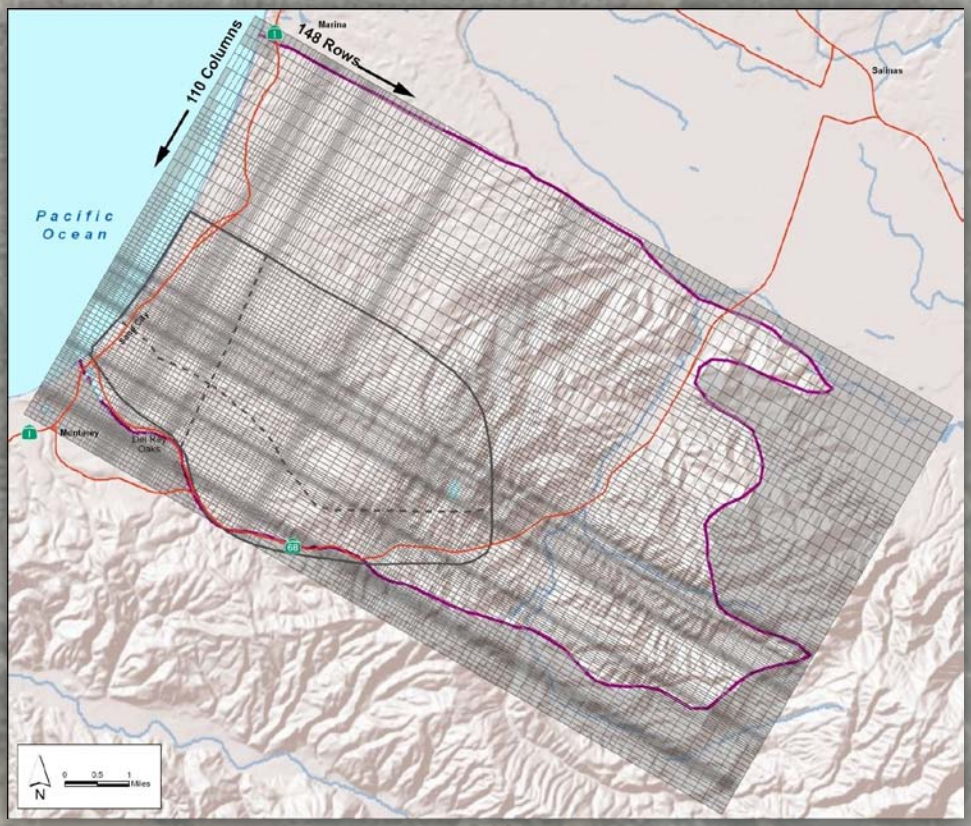
Seaside Groundwater Basin Modeling and Protective Groundwater Elevations

Prepared for:
Seaside Basin Watermaster

November 2009



Prepared by:

HydroMetrics LLC

This page left
intentionally blank

TABLE OF CONTENTS

Abbreviations ..... **ix**

Executive Summary **ES-1**

Section 1 Introduction **1**
1.1 Regional Groundwater Flow Model 2
1.2 Protective Groundwater Elevations 3

Section 2 Conceptual Model **6**
Geography and Land Use 6
2.1 Geologic Framework 13
2.1.1 Stratigraphy and Hydrostratigraphy 13
Structural Geology 14
2.2 Groundwater Occurrence 17
2.2.1 Groundwater in the Aromas Sands 17
2.2.2 Groundwater in Paso Robles Aquifer 17
2.2.3 Groundwater in Santa Margarita/ Purisima Aquifers 17
2.3 Groundwater Flow Directions 18
2.3.1 Horizontal Flow Directions and Gradients 18
2.3.2 Vertical Flow Directions and Gradients 21
2.4 Aquifer Parameters 21
2.4.1 Hydraulic Conductivity 21
2.4.2 Storage Coefficient 22
2.5 Water Balance 22
2.5.1 Inflows 23
2.5.2 Outflows 31
2.5.3 Water Balance 32

Section 3 Numerical Flow Model Construction **34**
3.1 Model Code 34
3.2 Model Domain 34
3.3 Finite Difference Grid 34
3.4 Model Layers 37
3.5 Boundary Conditions 42
3.5.1 No-Flow Boundaries 42
3.5.2 Boundary with Salinas Valley 42

3.5.3 Ocean Boundary 44
3.5.4 Top and Bottom Boundaries 44
3.6 Initial Hydrogeologic Parameters 48
3.7 Model Water Balance 48
3.7.1 Deep Groundwater Recharge 49
3.7.2 Pumping Data 55

Section 4 Model Calibration 58
4.1 Approach 58
4.2 Calibration Period 58
4.3 Stress Periods 58
4.4 Pilot Point Method for Model Calibration 59
4.5 Calibration Results 64
4.5.1 Model Parameter Modifications 64
4.5.2 Groundwater Elevation Calibration 64
4.5.3 Groundwater Divide 80

Section 5 Modeling for Protective Groundwater Elevations 84
5.1 Modeling Approach 84
5.2 Model Construction 88
5.2.1 Model Code 88
5.2.2 Finite Difference Grid 88
5.2.3 Steady-State Assumption 89
5.2.4 Model Layers 89
5.2.5 Model Boundary Conditions 92
5.2.6 Model Aquifer Parameters 93
5.3 Identification of Protective Groundwater elevations 96
5.3.1 Protective Interface for Base Parameters 96
5.3.2 Uncertainty Analysis 105
5.4 Protective Groundwater Elevation Summary 111

Section 6 Protective Model Scenarios 116
6.1 Baseline Scenario 116
6.2 Scenario 1: In-Lieu Recharge 125
6.3 Scenario 2: In-Lieu Recharge and Injection 126
6.4 Scenario 3: Groundwater Replenishment Project 128
6.5 Scenario 4: Coastal Injection Barrier 128
6.6 Scenario 5: Pumping Redistribution 131
6.7 Model Scenario Results 133
6.7.1 Graphical Results 133

6.7.2 Scenario Analysis 144

Section 7 References 148

Appendix A: Estimation of Deep Groundwater Recharge

Appendix B: Calibration Hydrographs

Appendix C: Protective Groundwater Elevation Sensitivities to Aquifer Parameter Values

This page left
intentionally blank

LIST OF FIGURES

Figure 1: Project Location 9
Figure 2: Present Land Use 10
Figure 3: 1991 Land Use 11
Figure 4: 1997 Land Use 12
Figure 5: Geology and Faults 15
Figure 6: Top of the Monterey Formation (Base of Basin) 16
Figure 7: Shallow Groundwater Elevation Map 19
Figure 8: Deep Groundwater Elevation Map 20
Figure 9: Precipitation and CIMIS Stations, with Isohyetals 25
Figure 10: Soils Classification 26
Figure 11: Service Areas, Water Delivery Pipelines and Septic Areas 27
Figure 12: Stormwater Ponds and Catchments 30
Figure 13: Finite Difference Model Grid 36
Figure 14: Model Bottom Layer Elevations 40
Figure 15: SVIGSM Model Nodes 43
Figure 16: Model Boundary Conditions 46
Figure 17: Average Annual Distribution of Deep Groundwater Recharge 50
Figure 18: Example Seasonal Variation of Deep Groundwater Recharge 52
Figure 19: Annual Deep Groundwater Recharge in the Seaside Groundwater Basin 54
Figure 20: Location of Production Wells Used in Model 56
Figure 21: Pilot Point Locations and Target Monitor Well Locations by Layer 62
Figure 22: Final Distribution of Horizontal Hydraulic Conductivity by Layer 66
Figure 23: Final Distribution of Vertical Hydraulic Conductivity by Layer 67
Figure 24: Final Distribution of Specific Storage by Layer 68
Figure 25: Target Well Locations by Layer Used for Calibration 69
Figure 26: Simulated Piezometric Surface – December 2008 72
Figure 27: Calibration Hydrographs – Northern Coastal Subarea 74
Figure 28: Calibration Hydrographs – Laguna Seca Subarea 75
Figure 29: Calibration Hydrographs – Southern Coastal Subarea 76
Figure 30: Calibration Hydrographs – Outside Seaside Groundwater Basin 77
Figure 31: Simulated Versus Observed Groundwater Elevations 78
Figure 32: Observed Groundwater Elevations Versus Model Residual 81
Figure 33: Comparison between Modeled Versus Contour Generated Groundwater Divides 82
Figure 34: Relationship between Regional Groundwater Flow Model and Protective Groundwater Elevation Models 86

Figure 35: Cross-Section Model Locations 87
Figure 36: Example Finite Difference Grid for a Protective Groundwater Elevation Model 88
Figure 37: SBWM-3 Monitoring Well and Aquifer Units 91
Figure 38: PCA-West Monitoring Well and Aquifer Units 91
Figure 39: MSC Monitoring Well and Aquifer Units 92
Figure 40: CDM-MW4 Monitoring Well and Aquifer Units 92
Figure 41: Protective Freshwater-Seawater Interface for SBWM-3 Protective Groundwater Elevation Model for Base Parameter Values (2x vertical exaggeration) 98
Figure 42: Protective Freshwater-Seawater Interface for PCA-W Protective Groundwater Elevation Model for Base Parameter Values (3x vertical exaggeration) 100
Figure 43: Protective Freshwater-Seawater Interface for MSC Protective Groundwater Elevation Model for Base Parameter Values (2.5x vertical exaggeration) 102
Figure 44: Protective Freshwater-Seawater Interface for CDM MW-4 Protective Groundwater Elevation Model for Base Parameter Values (3x vertical exaggeration) 104
Figure 45: Cumulative Distribution of Protective Elevations to Protect the Purisima Aquifer at SBWM-3 106
Figure 46: Cumulative Distribution of Protective Elevations to Protect the Santa Margarita Aquifer at the PCA-West Well 107
Figure 47: Cumulative Distribution of Protective Elevations to Protect the Paso Robles Aquifer at the PCA-West Well 108
Figure 48: Cumulative Distribution of Protective Elevations to Protect the Santa Margarita Aquifer at the MSC Well 109
Figure 49: Cumulative Distribution of Protective Elevations to Protect the Paso Robles Aquifer at the MSC Well 109
Figure 50: Cumulative Distribution of Protective Elevations to Protect the Santa Margarita Aquifer at CDM MW-4 110
Figure 51: Comparison of Historical Groundwater Elevations with Protective Groundwater Elevation - Well SBWM-3 111
Figure 52: Comparison of Historical Groundwater Elevations with Protective Groundwater Elevation - Well PCA-W 112
Figure 53: Comparison of Historical Groundwater Elevations with Protective Groundwater Elevation - Well MSC 113
Figure 54: Comparison of Historical Groundwater Elevations with Protective Groundwater Elevation - Well CDM MW-4 114
Figure 55: 2014 Land Use 118

Figure 56: 2019 Land Use 119
Figure 57: Estimated Annual Recharge for Predictive Scenarios 124
Figure 58: Injection Wells for Scenario 2 127
Figure 59: Location of GWRP Wells 129
Figure 60: Coastal Injection Barrier Well Locations 130
Figure 61: Locations of Moved Paralta and Ord Grove Wells 132
Figure 62: Estimated Groundwater in Storage for Predictive Scenarios 135
Figure 63: Monthly Estimated Outflow to the Ocean for Predictive Scenarios .. 137
Figure 64: Monthly Estimated Flow Into and Out of the Salinas Basin for Predictive Scenarios 139
Figure 65: Predicted Groundwater Elevations and Protective Groundwater Elevations for the MSC Wells 141
Figure 66: Predicted Groundwater Elevations and Protective Groundwater Elevations for the PCA West Wells 142
Figure 67: Predicted Groundwater Elevations and Protective Groundwater Elevations for Sentinel Well 3 and CDM Well MW-4 143

LIST OF TABLES

Table 1: Land Use Sources 8
Table 2: Summary of Hydraulic Conductivity 22
Table 3: Percent of Land Use Irrigated..... 28
Table 4: Estimated Seaside Groundwater Basin Average Annual Groundwater Budget Water Years 2003 through 2007, units in acre-feet per year..... 33
Table 5: Initial Hydrogeologic Parameters..... 48
Table 6: Protected Locations at Coastal Monitoring Wells 85
Table 7: Base Aquifer Flow Parameter Values..... 94
Table 8: Parameter Ranges by Hydrostratigraphic Unit 95
Table 9: Protective groundwater Elevation at SBWM-3 for Base Parameter Values 97
Table 10: Protective groundwater Elevation at PCA-W for Base Parameter Values 99
Table 11: Protective groundwater Elevation at MSC for Base Parameter Values 101
Table 12: Protective Groundwater Elevation at CDM MW-4 for Base Parameter Values 103
Table 13: Summary of Protective Groundwater Elevations 111
Table 14: Baseline Scenario Production for Standard Producers in the Coastal Subareas (units in acre-feet) 120
Table 15: Baseline Scenario Production for Standard Producers in the Laguna Seca Subarea (units in acre-feet) 121
Table 16: Baseline Scenario Production for Alternative Producers in the Coastal Subareas (units in acre-feet) 122
Table 17: Baseline Scenario Production for Alternative Producers in the Laguna Seca Subarea (units in acre-feet) 123
Table 18: Summary of Model Scenario Assumptions and Results 145

ABBREVIATIONS

AMBAG ..... Association of Monterey Bay Area Governments
ASR ..... aquifer storage and recovery
BMAP ..... Basin Management and Action Plan
CAW ..... California American Water
CHD ..... constant head boundary
CIMIS ..... California Irrigation Management Information System
CSUMB ..... California State University Monterey Bay
CWS ..... California Water Service
DEIR ..... Draft Environmental Impact Report
DWR ..... California Department of Water Resources
ET ..... evapotranspiration
FO ..... Fort Ord
GHB ..... general head boundary
GIS ..... Geographical Information Systems
GWRP ..... Groundwater Replenishment Project
K ..... hydraulic conductivity
Kh ..... horizontal hydraulic conductivity
Kv ..... vertical hydraulic conductivity
MAE ..... mean absolute error
MCWD ..... Marina Coast Water District
MCWRA ..... Monterey County Water Resources Agency
mg/L ..... milligram per liter
MOU ..... Memorandum of Understanding - Replenishment Credit
MPWMD ..... Monterey Peninsula Water Management District
MRWPCA ..... Monterey Regional Water Pollution Control Agency
MSL ..... Mean sea level
NOAA ..... National Oceanic and Atmospheric Administration
PEST ..... parameter estimation
RMSE ..... root mean square error
SBWM ..... Seaside Basin Watermaster

SIRP .....Seawater Intrusion Response Plan

SMB .....soil moisture budget

SVD .....singular value decomposition

SVIGSM .....Salinas Valley Integrated Groundwater Surface Water Model

TAC .....Technical Advisory Committee

GWRP .....Groundwater replenishment

EXECUTIVE SUMMARY

The Seaside Groundwater Basin Watermaster's Basin Management and Action Plan (BMAP) recommended that a calibrated groundwater flow model of the Seaside Groundwater Basin be constructed to assist with groundwater management decisions (HydroMetrics LLC, 2009a). The model will help the Watermaster predict potential impacts to the groundwater basin from various management actions, such as new supplemental water supply projects. Furthermore, as seawater intrusion is a primary concern for this coastal groundwater basin, the benefits of potential water projects on coastal groundwater elevations can be simulated, thereby providing a valuable tool for managing and optimizing future seawater intrusion mitigation or prevention activities in the Seaside Groundwater Basin.

The Seaside Groundwater Basin Watermaster Technical Advisory Committee (TAC) agreed that the model should address the following goals:

- Evaluate the effects of selected supplemental water projects on the Seaside Groundwater Basin,
- Evaluate selected management actions,
- Determine storage efficiency of recharged water,
- Determine Total Useable Stored Groundwater and Total Useable Storage Space,
- Refine the water budget and Basin safe yield, and
- Determine quantities of supplemental water necessary to achieve protective groundwater elevations.

In addition to these goals, the groundwater flow model has been constructed to be able to address where water should be recharged, how it would best be recharged and what its fate would be; how much inflow and outflow occurs from the ocean; groundwater level responses to potential water projects; location of the hydrogeologic northern Seaside Groundwater Basin boundary; and flow between subareas.

CONCEPTUAL BASIN MODEL

The regional groundwater flow model is based on a well developed conceptual model. The conceptual model includes the basic data, interpretations, and simplifications of the hydrogeologic system in the project area. The area covered by the groundwater model is larger than the Seaside Groundwater Basin defined by the Adjudicated Judgment (Figure ES-1). This regional area was modeled to allow simulation of groundwater pumping and recharge outside of the Basin that may have an influence on groundwater conditions within the Basin.

The conceptual geology recognizes four water bearing geologic units in the study area: Aromas Red Sands, continental deposits (Paso Robles aquifer), Santa Margarita Sandstone, and Purisima Formation. The Paso Robles aquifer is divided into upper, middle, and lower units for this model. The Monterey Formation is considered non-water bearing, and serves as the bottom of the modeled area. The depth and thickness of each of these geologic units was re-interpreted as part of this project. Additionally, estimated locations of geologic faults in the study area were moved slightly as part of the conceptual model development.

REGIONAL MODEL DATA SOURCES

Time-varying estimates of basin recharge for the study area were developed as part of an extensive basin–wide water balance. The recharge estimates incorporate 22 years of daily rainfall measurements from two nearby weather stations, combined with a rainfall distribution map (isohyetal map) developed by Monterey County Water Resources Agency (MCWRA). The rainfall data were combined with 22 years of monthly evapotranspiration data collected from three nearby California Irrigation Management Information System (CIMIS) stations, land use data collected from multiple sources, soil type maps from the U.S. Soil Conservation Service, and vegetation information to estimate deep recharge from rainfall. Additional sources of recharge include return flow from municipal irrigation, system losses from delivered water, return flow from septic systems, and recharge from stormwater detention ponds.

Groundwater pumping data were collected for 72 production wells in the study area. Pumping data were provided by the Monterey Peninsula Water Management District (MPWMD) for wells under the Watermaster's jurisdiction. California-American Water (CAW), City of Seaside, Marina Coast Water District (MCWD), and California Water Service (CWS) also provided monthly data. Where annual data were provided in the absence of monthly data, the historical monthly distribution provided by MPWMD was used to distribute the annual production data into months. For years where no data

were available but it was confirmed that the well was operating, the long-term annual average production was used and distributed by Monterey Peninsula Water Management District's (MPWMD) historic monthly distribution.

REGIONAL MODEL DEVELOPMENT

The numerical groundwater model was built using the U.S. Geological Survey's MODFLOW 2005 model code (Harbaugh, 2005). The model simulates five geologic layers: Aromas Red Sands, upper Paso Robles aquifer, middle Paso Robles aquifer, lower Paso Robles aquifer, and Santa Margarita Sandstone/Purisima Formation. The model simulates groundwater conditions between January 1987 and December 2008. The model incorporates the time-dependent recharge calculated as part of the conceptual model and all of the pumping data. The model simulates the interaction of groundwater in the study area with the Pacific Ocean, as well as the interaction with the adjacent Salinas Groundwater Basin.

REGIONAL MODEL CALIBRATION

Calibrating the regional groundwater flow model involved an iterative approach to best match model output to measured groundwater elevation data from the calibration period. Simulated hydraulic heads were compared against available measured groundwater elevations at 60 wells throughout the study area. The model was considered calibrated when simulated results matched the measured data within an acceptable measure of accuracy, and when successive calibration attempts did not further improve the calibration statistics. Model calibration was carried out using both hand-calibration and parameter estimation (PEST) software (Watermark Numerical Computing, 2004). As a result of the successful model calibration, the groundwater model accurately simulates historical groundwater level fluctuations and trends in all 60 wells.

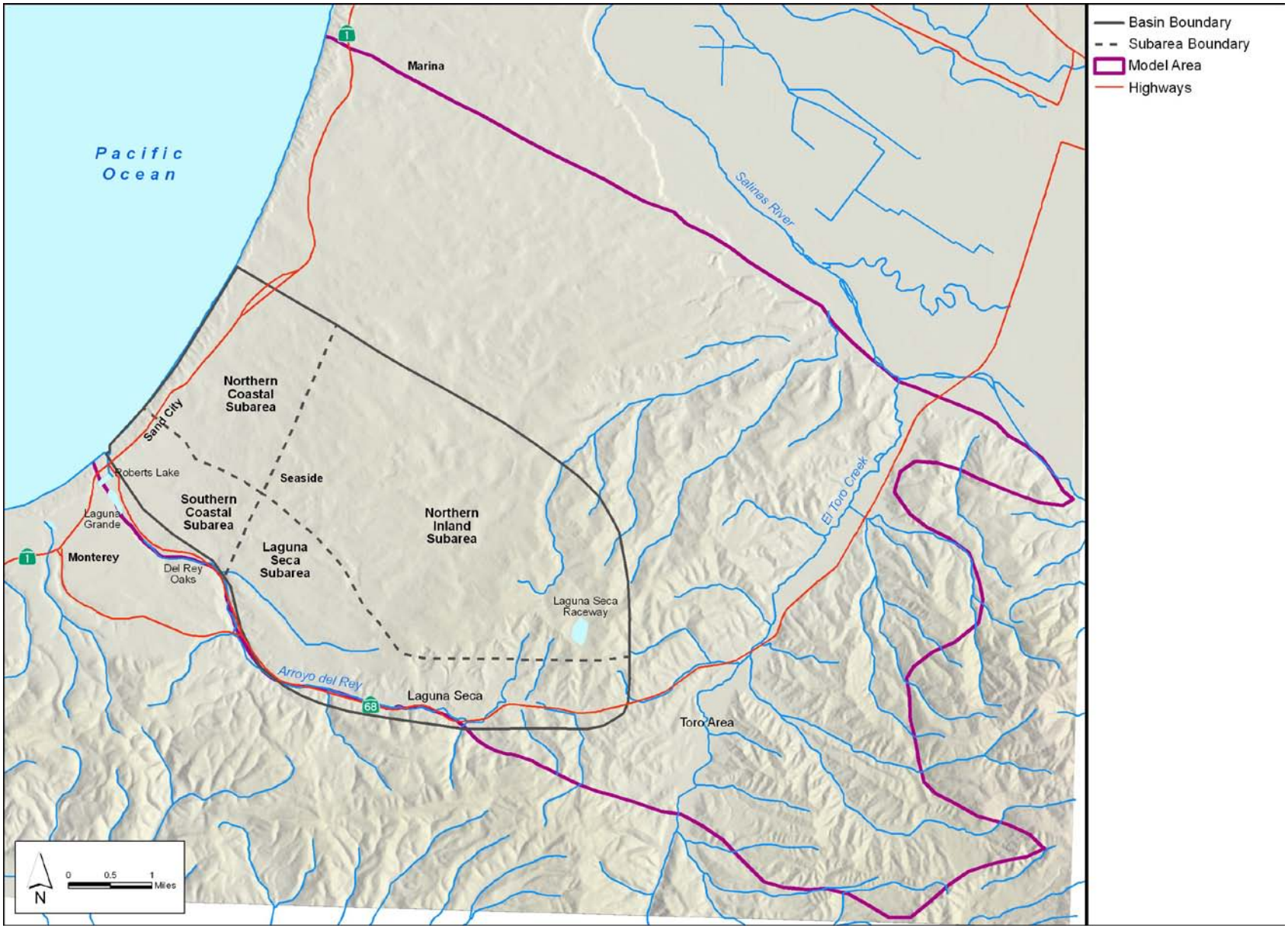


Figure ES-1: Model Area

DEVELOPMENT OF PROTECTIVE GROUNDWATER ELEVATIONS

In order to measure how successful any groundwater management scenario is, groundwater elevation targets were established. The targets are groundwater elevations that are high enough to protect the Seaside Groundwater Basin from seawater intrusion. These protective groundwater elevations were established using a different series of models than the regional groundwater flow model. The models were required to be different because variable density models are needed for establishing protective groundwater elevations, while the regional groundwater flow model does not require variable density ability. Furthermore, the size of the regional model would cause prohibitively long model run times if variable density was included. The U.S. Geological Survey's SEAWAT 2000 model code (Guo and Langevin, 2002) was used for protective groundwater elevation modeling. Figure ES-2 shows the relationship between the regional flow model and the protective groundwater elevation models.

The protective groundwater elevation models simulate groundwater conditions in four vertical planes through the earth, extending out under the ocean. The inland side of each protective groundwater elevation model is anchored to one of the four coastal monitoring wells: CDM-MW-4, MSC well, PCA-West well, or Sentinel Well 3 (SBWM-3). The locations of these four vertical planes (cross-sections) are shown in Figure ES-3. The models were used to estimate the groundwater elevation that must be maintained in each monitoring well to prevent seawater from intruding into the Santa Margarita aquifer. Additional analyses were performed to estimate the groundwater elevation that must be maintained to prevent seawater from intruding into the Paso Robles aquifer, and to prevent seawater from intruding into the top 90% of the Santa Margarita Sandstone aquifer. To account for uncertainty of offshore geology and aquifer parameters, the modeling included an uncertainty analysis that allowed us to attach a level of confidence to the protective groundwater elevation targets. The target elevations for each monitoring well are shown in Table ES-1.

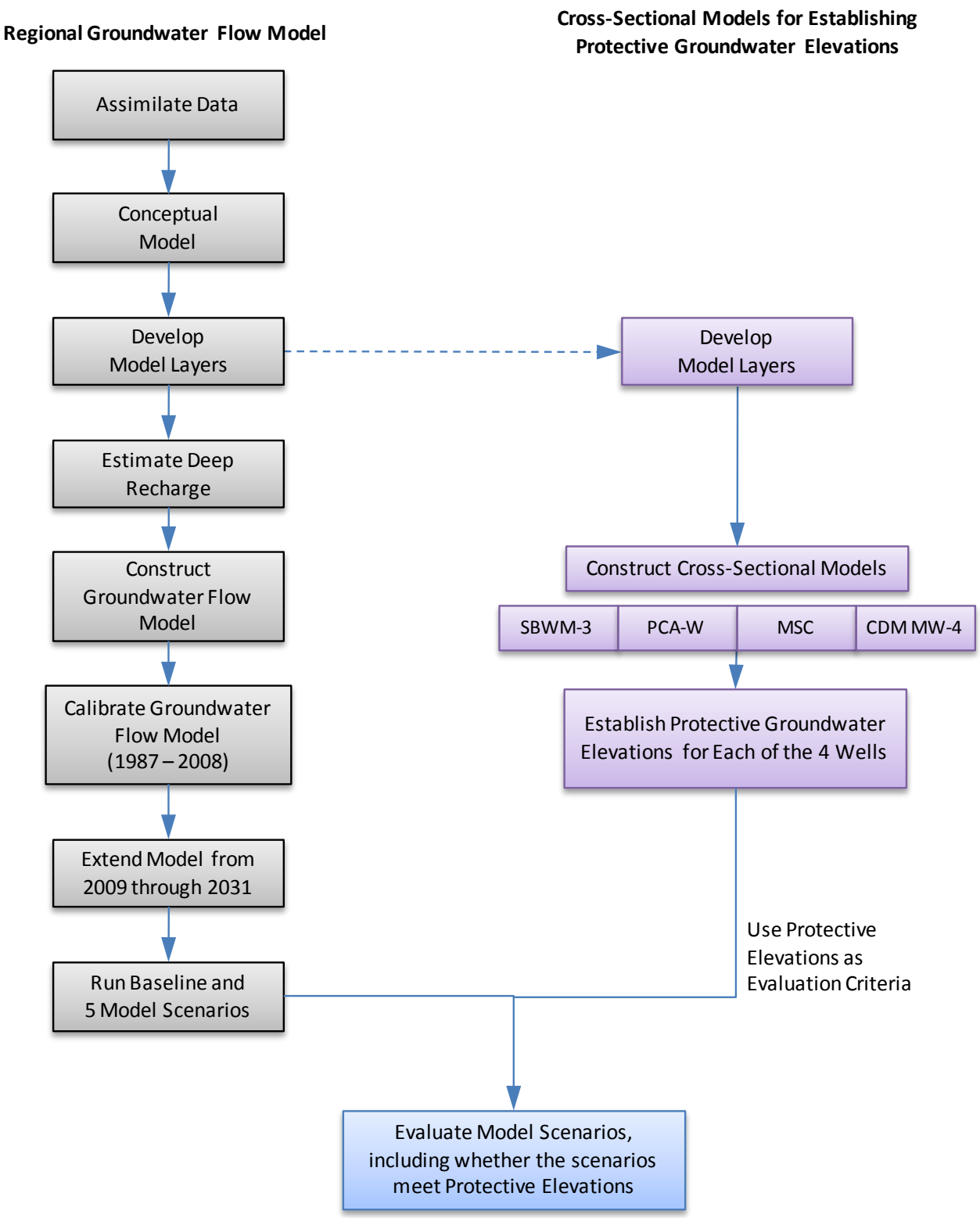


Figure ES-2: Relationship between Regional Groundwater Flow Model and Protective Groundwater Elevation Models

Figure ES-3: Cross-Section Model Locations

Table ES-1: Summary of Protective Groundwater Elevations

Well	Protected Aquifer	Range of Protective Elevations from Uncertainty Analysis (feet MSL)	Final Estimate of Protective Elevation Measured in the Well (feet MSL)
SBWM-3	Purisima	2-6	4
PCA-W	Paso Robles	2-4	2
	Santa Margarita	11-19	17
MSC	Paso Robles	3-14	11
	Santa Margarita	15-18	17
CDM MW-4	Paso Robles	2-3	2

MSL = mean sea level

SIMULATION OF MODEL SCENARIOS

The calibrated regional groundwater flow model was used to analyze the groundwater management scenarios developed by the Watermaster TAC. The ability of the scenarios to reach and maintain target protective groundwater elevations was used as one criterion to evaluate the success the each scenario. One baseline and five scenarios developed by the TAC were simulated. A 22 year predictive period was used from January 2009 through December 2031, which was a repeat of the 22 year hydrologic period used in the calibrated model. Each scenario included a specific set of pumping, in-lieu recharge, and artificial recharge conditions. Table ES-2 summarizes the main assumptions used for each scenario.

CONCLUSIONS

The five groundwater management scenarios show that the mandated triennial pumping reduction will result in a slow increase in most groundwater elevations. Additionally, the mandated pumping reduction decreases, but does not eliminate inflow from the ocean. Model scenarios with significant injection are most successful at raising groundwater elevations to protective elevations. Because the Santa Margarita aquifer is highly confined beneath thick clay beds near the ocean, it does not receive significant deep percolation recharge near the ocean. Therefore, it will take a long time for wells in the Santa Margarita aquifer to reach protective elevations without artificial recharge.

Results from the five scenarios show that the amount of water in storage is highly dependent on rainfall. The two scenarios with inland artificial recharge provide the Seaside Groundwater Basin with the most groundwater in storage. It is worth noting, however, that the quantity of groundwater in storage does not necessarily equate to recoverable groundwater. Groundwater stored in the shallow Paso Robles aquifer in some scenarios may not be easily recovered with existing wells, which mostly extract from the underlying Santa Margarita aquifer. New wells will be required in the Paso Robles aquifer to recover more of the stored water.

Table ES-2 summarizes the results for each model scenario.

Table ES-2: Summary of Model Scenario Assumptions and Results

Scenario	Assumptions	Results	Observations and Analyses
Baseline	Future land use changes phased in 25% of build-out by 2014, remainder by 2019*	Coastal groundwater levels in both the shallow and deep aquifers show a modest rise in response to the reduced pumping. Most groundwater elevations level off below the protective groundwater elevation around 2028.	This scenario has insufficient water to restore the Basin and raise groundwater levels above protective elevations. Additional actions are needed.
	Water for new developments is obtained from outside of Basin*		
	MPWMD ASR program included*		
	Standard Allocation pumping reduced triennially (every three years) in proportion to pumping rates		
	Alternative Allocation pumping set at Decision-allocated rates		
1	CAW forgoes all pumping between October 2015 and March 2027	Deep groundwater levels rise more quickly than in the Baseline simulation, but the rise is limited. Shallow groundwater elevations decline compared to the Baseline simulation during the time other Standard Allocators are producing the same amount they produced in 2005. Approximately 3,600 acre-feet of additional water are stored compared to the baseline scenario.	The limited pumping in the deep aquifer does not result in groundwater elevations above protective elevations because deep percolation is limited by overlying clay layers. 60% of the additional stored groundwater is in the deep aquifer.
	All other Standard Producers pump at 2005 rates between October 2015 and March 2027		
	Pumping continues at Decision-allocated rate with triennial 10% reduction after March 2027		
2	As in Scenario 1, CAW forgoes all pumping between October 2015 and March 2027	This scenario shows the highest coastal water elevations in the deep aquifer out of all the scenarios. Approximately 11,100 acre-feet of additional water are stored compared to the baseline scenario.	Injection along General Jim Moore Blvd can raise groundwater levels significantly at the coast when combined with limited pumping. 70% of additional stored groundwater is in the deep aquifer.
	2,000 acre-feet per year of injection well recharge is added along General Jim Moore Boulevard		

Table ES-2: Summary of Model Scenario Assumptions and Results, continued

Scenario	Assumptions	Results	Observations and Analyses
3	The MRWPCA GWRP recharges 2,800 acre-feet of water per year, split between the shallow and deep aquifers Pumping is the same as in the baseline scenario.	This scenario shows significant groundwater elevation rises in the deep aquifer, although not as great as Scenario 2. Groundwater elevation rises in the shallow aquifer are similar to those observed in Scenario 2. This scenario stores the most water in the Basin: approximately 17,800 acre-feet more than are stored in the baseline scenario.	Deep aquifer groundwater level rises are not as great as in Scenario 2 because the amount of deep injection is less and the deep aquifer pumping is greater in this scenario. Shallow coastal groundwater elevations are approximately equal to those in Scenario 2, suggesting a maximum level these shallow groundwater levels can rise to. Unlike Scenario 1 and Scenario 2, 62% of the additional stored groundwater is in the shallow aquifer.
4	Inject 2,600 acre-feet per year into a line of wells along the coast All Standard and Alternative Producers pump at the 2005 rates (5,600 AFY)	Groundwater elevation rises in the deep aquifer are similar to those seen in Scenario 3. Groundwater elevation rises in the shallow aquifer are small. No water is stored in the Basin.	The coastal injection raises water at the coast, but stores no water because of the aggressive pumping.
5	Move CAW's largest pumping wells inland to reduce stress on coastal groundwater levels Pumping includes the triennial 10% reductions	This scenario shows very little impact on either groundwater elevations or groundwater in storage.	Moving pumping wells inland has little advantage, and is not a useful management strategy.

SECTION 1
INTRODUCTION

The Seaside Groundwater Basin Watermaster's Basin Management and Action Plan (BMAP) recognized that to improve overall basin management, a number of tools and techniques needed to be developed (HydroMetrics LLC, 2009a). The BMAP recommended that a calibrated groundwater flow model be constructed. The model would be used to predict potential impacts to the groundwater basin from new supplemental water supply projects. Furthermore, as seawater intrusion is a primary concern for this coastal groundwater basin, the benefits of potential water projects on coastal groundwater elevations can be simulated, thereby providing a valuable tool for managing and optimizing future activities in the Seaside Groundwater Basin.

Two regional groundwater models have previously been developed in the area of the Seaside Groundwater Basin. The first was a model of the Laguna Seca Subarea by Yates et al. (2002). The purpose of this model was to evaluate water supply conditions in the Laguna Seca area. The second was a model, covering the same area as the regional model developed for this report, prepared by Timothy Durbin in 2005. This model was a steady-state groundwater flow and solute transport model of the Seaside Groundwater Basin that was used by California American Water (CAW) during the adjudication trial. The model was later documented in 2007 at the request of the Watermaster.

As the Durbin model was only a steady-state model that was considered an interim tool (Feeney, 2007) and because the Laguna Sea model did not cover the entire Seaside Groundwater Basin, neither was found to be suitable to be used as a management tool that could predict future basin impacts to the level of detail required by the Watermaster. The Watermaster also wanted to establish protective groundwater elevations at the coast in order to protect the groundwater resources of the Basin. In the evaluation of future scenarios, the ability to meet the required protective elevations was regarded as an important criterion.

This report documents the development and results of three separate tasks:

1. Developing a regional transient calibrated groundwater flow model used to run predictive model scenarios; and

2. Developing a series of smaller models used to establish protective groundwater elevations for the Seaside Groundwater Basin.
3. Using results from the protective groundwater elevation models as an evaluation criteria in the regional model's management scenarios.

1.1 REGIONAL GROUNDWATER FLOW MODEL

Establishing the goals and purposes of a groundwater model is the first step in its development. The identified goals and objectives dictate how the model will be constructed, its required level of simplification, and the type of data that will be used as input.

The Watermaster's Technical Advisory Committee (TAC) participated in and guided the development of the model. Based on findings in the Amended Decision, the Seawater Intrusion Response Plan (SIRP), and the BMAP, the TAC felt the model should address the following goals:

- Evaluate the effects of selected supplemental water projects on the Seaside Groundwater Basin,
- Evaluate selected management actions,
- Determine storage efficiency of recharged water,
- Determine Total Useable Stored Groundwater and Total Useable Storage Space,
- Refine the water budget and Basin safe yield, and
- Determine quantities of supplemental water necessary to achieve protective groundwater elevations.

The above goals were used to generate objectives that the model needs to address for each model scenario. These objectives include:

- Assist in determining where water should be recharged, how it would best be recharged and what would its fate be.
- Determine how much inflow and outflow occurs from the ocean.
- Evaluate groundwater level responses to any new water project described in the Coastal Water Project Draft Environmental Impact Report (DEIR) which would deliver water to the Seaside Groundwater Basin.

- Evaluate well interference or how drawdown from wells impact other wells.
- Evaluate impacts on the hydrogeologic northern Seaside Groundwater Basin boundary.
- Evaluate impacts to protective groundwater elevations.
- Evaluate flow between subareas, e.g., impact on flow between subbasins as a result of reducing pumping by 10 percent.

In addition to the specific issues addressed in each model run, the flow model should be able to:

- Assist with a proactive plan to manage seawater intrusion before intrusion occurs.
- Assist in determining how to implement the SIRP, including
- How to change groundwater gradients, and
- How to introduce supplemental supplies.
- Include future development in the Basin, such as development projected in the Fort Ord Reuse Plan, and evaluate its influence on groundwater flows.
- Be inclusive enough to be able to run all potential scenarios without the need to construct an additional model.

1.2 PROTECTIVE GROUNDWATER ELEVATIONS

The freshwater-seawater interfaces in the Seaside Groundwater Basin aquifers are currently offshore and their locations unknown. Knowing the location of the interface in each aquifer is necessary to develop a groundwater model that can predict intrusion rates and time-dependent seawater concentrations in aquifers. Estimating the current location of the interface with offshore wells is prohibitively expensive, and would be extremely difficult to permit. Estimating the location of the interface, however, does not depend on the current interface position. This interface will move only in response to changes in onshore groundwater elevations relative to sea level. Simulating the interface position allows us to estimate the onshore groundwater elevation that moves the interface to a specified position, i.e., at an elevation that will protect inland groundwater from intrusion.

Seawater intrusion can be avoided by maintaining a net outflow of fresh water. A net outflow of fresh water can be assured by holding the groundwater onshore at a high enough elevation above mean sea level (MSL). This elevation is referred to as the protective groundwater elevation.

The purpose of this part of the project is to determine protective groundwater elevations for the main producing aquifers at four selected existing coastal monitoring wells. These protective groundwater elevations are estimated with separate variable density vertical protective groundwater elevation models for each well.

This page left
intentionally blank

SECTION 2
CONCEPTUAL MODEL

A conceptual model is a simplified representation of the essential features of the physical hydrogeologic system and its hydrologic behavior. As such, the conceptual model includes the basic data, interpretations, and simplifications of the hydrogeologic system in the project area that are available. These data, interpretations, and simplifications form the basis of the numerical model. The conceptual model incorporates the following attributes:

- Site geography and land use,
- Geologic framework,
- Groundwater occurrence,
- Aquifer parameters, and
- A water balance, including estimates of all known inflows, outflows, and changes in storage.

GEOGRAPHY AND LAND USE

The area covered by the groundwater model is larger than the Seaside Groundwater Basin defined by the Adjudicated Judgment (Figure 1). This larger area was modeled to allow simulation of groundwater pumping and recharge outside of the Basin that may have an influence on groundwater conditions within the Basin.

The project area is located between the Salinas River Valley and the coastal range that forms the Monterey Peninsula (Figure 1). The area covered by the model is approximately 76 square miles. An active dune system along the coast dominates the coastal topography, with older less active dunes found inland, mostly within the former Ford Ord open space. This hilly coastal plain, slopes both northwards to the Salinas River Valley and westwards towards the Monterey Bay. The maximum elevation is approximately 1,900 feet above mean sea level (MSL) in the southeastern corner of the model area.

Cites within the project area include: Marina, Seaside, Sand City, Del Rey Oaks, Monterey and unincorporated parts of Monterey County. The former Ford Ord military facility covers a large portion of the project area.

There are few creeks in the project area because of the permeable nature of the soils. The creeks that have defined channels are the Arroyo del Rey which flows in Canyon del Rey to the south of the project area and out to the ocean, and El Toro Creek which flows northwards to the Salinas River (Figure 1). Flow in these creeks respond rapidly to rainfall, and are usually dry in the summer months. These creeks have a "flashy" nature and readily lose water to streambed seepage.

Land use along the coastal area east of Highway 1 comprises an approximately 1.5 mile wide strip of residential, light industrial, commercial and institutional facilities (Figure 2). The Bayonet and Black Horse Golf Courses are also found within this developed strip.

The other main developed artery is alongside Highway 68 (Monterey Salinas Highway) in the Laguna Sea area. Residential land use predominates, but there is also some industrial and commercial property. Two golf courses, the Laguna Seca Golf Resort and the Pasadera Country Club are found in this area. The Laguna Seca Regional Park and Raceway is located north of Highway 68.

The Toro area is a developed hub in the southeast corner of the project area. The main developed land use is residential housing and the Corral De Tierra Country Club. It is expected that this area will undergo more development in the future. As Highway 68 turns northwards and heads toward the Salinas River Valley, there is another residential community called Toro Estates.

The central part of the project area comprises open space that was formerly part of the Fort Ord military facility. Although there are plans to develop a small amount of former Fort Ord land near the already developed area east of Seaside, the remainder of the open space will stay undeveloped.

A small amount of agricultural land is found along the northeastern edge of the project area. These fields are part of the Salinas River Valley area.

Figure 3 and Figure 4 show land use for 1991 and 1997, respectively. A review of these figures and Figure 2 shows the progression of development in the area. Table 1 summarizes the sources of the land use data used to generate the figures.

Table 1: Land Use Sources

Year	**Land Use**
1991	1989-91 DWR + AMBAG vegetation
1997	1997 DWR + AMBAG vegetation
Present	1997 DWR + City of Seaside land use, aerial photo

Note: land use shown in the figures were grouped from the original data according to similar water use activities.

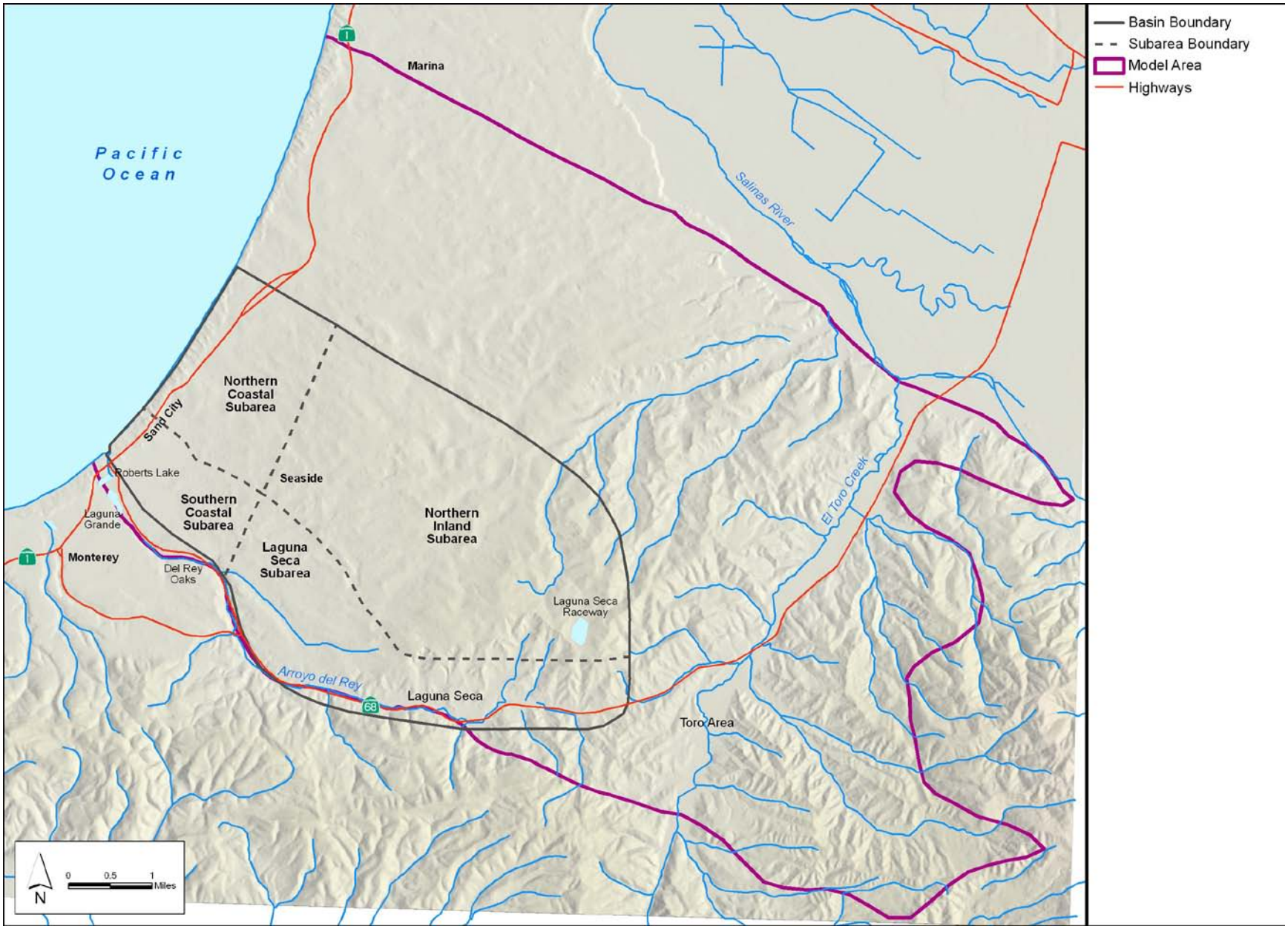


Figure 1: Project Location

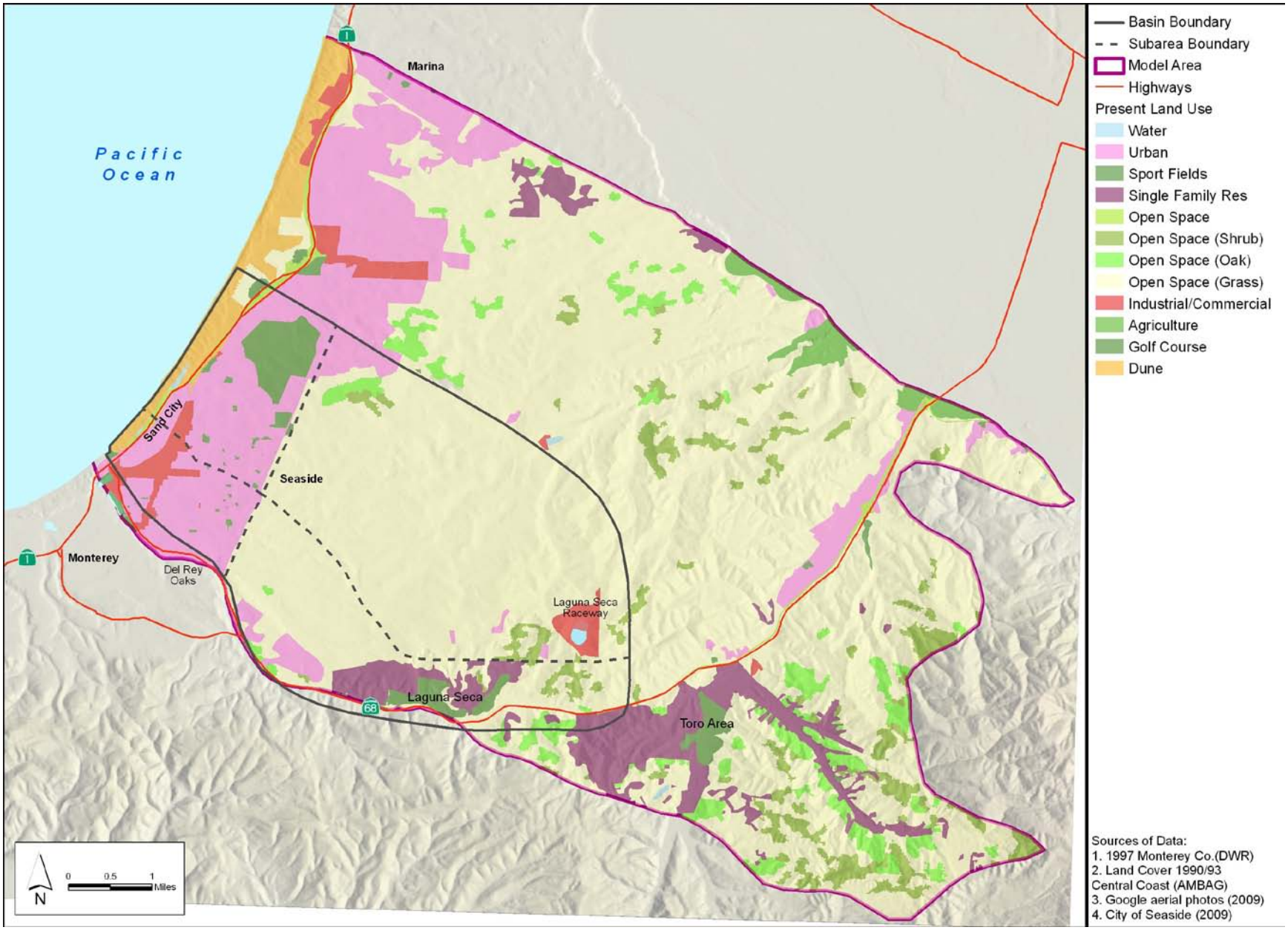


Figure 2: Present Land Use

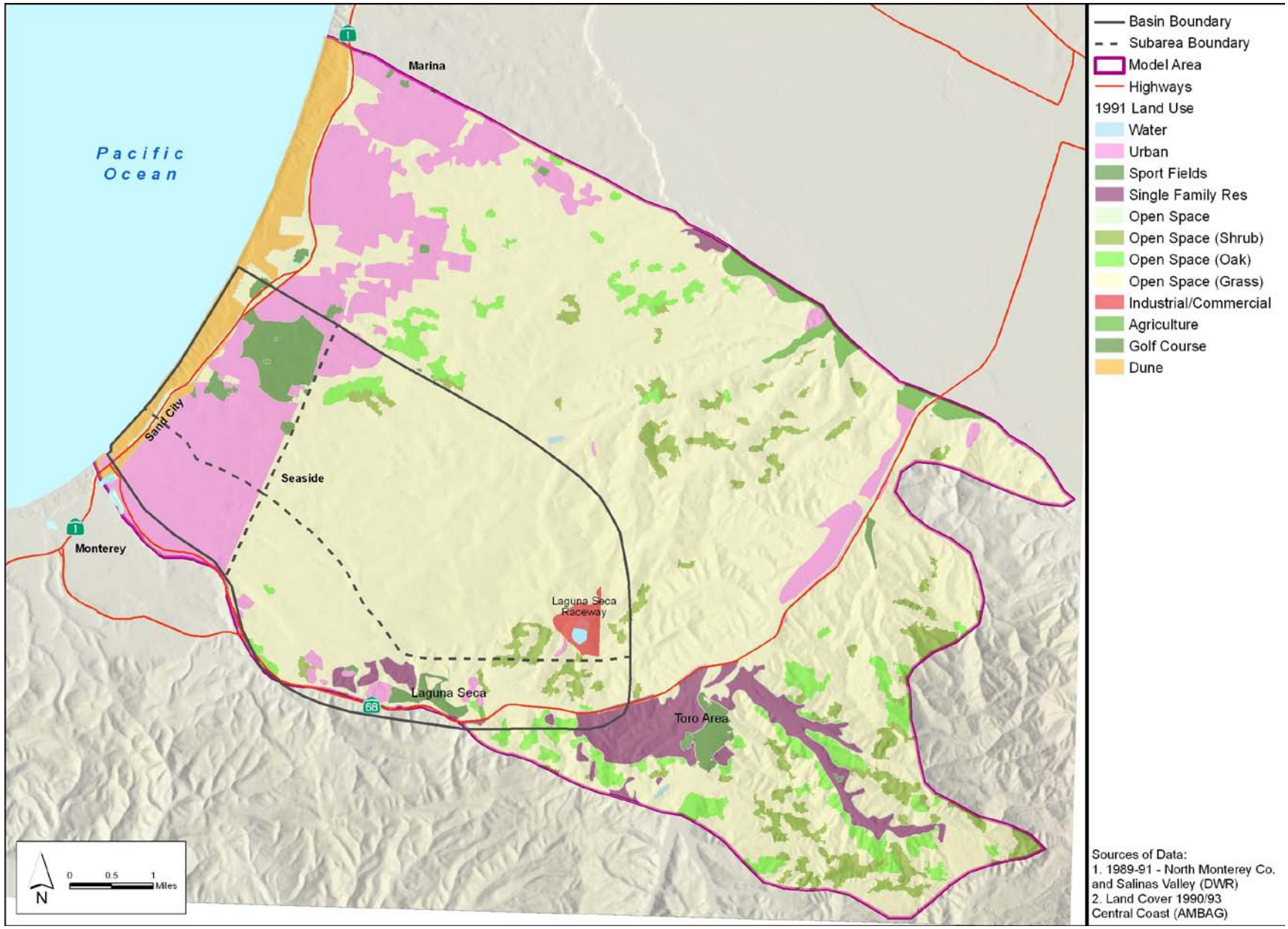


Figure 3: 1991 Land Use

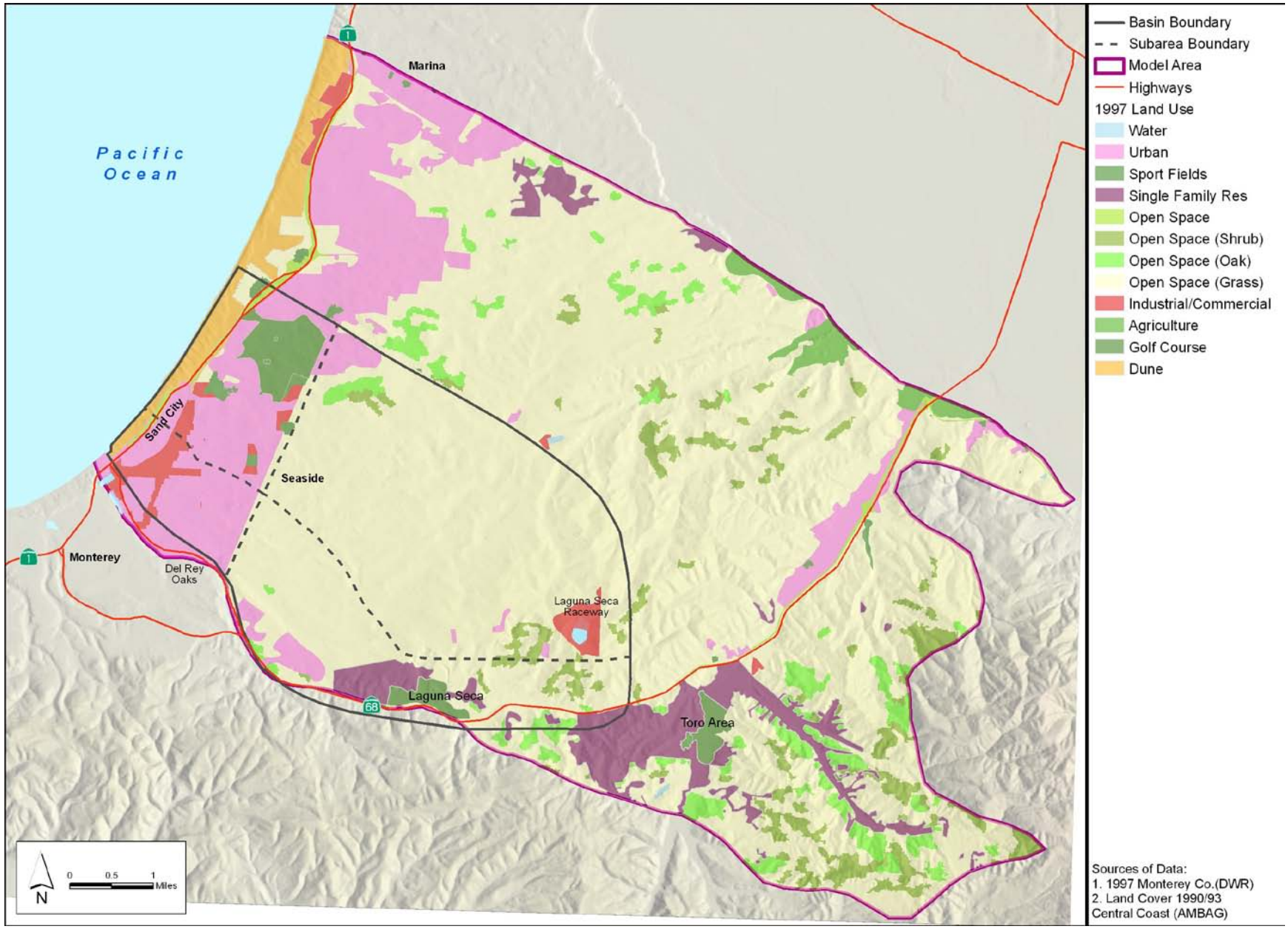


Figure 4: 1997 Land Use

2.1 GEOLOGIC FRAMEWORK

2.1.1 STRATIGRAPHY AND HYDROSTRATIGRAPHY

The study area contains the Seaside Groundwater Basin which consists of a sequence of unconsolidated marine, fluvial and aeolian sediments that overlie relatively impermeable Monterey Formation of Miocene age and older crystalline rocks. The geologic map in Figure 5 shows the surface geology as mapped by Rosenberg (2001).

Conformably overlying the Monterey Formation is the Santa Margarita Sandstone, which is also referred to as the Santa Margarita aquifer or deep aquifer. The Santa Margarita Sandstone consists primarily of marine-derived, sedimentary sandstone. Exploratory drilling associated with the Watermaster's sentinel wells suggests that parts of the deep aquifer previously assigned to the Santa Margarita Sandstone in and near the Northern Coastal and Northern Inland Subareas consist of generally finer-grained sediments that should be assigned to the Purisima Formation. The only outcrop of Santa Margarita Sandstone within the project area occurs in a small area either side of the El Toro Creek.

The Purisima Formation interfingers with the Santa Margarita Sandstone in the northern portion of the project area. The location of the transition is poorly understood due to a paucity of wells in the central part of the project area where this transition may occur. The Purisima Formation is similar to the Santa Margarita Sandstone in that it is a marine deposit consisting of poorly indurated, gravels, sands, silts, and silty clay. Where the Purisima Formation is known to occur in the Marina area, it is deeper than 1,500 feet below MSL. There is no Purisima Formation outcrop in the project area.

The geologic unit unconformably overlying the Santa Margarita Sandstone and Purisima Formation is a Tertiary and Quaternary continental deposit locally called the Paso Robles or shallow aquifer. This unit consists of a mixture of continentally-derived gravel, sand, silt and clay sedimentary deposits. The unit is exposed in the foothills of the Laguna Seca Subarea. It is an unconfined aquifer that is overlain by the surficial Aromas Sand.

The Aromas Red Sands and Older Dune deposits are the uppermost geologic unit in the project area. These deposits are a variety of continental deposits,

including: fluvial and coastal terrace, flood-plain, stream alluvium, colluviums and basin deposits (Yates, et al., 2002).

STRUCTURAL GEOLOGY

Two faults roughly bound the project area. These are the Reliz Fault to the north, and the Chupines Fault which is just north of the southern edge of the project area (Figure 5). The Seaside and Ord Terrace Faults are found in the project area north of the Chupines Fault. The northeast side of the each of the faults is typically downthrown. This has resulted in a loss of Santa Margarita Sandstone south of the Seaside Fault, and as a result there is also very little Paso Robles aquifer or alluvial sediments in the area between the Chupines and Seaside Faults. For the conceptual model the faults are considered partial groundwater flow barriers although the offset in geology likely causes more of a barrier to groundwater flow than any fault gouge.

During review of hydrographs either side of the Seaside Fault in the calibration process, it was noticed that the location of the Seaside Fault should be farther north than it was currently mapped near the MPWMD FO-4 well pair (Rosenberg, 2001). The Seaside Fault shown on Figure 5 reflects the revised location. This new location allows for hydraulic separation of wells with different groundwater elevation and long-term trends.

The Laguna Seca Anticline separates the northern and southern subbasins of the Seaside Groundwater Basin (Figure 5). This feature—including the segment of the Ord Terrace Fault that offsets the anticline—forms a subsurface hydraulic partial barrier to groundwater flow.

The top of the Monterey Formation is considered non-water bearing due to low yields and poor water quality, and is therefore regarded as the base of the groundwater basin. A contour map showing its elevation and topography in the project area is provided in Figure 6. Major features to note are the undulations in the Laguna Seca area due to the Laguna Seca anticline; and the depth of the Basin towards the northern portion of the project area, where it reaches an elevation of 2,500 feet below MSL. Its highest elevation is approximately 1,100 feet above MSL, which is found in the highlands in the southeastern corner of the project area.

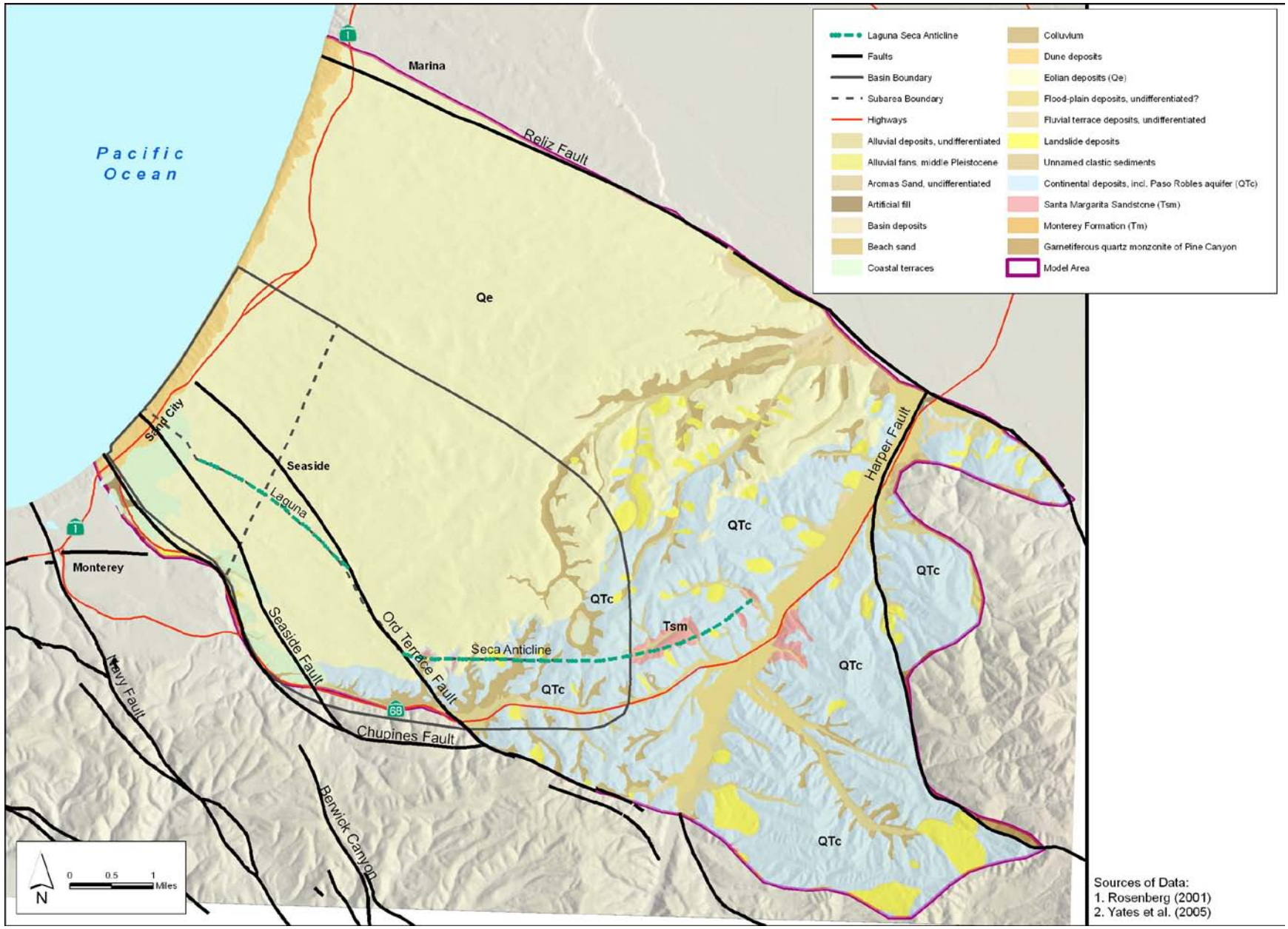


Figure 5: Geology and Faults

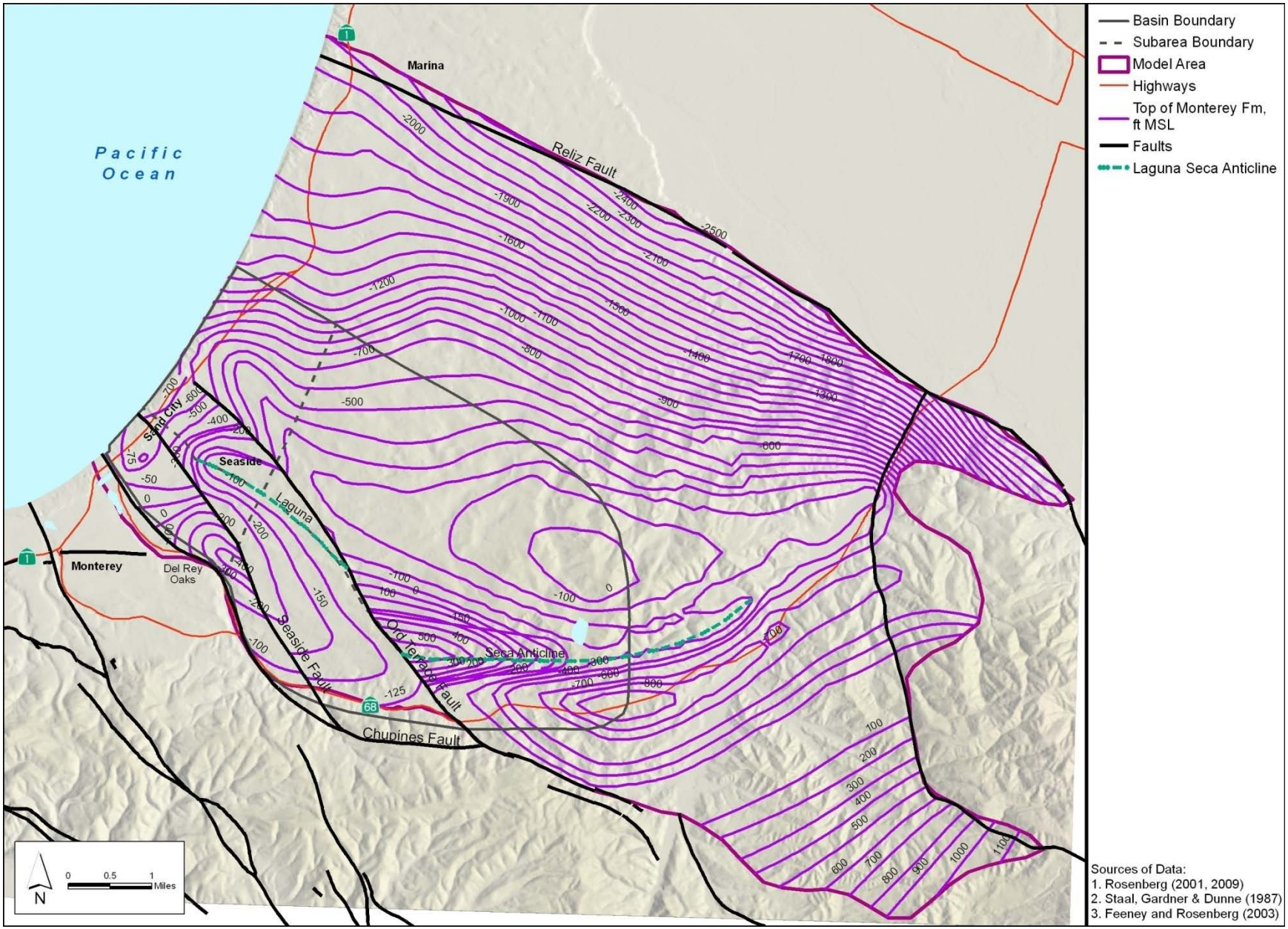


Figure 6: Top of the Monterey Formation (Base of Basin)

2.2 GROUNDWATER OCCURRENCE

2.2.1 GROUNDWATER IN THE AROMAS SANDS

The Aromas Sands and other surficial deposits are unsaturated in many parts of the Seaside Groundwater Basin, and are not extensively pumped for municipal use. Only near the coast are they partly saturated. These sediments are not significant sources of groundwater supply (Yates, et al., 2002).

2.2.2 GROUNDWATER IN PASO ROBLES AQUIFER

The Paso Robles aquifer is an unconfined aquifer that is tapped by production wells in the project area. Many of the wells that are screened in the Paso Robles aquifer are also screened in the underlying Santa Margarita aquifer.

The water-bearing characteristics of the Paso Robles aquifer are variable due to the flood plain depositional environment, which formed coarse-grained channel deposits cutting into fine-grained overbank deposits (Yates, et al., 2002). The Paso Robles aquifer is hydraulically linked to the ocean, which increases its susceptibility to seawater intrusion.

2.2.3 GROUNDWATER IN SANTA MARGARITA/ PURISIMA AQUIFERS

The majority of production wells in the project area produce groundwater from the deep or Santa Margarita/Purisima aquifer. Groundwater levels in this aquifer have shown a decline since production started in earnest in the 1990s. This in part has been attributable to pumping restrictions imposed on CAW's Carmel River pumping by the State Water Resources Control Board's Order 95-10.

Due to overlying low conductivity sediments, the Santa Margarita/Purisima aquifer is confined. Based on observed groundwater level behavior in the Santa Margarita aquifer, there appears to be limited leakage from the overlying shallow aquifer and limited connection to the ocean.

The Purisima Formation is less permeable than the Santa Margarita aquifer. However, it is much thicker than the Santa Margarita aquifer, which translates to similar transmissivity values (Feeney, 2007).

In our conceptual model, we have regarded the Santa Margarita aquifer and the Purisima Formation as one model layer. Differentiation between them is made by the Purisima having a lower hydraulic conductivity than the Santa Margarita aquifer.

2.3 GROUNDWATER FLOW DIRECTIONS

2.3.1 HORIZONTAL FLOW DIRECTIONS AND GRADIENTS

Figure 7 and Figure 8 show groundwater elevation contours for the shallow (Paso Robles) and deep (Santa Margarita/Purisima) aquifers, respectively. These contours were produced as part of the Water Year 2009 Seawater Intrusion Analysis report for the Watermaster (HydroMetrics LLC, 2009b). Both aquifers have pumping depressions: in the Northern Coastal Subarea and in the Laguna Seca Subarea. The deep aquifer has an additional pumping depression at the northern boundary in Marina. All these pumping depressions are caused by two or more wells that pump the majority of the water in those areas.

Horizontal hydraulic gradients range between 0.008 feet/feet and 0.01 feet/feet. Both shallow and deep aquifers have similar gradients, although the deep Santa Margarita aquifer has slightly steeper gradients at the pumping depressions.

In general, groundwater flows from the higher inland areas to the lower coastal areas. There is also a component of flow in the El Toro Creek area that flows northwards towards the Salinas River Valley.

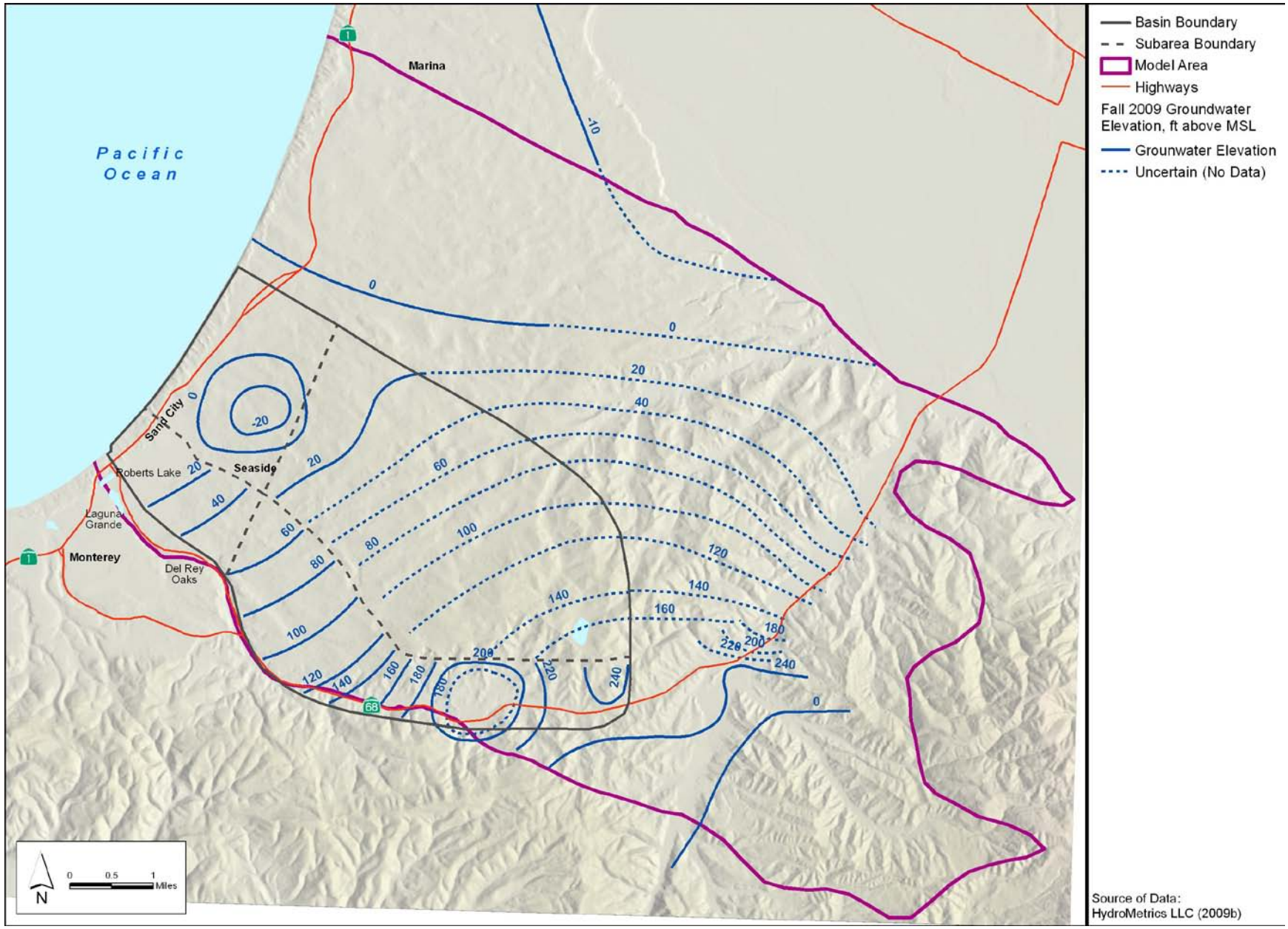


Figure 7: Shallow Groundwater Elevation Map

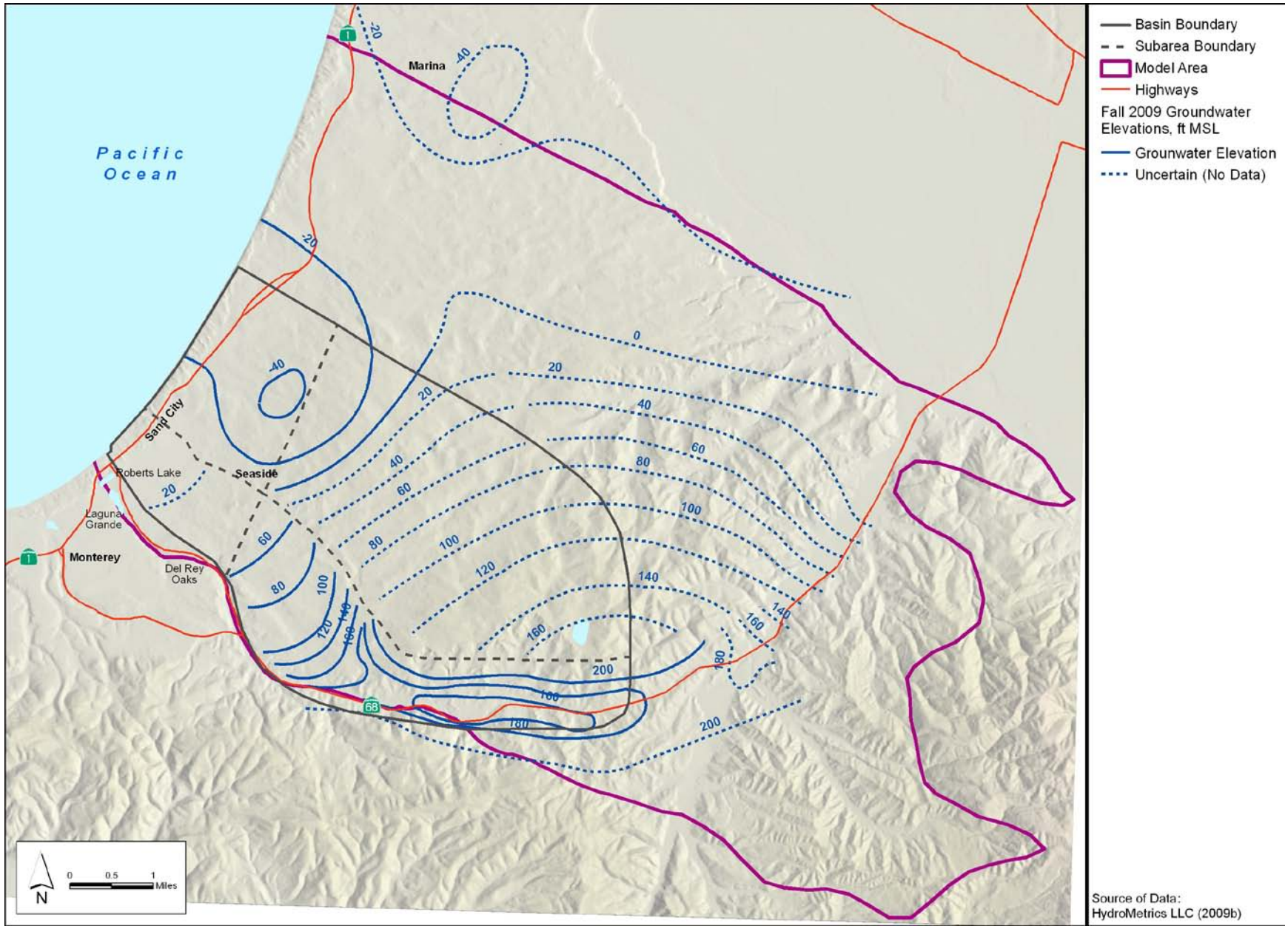


Figure 8: Deep Groundwater Elevation Map

2.3.2 VERTICAL FLOW DIRECTIONS AND GRADIENTS

Head differences between shallow and deep monitoring wells can be used to determine vertical hydraulic gradients. The data from paired wells showed that in the 1980's vertical gradients were upwards, or from the deep aquifer to the shallow aquifer; but as groundwater pumping in the Seaside Groundwater Basin increased, the gradients reversed to downwards, or from the shallow aquifer to the deep aquifer.

In the area of Roberts Lake and Laguna Grande in the Southern Coastal Subarea, there is a probability that an upwards vertical gradient persists due to the area being a groundwater discharge point. This assumption, however, cannot be confirmed with groundwater elevation data as there are no paired monitoring wells in this area.

2.4 AQUIFER PARAMETERS

The aquifer parameters of hydraulic conductivity and storage coefficient of an aquifer represent its capacity to transmit and store groundwater. Estimates of these properties are needed to model three-dimensional, transient groundwater flow. Aquifer parameters are generally estimated from the results of long-term aquifer tests performed on production wells.

2.4.1 HYDRAULIC CONDUCTIVITY

Hydraulic conductivity measures an aquifer's capacity to transmit groundwater. Groundwater flows more readily through an aquifer with a relatively higher conductivity. Hydraulic conductivity is measured in units of length per time. An optional measure of an aquifer's capacity to transmit groundwater is transmissivity. Transmissivity is equal to hydraulic conductivity multiplied by aquifer thickness, and is measured in units of square length per time.

Aquifer tests that can be used to determine aquifer parameters are limited. Those that are available from previous studies are summarized in Table 2.

Table 2: Summary of Hydraulic Conductivity

Hydraulic Conductivity (feet per day)	Aquifer	Source	Reference
20	Paso Robles	Pump test	Fugro West, Inc. (1997)
2		Model calibration	Yates et al. (2005)
16.4-25.4	Purisima	Pump test	CH2M Hill (2004)
63	Santa Margarita	Pump test	Fugro West, Inc. (1997)
3-5		Model calibration	Yates et al. (2005)

2.4.2 STORAGE COEFFICIENT

Storage coefficient measures an aquifer's ability to store groundwater. Storage coefficients are expressed as a specific yield in unconfined aquifers, and as either specific storage or storativity in confined aquifers. Storativity is unitless, and specific storage has units of feet^{-1}.

The only storage estimates available are from calibrated models. Yates et al. (2005) reported a calibrated specific yield of 0.08 for unconfined aquifers. Yates (2005) also reported a specific storage of 0.0006 for confined aquifers.

2.5 WATER BALANCE

A water balance consists of developing quantitative estimates of all of the inflows, outflows, and change in storage for the model area. If estimates of the individual water balance components are accurate, the sum of all recharge, discharge, and boundary flows over a period of time equals the change in groundwater storage during that same time period. The standard water balance equation is written as:

$$\sum Inflows - \sum Outflows = Change\ in\ Storage$$

The following sections describe the project area's inflow and outflow components.

2.5.1 INFLOWS

Inflows to project area include all recharge mechanisms that add water to the groundwater system. Recharge mechanisms identified include:

1. Deep percolation of rainfall,
2. System losses from delivery systems,
3. Septic systems,
4. Return flow from irrigation,
5. Inflow from onshore and offshore areas, and
6. Infiltration from stormwater ponds.

Discussions of each of the recharge mechanisms are presented below. Section 3.7.1 in this report discusses how the recharge was incorporated into the numerical model.

2.5.1.1 DEEP PERCOLATION OF RAINFALL

Daily rainfall data were obtained from Monterey Co-op Station 45795 and Salinas Co-op Station 47668 (Figure 9). The annual rainfall for the period between 1987 and 2008 was averaged for both stations, yielding an average rainfall of 17.02 inches per year.

Rainfall was spatially distributed across the model area using the isohyetal map developed by MCWRA (undated). A factor representing the proportion of the overall average rainfall for each model cell was calculated by dividing the isohyetal value by the average rainfall (17.02). Daily rainfall for each cell could then be estimated by multiplying the resulting factor by an average of daily precipitation from the Monterey and Salinas Co-op Stations.

The deep percolation from rainfall was calculated at each model cell using a combination of daily rainfall, monthly evapotranspiration, land use type, and soil classifications shown on Figure 10. A more complete description of the methodology used to estimate recharge from rainfall is included in Appendix A.

2.5.1.2 SYSTEM LOSSES FROM DELIVERY SYSTEMS

Within the water purveyor service areas, there are system losses that contribute a small amount to groundwater recharge. Service areas are shown in Figure 11. Pipeline and land use data were used to delineate areas where systems losses may occur within each service area. These actual delivery areas shown as thicker black lines on Figure 11 are smaller than the actual service areas. System losses were applied uniformly across the delivery areas.

A loss of 8.5% of delivered water was assumed for all service areas. Delivered water volumes were provided by MPWMD, Marina Coast Water District (MCWD), California Water Service (CWS) and California American Water (CAW). Water from system losses was assumed to directly recharge groundwater, and is not involved in evapotranspiration (ET). The average recharge from system losses for the entire project area is approximately 800 acre-feet per year.

2.5.1.3 SEPTIC SYSTEMS

Recharge from septic systems occurs within six septic areas (Figure 11). A total septic leakage volume was specified for each septic area based on previous estimates by Yates, et al. (2005). Within each septic area, the septic leakage is applied uniformly. The septic leakage volume was assumed to be constant for all model stress periods. Septic leakage was assumed to directly recharge groundwater, and is not involved in ET. The average recharge from septic systems is 0.1 acre-feet per year.

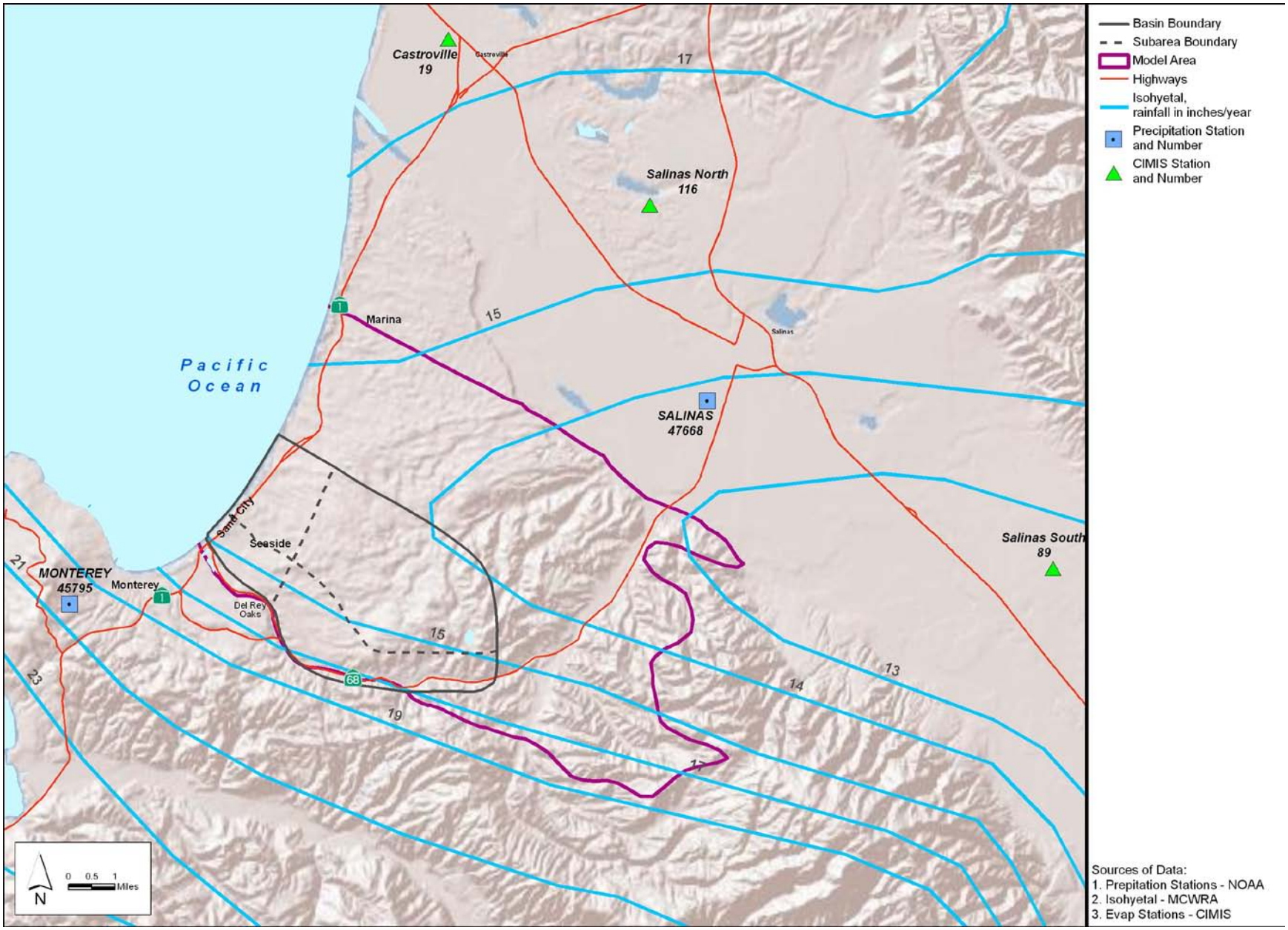


Figure 9: Precipitation and CIMIS Stations, with Isohyetals

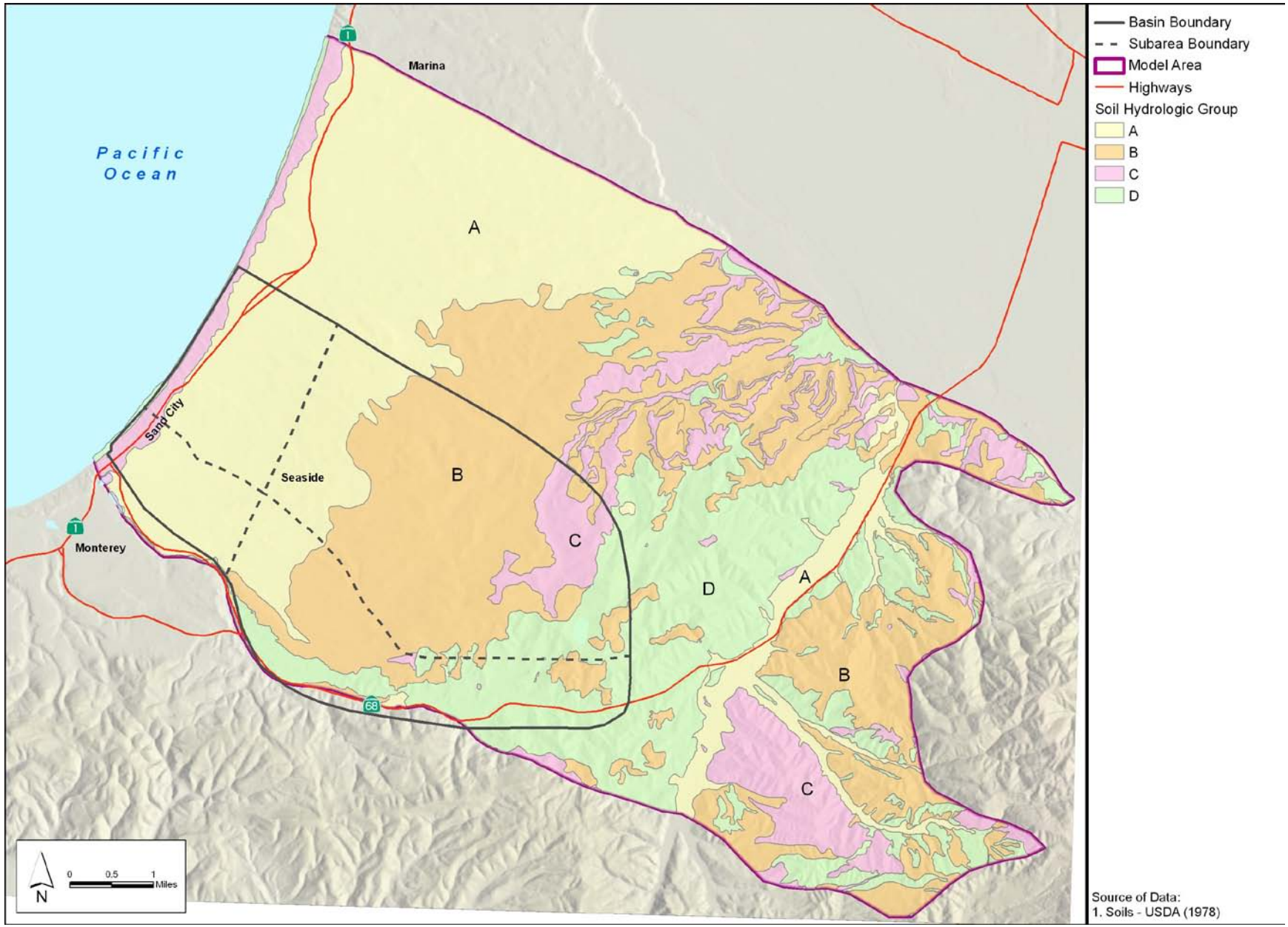


Figure 10: Soils Classification

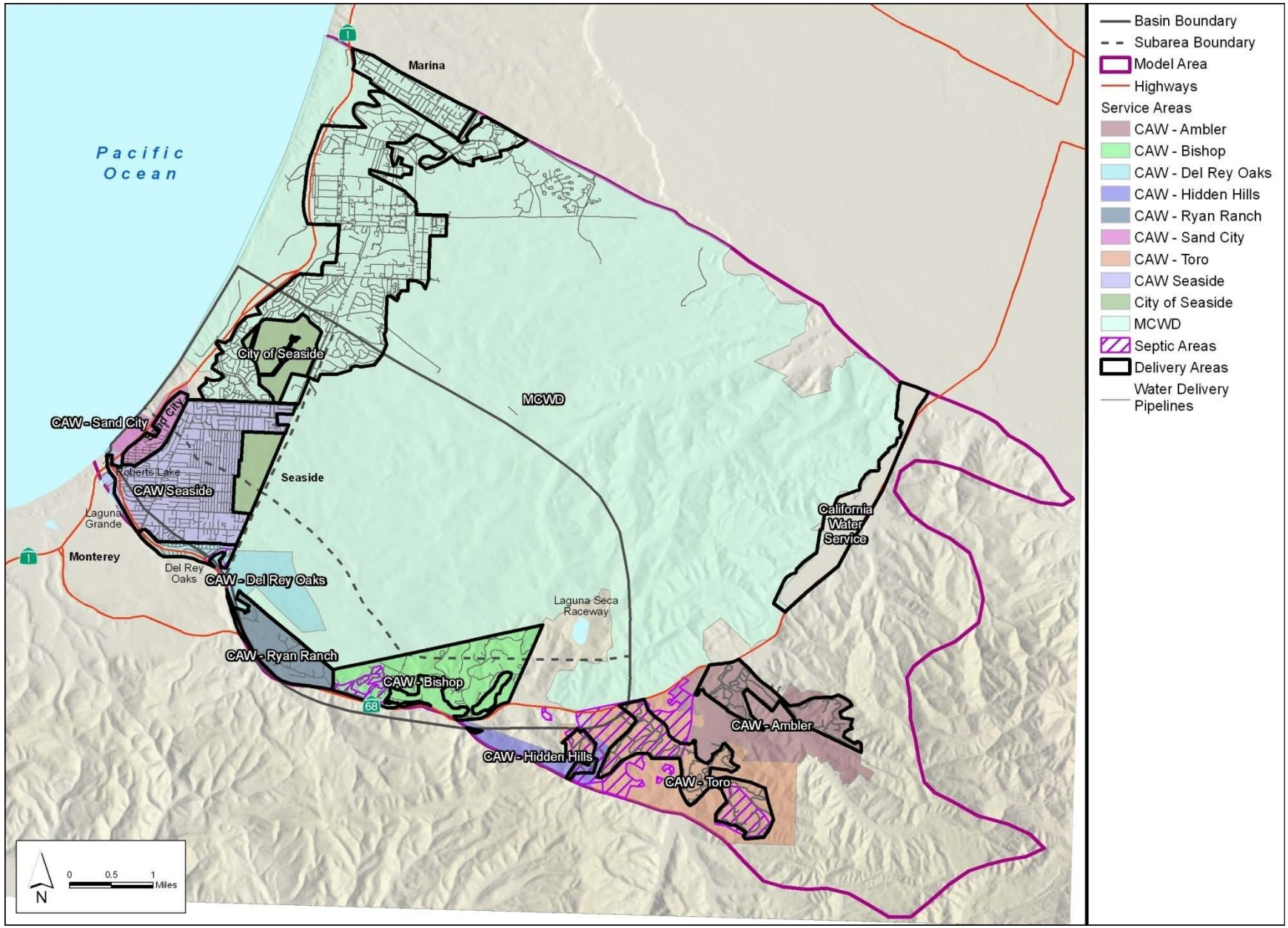


Figure 11: Service Areas, Water Delivery Pipelines and Septic Areas

2.5.1.4 RETURN FLOW FROM IRRIGATION

Irrigation within the model area occurs primarily from domestic, municipal and golf course irrigation. A small amount of agricultural irrigation occurs within the model area; however, it was considered insignificant and is represented as open space in the recharge estimate. Irrigation occurs only within the areas that have access to delivered water, shown as delivery areas on Figure 11. A percentage of each land use that was likely to be irrigated with delivered water had irrigation water applied uniformly. Table 3 lists the percentage of the land use that had irrigation applied to it.

Table 3: Percent of Land Use Irrigated

Land Use	Percent of Land Use Irrigated with Delivered Water
Industrial/Commercial	7%
Urban Areas	19%
Single Family Residence	29%
Golf Course	70%
Sport Fields	70%

2.5.1.5 INFLOW FROM ONSHORE AND OFFSHORE AREAS

Inflow to the model area from adjacent areas is limited to the northern boundary connection to the Salinas River Valley. The eastern and southern boundaries were considered no-flow boundaries. This is because the eastern boundary represents the extent of the sedimentary basin where it meets hard rock geology; and the southern boundary coincides with the Chupines Fault that marks the southernmost extent of the Seaside Groundwater Basin.

Where an aquifer, such as the Paso Robles aquifer, is hydraulically connected to the ocean, inflow from the ocean to the onshore basin is possible. As discussed previously, the Santa Margarita/Purisima aquifer's connection to the ocean is limited.

2.5.1.6 INFILTRATION FROM STORMWATER PONDS

There are 37 stormwater ponds in the model area (Figure 12). The City of Marina has numerous small ponds that are located on the northern boundary of the project area. There are also several stormwater ponds within the City of Seaside. The City of Seaside requires that all new developments have onsite stormwater percolation.

The ponds are constructed to capture storm runoff and allow for percolation into the groundwater. Each percolation pond has a catchment area defined within the model area. Runoff from the catchment is diverted to its corresponding stormwater pond. Water diverted to stormwater ponds in the area typically infiltrates within 48 hours. Consequently, losses of recharge to ET are assumed to be negligible, and water recharged through the ponds is applied directly to groundwater recharge.

The period of operation differs for various ponds, with some ponds only being constructed in 2003. During time when a pond is not in operation, the corresponding catchment runoff is routed to outfall to the ocean and thus out of the model.

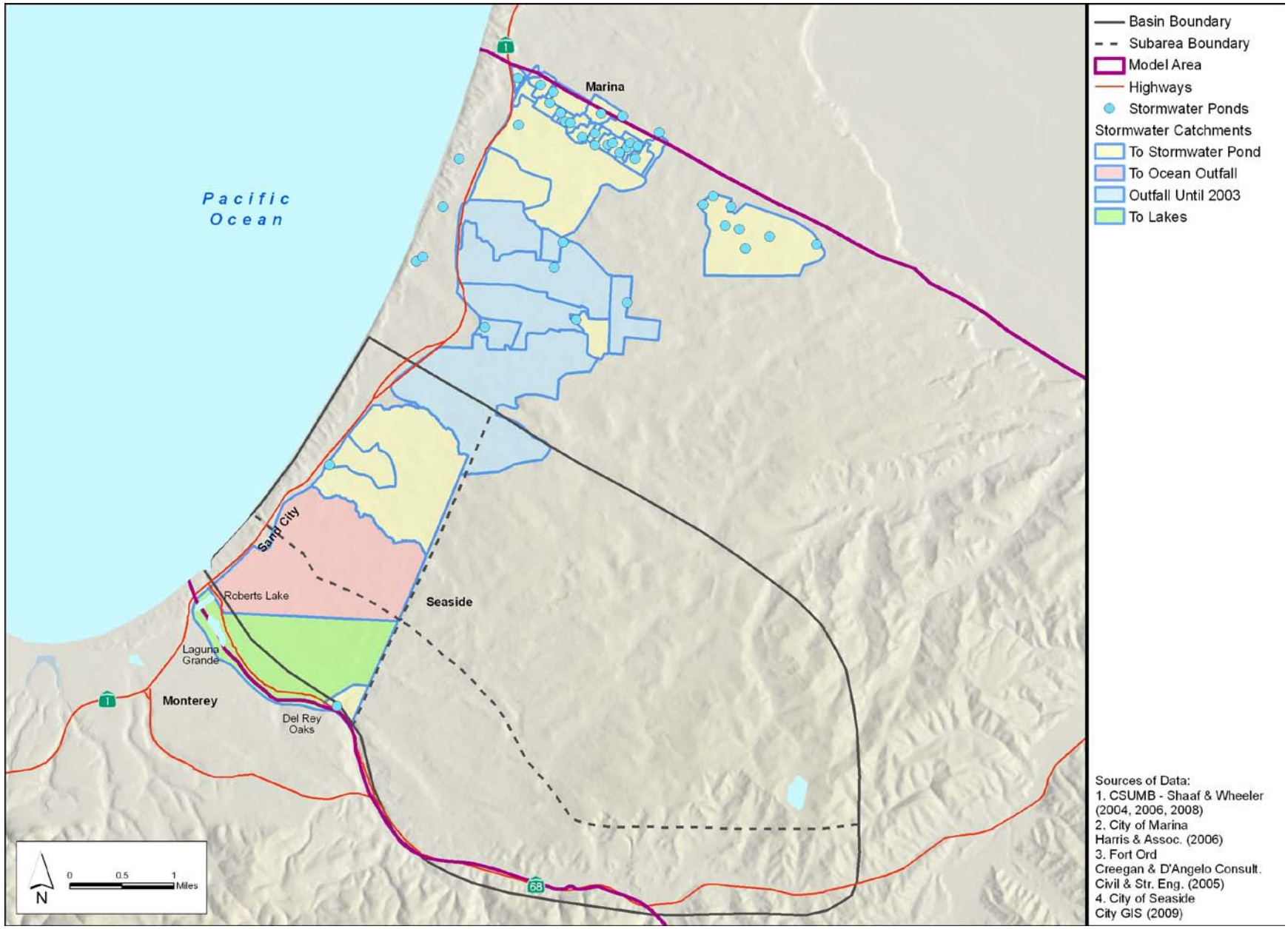


Figure 12: Stormwater Ponds and Catchments

2.5.2 OUTFLOWS

Outflows from project area include all discharge mechanisms that remove water from the groundwater system. Discharge mechanisms identified include:

1. Groundwater pumping by water agencies and private landowners,
2. Discharge of stormwater to ocean outfalls,
3. Outflow to onshore and offshore areas, and
4. Evapotranspiration.

2.5.2.1 GROUNDWATER PUMPING BY WATER AGENCIES AND PRIVATE LANDOWNERS

The water agencies that currently pump groundwater in the model area include CAW, MCWD, City of Seaside, and CWS. Of these four agencies, CWS and MCWD pump outside of the Seaside Groundwater Basin. The annual production for CWS is approximately 400 acre-feet per year, although this has declined over the past few years due to use of water from the Salinas Valley. MCWD has a couple of wells on the northern boundary of the model area that produce approximately 900 acre-feet per year.

The Seaside Groundwater Basin producers include CAW and City of Seaside, together with a number of private pumpers. Production is reported to the Watermaster. Between Water Year 2003 and Water Year 2009, an average of approximately 5,000 acre-feet per year was extracted from the Seaside Groundwater Basin.

Other significant groundwater producers outside of the Seaside Groundwater Basin are the Corral De Tierra Country Club and some small water systems in the Toro area. Production data for these sources was limited to previous reports. Groundwater pumping for the country club was assumed to be similar to pumping of the nearby Laguna Seca golf course. Water pumped by the small water systems was assumed to be 680 acre-feet per year (Fugro West, Inc., 1997).

2.5.2.2 DISCHARGE OF STORMWATER TO OCEAN OUTFALLS

As mentioned previously, not all the stormwater systems deliver stormwater to ponds for percolation. There are some areas where the stormwater is discharged to the ocean through outfalls. Any water that was discharged to these outfalls was considered lost water to the groundwater system.

2.5.2.3 Outflow to Onshore and Offshore Areas

The same onshore and offshore sources as described in the inflow section above apply to the outflows that occur in the model area, i.e., across the northern project boundary and to the ocean.

2.5.2.4 Evapotranspiration

Evapotranspiration (ET) is water absorbed directly from the groundwater by plants or lost through evaporation. Evapotranspiration data were obtained from the closest California Irrigation Management Information System (CIMIS) stations with long-term data. Figure 9 shows the location of the three closest stations. By plotting distance from the coast, a linear correlation was established that could be used to interpolate ET for any location within the model area.

2.5.3 Water Balance

The standard water balance equation balances basin inflows, outflows, and change in storage. The water balance equation is commonly written as:

$$\sum Inflows - \sum Outflows = Change\ in\ Storage$$

A water balance for the model area was not estimated. However, a recent water balance from the Seaside Groundwater Basin's BMAP (HydroMetrics LLC, 2009a) provided an estimate for a greater portion of the model area (Table 4).

Table 4: Estimated Seaside Groundwater Basin Average Annual Groundwater Budget
Water Years 2003 through 2007, units in acre-feet per year

Recharge Source	Northern Coastal Subarea	Northern Inland Subarea	Southern Coastal Subarea	Laguna Seca Subarea	Total
Inflows					
Percolation from streams	0	0	0	0	0
Rainfall and irrigation deep percolation					
Runoff from impervious areas	190	10	140	40	380
Irrigated areas	470	20	150	130	770
Nonirrigated areas	250	1,050	100	530	1,930
Pipe leaks					
Water pipes	160	10	120	80	370
Sewer pipes	50	0	40	10	100
Septic systems	0	0	0	20	20
Injection wells	230	0	0	0	230
Groundwater inflow					
From onshore Subareas	2,850	0	450	180	3,480
From offshore area	100	0	0	0	100
Total inflows	*4,300*	*1,090*	*1,000*	*990*	*7,380*
Outflows					
Wells	4,250	0	160	1,000	5,410
Groundwater outflow					
To onshore Subareas	0	2,060	790	450	3,300
To offshore area	70	0	30	0	100
Total outflows	*4,320*	*2,060*	*980*	*1,450*	*8,810*
Storage Change					
Based on Inflows-Outflows	-20	-970	20	-460	-1,430
Based on Water-Level Change*	-170	-730	30	-440	-1,310

* Storage change based on measured groundwater levels is included in this table as a common-sense check on the inflow-outflows approach. The results from the two approaches compare thereby providing greater confidence in the values.

Source: HydroMetrics LLC (2009a)

SECTION 3
NUMERICAL FLOW MODEL CONSTRUCTION

Numerical flow model construction consists of first defining the structure of the model, and then incorporating data from the conceptual model. Defining the model structure includes defining the model domain, constructing a model grid, and defining model layers. Incorporating the conceptual model includes assigning boundary conditions, assigning hydrogeologic parameters, and incorporating components of the water balance. The recharges and discharges in the water balance are expressed in the model through areal recharge rates, well pumping rates, and flow rates across model boundaries.

3.1 MODEL CODE

The model code MODFLOW 2005 (Harbaugh, 2005) was selected for the regional groundwater flow model. This model program is an industry standard and is well documented. A finite difference code was selected over a finite element code such as FEFLOW because finite difference codes allow evaluation of the groundwater budget for smaller areas within the model.

3.2 MODEL DOMAIN

The regional groundwater model covers approximately 76 square miles, and includes the entire approximately 24 square mile Seaside Groundwater Basin (Figure 1). The northwestern boundary lies approximately 1,500 feet offshore from the coastline. The southwestern and southeastern boundaries lie along bedrock outcrops. The northeastern boundary follows the boundary established in the previous modeling effort by Durbin (2007). This northeastern boundary was established far enough north of the Seaside Groundwater Basin that the groundwater divide that defines the northern basin boundary could move in response to pumping and recharge changes.

3.3 FINITE DIFFERENCE GRID

Figure 13 shows the finite difference model grid on which the numerical model is built. The grid comprises 148 rows and 110 columns. The largest grid dimension is 1,500 feet, and the smallest grid dimension is 100 feet. The smallest grid dimensions are placed around municipal and irrigation wells to help define the steeper groundwater gradients expected near these wells. Smaller grid cells are

required to accurately model strongly curving piezometric surfaces, such as those induced by groundwater pumping (Anderson and Woessner, 1992). To minimize numerical errors, cell dimensions are always less than or equal to 1.5 times any neighboring cell dimension.

Groundwater generally flows along the length of the Basin, from the southeast towards the coast in the northwest. To best accommodate this general flow direction, the model grid was rotated 80 degrees counterclockwise.

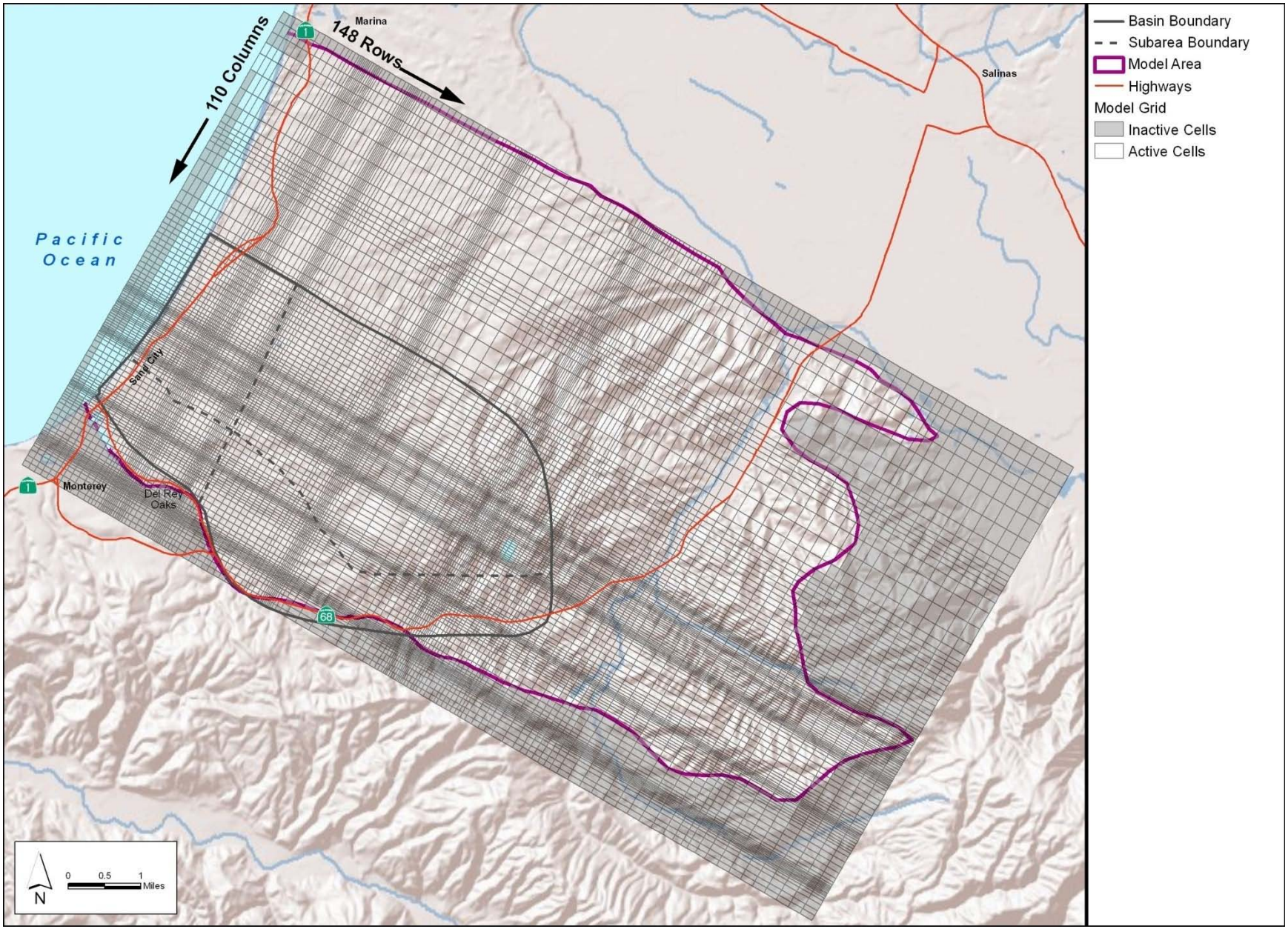


Figure 13: Finite Difference Model Grid

3.4 MODEL LAYERS

As discussed in Section 2.3.2, significant vertical gradients have been observed in the Seaside Groundwater Basin. To represent the multiple piezometric surfaces, hydrostratigraphic complexity, and three-dimensional flow characteristics of the Basin, the numerical groundwater model is divided into five layers. Layering generally followed the stratigraphy detailed in Section 2.1.1. All model layers were simulated as confined if the overlying layer was saturated, or unconfined when the overlying layer becomes unsaturated. This is simulated using MODFLOW layer type 3 in all layers except the top layer, which is simulated a MODFLOW layer type 1.

Data to support model layering was based on a number of previous studies and data sources including:

- Reports by Logan (1982); Staal Gardner & Dunne (1990); Fugro West, Inc.. (1997), Yates, Feeney and Rosenberg (2002); Feeney and Rosenberg (2003); Yates, Feeney and Rosenberg (2005); and Durbin (2007).
- Geologic outcrop elevations derived by overlaying the geologic map of Rosenberg (2001) on a 10-meter digital elevation model.
- Contour maps of interpreted stratigraphic boundaries provided by Mr. Lew Rosenberg.
- Groundwater elevation data and hydrographs.
- Conversations with Mr. Lew Rosenberg, Mr. Martin Feeney, Mr. Joe Oliver, and others.

Many of the data sources conflicted with each other, therefore new stratigraphic elevations were developed for this model. The stratigraphy represented by the model layering is the first complete and internally consistent interpretation of the model area's geologic layering.

Model layer 1 is the top layer in the model grid. Model layer 1 simulates the Aromas Red Sands and Older Dune deposits. Because these shallow deposits do not exist throughout the project area, layer 1 only exists in part of the model. Model layer 1 is up to 460 feet thick in the northwestern corner of the model. A map showing the elevation of the base of model layer 1 is shown on Figure 14.

Model layers 2, 3, and 4 represent the Paso Robles aquifer. Stratigraphic analysis by both Logan (1982) and Staal, Gardiner, and Dunne (1990) suggests that near

the coast, the Paso Robles aquifer contains some semi-continuous stratigraphic features. The base of the Paso Robles aquifer is dominated by semi-continuous layers of blue clay. These clays are approximately 80 feet thick. A noticeable brown sand layer overlies the blue clays. The brown sand is also approximately 80 feet thick.

To honor this stratigraphy, the bottom 80 feet of the Paso Robles aquifer was assigned to layer 4. Layer 4 therefore simulates the continuous blue clays where they exist. The 80 feet of Paso Robles aquifer overlying layer 4 was assigned to layer 3. Layer 3 therefore simulates the brown sand layer where it exists. The remainder of the Paso Robles aquifer was assigned to layer 2. Because model layer 2 does not represent a unique stratigraphic feature, the thickness of model layer 2 varies significantly across the model. Model layer 2 is up to 1,022 feet thick near the eastern end of the Laguna Seca Subarea. A map showing the elevation of the base of model layer 2 is shown on Figure 14. Where the Paso Robles aquifer is too thin to accommodate all the model layers defined above model layer 2 was assigned a minimum thickness of 5 feet, and the remainder of the Paso Robles aquifer was split equally between model layers 3 and 4. A map showing the elevation of the base of the model layers is shown on Figure 14.

Model layer 5 represents the Santa Margarita/Purisima aquifer. Because the transition between these two formations is poorly understood, no attempt was made to simulate them separately. Model layer 5 is up to 2,650 feet thick in the northeast corner of the model. A map showing the elevation of the base of model layer 5 is shown on Figure 14.

This page left
intentionally blank

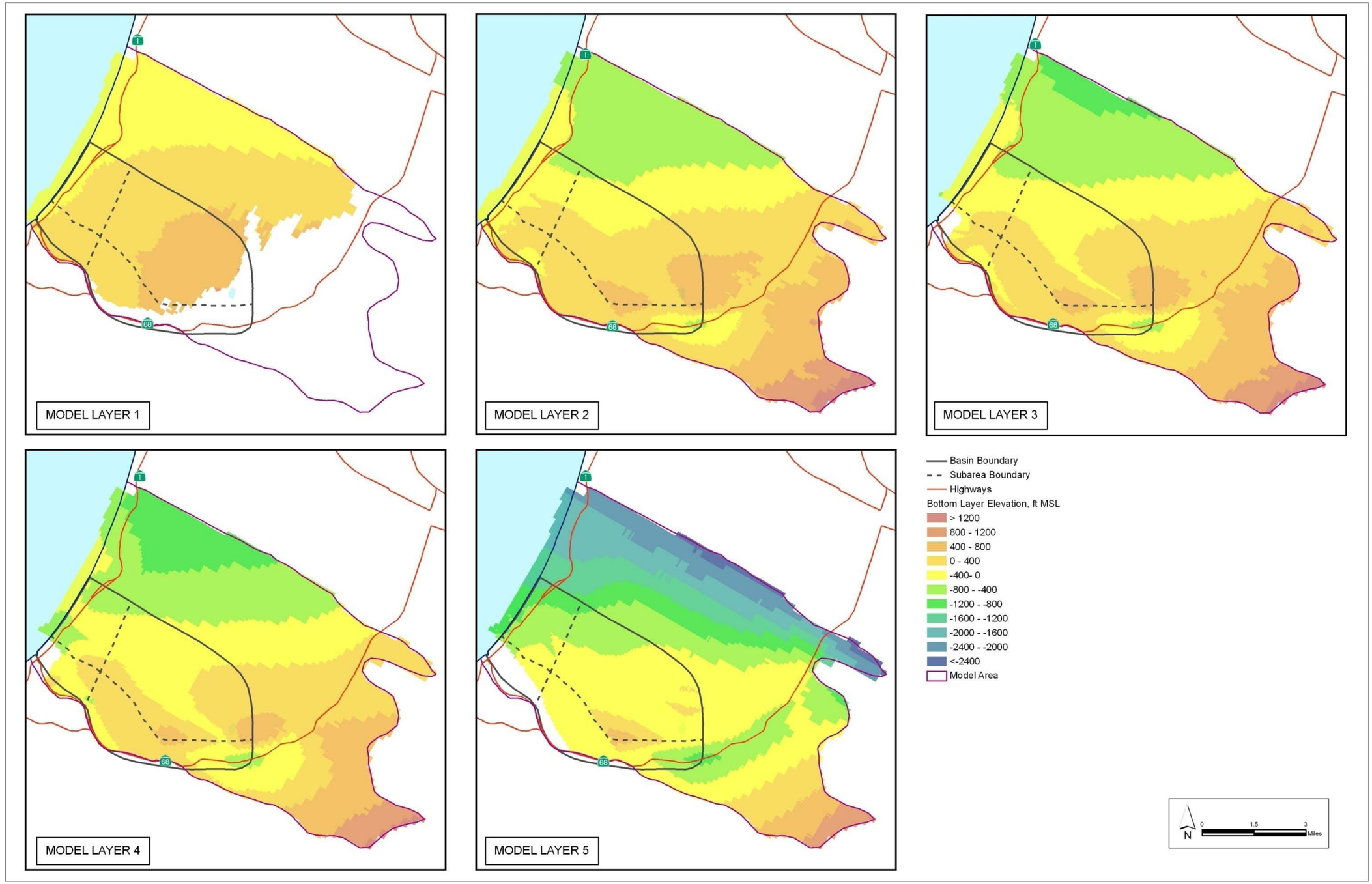


Figure 14: Model Bottom Layer Elevations

This page left
intentionally blank

3.5 BOUNDARY CONDITIONS

The numerical model requires defined boundary conditions for all sides, the top, and the bottom of the model. Boundary conditions along the top and sides of the model are designated explicitly in the model input; the boundary condition along the bottom surface of the model is controlled by layer definition. Horizontal boundaries that are not explicitly assigned boundary conditions are treated as no-flow boundaries by MODFLOW.

3.5.1 NO-FLOW BOUNDARIES

No-flow boundaries are used to simulate boundaries between water-bearing and non-water bearing rocks. The regional model is bounded by outcrops of relatively impermeable rocks on the southwest and southeast sides. The amount of groundwater entering the model area through these relatively impermeable rocks is assumed to be small, so the southwest and southeast sides of the model are simulated with no-flow boundaries.

3.5.2 BOUNDARY WITH SALINAS VALLEY

Groundwater flows freely into and out of the Salinas Valley along the model's northeastern boundary. The boundary with Salinas Valley was simulated with the MODFLOW Constant Head (CHD) option. This option assigns a known groundwater elevation to each model cell along the northwestern boundary. If simulated groundwater elevations in the model are higher than the assigned boundary elevations, water will flow out of the model towards Salinas Valley. If simulated groundwater elevations in the model are lower than the assigned boundary elevations, water will flow from Salinas Valley into the model.

The groundwater elevations assigned to model nodes along the northeastern boundary were derived from the Salinas Valley Integrated Groundwater Surface Water Model (SVIGSM). Wrime Inc. provided estimated groundwater elevations from a number of the SVIGSM nodes that are near the regional model boundary. Groundwater elevations from the SVIGSM nodes were interpolated onto the regional model boundary nodes using GIS. Figure 15 shows the locations of the SVIGSM nodes used to interpolate the groundwater elevations along the model's northeastern boundary.

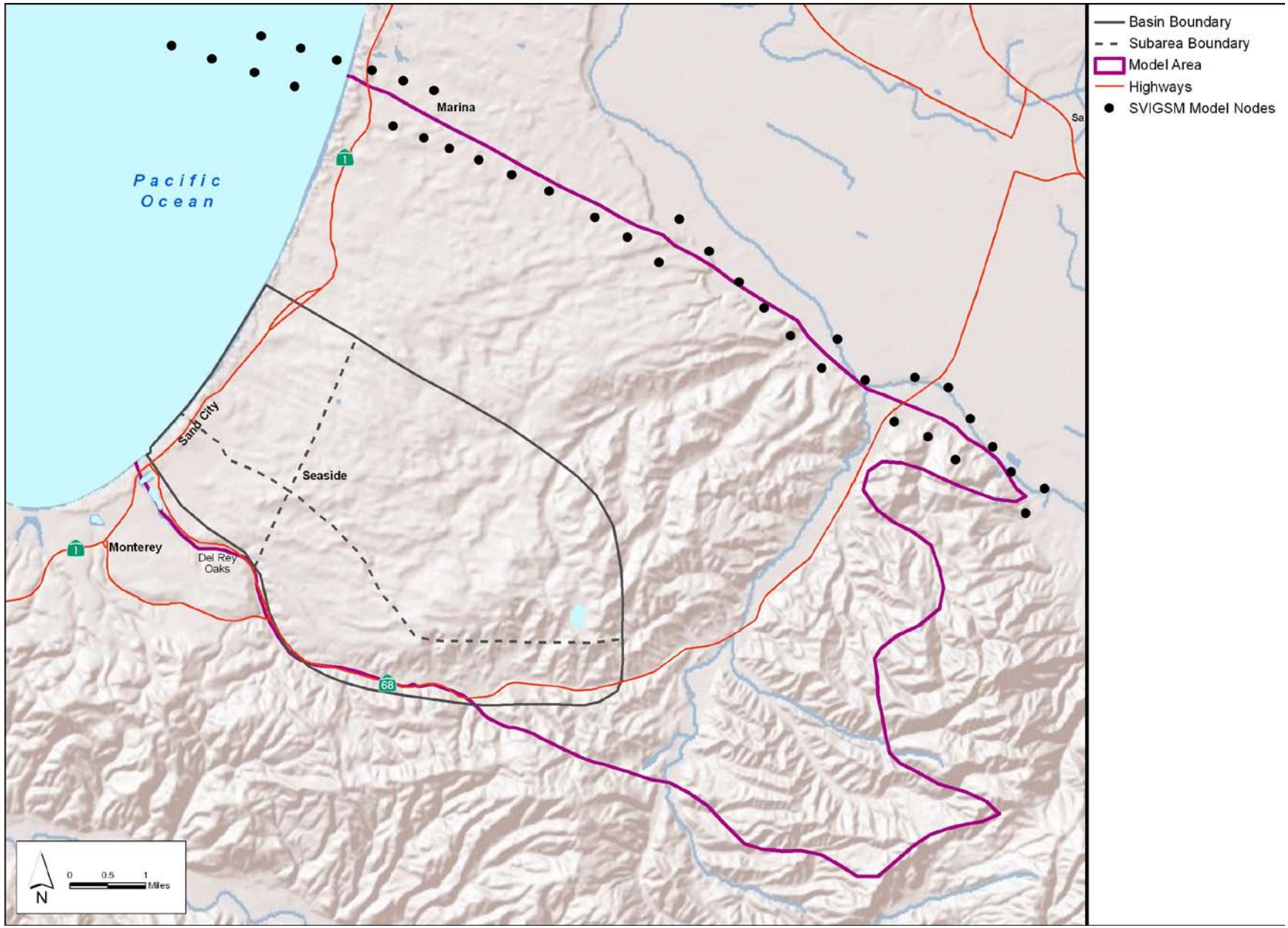


Figure 15: SVIGSM Model Nodes

3.5.3 OCEAN BOUNDARY

Groundwater may flow into or out of the Pacific Ocean along the northwestern boundary of the model. The ocean boundary was simulated using MODFLOW's General Head Boundary (GHB) option. As with the CHD option discussed above, the GHB option assigns a known groundwater elevation to the model boundary. The significant difference between the two options is that the CHD option assigns the known groundwater elevation at the model boundary, and the GHB option allows the modeler to move the known elevation away some distance from the model boundary. The GHB option was used to simulate the ocean boundary, because the model area's aquifers outcrop along the ocean bottom some distance offshore, not at the model edge. Figure 16 shows the locations of the GHB model cells that represent the ocean boundary.

During model calibration, it became apparent that the Santa Margarita Sandstone is poorly connected to the ocean. This is consistent with the current offshore geologic maps that do not show Santa Margarita Sandstone outcropping along the ocean floor. Therefore, the GHB boundary condition was removed from model layer 5. The lower model layer is only connected to the ocean through leakage from overlying units.

3.5.4 TOP AND BOTTOM BOUNDARIES

The top of the model represents ground surface. Ground surface elevations were derived from a 10-meter digital elevation model. Twelve MODFLOW drain cells were used to simulate Roberts Lake and Laguna Grande (Figure 16). These two lakes are known groundwater discharge areas, and the drains used to simulate them provide the model with a realistic groundwater discharge mechanism. The bottom boundary is a no-flow boundary. This boundary represents the contact between the bottom of the Santa Margarita/Purisima, and the underlying Monterey Formation.

This page left
intentionally blank

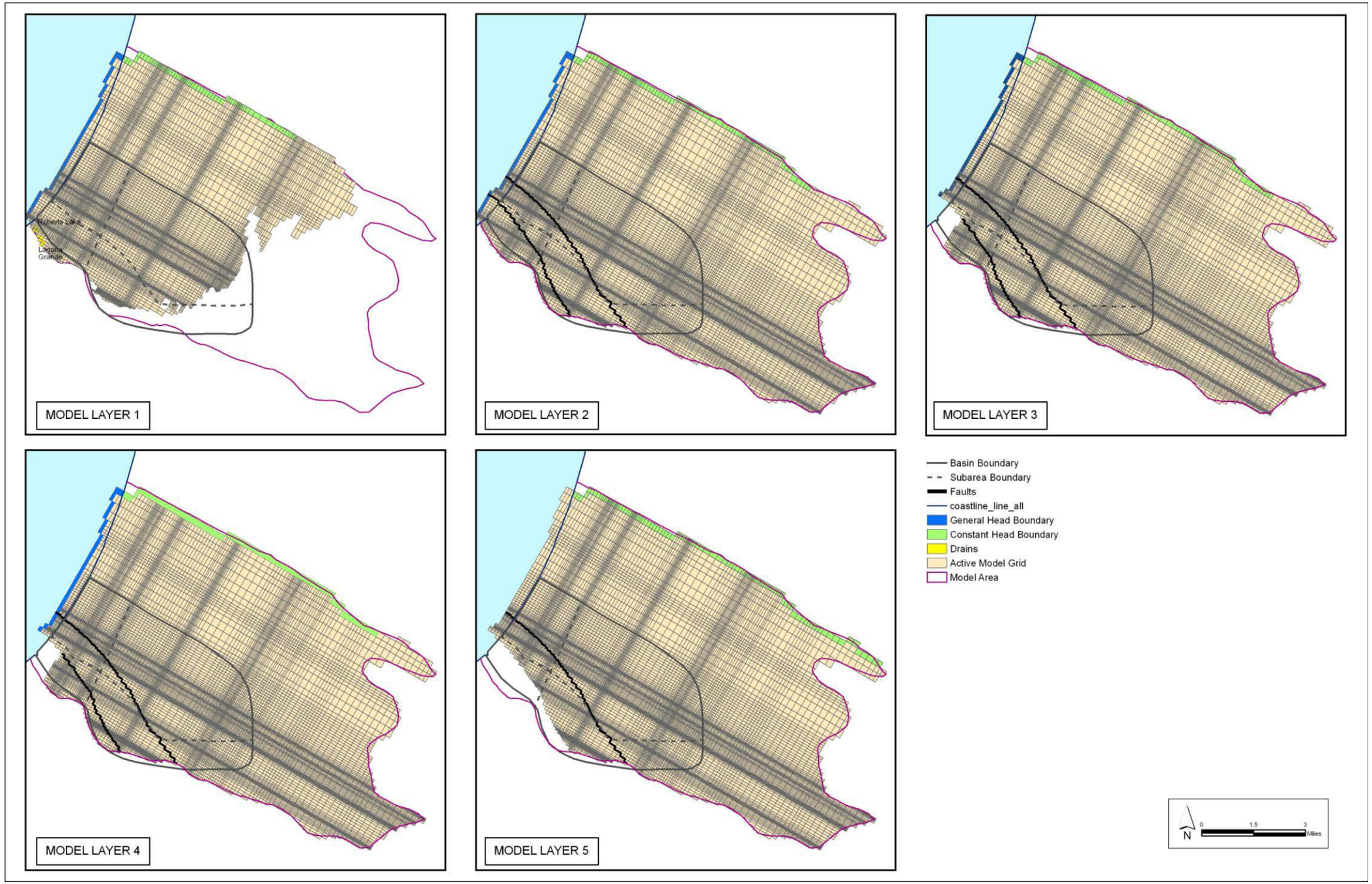


Figure 16: Model Boundary Conditions

This page left
intentionally blank

3.6 INITIAL HYDROGEOLOGIC PARAMETERS

The groundwater model software requires hydrogeologic parameters be assigned to every active cell in the model domain. Required hydrogeologic parameters may include horizontal conductivity or transmissivity, vertical hydraulic conductivity, and storage coefficients.

Limited site-specific hydrogeologic parameter exist: the data are summarized in Section 2.4. Previous modeling attempts have assigned single parameter values to entire model layers, or used only limited parameters in each model layer (Durbin, 2007; Yates et al., 2005). Following the example of previous models, only a limited range of hydrologic parameters were initially assigned to model layers. Complexity and a wider range of hydrologic parameters were introduced during calibration, as necessary. The initial hydrologic parameters are summarized in Table 5.

Table 5: Initial Hydrogeologic Parameters

Model Layer	Aquifer	Horizontal K (feet/day)	Vertical K (feet/day)	Specific Yield (unitless)	Specific Storage ($feet^{-1}$)
1	Aromas Red Sands	20	0.1	0.12	0.0001
2	Upper Paso Robles	2, 5, 20	0.02, 0.1	0.12	0.0001
3	Middle Paso Robles	2, 5, 20	0.02, 0.1	0.12	0.0001
4	Lower Paso Robles	2, 10, 20	0.001, 0.02, 0.1	0.12	0.0001
5	Santa Margarita and Purisima	2, 10, 80	0.0001, 0.01, 0.02	0.12	0.0001

K = hydraulic conductivity

3.7 MODEL WATER BALANCE

Specific elements of the water balance described in the conceptual model section are simulated using the MODFLOW recharge and well packages. Flow across boundaries is incorporated through the boundary conditions described previously. Special considerations for both the recharge and well inputs are described below.

3.7.1 DEEP GROUNDWATER RECHARGE

The sources of deep recharge to groundwater in the model area include percolation of rainfall, return flows from municipal, domestic and golf course irrigation, recharge through stormwater ponds, and system losses. Recharge from streams was assumed to be negligible (Yates et al., 2005); as was return flow from agricultural irrigation, which occurs minimally within the model area. Details of the techniques used to estimate deep recharge are included in Appendix A.

Figure 17 shows the average annual distribution of recharge in the numerical model over the model period. This distribution is based on data discussed in Section 2. Seasonal variation of recharge is shown in Figure 18. This figure shows how summer recharge is dependent on system losses and irrigation return flow, and is therefore concentrated in urban areas. Winter recharge is dependent on rainfall, and is therefore heavier in non-urban areas where there is limited or no runoff. The areas showing recharge greater than 20 inches on these two figures are stormwater ponds. These ponds collect stormwater from larger watersheds, and therefore have unusually high recharge rates.

Figure 19 shows the annual variation in deep groundwater recharge estimated for the Seaside Groundwater Basin portion of the model. This graph shows significant variation in the annual amount of deep groundwater recharge mostly due to annual changes in rainfall. The average annual recharge is 3,356 acre-feet per year; similar to previous estimates developed by Yates et al. (2002) and CH2M Hill (2004).

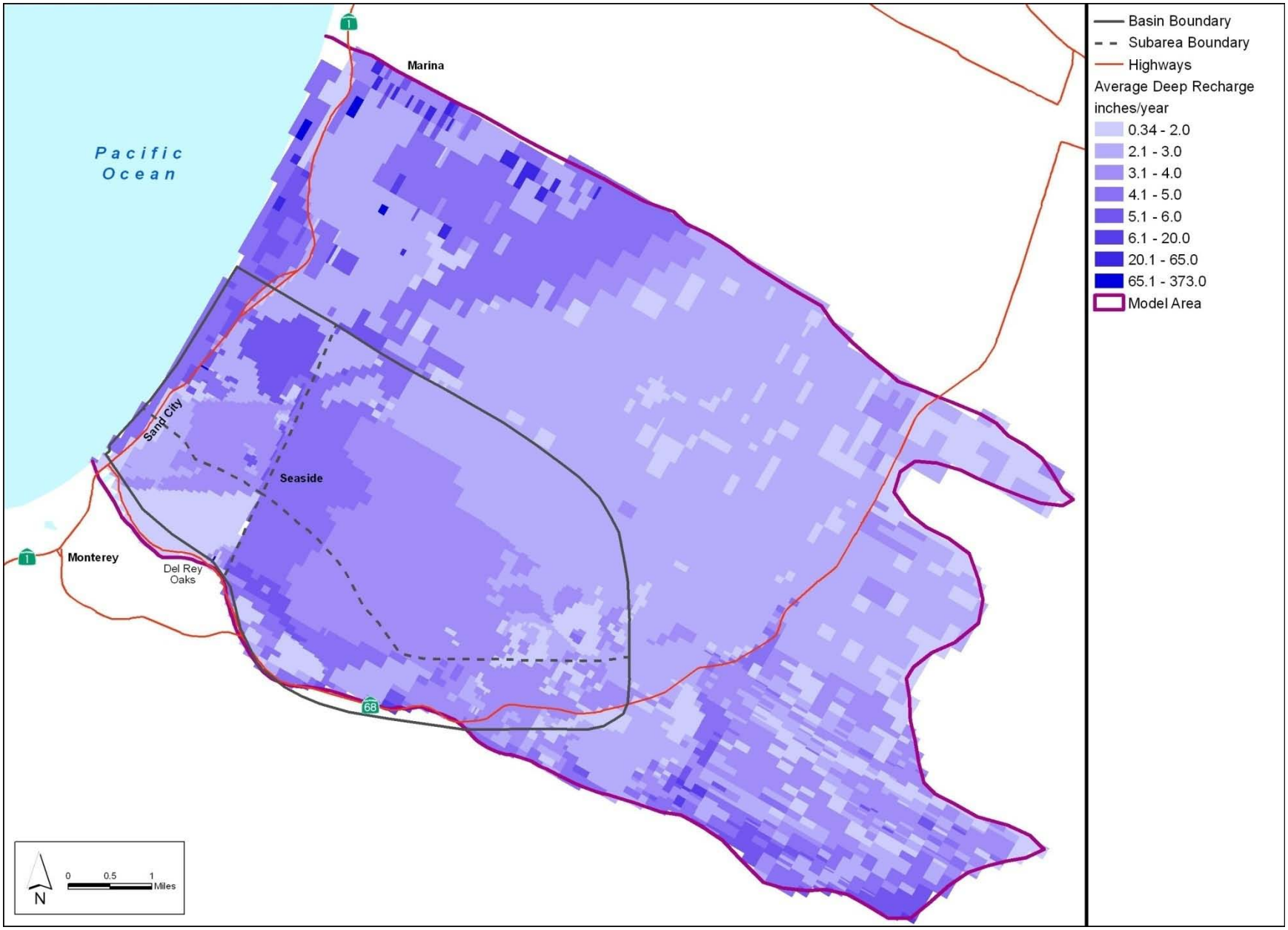


Figure 17: Average Annual Distribution of Deep Groundwater Recharge

This page left
intentionally blank

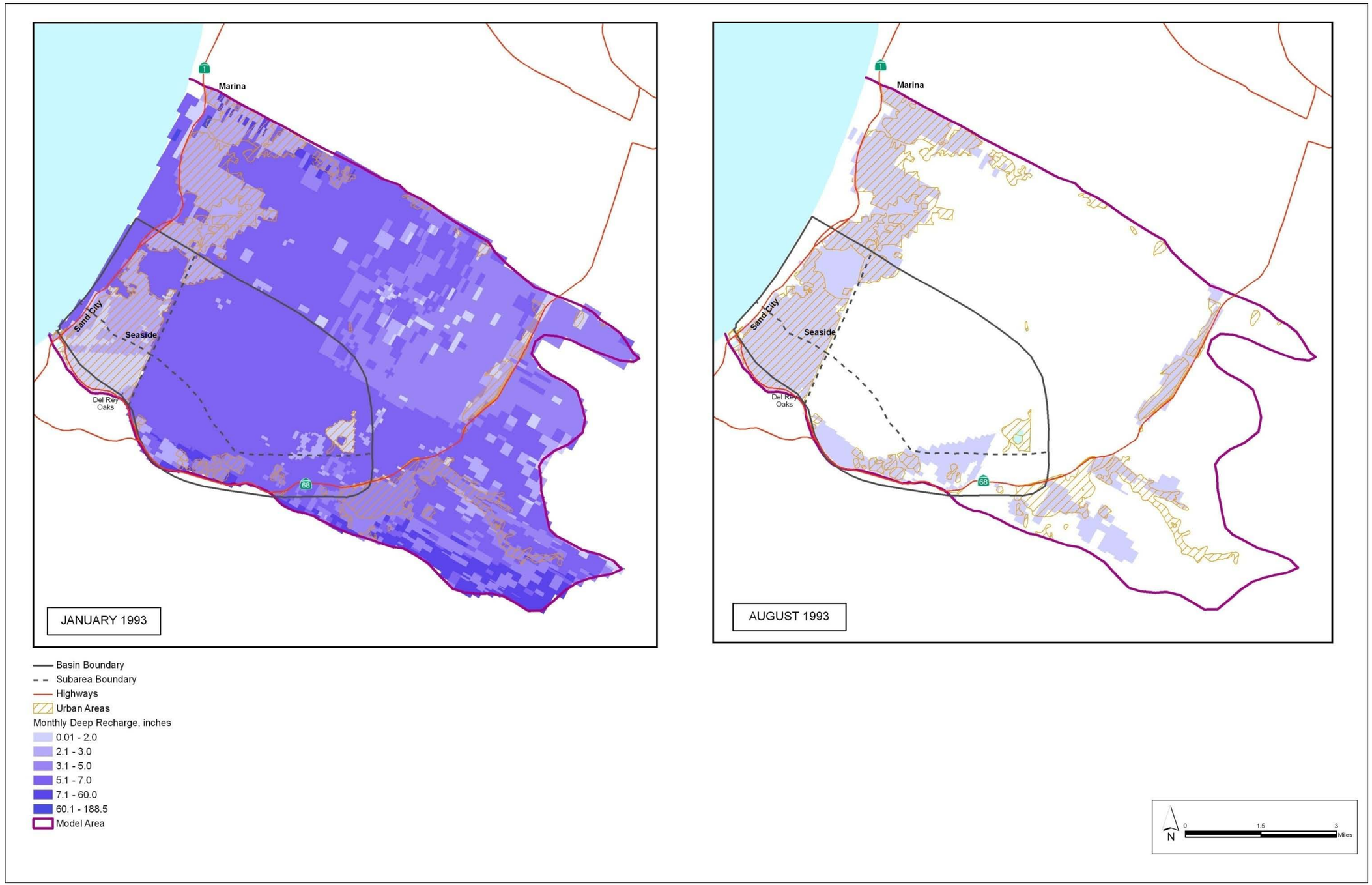


Figure 18: Example Seasonal Variation of Deep Groundwater Recharge

This page left
intentionally blank

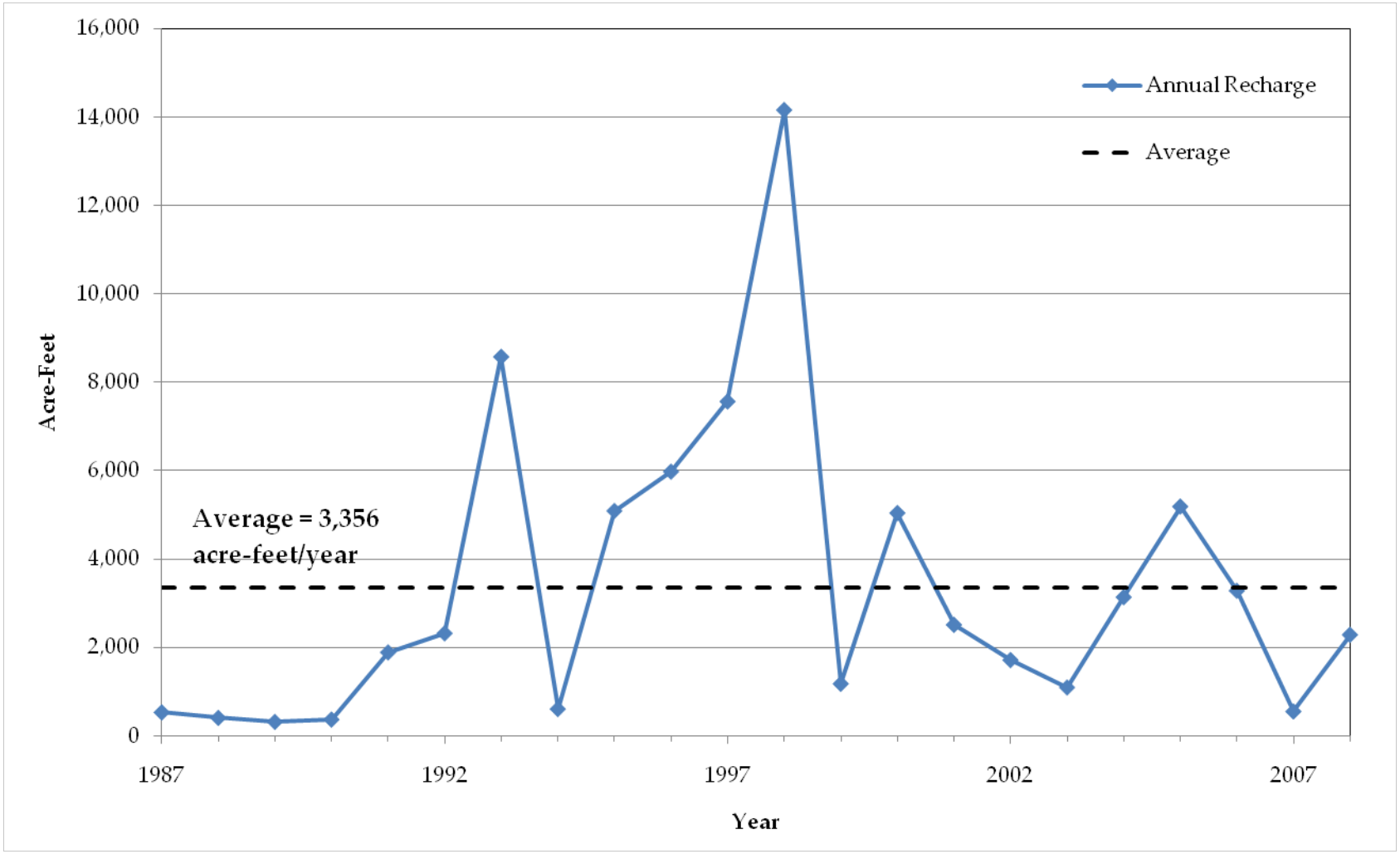
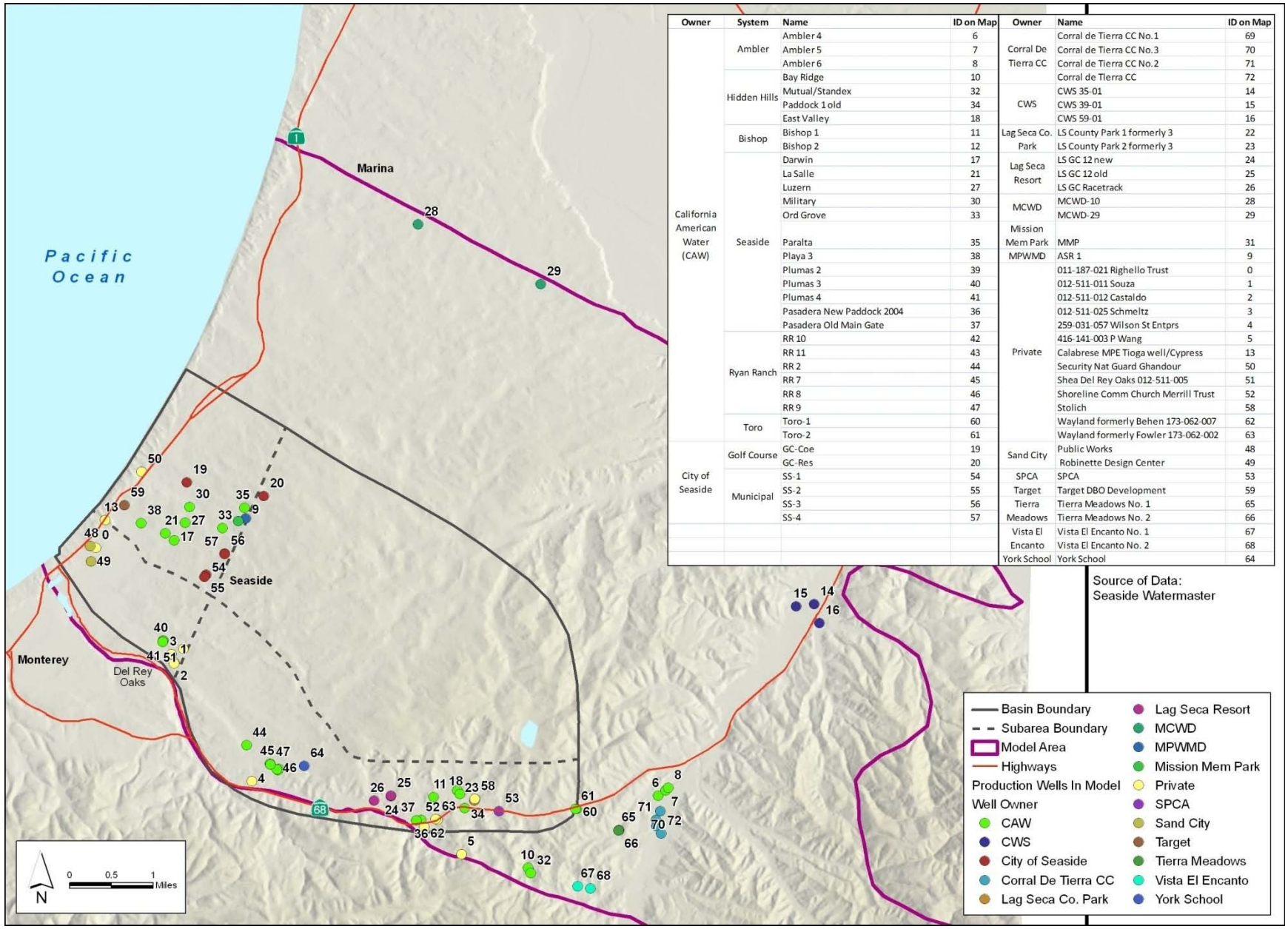


Figure 19: Annual Deep Groundwater Recharge in the Seaside Groundwater Basin

3.7.2 PUMPING DATA

Figure 20 shows the locations of pumping wells used in the regional model. Monthly production data were provided by MPWMD for wells under the Watermaster's jurisdiction. CAW, City of Seaside, MCWD, and CWS also provided monthly data that was used to supplement the MPWMD data. Where annual data were provided in the absence of monthly data, the historical monthly distribution for that particular well, or a distribution provided by MPWMD was used to distribute the annual production data into months. For years where no data were available but it was confirmed that the well was operating, the long term annual average production was used and distributed by monthly trends. It was noted that groundwater production in the Fort Ord and Seaside area was reduced after the closure of Fort Ord in 1994.

Production was assigned to the appropriate model layer based on a combination of screen elevation, and hydrograph behavior. Use of hydrographs was possible as there are distinct groundwater level patterns observed in wells screened in the Paso Robles and Santa Margarita aquifers.



Owner	System	Name	ID on Map
California American Water (CAW)	Ambler	Ambler 4	6
		Ambler 5	7
		Ambler 6	8
	Hidden Hills	Bay Ridge	10
		Mutual/Standex	32
		Paddock 1 old	34
		East Valley	18
	Bishop	Bishop 1	11
		Bishop 2	12
	Seaside	Darwin	17
		La Salle	21
		Luzern	27
		Military	30
		Ord Grove	33
		Paralta	35
		Playa 3	38
		Plumas 2	39
		Plumas 3	40
		Plumas 4	41
		Pasadera New Paddock 2004	36
		Pasadera Old Main Gate	37
	Ryan Ranch	RR 10	42
		RR 11	43
		RR 2	44
		RR 7	45
		RR 8	46
		RR 9	47
	Toro	Toro-1	60
		Toro-2	61
City of Seaside	Golf Course	GC-Coe	19
		GC-Res	20
	Municipal	SS-1	54
		SS-2	55
		SS-3	56
		SS-4	57

Owner	Name	ID on Map
Corral De Tierra CC	Corral de Tierra CC No.1	69
	Corral de Tierra CC No.3	70
	Corral de Tierra CC No.2	71
	Corral de Tierra CC	72
CWS	CWS 35-01	14
	CWS 39-01	15
	CWS 59-01	16
Lag Seca Co. Park	LS County Park 1 formerly 3	22
	LS County Park 2 formerly 3	23
Lag Seca Resort	LS GC 12 new	24
	LS GC 12 old	25
	LS GC Racetrack	26
MCWD	MCWD-10	28
	MCWD-29	29
Mission Mem Park	MMP	31
MPWMD	ASR 1	9
Private	011-187-021 Righello Trust	0
	012-511-011 Souza	1
	012-511-012 Castaldo	2
	012-511-025 Schmeltz	3
	259-031-057 Wilson St Entprs	4
	416-141-003 P Wang	5
	Calabrese MPE Tioga well/Cypress	13
	Security Nat Guard Ghandour	50
	Shea Del Rey Oaks 012-511-005	51
	Shoreline Comm Church Merrill Trust	52
	Stolich	58
	Wayland formerly Behen 173-062-007	62
	Wayland formerly Fowler 173-062-002	63
Sand City	Public Works	48
	Robinette Design Center	49
SPCA	SPCA	53
Target	Target DBO Development	59
Tierra Meadows	Tierra Meadows No. 1	65
	Tierra Meadows No. 2	66
Vista El Encanto	Vista El Encanto No. 1	67
	Vista El Encanto No. 2	68
York School	York School	64

Figure 20: Location of Production Wells Used in Model

This page left
intentionally blank

SECTION 4
MODEL CALIBRATION

4.1 APPROACH

Calibrating the regional groundwater flow model involved successive attempts to match model output to measured data from the calibration period. Simulated hydraulic heads were compared against available observed groundwater elevations. The model was considered calibrated when simulated results matched the measured data within an acceptable measure of accuracy, and when successive calibration attempts did not notably improve the calibration statistics. Calibration was conducted by varying relatively uncertain and sensitive parameters such as horizontal and vertical hydraulic conductivities, over a reasonable range of values.

4.2 CALIBRATION PERIOD

The primary criterion for choosing the appropriate calibration period was the availability of a relatively complete set of data. The necessary data included complete pumping data, recharge data, and groundwater elevation data from the network of groundwater monitoring wells. Taking into account these criteria, it was decided together with the TAC, for the calibration period to extend from January 1987 through December 2008.

4.3 STRESS PERIODS

Stress periods define a time period in the groundwater model over which hydraulic stresses such as pumping and recharge are held constant. Stress period selection depends on the model objectives and the time frame of interest. The primary objective of the model is to assist with groundwater management strategies and simulating impacts from potential water projects. Because seasonal fluctuations in groundwater elevations are important in groundwater management, the stress periods must be at least seasonal. Based on the existing data and model objectives, monthly stress periods were chosen. These stress periods allow adequate resolution of seasonal groundwater level fluctuations while performing the simulations in a reasonable amount of time.

Stress periods can be subdivided into separate time steps in MODFLOW. In the current model, each stress period is divided into five time steps. This was done to assure that the model code converged with an acceptably small error.

4.4 PILOT POINT METHOD FOR MODEL CALIBRATION

A pilot point approach, rather than a zoned conductivity approach, was used to distribute aquifer parameters during calibration. The pilot point approach results in a smoothly varying hydraulic conductivity field. Doherty (2003) describes the methodology for the use of pilot points in groundwater model calibration. Using this method, the values of aquifer hydraulic properties are estimated at the locations of a number of points spread throughout the model domain. Hydraulic properties are then assigned to the model grid through spatial interpolation from those points (Doherty, 2007). Spatial interpolation from pilot points to the finite difference grid defines a hydraulic property array on a cell-by-cell basis. As a result of using pilot points for spatial parameterization, we did not need to guess where unmapped heterogeneity might exist within a model domain ahead of the calibration process. Instead, the calibration process informs where heterogeneity exists.

Prior to estimating any hydraulic parameters, the pilot points were selected manually based on following criteria (Doherty, 2002):

1) More pilot points were placed where there are more data;
2) Pilot points were placed between data points in order to calibrate to head difference between wells;
3) Pilot points were placed in between wells and outflow boundaries.
4) Pilot points were placed to eliminate big gaps between adjacent pilot points;

For the regional model, 40-50 pilot points were selected for each layer. The plotted pilot points are created for horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific storage. Layer 1 was treated as homogeneous, with one uniform value for the three hydraulic properties used for the layer. This was a reasonable assumption because only one target monitoring well is located in layer 1. The locations of the pilot points for layers 2-5 are shown on Figure 21. Spatial interpolation was performed separately for each area bounded by faults using pilot points in that area. The initial values for

the pilot points were based on values obtained during a preliminary manual calibration.

The use of pilot points methodology results in over 600 parameter values that can be varied in the calibration. PEST software and its Singular Value Decomposition (SVD)-assist functionality (Watermark Numerical Computing, 2004) was used to help update the full set of parameter values and improve the calibration.

This page left
intentionally blank

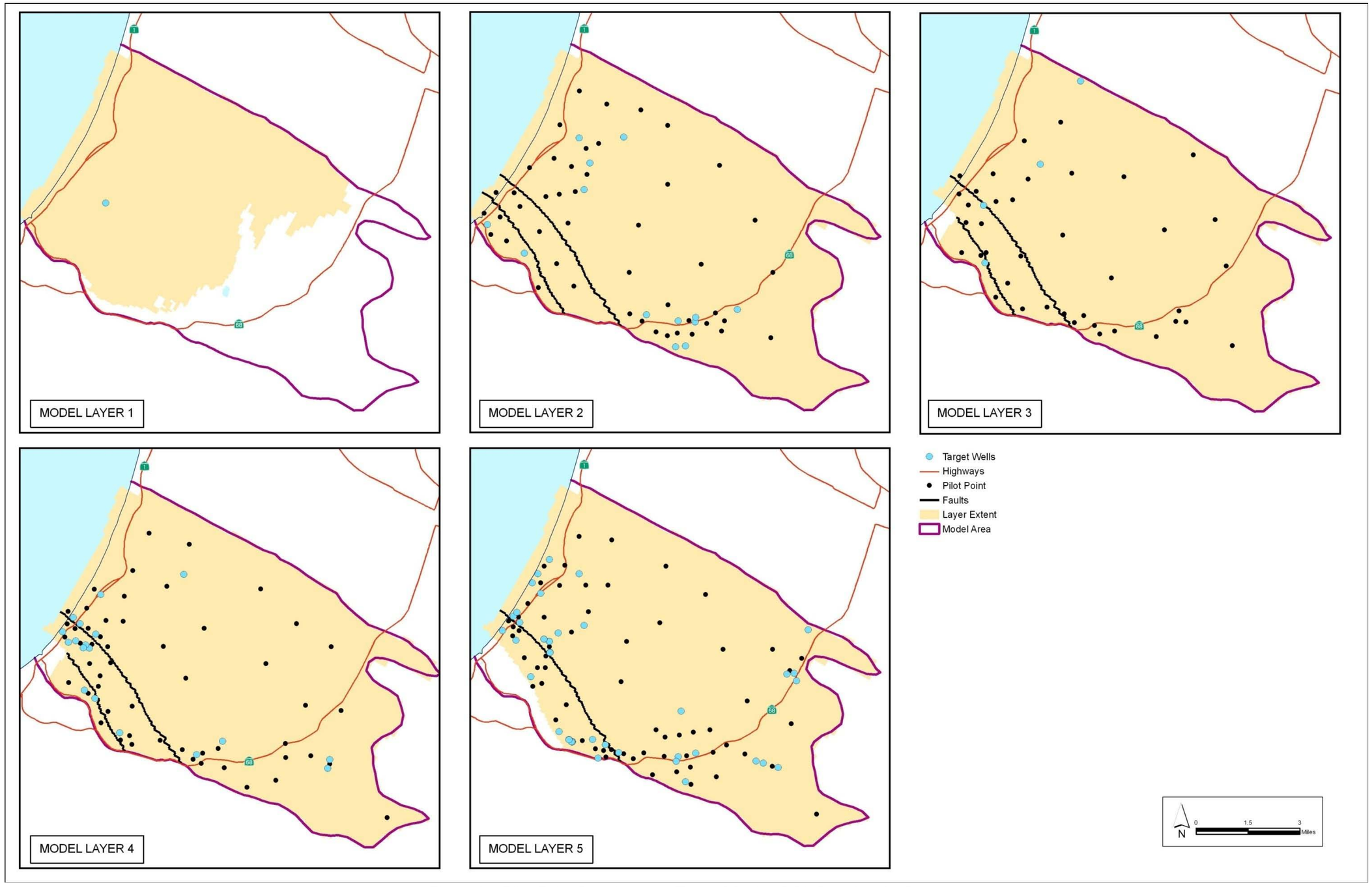


Figure 21: Pilot Point Locations and Target Monitor Well Locations by Layer

This page left
intentionally blank

4.5 CALIBRATION RESULTS

4.5.1 MODEL PARAMETER MODIFICATIONS

Model parameters are adjusted during model calibration to improve the model's ability to simulate known conditions. Calibration of the model consisted of modifying the distribution and magnitude of horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific storage values using the pilot point method discussed above. The final distributions of the aquifer parameter values are shown for each of the five model layers in Figure 22 through Figure 24.

The fault conductance was relatively insensitive because the thickness of units and hydraulic conductivity of the units was allowed to change across faults. Therefore, groundwater levels could be simulated with lithologic changes as well as fault conductances. The calibrated value for the Ord Terrace Fault hydraulic conductivity is 2.6 feet per day, assuming a one-foot thick fault. The calibrated value for the Seaside Fault conductance is 0.1 feet per day, assuming a one-foot thick fault. Both of these values are lower than the surrounding aquifer material.

4.5.2 GROUNDWATER ELEVATION CALIBRATION

Flow model calibration is commonly evaluated by comparing simulated water elevations with observed groundwater elevations from monitoring and production wells. Hydrographs of simulated groundwater elevations should generally match the trends and fluctuations observed in measured hydrographs. Furthermore, the average errors between observed and simulated groundwater elevations should be relatively small and unbiased. The target well locations used for calibration of the regional groundwater flow model are shown in Figure 25. For wells screened over multiple model layers, simulated groundwater levels in each of the layers are weighted by layer transmissivity and averaged before comparing with measured data.

This page left
intentionally blank

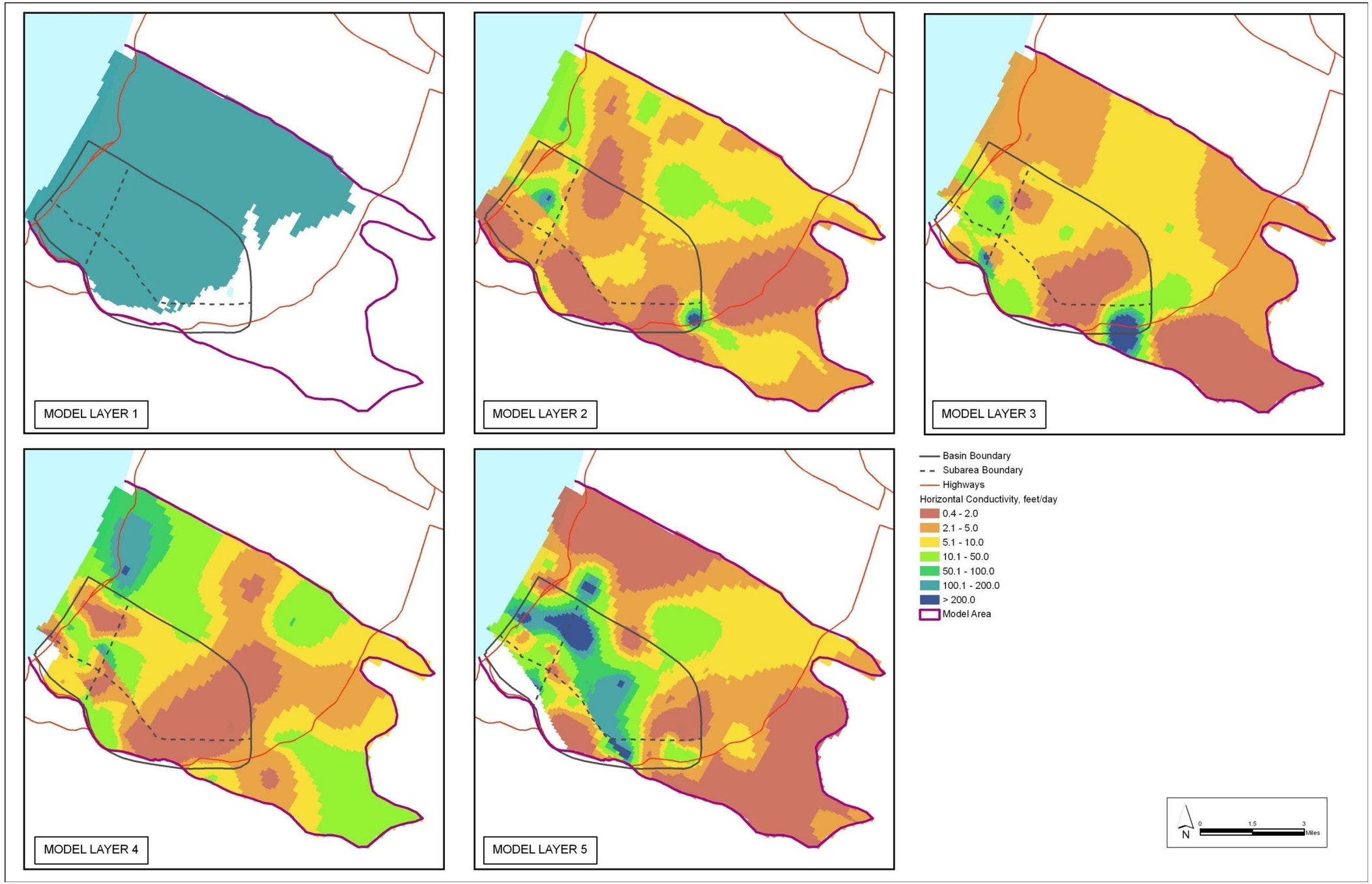


Figure 22: Final Distribution of Horizontal Hydraulic Conductivity by Layer

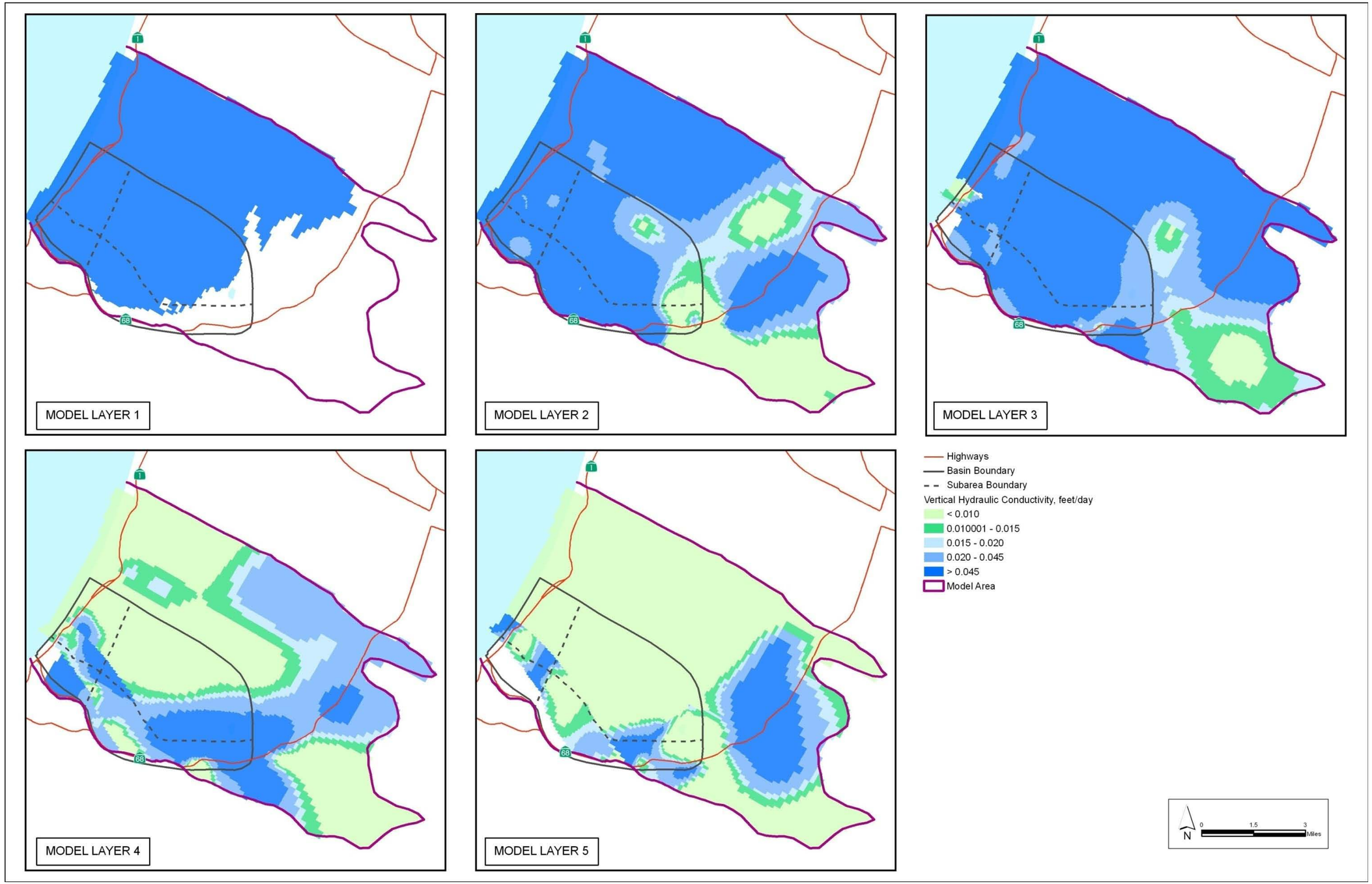


Figure 23: Final Distribution of Vertical Hydraulic Conductivity by Layer

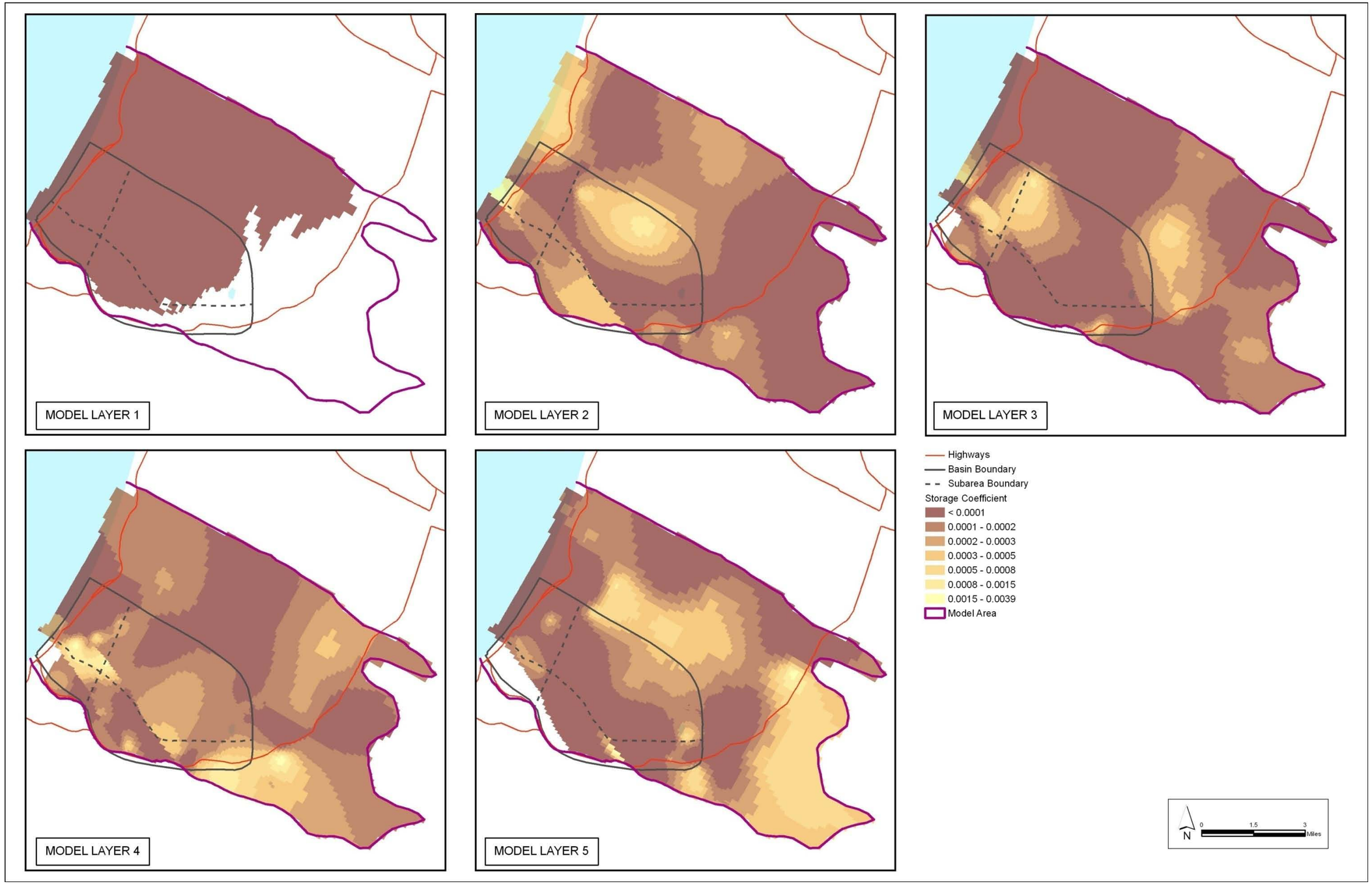


Figure 24: Final Distribution of Specific Storage by Layer

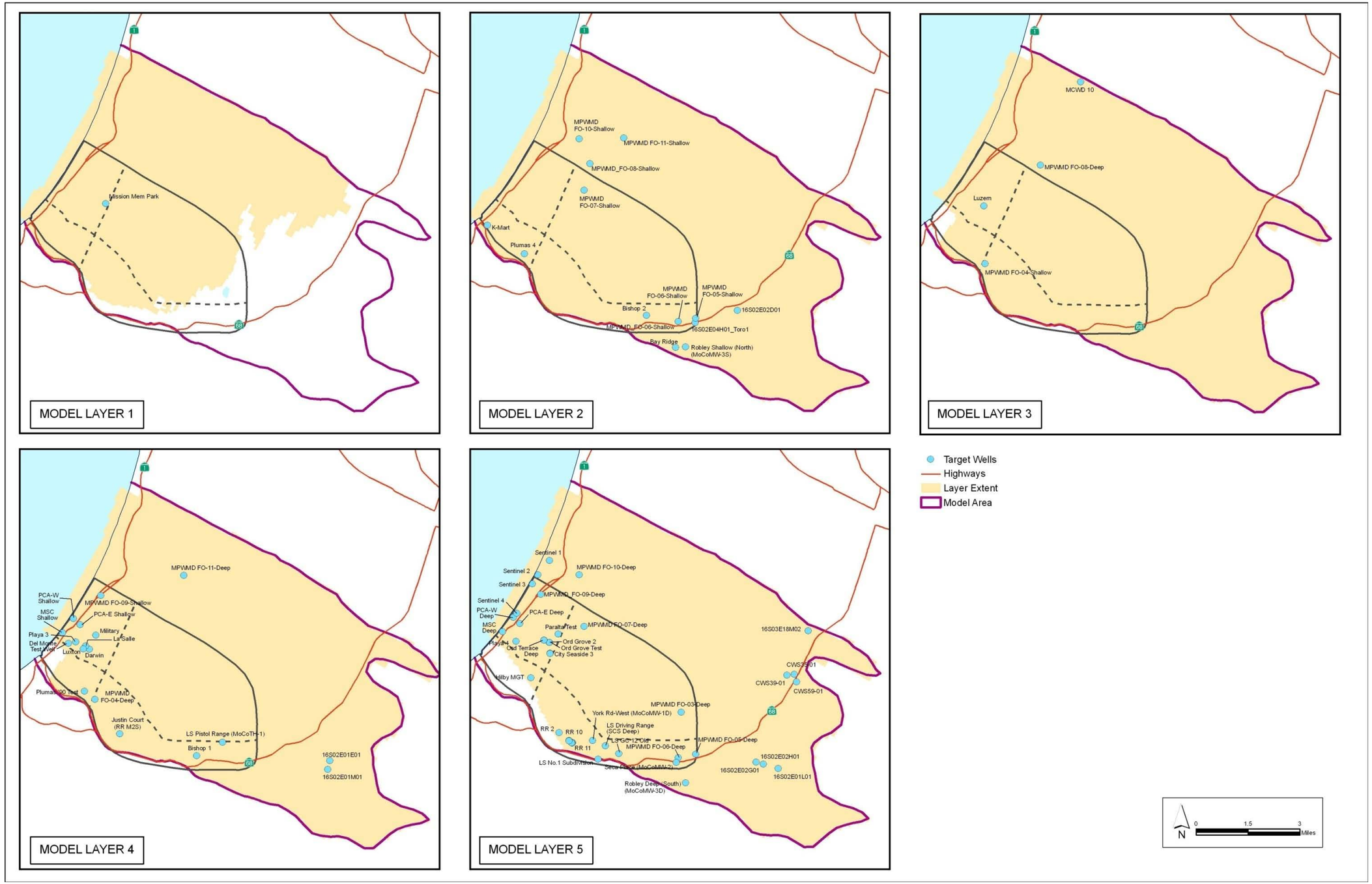


Figure 25: Target Well Locations by Layer Used for Calibration

Example maps of simulated piezometric surfaces for each model layer are displayed on Figure 26. Example hydrographs showing both observed and simulated groundwater elevations are shown in Figure 27 through Figure 30. These example hydrographs were chosen to demonstrate the model's accuracy in various parts of the Seaside Groundwater Basin. The hydrographs show that the model accurately simulates both the magnitude of groundwater fluctuations and trends observed in monitoring well data. A complete set of hydrographs showing both observed and simulated groundwater elevations are included in Appendix B.

Various graphical and statistical methods can be used to demonstrate the magnitude and potential bias of the calibration errors. Figure 31 shows all simulated groundwater elevations plotted against observed groundwater elevations for all stress periods in the calibration. Results from an unbiased model will scatter around a 45º line on this graph. If the model has a bias such as exaggerating or underestimating groundwater level differences, the results will diverge from this 45º line. The line drawn on Figure 31 demonstrates that the results lie close to a 45º line, suggesting that the model results are not biased towards overestimating or underestimating average groundwater level differences.

This page left
intentionally blank

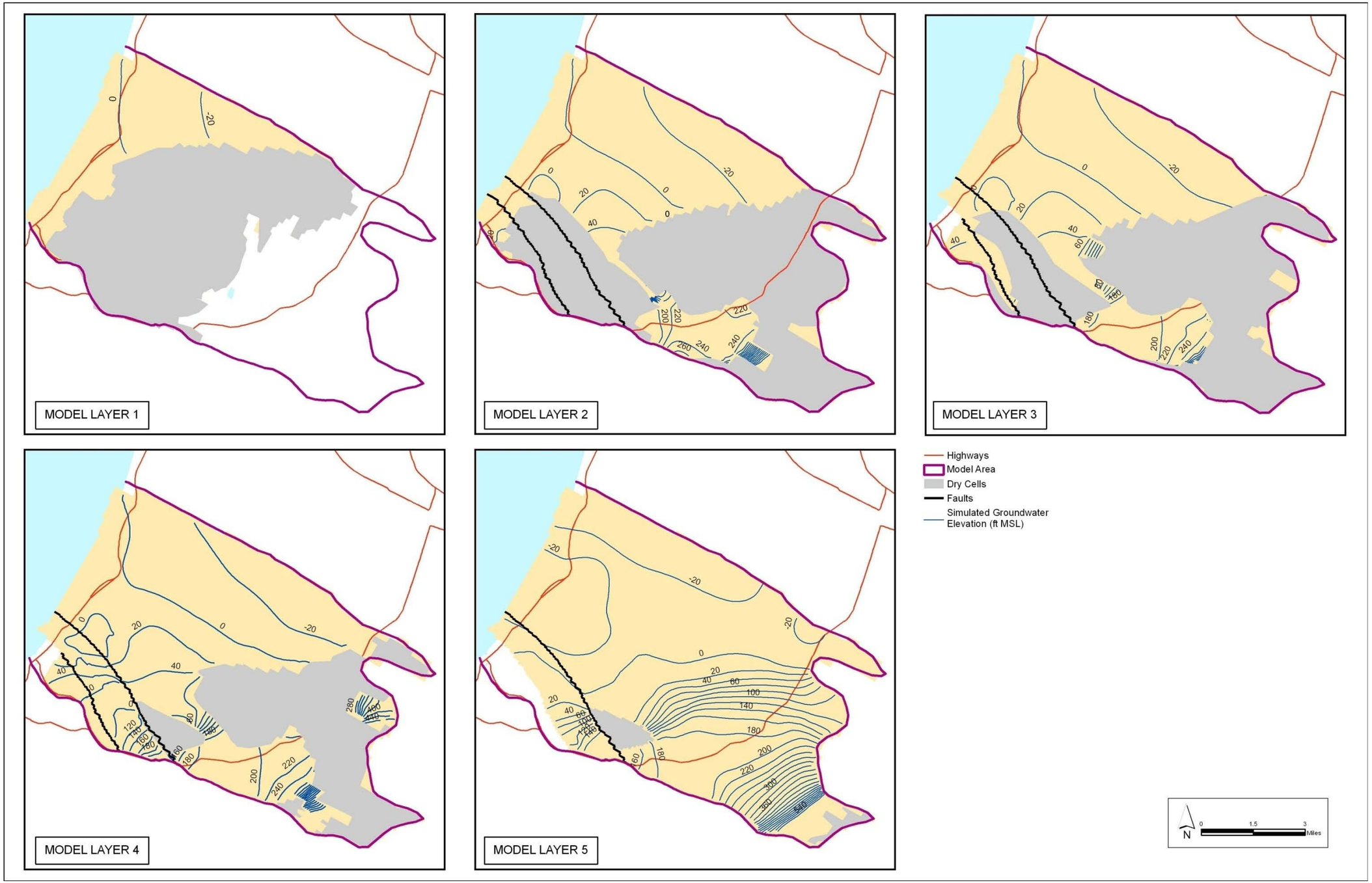


Figure 26: Simulated Piezometric Surface – December 2008

This page left
intentionally blank

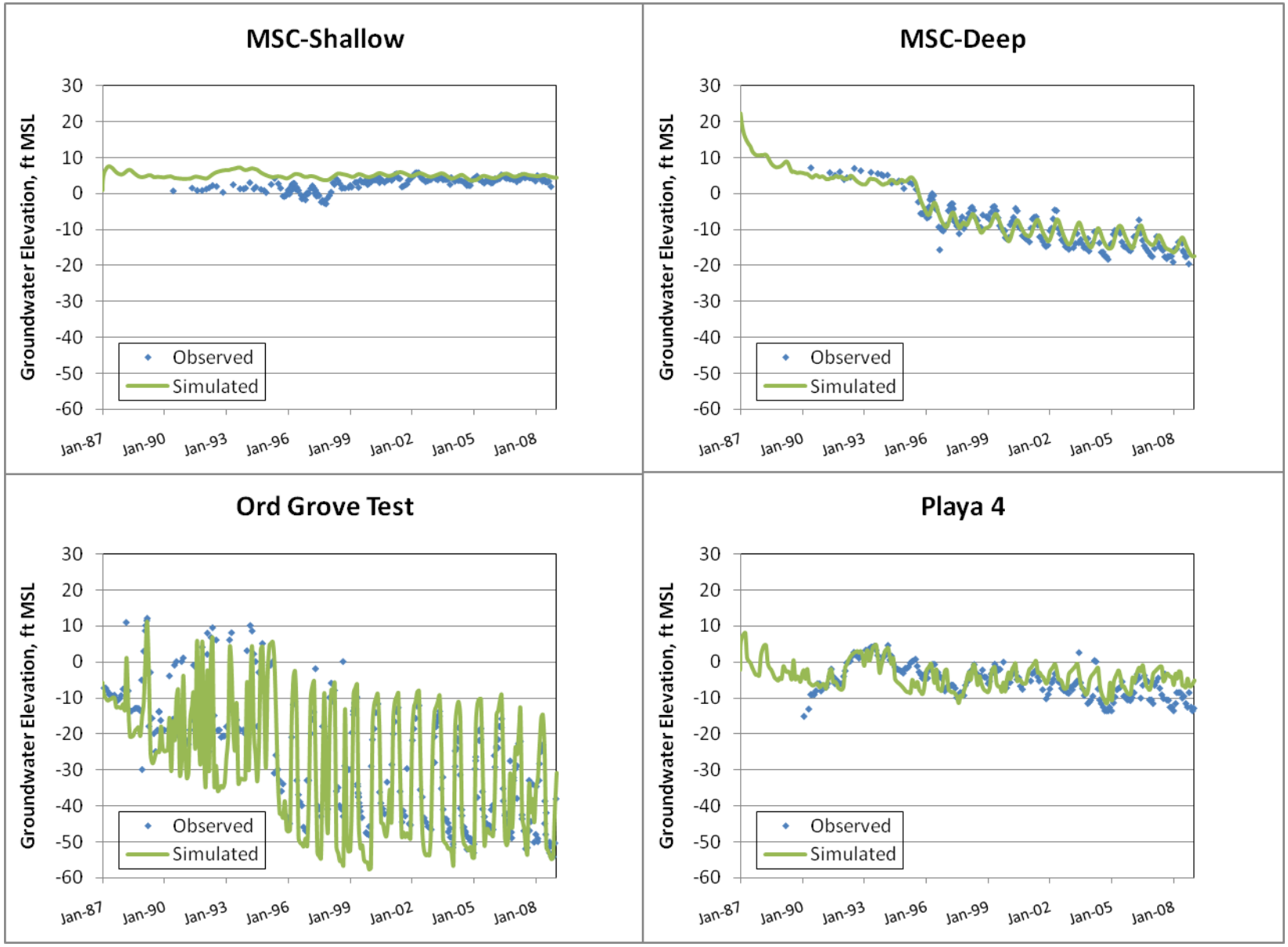


Figure 27: Calibration Hydrographs – Northern Coastal Subarea

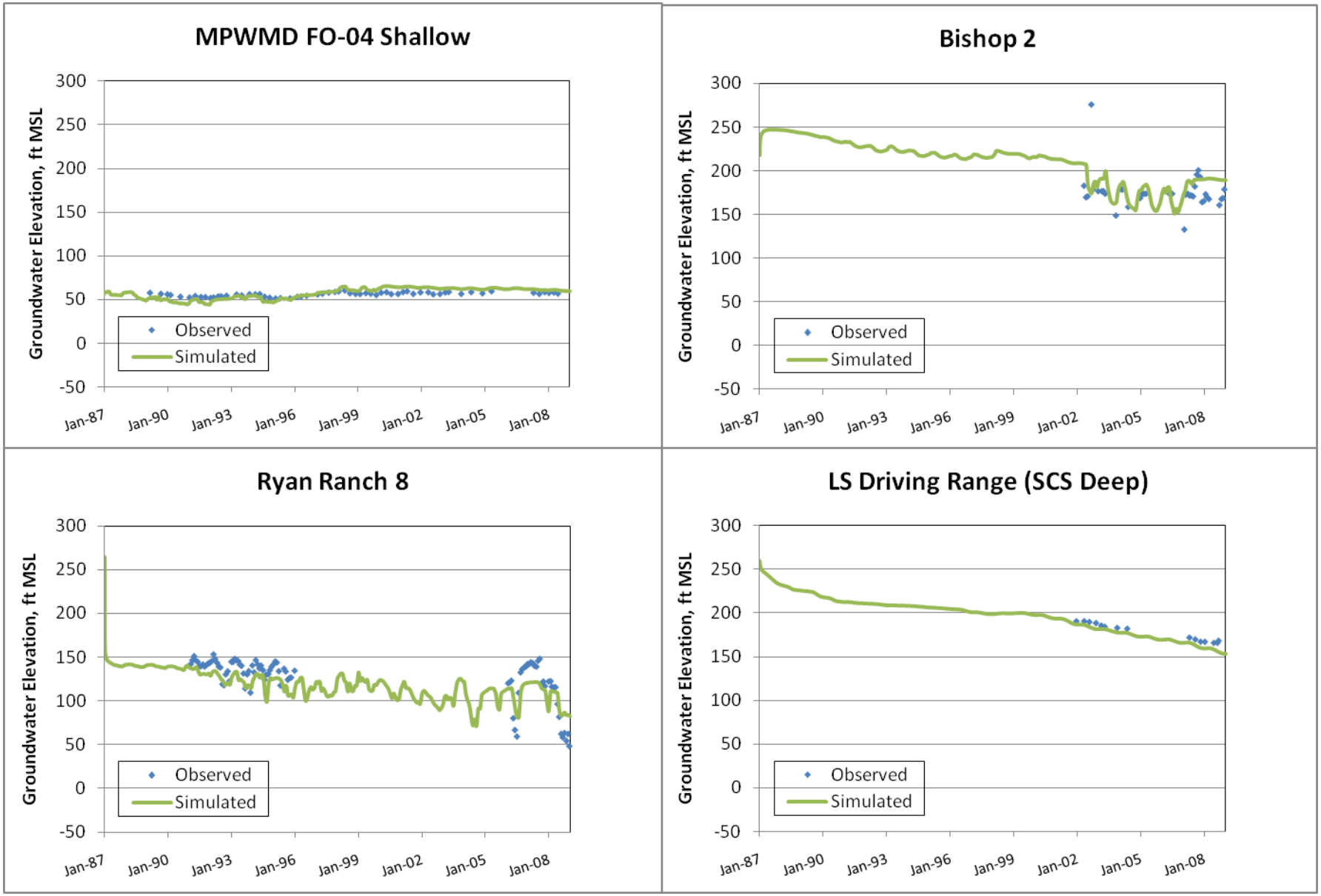


Figure 28: Calibration Hydrographs – Laguna Seca Subarea

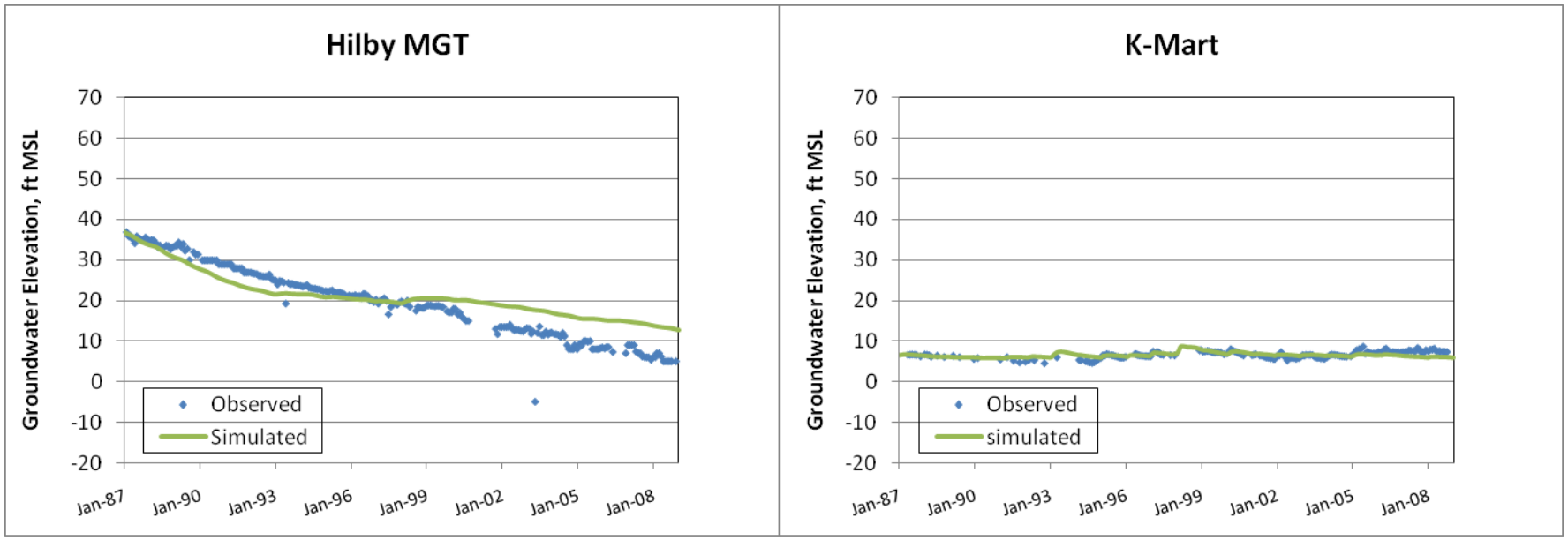


Figure 29: Calibration Hydrographs – Southern Coastal Subarea

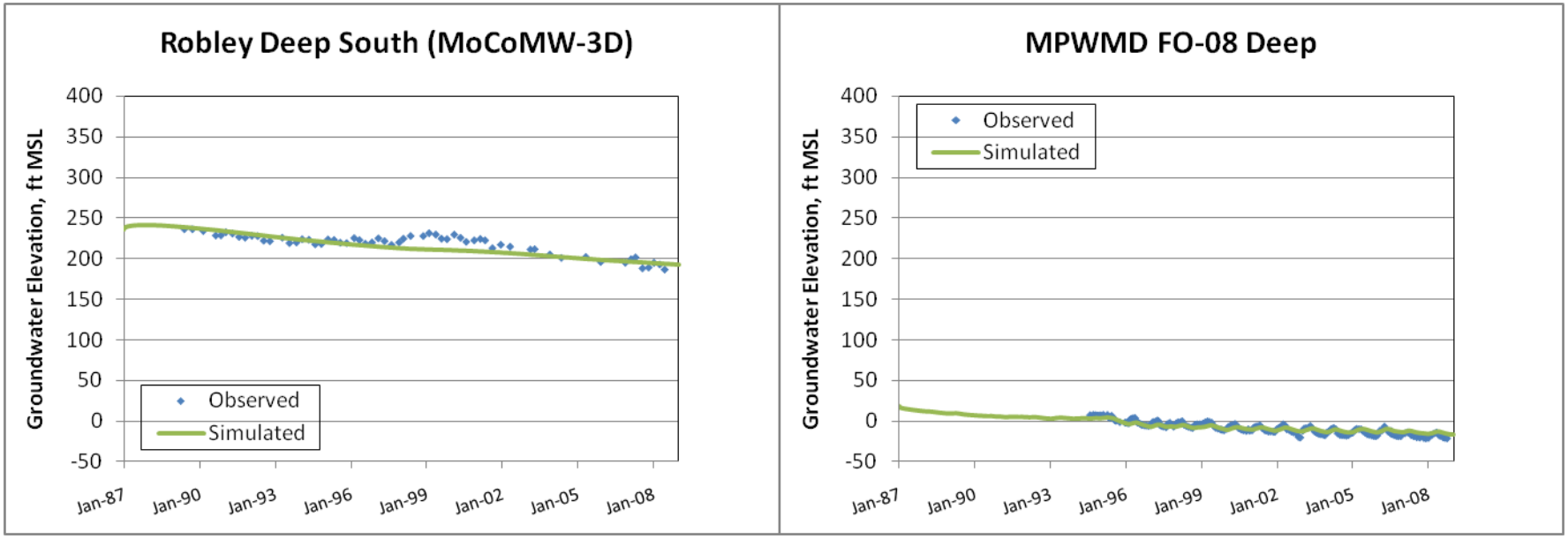


Figure 30: Calibration Hydrographs – Outside Seaside Groundwater Basin

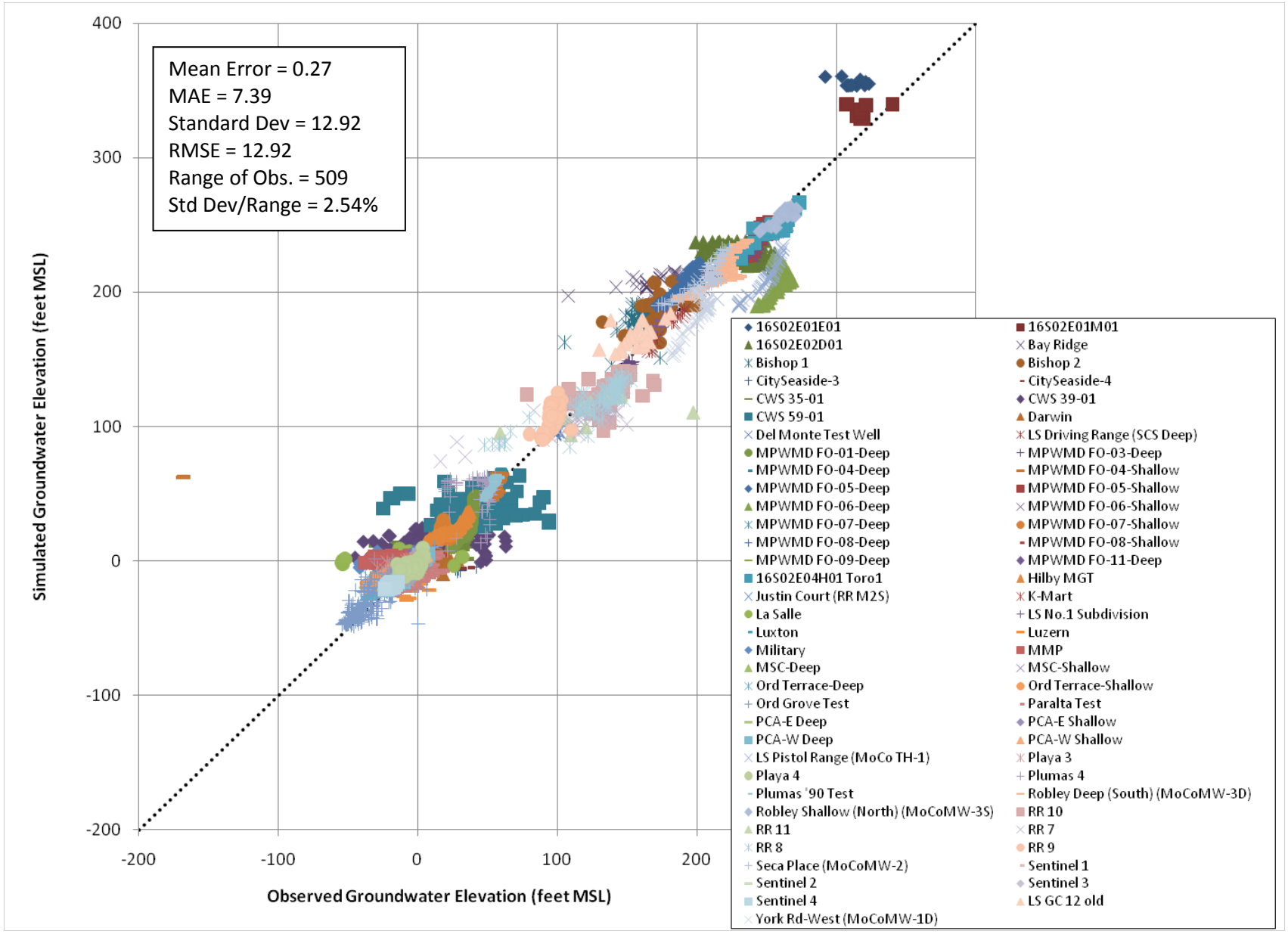


Figure 31: Simulated Versus Observed Groundwater Elevations

Figure 31 also includes various statistical measures of calibration accuracy. The four statistical measures used to evaluate calibration are the mean error (ME), the mean absolute error (MAE), the standard deviation of the errors (STD), and the root mean squared error (RMSE). The mean error is the average error between measured and simulated groundwater elevations for all data on Figure 31,

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left(h_m - h_s\right)_i$$

Where h_m is the measured groundwater elevation, h_s is the simulated groundwater elevation, and n is the number of observations.

The mean absolute error is the average of the absolute differences between measured and simulated groundwater elevations.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|h_m - h_s\right|_i$$

The standard deviation of the errors is one measure of the spread of the errors around the 45º line in Figure 31. The population standard deviation is used for these calculations

$$STD = \sqrt{\frac{n\sum_{i=1}^{n}\left(h_m - h_s\right)_i^2 - \left(\sum_{i=1}^{n}\left(h_m - h_s\right)\right)_i^2}{n^2}}$$

The RMSE is similar to the standard deviation of the error. It also measures the spread of the errors around the 45º line in Figure 31, and is calculated as the square root of the average squared errors.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(h_m - h_s\right)_i^2}$$

As a measure of successful model calibration, Anderson and Woessner (1992) state that the ratio of the spread of the errors to the total head range in the system should be small to ensure that the errors are only a small part of the overall model response. As a general rule, the standard deviation of errors should be less than 10% of the total head range in the model. The standard deviation of 16.55 is approximately 2.90% of the total head range of 571 feet. A second

general rule that is occasionally used is that the mean error should be less than 5% of the total head range in the model. The mean error of 2.18 is approximately 0.38% of the total head range. Therefore, on average, the model errors are within an acceptable range.

A second graph used to evaluate bias in model results is shown on Figure 32. This figure is a graph of observed groundwater elevations versus model residual (simulated elevation minus observed elevation). Results from a non-biased simulation will appear as a cloud of data points clustered around the zero model residual line. Results that do not cluster around the zero residual line show potential model bias. Results that display a trend instead of a random cloud of points may suggest additional model bias. The results plotted on Figure 32 show that the calibrated model results are generally unbiased.

4.5.3 GROUNDWATER DIVIDE

As another measure of how well the model matched available data, the groundwater divide in model layer 5 (Santa Margarita or deep aquifer) simulated by the regional groundwater flow model was found to closely match the deep aquifer groundwater divide derived from hand-drawn contouring of groundwater elevations (HydroMetrics LLC, 2008). Figure 33 shows the area in which the modeled groundwater divide occurred during the calibration period. This area compares well with the groundwater divide obtained from groundwater elevation contouring.

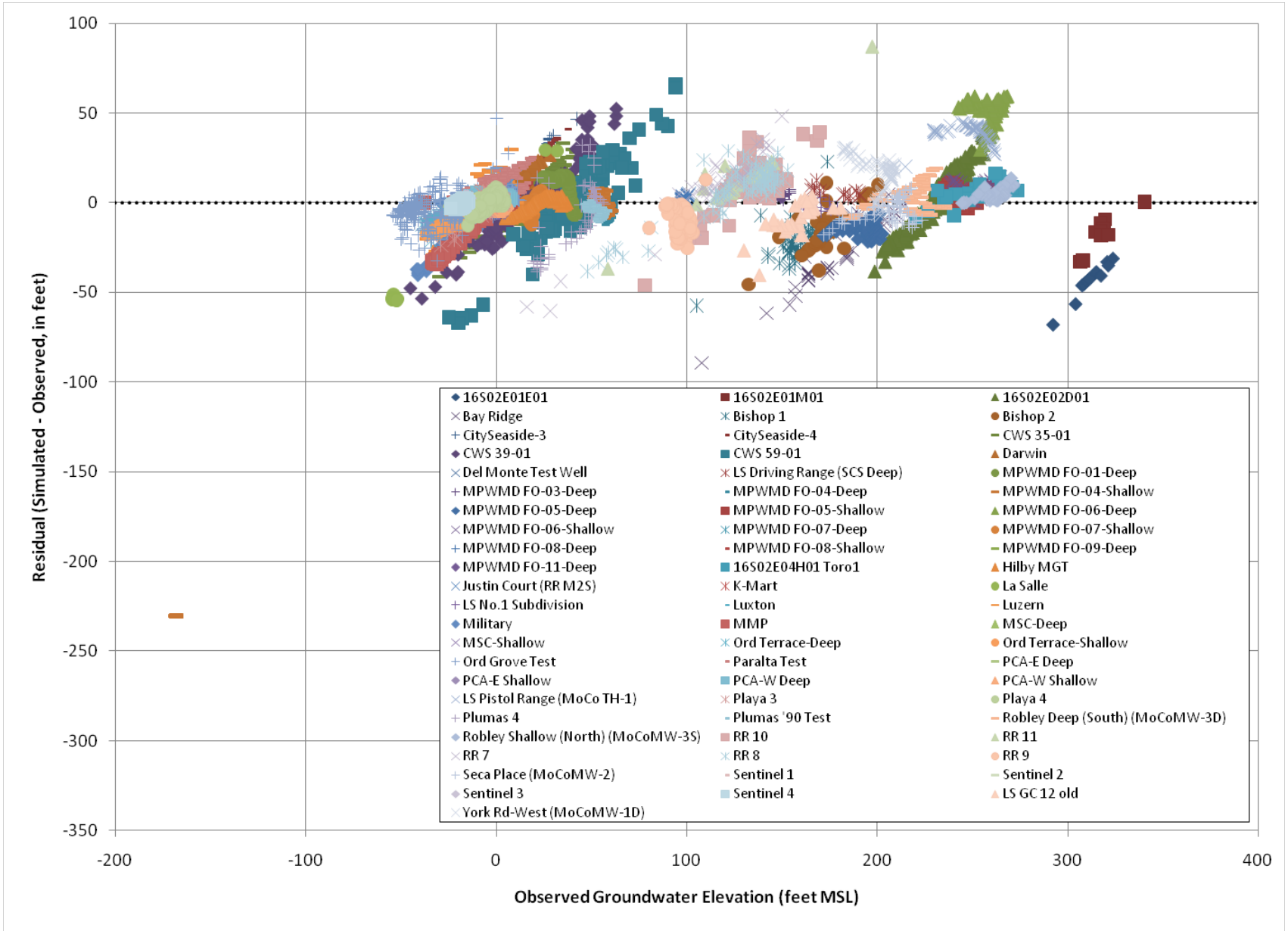


Figure 32: Observed Groundwater Elevations Versus Model Residual

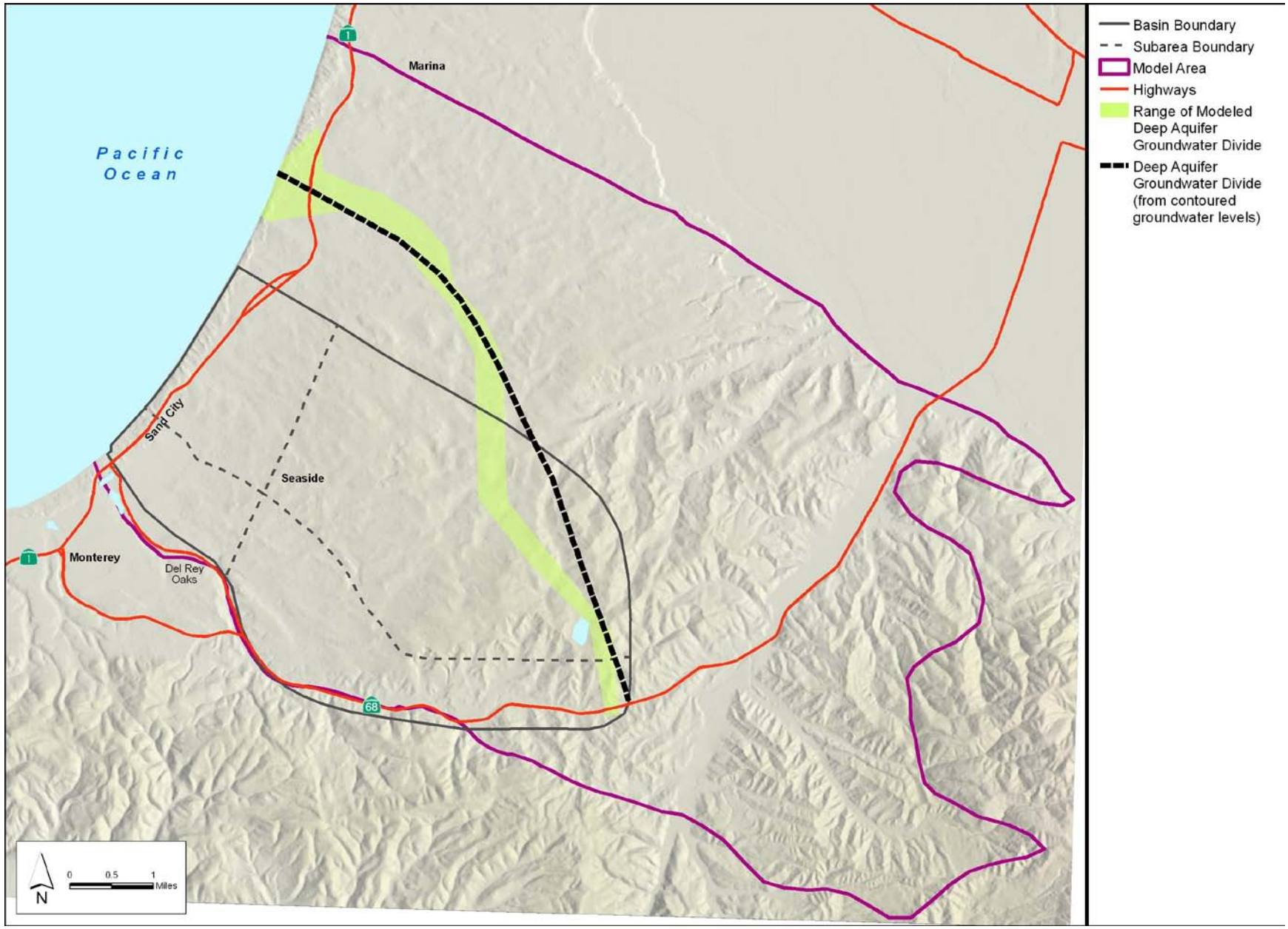


Figure 33: Comparison between Modeled Versus Contour Generated Groundwater Divides

This page left
intentionally blank

SECTION 5
MODELING FOR PROTECTIVE GROUNDWATER ELEVATIONS

One consequence of excessive long-term pumping of the Seaside Groundwater Basin is potential seawater intrusion. Seawater intrusion occurs when the freshwater-seawater interface moves onshore from beneath the ocean, into the productive aquifers of the Basin. The freshwater-seawater interface moves in response to changes in onshore groundwater elevations. Simulating the location of the interface allows us to estimate the onshore groundwater elevation that keeps the productive onshore aquifers fresh. The groundwater elevation that prevents seawater intrusion is referred to as the protective groundwater elevation. This section documents the groundwater modeling performed to estimate the protective groundwater elevations at coastal wells in the Seaside Groundwater Basin. Results from protective groundwater elevation modeling are used in **Error! Reference source not found.** as one of the evaluation criteria to determine whether the different model scenarios are able to increase groundwater elevations to protective levels.

5.1 MODELING APPROACH

The protective elevations are estimated with a series of steady-state, two-dimensional protective groundwater elevation models that are completely different from the regional flow model discussed in previous sections. The relationship between the regional groundwater flow model and the protective groundwater elevation models is shown on Figure 34.

The models for establishing protective groundwater elevations comprise four separate models representing four vertical planes through the earth extending out under the ocean. The locations of these four vertical planes are shown in Figure 35. The inland side of each protective groundwater elevation model is anchored to each of the four coastal monitoring wells selected by the TAC: CDM-MW-4, MSC, PCA-W, and SBWM-3. The protective groundwater elevation models simulate the full depth of the aquifer units and extend offshore beneath the ocean. Each protective groundwater elevation model is layered to reflect the aquifer units according to the current conceptual hydrogeologic model as described earlier in the regional model discussion (Section 2.1.1). Aquifer parameters such as hydraulic conductivity for each unit are taken from existing estimates of these parameters for the various aquifer units.

Each protective groundwater elevation model shows where the freshwater-seawater interface is located, assuming a known groundwater elevation in the associated monitoring well. The groundwater elevations in all model layers at the anchor monitoring well are systematically raised and lowered, which in turn moves the location of the seawater interface either towards the ocean or towards the inland production wells. In this way, the models can estimate protective groundwater elevations that maintain the position of the interface at a location that protects the Basin's aquifers. This location is referred to as the protective location and has been defined for each of the coastal monitoring wells as shown in Table 6.

Table 6: Protected Locations at Coastal Monitoring Wells

<table>
<tr><th>Coastal Monitoring Well</th><th>Subarea</th><th>Protected Depth</th><th>Protected Horizontal Location of Freshwater-Seawater Interface</th></tr>
<tr><td>SBWM-3</td><td>Northern Coastal (northern portion)</td><td>Extrapolated bottom of Santa Margarita in Purisima Formation</td><td rowspan="4">At the well</td></tr>
<tr><td>PCA-W</td><td rowspan="2">Northern Coastal (southern portion)</td><td rowspan="2">Bottom of Santa Margarita/Top of Monterey</td></tr>
<tr><td>MSC</td></tr>
<tr><td>CDM-MW-4</td><td>Southern Coastal</td><td>Bottom of Paso Robles/Top of Monterey</td></tr>
</table>

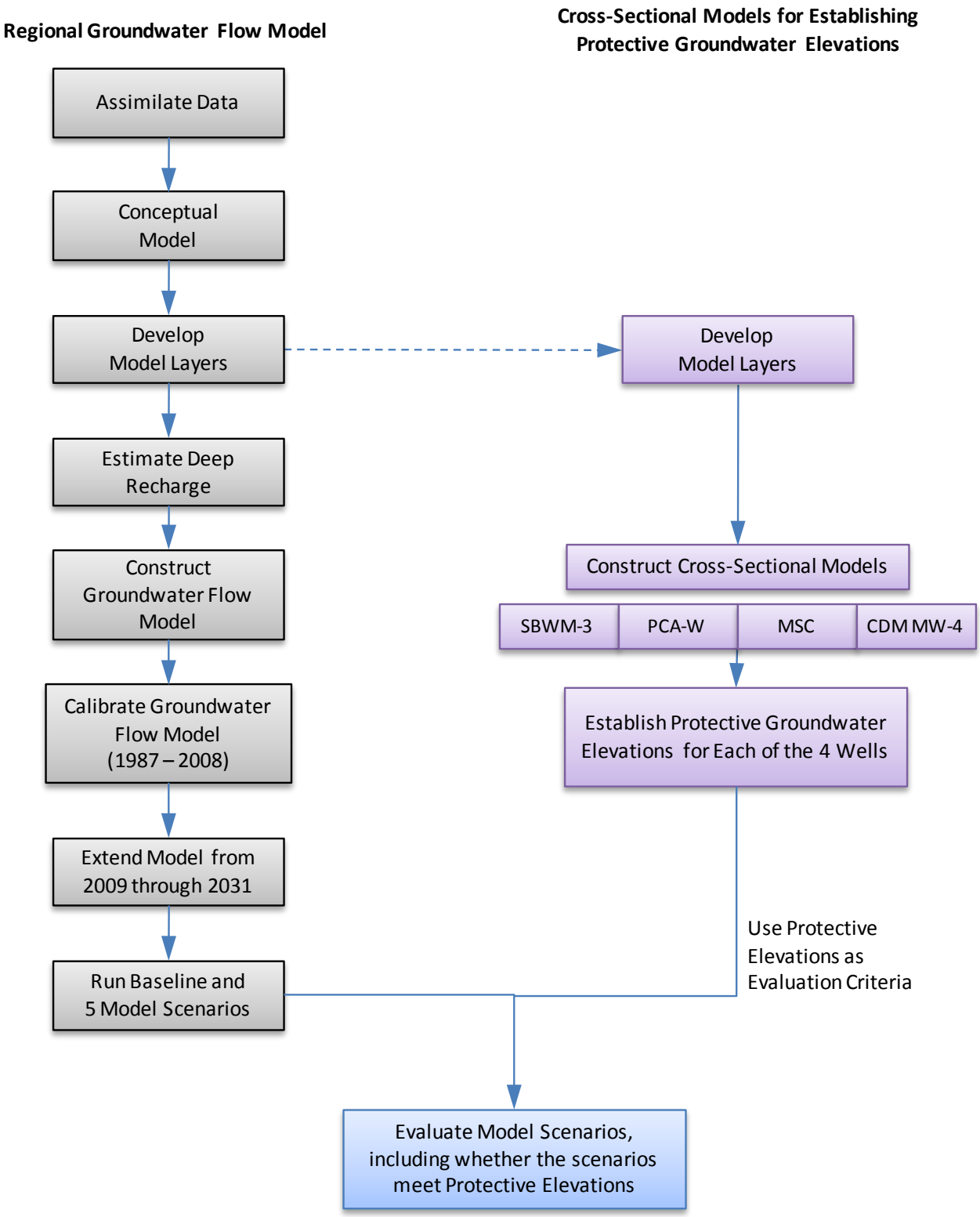


Figure 34: Relationship between Regional Groundwater Flow Model and Protective Groundwater Elevation Models

Figure 35: Cross-Section Model Locations

5.2 MODEL CONSTRUCTION

5.2.1 MODEL CODE

To establish protective groundwater elevations, a variable density groundwater flow and transport model was used. The model code SEAWAT 2000 (Guo and Langevin, 2002) was selected for the groundwater flow and transport model. SEAWAT 2000 is well documented and benchmarked and is a public domain code developed by the U.S. Geological Survey.

5.2.2 FINITE DIFFERENCE GRID

Figure 36 shows an example finite difference grid used by SEAWAT 2000 for a protective groundwater elevation model. Four of these finite difference grids were created, one specific to each of the cross-sections. The grids are two dimensional and are oriented in a vertical plane. The two-dimensional vertical grid assumes that groundwater flows directly offshore, perpendicular to the shoreline.

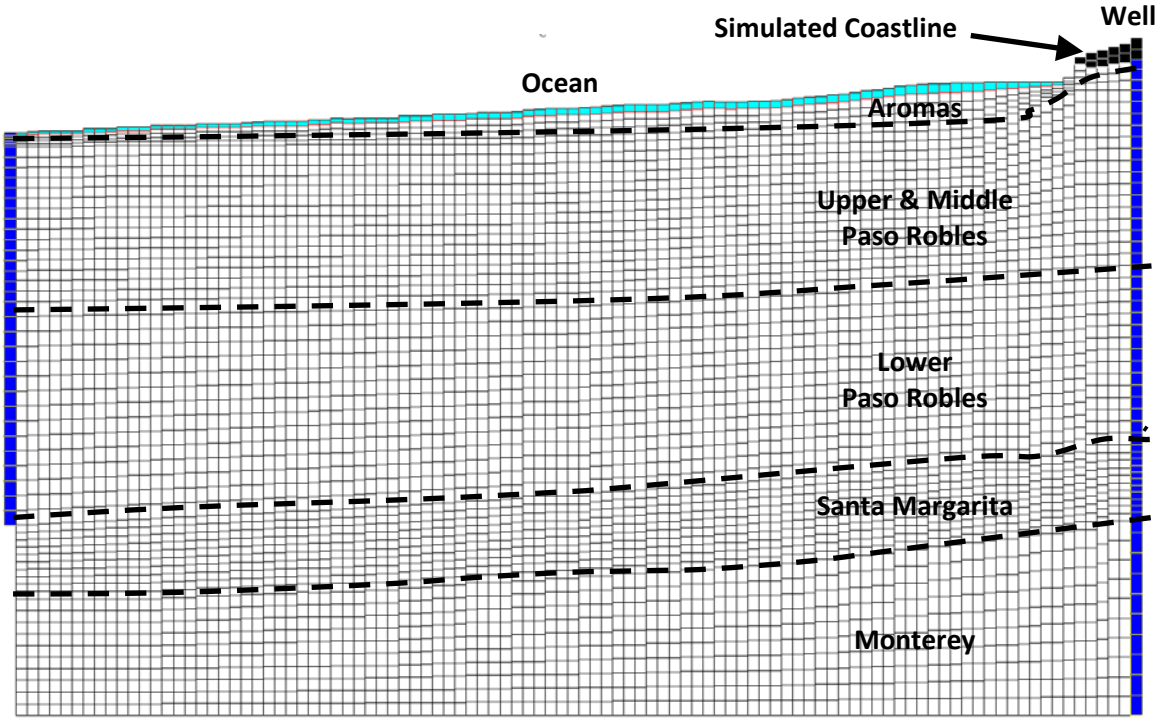


Figure 36: Example Finite Difference Grid for a Protective Groundwater Elevation Model

5.2.3 STEADY-STATE ASSUMPTION

The protective groundwater elevation model results represent steady-state conditions, and have no time component to them. The model will therefore not tell when the freshwater-seawater interface gets to the protected location, but will provide assurance that the interface will not continue to intrude inland of the protective location. The intension is that the groundwater level in the well must be maintained so that seawater will not advance past the protected locations chosen by the Watermaster.

One advantage of this approach is that no information about the current location of the interface is required. If the interface is currently landward of the protective location, maintaining protective elevations will move the interface out to the protective location. If the interface is currently seaward of the protective location, maintaining protective elevations will allow the interface to move landward to the protective location, but no farther. Furthermore, attempting to install the offshore wells necessary for estimating the current location of the interface is prohibitively expensive, and would be almost impossible to permit.

The other advantage of the steady-state assumption is that groundwater management can be based on long-term average elevations without too much concern about short-term fluctuations such as seasonal and tidal fluctuations. The Watermaster can also use the long-term nature of the protective groundwater elevations to help manage the response to a short-term increase in pumping. The increase can be offset by a subsequent decrease in pumping such that the average groundwater level remains at the protective elevation.

5.2.4 MODEL LAYERS

Development of the regional groundwater model (Section 2 and Section 3) resulted in five vertical hydrostratigraphic layers: Aromas Red Sands, Upper Paso Robles aquifer, Middle Paso Robles aquifer, Lower Paso Robles aquifer, and Santa Margarita/Purisima aquifer. The top of the Monterey Formation serves as the bottom of the regional model. For the protective groundwater elevation models, the stratigraphy documented in Section 2 was extended offshore to develop the layer elevations needed to model the freshwater-seawater interface. Where interpolated offshore stratigraphic information was unavailable, layer elevations were linearly extrapolated over the extent of the protective groundwater elevation models.

The hydrostratigraphic layers of the regional model were modified as follows:

- Models representing wells PCA-West, MSC, and CDM MW-4 include an underlying aquifer unit with low conductivity that represents the Monterey Formation. This allows flow of denser saline water underneath the protected aquifers. A minimum 200 foot thick unit representing the Monterey Formation was used for wells PCA-West and MSC, while a minimum 35 foot thick unit was used for well CDM MW-4. This was required as a technical modeling issue related to ensuring that the modeled interface did not intersect the bottom of the model at any time.

- Sentinel well SBWM-3 did not require the Monterey Formation at the bottom of the model because of the occurrence of a great thickness of Purisima Formation that allows for saline water to pass beneath the protected elevation and provides enough depth that the modeled seawater interface does not intersect the bottom of the model.

- For wells PCA-West, MSC, and SBWM-3 the Upper and Middle Paso Robles layers were combined into a single aquifer unit due to the thinness of the Paso Robles aquifer. The lower Paso Robles unit was modeled as a separate unit for these wells.

- For well CDM MW-4, due to the thinness of the Paso Robles aquifer, it was modeled as a single unit overlying the Monterey Formation.

As a result, the aquifer units in each of these cross-sections are as follows:

- The model of sentinel well SBWM-3 has 4 units: Aromas Red Sands, Upper/Middle Paso Robles aquifer, Lower Paso Robles aquifer, and Purisima Formation (Figure 37).

- The model of the PCA-West well has 5 units: Aromas Red Sands, Upper/Middle Paso Robles aquifer, Lower Paso Robles aquifer, Santa Margarita/Purisima Formations, and Monterey Formation (Figure 38).

- The model of the MSC well has 5 units: Aromas Red Sands, Upper/Middle Paso Robles aquifer, Lower Paso Robles aquifer, Santa Margarita aquifer, and Monterey Formation (Figure 39).

- The model of CDM well MW-4 has 3 units: Aromas Red Sands, Paso Robles aquifer, and Monterey Formation (Figure 40).

Multiple model layers are used for each aquifer unit, following guidance by Guo and Langevin (2002) that ten model layers are generally adequate to simulate the flow patterns that can occur in variable density modeling. Five model layers were used for very thin units and up to fifty model layers were used for very thick units in order to minimize the variation of cell thicknesses from layer to layer.

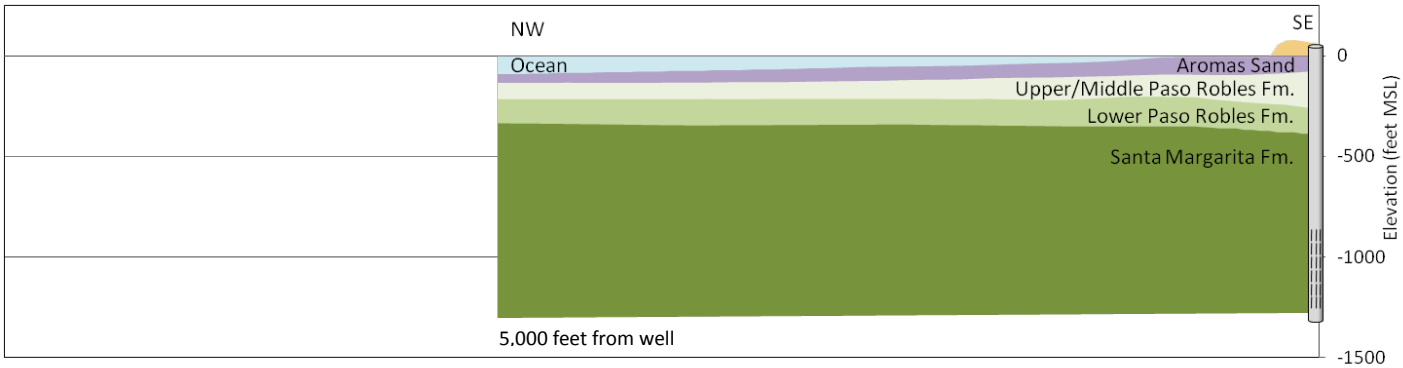


Figure 37: SBWM-3 Monitoring Well and Aquifer Units

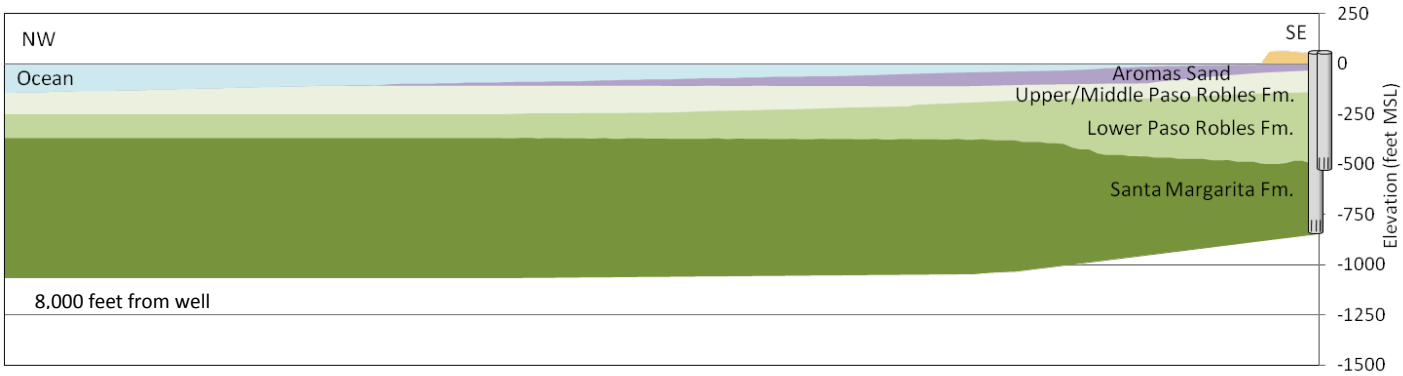


Figure 38: PCA-West Monitoring Well and Aquifer Units

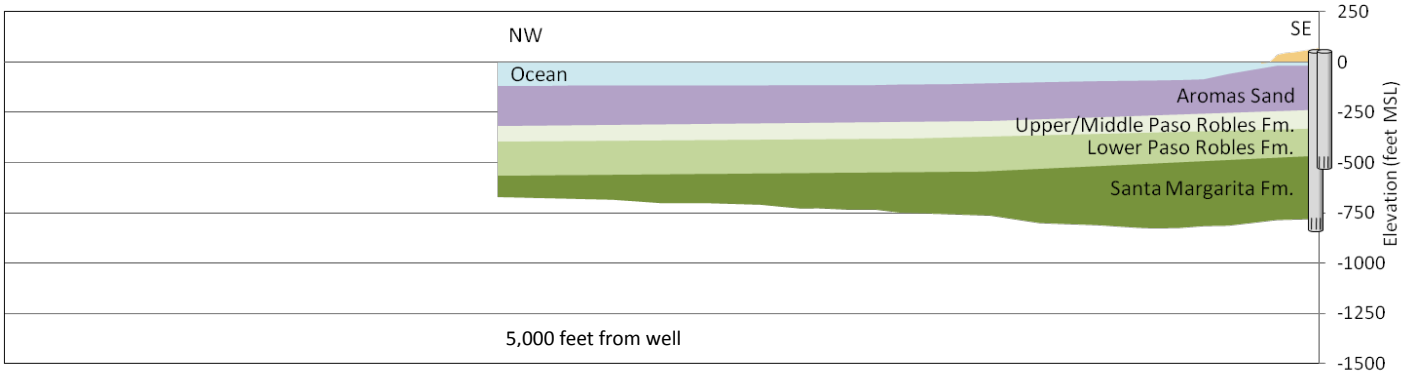


Figure 39: MSC Monitoring Well and Aquifer Units

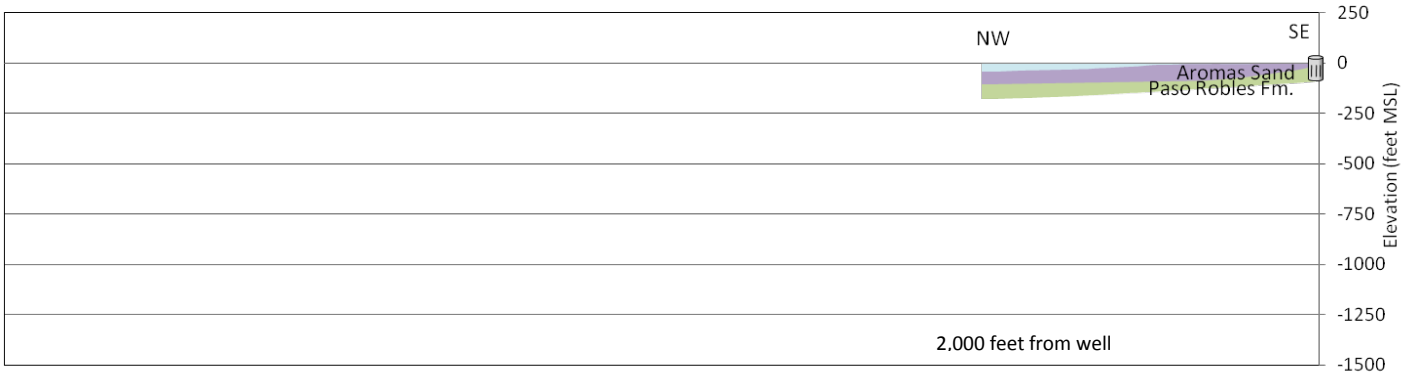


Figure 40: CDM-MW4 Monitoring Well and Aquifer Units

5.2.5 MODEL BOUNDARY CONDITIONS

Numerical models require boundary conditions be defined for the sides, the top, and bottom of the model. The boundary conditions imposed on the cross sectional models are as follows.

- Inland end of model: Groundwater elevations are held at a constant level, simulating the desired protective groundwater elevation in the monitoring wells. Any water entering the model from the inland end of the model is fresh water.

- Ocean end of model: Groundwater elevations are held at sea level for the Aromas Red Sands and Paso Robles aquifer. Any water entering the model from the ocean end of the model is always full strength seawater. Data analysis during construction of the regional groundwater flow model indicates that the

aquifer unit underlying the Paso Robles aquifer, particularly the Santa Margarita aquifer, does not outcrop in the ocean. Although there is an outcrop of Purisima Formation four miles offshore of sentinel well SBWM-3, observed groundwater elevations in this well suggest that the local Purisima Formation is highly confined, in close hydraulic connection with the Santa Margarita aquifer, and not influenced by ocean water levels. Therefore, aquifer units representing the Purisima Formation and Santa Margarita aquifer are not assigned ocean boundary conditions. The connection to the ocean indirectly occurs through the Paso Robles aquifer.

- Top boundary: Onshore, no water percolates into or out of the top boundary. This implies that we do not simulate rainfall recharge with this model. Offshore, the top boundary simulates silt on the ocean floor. The water level above the silt is tied to sea level. Any water entering the model from the top boundary offshore is set to full strength seawater.

- Bottom boundary: The bottom is impermeable. No groundwater flows in or out of the model bottom

5.2.6 MODEL AQUIFER PARAMETERS

5.2.6.1 FLOW PARAMETERS

Table 7 presents the base values of aquifer parameters for each aquifer unit, including seabed conductance, horizontal hydraulic conductivity (Kh), and vertical hydraulic conductivity (Kv). The base values are estimates based on existing hydrogeologic information and previous models. Because the protective groundwater elevation models are run to equilibrium, the aquifer storage parameters have no effect on the final solution and are therefore not presented here.

Table 7: Base Aquifer Flow Parameter Values

Hydrostratigraphic Unit	Kh (feet/day)	Kv (feet/day)	Wells
Seabed	Conductance = 1 day^{-1}		All
Aromas Red Sands	10	0.5	All
Upper & Middle Paso Robles (Northern Coastal)	4	0.04	SBWM-3, PCA-W. MSC
Lower Paso Robles (Northern Coastal)	4	0.04	SBWM-3, PCA-W. MSC
Paso Robles (Southern Coastal)	10	0.5	CDM MW-4
Purisima	4	0.2	SBWM-3
Santa Margarita/Purisima	10	0.5	PCA-W
Santa Margarita	10	0.5	MSC
Monterey	0.5	0.025	PCA-W, MSC, CDM MW-4

There is substantial uncertainty about the parameter values due to a lack of groundwater level, water quality, and geologic data in the offshore aquifers being modeled. As a result, an uncertainty analysis based on the reasonable range of parameters shown in Table 8 was also performed. The uncertainty analysis described in Section 5.3.2 provides a range of results that can provide additional guidance to the Watermaster for establishing protective groundwater elevations.

Table 8: Parameter Ranges by Hydrostratigraphic Unit

Hydrostratigraphic Unit	Kh (feet per day)	Kv (feet per day)	Wells
Seabed	Conductance = 0.01 – 10 day^{-1}		All
Aromas	5 - 20	0.05 – 1.0	All
Upper & Middle Paso Robles	2 - 8	0.01 – 0.1	SBWM-3, PCA-W, MSC
Lower Paso Robles	2 - 8	0.01 – 0.1	SBWM-3, PCA-W, MSC
Paso Robles Upper, Middle & Lower	5 – 20	0.05 – 1.0	CDM MW-4
Purisima	2 – 8	0.02 - 0.4	SBWM-3
Santa Margarita/Purisima	5 – 20	0.05 – 1.0	PCA-W
Santa Margarita	5 – 20	0.05 – 1.0	MSC
Monterey	0.5	0.025	PCA-W, MSC, CDM MW-4

5.2.6.2 TRANSPORT PARAMETERS

The dispersivity and molecular diffusion parameters were set to zero. Setting these parameters to zero removes mixing of freshwater and seawater at the interface, allowing the simulation of a relatively sharp interface.

5.3 IDENTIFICATION OF PROTECTIVE GROUNDWATER ELEVATIONS

This subsection discusses the definition of the protective interface, presents the methodology and model results for identifying protective groundwater elevations, and presents an uncertainty analysis.

5.3.1 PROTECTIVE INTERFACE FOR BASE PARAMETERS

The protective interface occurs when the toe of the intruding seawater wedge just reaches the well end of the model at a specified depth. In this case, the aquifer inland from the well, and above the specified depth, contains freshwater.

For the protective locations defined in Table 6, freshwater is defined as a chloride concentration below the National Secondary Drinking Water maximum contaminant limit (MCL) of 250 milligrams per liter (mg/L). The protective location is considered to have seawater in it if it has a modeled chloride concentration above this limit.

The Santa Margarita aquifer's apparent lack of connection with the ocean discussed in Section 2.2.3 led us to investigate the groundwater elevation necessary to protect the Paso Robles aquifer only. This was performed at the PCA-West and MSC wells, where protecting the bottom of the Santa Margarita aquifer requires a relatively high groundwater elevation. This alternate protected depth is at the bottom of the lower Paso Robles aquifer unit for these two wells.

In addition to developing protective groundwater elevations for the entire Santa Margarita aquifer, we have included groundwater elevations that protect 90% of the Santa Margarita aquifer. There may be groundwater management advantages to protecting only 90% of the Santa Margarita aquifer that need to be further discussed at the TAC level.

The following subsections show the model results for protective groundwater elevations at each of the wells using the base parameter values shown in Table 7.

5.3.1.1 SENTINEL WELL 3

At sentinel well SBWM-3 in the northern portion of the Northern Coastal Subarea, the Santa Margarita aquifer is not present, and thus the protected depth is the extrapolated bottom of the Santa Margarita aquifer. This is approximately 800 feet below MSL, which is in the middle of the approximately 900 feet thick Purisima Formation. As the Purisima Formation is assumed to be equivalent to the Santa Margarita aquifer in the model, it was also modeled like the Santa Margarita aquifer without an ocean boundary condition.

Due to the presence of more than 400 feet of Purisima Formation below the protective elevation, denser seawater is able to flow underneath the protective elevation which results in a relatively low groundwater elevation required at SBWM- 3 to protect the aquifer from seawater intrusion (Figure 41). At the location of SBWM-3, a groundwater elevation of 3 feet MSL is able to protect the aquifer from seawater intrusion for the base parameter values (Table 6). Currently, the groundwater elevation in well SBWM-3 is -18.7 MSL.

Table 9: Protective groundwater Elevation at SBWM-3 for Base Parameter Values

Aquifer Unit	**Kh (feet per day)**	**Kv (feet per day)**	**Protected Depth**	**Protective Groundwater Elevation (feet MSL)**
Seabed	Conductance = 1 day^{-1}		Extrapolated Bottom of Santa Margarita (in Purisima) ~ -800 feet MSL	3
Aromas	10	0.5		
Upper & Middle Paso Robles	4	0.04		
Lower Paso Robles	4	0.04		
Purisima	4	0.2		

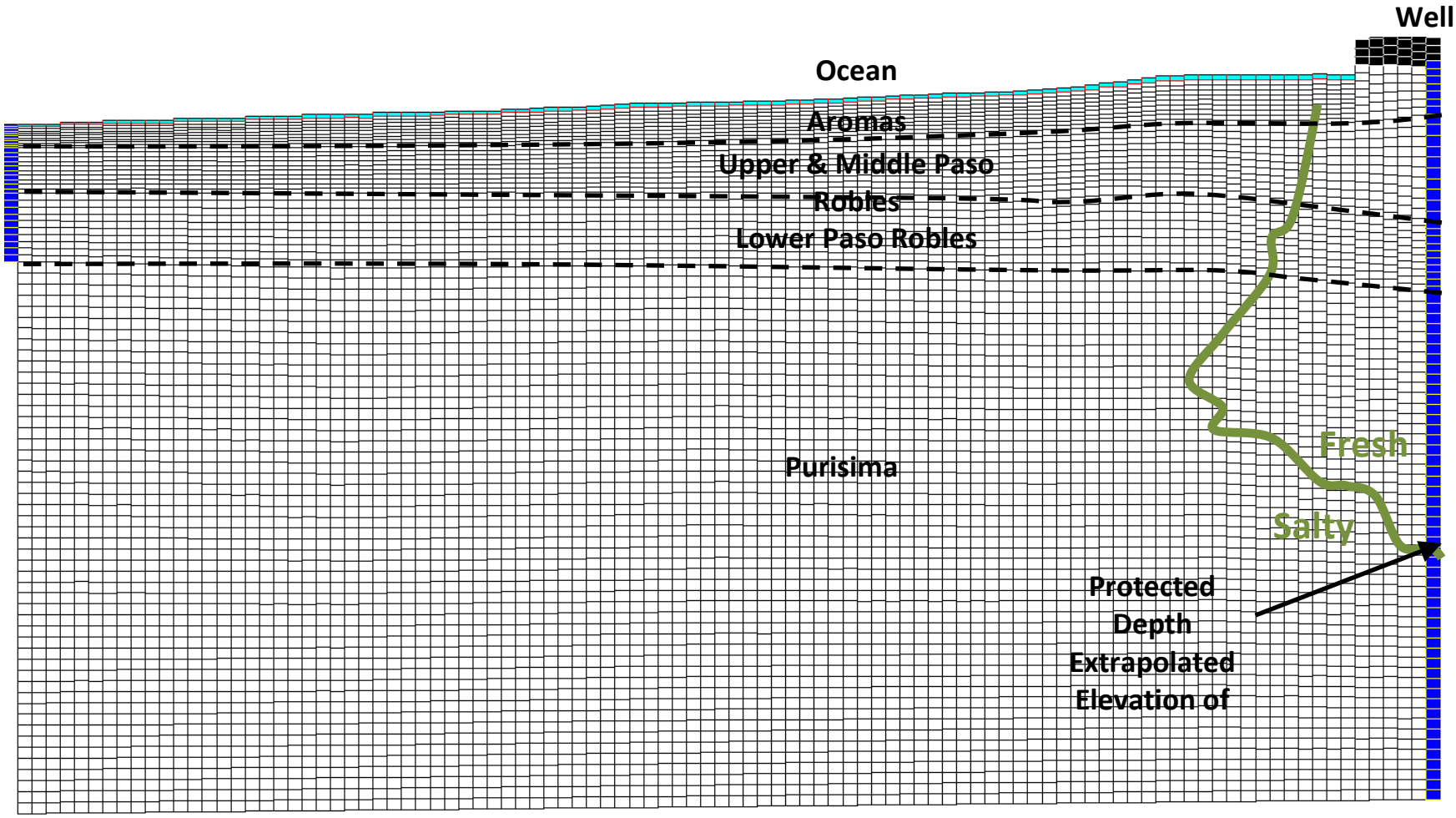


Figure 41: Protective Freshwater-Seawater Interface for SBWM-3 Protective Groundwater Elevation Model for Base Parameter Values (2x vertical exaggeration)

5.3.1.2 PCA-WEST WELL

At the PCA-West well in the southern portion of the Northern Coastal Subarea, the protected depth is the bottom of the Santa Margarita aquifer. Because the low conductivity of the Monterey Formation restricts flow underneath the Santa Margarita aquifer, a relatively high groundwater elevation is required to protect the aquifer from seawater intrusion (Figure 42). A groundwater elevation of 18 feet MSL protects the entire aquifer from seawater intrusion for the base parameter values (Table 10). This elevation can be lowered if only 90% of the Santa Margarita/Purisima aquifer is protected, shown in Table 10.

The elevation required to protect the Paso Robles aquifer only is 2 feet MSL. Currently, the groundwater elevation in the Paso Robles aquifer is 3.6 feet MSL, which is above the protective elevation and thus that location is already protected.

Table 10: Protective groundwater Elevation at PCA-W for Base Parameter Values

Aquifer Unit	**Kh (feet per day)**	**Kv (feet per day)**	**Protected Depth**	**Protective Groundwater Elevation (feet MSL)**
Seabed	Conductance = 1 day^{-1}			
Aromas	10	0.5	Bottom of Paso Robles ~ -490 feet MSL	2
Upper & Middle Paso Robles	4	0.04		
Lower Paso Robles	4	0.04		
Purisima/ Santa Margarita	10	0.5	90% of Purisima/ Santa Margarita	12
Purisima/ Santa Margarita	0.5	0.025	100% of Purisima/ Santa Margarita ~ -850 feet MSL	18

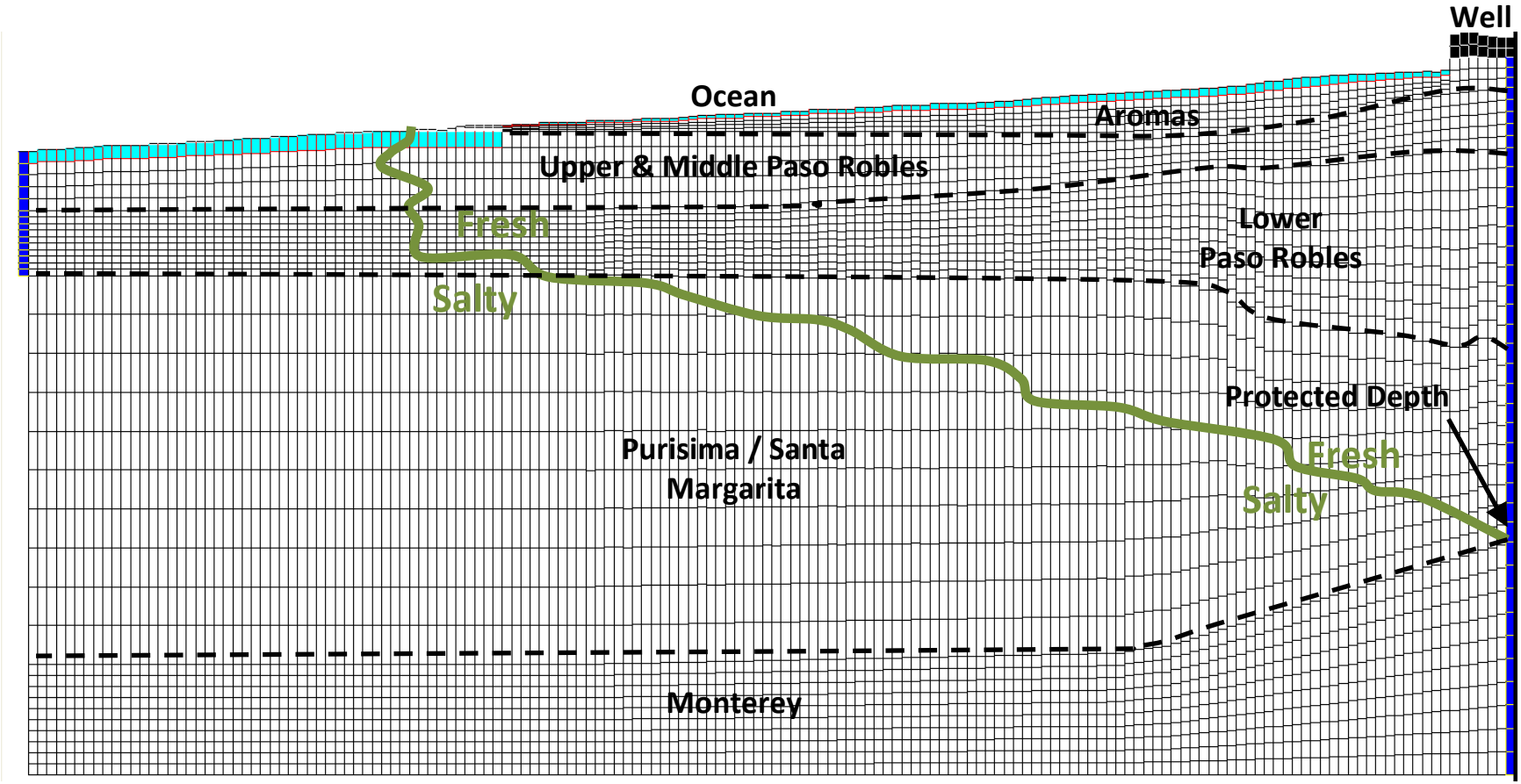


Figure 42: Protective Freshwater-Seawater Interface for PCA-W Protective Groundwater Elevation Model for Base Parameter Values (3x vertical exaggeration)

5.3.1.3 MSC WELL

At the MSC well in the southern portion of the Northern Coastal Subarea, the protective depth is the bottom of the Santa Margarita aquifer or top of the Monterey Formation. Because the low conductivity of the Monterey Formation restricts flow underneath the Santa Margarita aquifer, a relatively high groundwater elevation is required to protect the aquifer from seawater intrusion (Figure 43). A groundwater elevation of 18 feet MSL protects the entire aquifer from seawater intrusion for the base parameter values (Table 11). This elevation can be lowered if only 90% of the Santa Margarita aquifer is protected, as shown in Table 11. The elevation required to protect the Paso Robles aquifer only is 9 feet MSL; currently the groundwater elevation in the Paso Robles aquifer is 3 feet MSL which makes it currently vulnerable to seawater intrusion.

Table 11: Protective groundwater Elevation at MSC for Base Parameter Values

Aquifer Unit	**Kh (feet per day)**	**Kv (feet per day)**	**Protected Depth**	**Protective Groundwater Elevation (feet MSL)**
Seabed	Conductance = 1 day^{-1}			
Aromas	10	0.5	Bottom of Paso Robles ~ -470 feet MSL	9
Upper & Middle Paso Robles	4	0.04		
Lower Paso Robles	4	0.04		
Santa Margarita	10	0.5	90% of Santa Margarita	17
Santa Margarita	0.5	0.025	100% of Santa Margarita ~ - 770 feet MSL	18

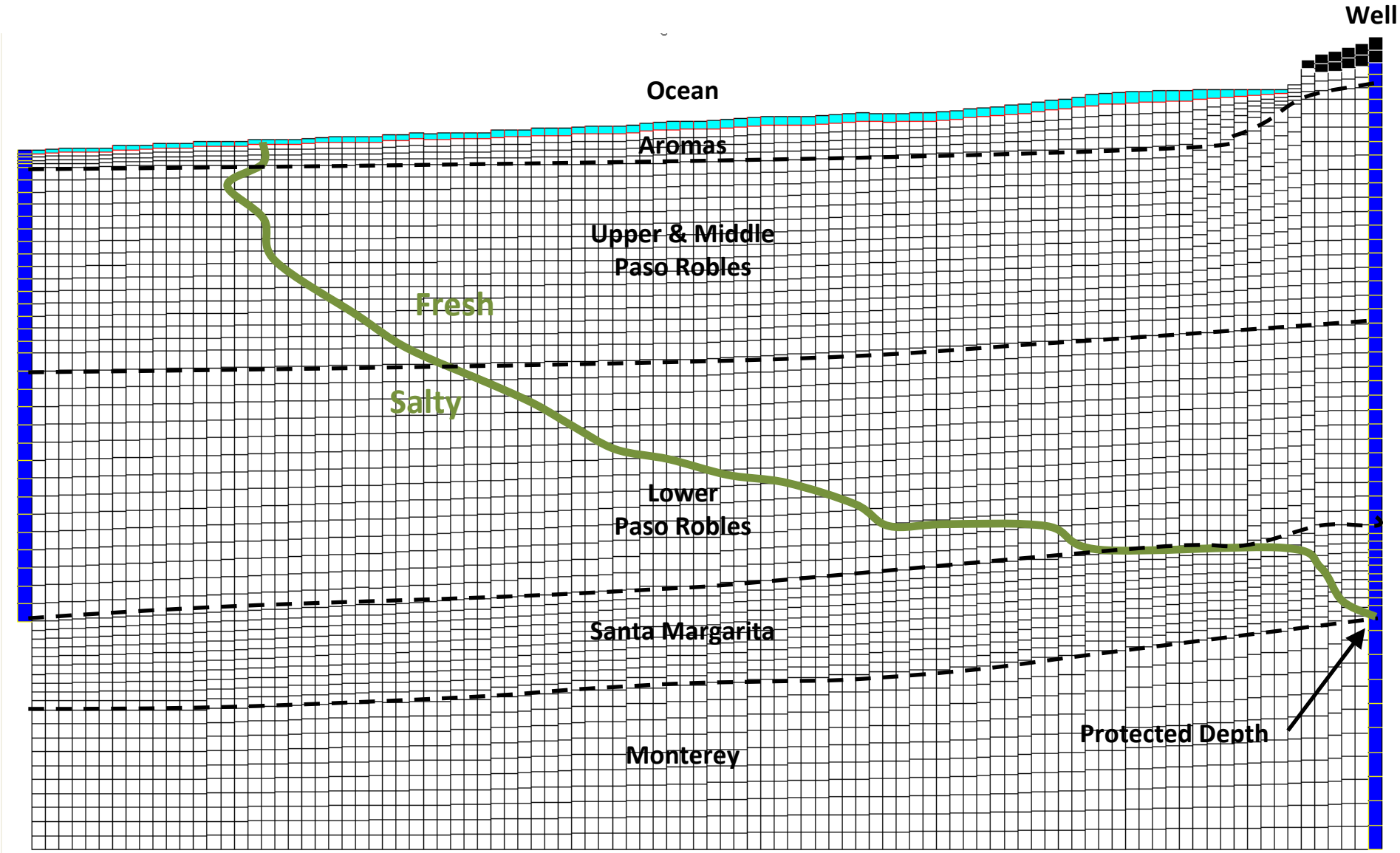


Figure 43: Protective Freshwater-Seawater Interface for MSC Protective Groundwater Elevation Model for Base Parameter Values (2.5x vertical exaggeration)

5.3.1.4 CDM MW-4 WELL

At the CDM MW-4 well in the Southern Coastal Subarea, neither the Purisima or Santa Margarita aquifers are present. The only aquifer is a thin layer of Paso Robles aquifer. The goal for this area is to protect the Paso Robles aquifer to the top of the Monterey Formation. A low protective groundwater elevation is all that is required to protect the aquifer from seawater intrusion (Figure 44), because the protected depth is less than 100 feet below MSL. A groundwater elevation of 2 feet MSL is able to protect the entire aquifer from seawater intrusion for the base parameter values (Table 12). Currently, the groundwater elevation in well CDM MW-4 is 3.5 feet MSL, and thus the protective elevation is currently met.

Table 12: Protective Groundwater Elevation at CDM MW-4 for Base Parameter Values

Aquifer Unit	**Kh (feet per day)**	**Kv (feet per day)**	**Protected Depth**	**Protective Groundwater Elevation (feet MSL)**
Seabed	Conductance = 1 day^{-1}		Top of Monterey ~ -90 feet MSL	2
Aromas	10	0.5		
Upper, Middle and Lower Paso Robles	10	0.5		
Monterey	0.5	0.025		

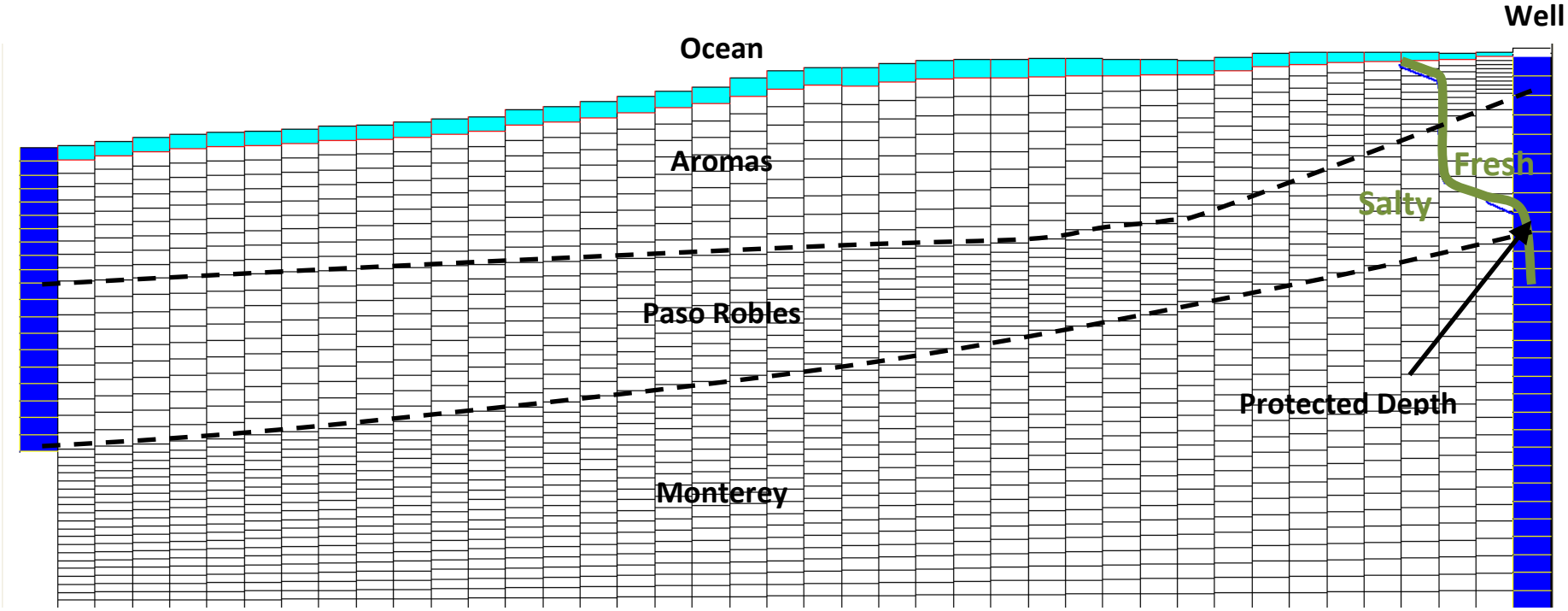


Figure 44: Protective Freshwater-Seawater Interface for CDM MW-4 Protective Groundwater Elevation Model for Base Parameter Values (3x vertical exaggeration)

5.3.2 UNCERTAINTY ANALYSIS

Specific hydrogeologic parameters such as vertical and horizontal hydraulic conductivity, and seabed conductance (referred to collectively as hydrogeologic parameter sets) for each protective groundwater elevation model cannot be determined with any certainty because there are insufficient data to calibrate the models to groundwater elevation or concentration data. Additionally, there are no known hydrogeologic parameter data for the offshore aquifers, adding further uncertainty. To develop reliable protective groundwater elevations, it is necessary to perform an uncertainty analysis that evaluates the range of reasonable outcomes given the lack of precise parameter data.

A statistically technique called the Monte Carlo approach was used for the uncertainty analysis. This approach uses a series of randomized inputs to the model to create a range of possible model results. Each set of input parameters results in a unique protective groundwater elevation. The parameters varied were the horizontal hydraulic conductivities and vertical hydraulic conductivities of the aquifer units, and the seabed conductance. Parameters were varied within the ranges shown in Table 8. Vertical and horizontal hydraulic conductivity and seabed conductance were varied using a random uniform log-transformed distribution. The log-transformed distribution is appropriate because hydrologic parameter values are typically distributed not by absolute value, but by order of magnitude. A uniform distribution is used because there is no information that any value within the range is more likely than any other.

The sensitivities of parameter values on the protective groundwater elevation are shown in the figures in Appendix C.

5.3.2.1 SBWM-3WELL

The uncertainty analysis estimates the range of protective elevations at SBWM-3 to be between 2 and 6 feet MSL. Figure 45 shows the cumulative distribution of the protective groundwater elevations for the SBWM-3 well. This figure shows that a groundwater elevation of two feet protects the aquifer in 20% of the 100 simulations; a groundwater elevation of 3 feet protects the aquifer in 55% of the 100 simulations, etc. Although the model using the base parameter values results in a protective groundwater elevation of 3 feet MSL at this well (Table 9), establishing a protective groundwater elevation of 4 feet MSL will better account for the uncertainty in the parameter estimates.

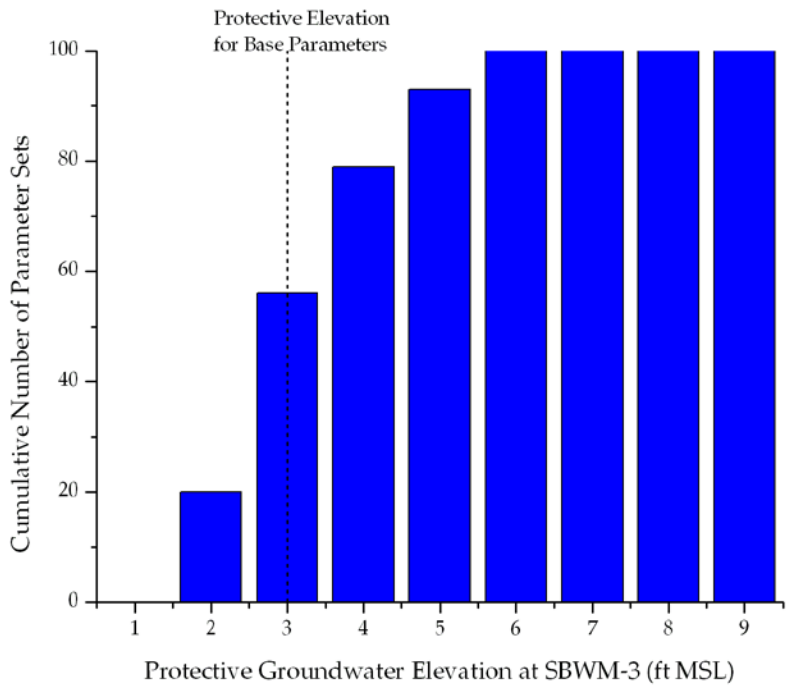


Figure 45: Cumulative Distribution of Protective Elevations to Protect the Purisima Aquifer at SBWM-3

5.3.2.2 PCA-W WELL

The uncertainty analysis estimates the range of protective elevations at the PCA-West well to be between 11 and 19 feet MSL to protect the Santa Margarita aquifer. Figure 46 shows the cumulative distribution of the protective groundwater elevations for the PCA-West well. Although the base parameter set suggested a protective groundwater elevation of 18 feet, the uncertainty analysis shows a groundwater elevation of 17 feet likely protects the Santa Margarita aquifer adequately.

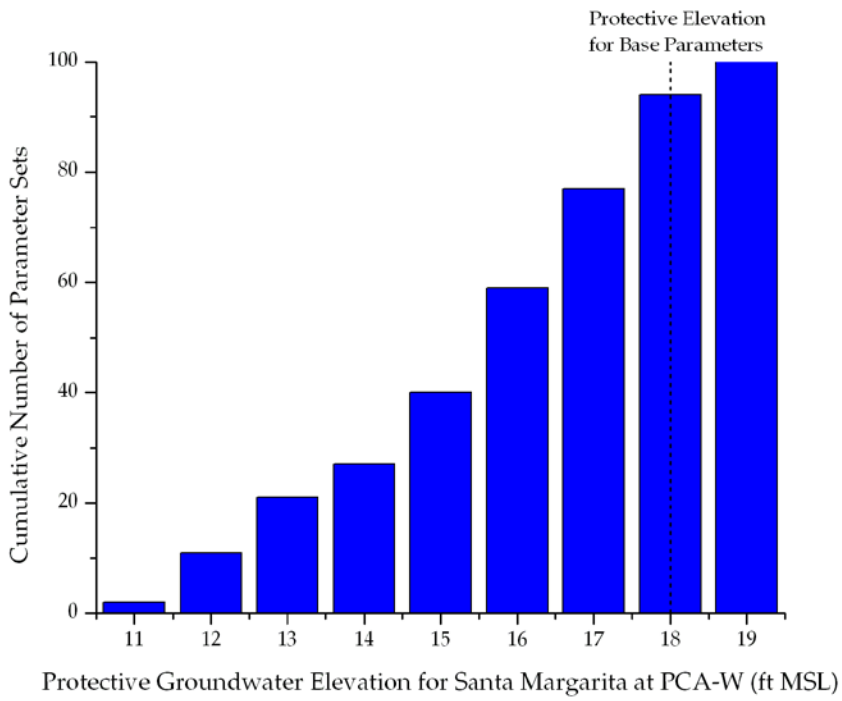


Figure 46: Cumulative Distribution of Protective Elevations to Protect the Santa Margarita Aquifer at the PCA-West Well

The uncertainty analysis estimates the range of protective elevations at the PCA-West well to be between 2 and 4 feet MSL to protect only the Paso Robles aquifer. Figure 47 shows the cumulative distribution of the protective groundwater elevations for the Paso Robles aquifer at the PCA-West well. The groundwater elevation of 2 feet MSL using the base parameter set adequately protects the Paso Robles aquifer.

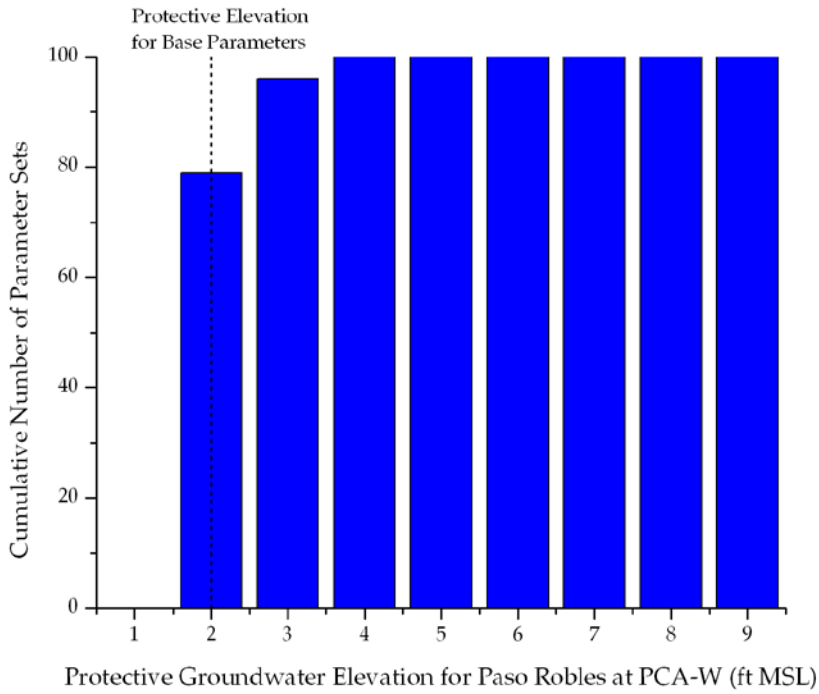


Figure 47: Cumulative Distribution of Protective Elevations to Protect the Paso Robles Aquifer at the PCA-West Well

5.3.2.3 MSC WELL

The uncertainty analysis estimates the range of protective elevations at the MSC well to be between 15 and 18 feet MSL to protect the Santa Margarita aquifer. Figure 48 shows the cumulative distribution of the protective groundwater elevations for the MSC well. Although the base parameter set suggested a protective groundwater elevation of 18 feet, the uncertainty analysis shows a groundwater elevation of 17 feet adequately protects the Santa Margarita aquifer.

The uncertainty analysis estimates the range of protective elevations at the MSC well to be between 3 and 14 feet MSL to protect only the Paso Robles aquifer.

Figure 54 shows the cumulative distribution of the protective groundwater elevations for the Paso Robles aquifer at the MSC well. Although the model using the base parameter values results in a protective groundwater elevation of 9 feet MSL at this well (Table 11), establishing a protective groundwater elevation of 11 feet MSL will better account for the uncertainty in the parameter estimates.

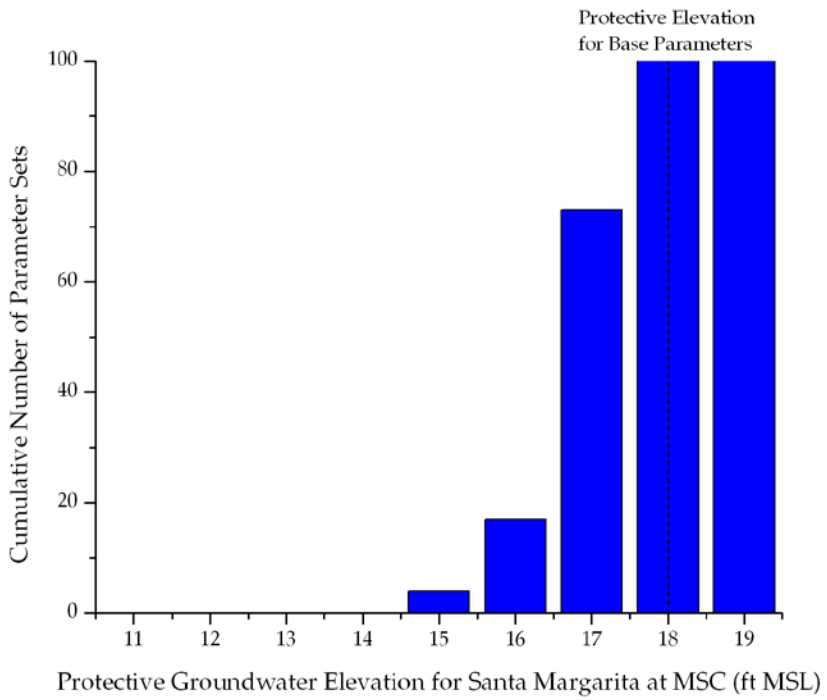


Figure 48: Cumulative Distribution of Protective Elevations to Protect the Santa Margarita Aquifer at the MSC Well

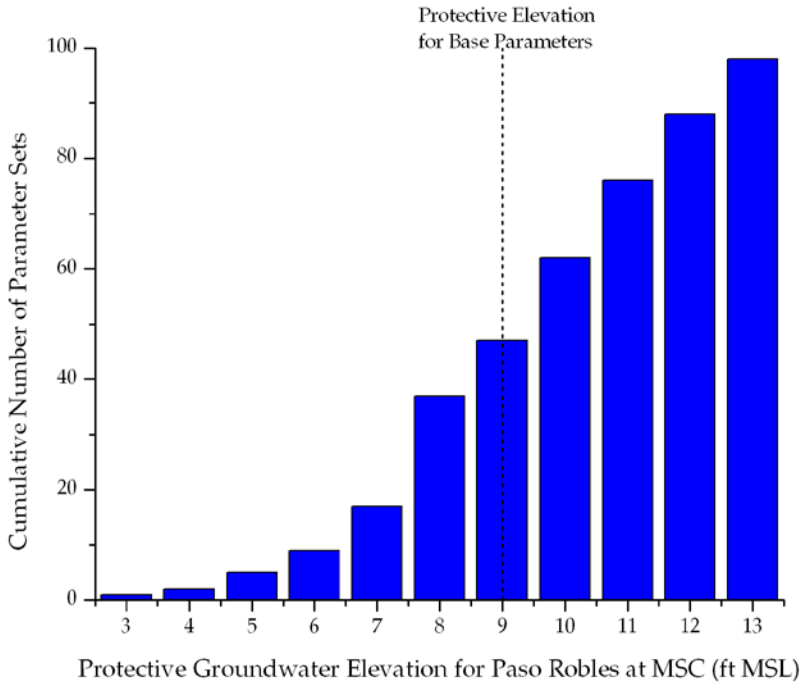


Figure 49: Cumulative Distribution of Protective Elevations to Protect the Paso Robles Aquifer at the MSC Well

5.3.2.4 CDM MW-4 WELL

The uncertainty analysis estimates the range of protective elevations at the CDM MW-4 well to be between 2 and 3 feet MSL. Figure 50 shows the cumulative distribution of the protective groundwater elevations for the CDM MW-4 well. It is appropriate to establish the protective groundwater elevation of 2 feet based on the model using base parameter values (Table 12) because that result accounts for most of the parameter uncertainty.

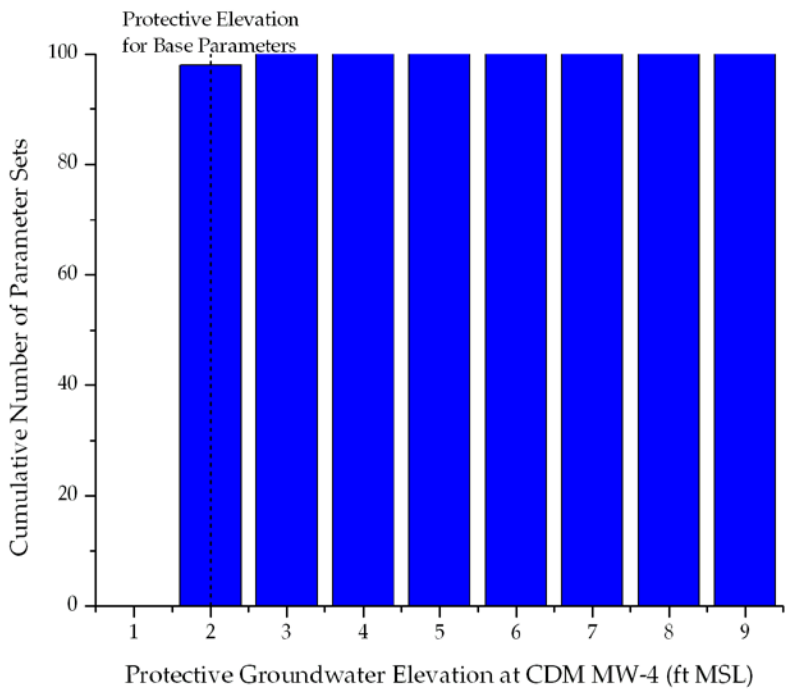


Figure 50: Cumulative Distribution of Protective Elevations to Protect the Santa Margarita Aquifer at CDM MW-4

5.4 PROTECTIVE GROUNDWATER ELEVATION SUMMARY

Table 13 summarizes the results of the protective groundwater elevations modeling. For each monitoring well and aquifer, this table shows the initial estimated protective elevations that were derived from the base aquifer parameters, the range of protective elevations derived from the uncertainty analysis and the final estimated groundwater elevations that protect 100% of the aquifer. Figure 51 through Figure 54 show the protective groundwater elevations compared to historical elevations.

Table 13: Summary of Protective Groundwater Elevations

Well	Protected Aquifer	Base Protective Elevation (feet MSL)	Range of Protective Elevations (feet MSL)	Final Estimate of Protective Elevation (feet MSL)
SBWM-3	Purisima	3	2-6	4
PCA-W	Paso Robles	2	2-4	2
	Santa Margarita	18	11-19	17
MSC	Paso Robles	9	3-14	11
	Santa Margarita	18	15-18	17
CDM MW-4	Paso Robles	2	2-3	2

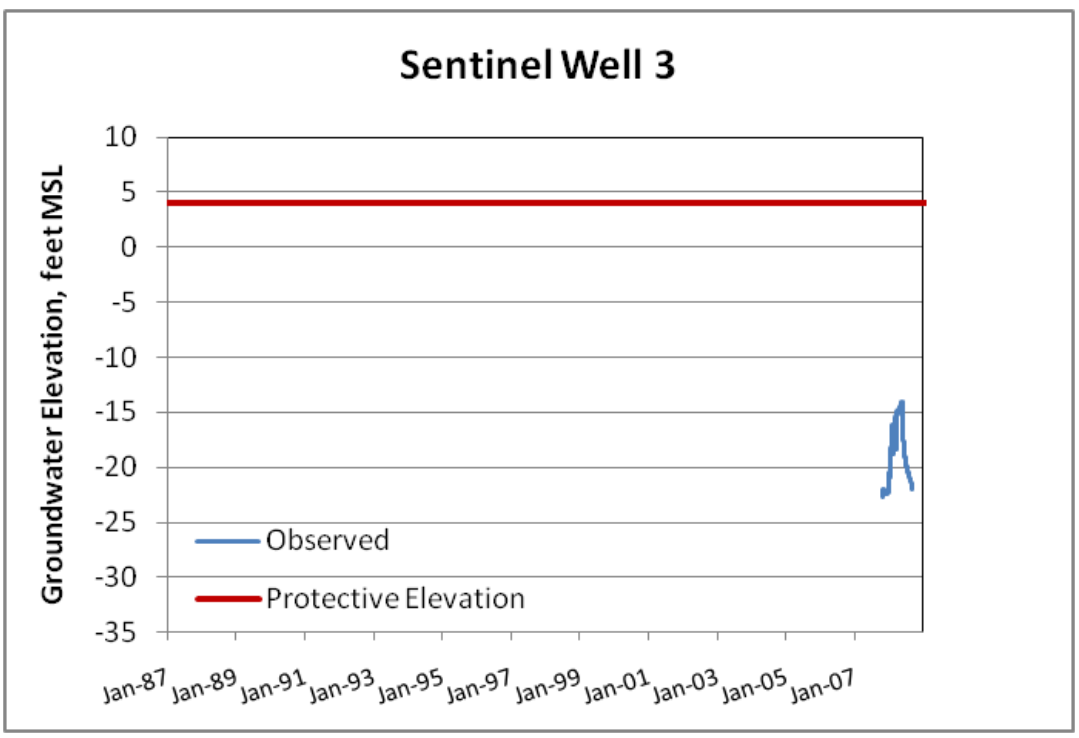


Figure 51: Comparison of Historical Groundwater Elevations with Protective Groundwater Elevation - Well SBWM-3

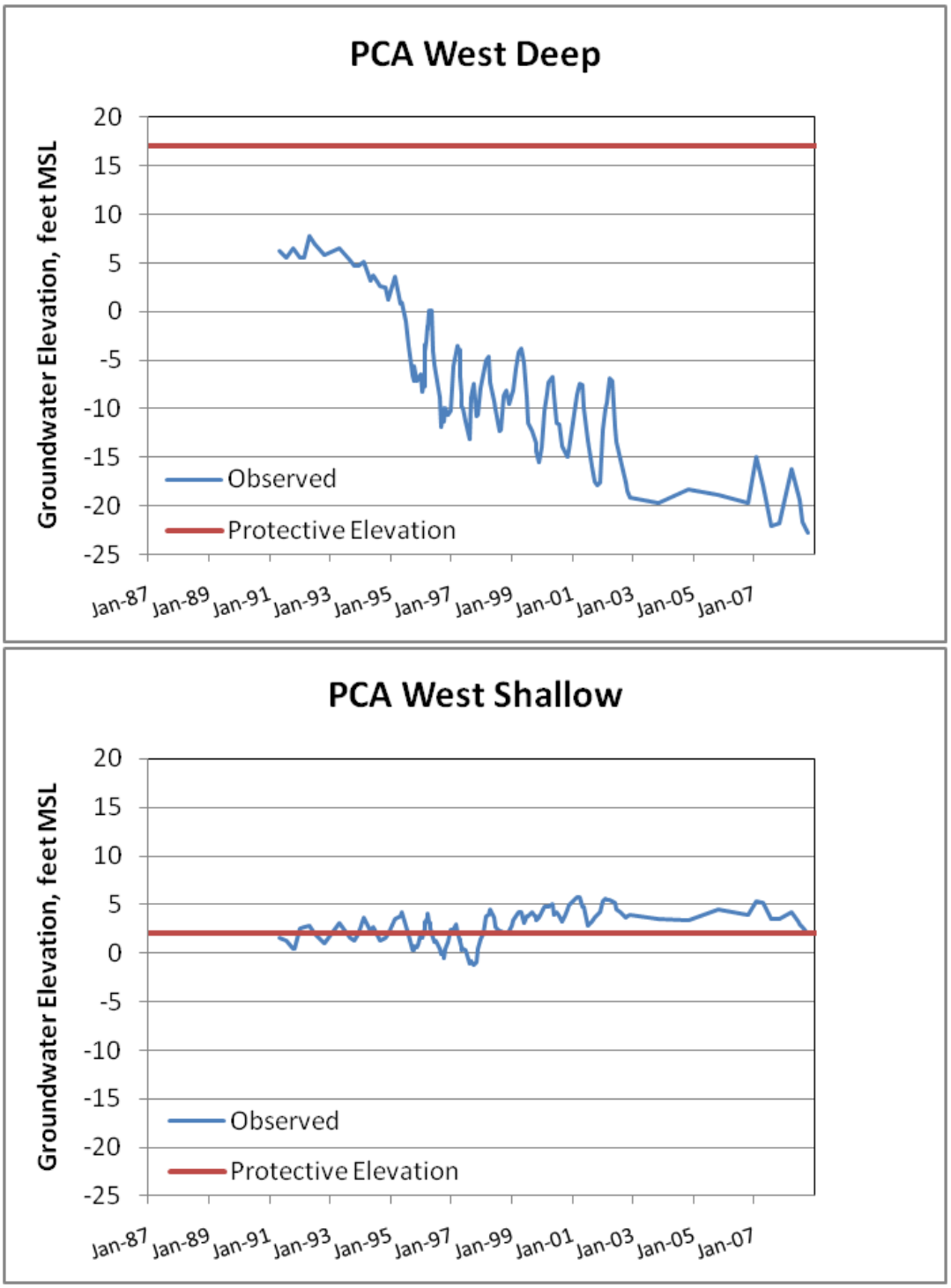


Figure 52: Comparison of Historical Groundwater Elevations with Protective Groundwater Elevation - Well PCA-W

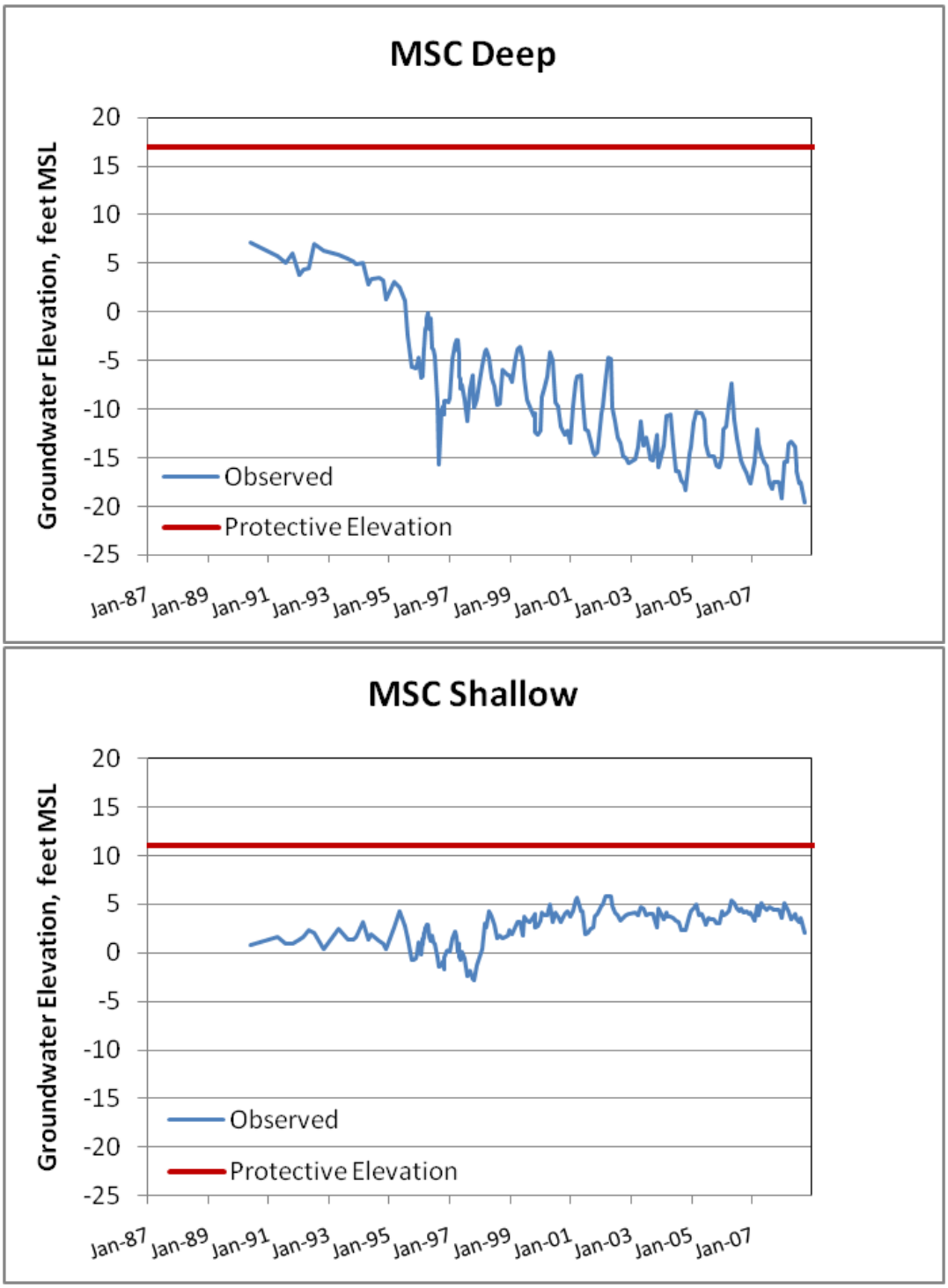


Figure 53: Comparison of Historical Groundwater Elevations with Protective Groundwater Elevation - Well MSC

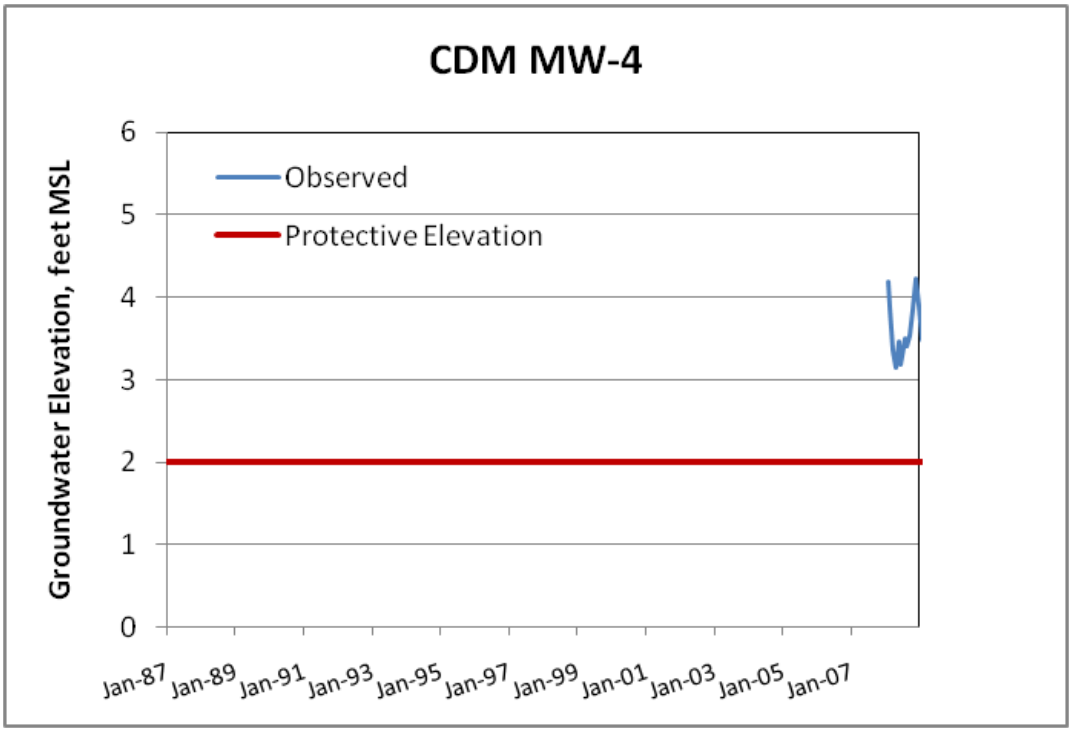


Figure 54: Comparison of Historical Groundwater Elevations with Protective Groundwater Elevation - Well CDM MW-4

This page left
intentionally blank

SECTION 6
PROTECTIVE MODEL SCENARIOS

A baseline and five predictive model scenarios were developed and run using the regional groundwater flow model to estimate the impacts of different groundwater management strategies on the Seaside Groundwater Basin. The results of each model scenario were compared against their ability to meet protective groundwater elevations obtained with the protective groundwater elevation models (Section 5), groundwater in storage, and inflow and outflow to the ocean and the Salinas Basin.

The scenarios simulated 22 years, from 2009 through 2030. This simulation period was used it relied on a repeat of the 22 year hydrology used for the 1987 through 2008 calibration period. Each scenario comprises a number of changes to the predictive model input. For example, importing new water into the Seaside Groundwater Basin might involve a scenario that takes into account:

- The amount of water imported into the Basin,
- How the water is used in the Basin, e.g., injection, surface recharge or in-lieu of groundwater pumping,
- Changes to the operation of existing wells as a result of the imported water being used,
- Changes in future land use, and
- Changes in future boundary conditions.

6.1 BASELINE SCENARIO

The first model scenario is a baseline scenario against which other scenarios can be compared. The baseline scenario includes all anticipated changes to the groundwater basin that are independent of the proposed groundwater management actions and supplemental supply projects planned in the future.

The twenty-two years of rainfall and evaporation used in the calibrated model (1987 – 2008) was repeated for the baseline scenario. In addition, the planned development in the former Ford Ord was simulated based on the Fort Ord Base Reuse Plan, including development of the Del Rey Oaks Golf Course and Resort. Land use changes and development were phased in, with 25% of the final planned build-out implemented after 5 years (Year 2014) and the remaining 75% implemented after 10 years (Year 2019). Figure 55 and Figure 56 show the land use patterns used for 2014 and 2019, respectively.

Water for new development on the former Fort Ord is assumed to come from the Salinas Valley. Land use changes in Laguna Seca were also simulated. The additional water deliveries to new developments resulted in additional recharge due to more system losses and irrigation. For the Seaside Groundwater Basin, the average annual recharge increased from 3,365 acre-feet per year during the calibration period to approximately 3,454 acre-feet per year for the predictive period (Figure 57).

Standard Producer's pumping was reduced triennially in accordance with the Decision-allocated reduction in Basin production. The reduction was implemented by reducing pumping from all of the Standard Producer's wells in proportion to their pumping rates. Pumping was distributed only to wells that produced water in the last five years of the calibration period. The exceptions were the Granite and Target (DBO Development) wells. Neither of those two wells pumped water in the last five years of the calibration period, but they were assigned their Decision-allocated amounts in the baseline scenario. Table 14 and Table 15 show the annual production assigned to all Standard Producer wells.

Alternative Producer allocations were set at the Decision-allocated values (Table 16 and Table 17). Small private pumpers (*de minimis* pumpers) in the Seaside Groundwater Basin are exempt from the Adjudication Decision, and were therefore assigned future pumping equal to their average pumping during the last five years of the calibration period. Similarly, all pumpers outside of the Seaside Groundwater Basin that are in the model area were assigned future pumping equal to their average pumping during the last five years of the calibration period.

The MPWMD ASR program was included and expanded during the predictive period. The existing ASR Well 1 and Well 2 both inject and recover a combined total of 460 acre-feet of water each year during the predictive period. Beginning in 2012, new ASR Well 3 and Well 4 both inject and recover a combined total of an additional 500 acre-feet of water each year for the remainder of the predictive period.

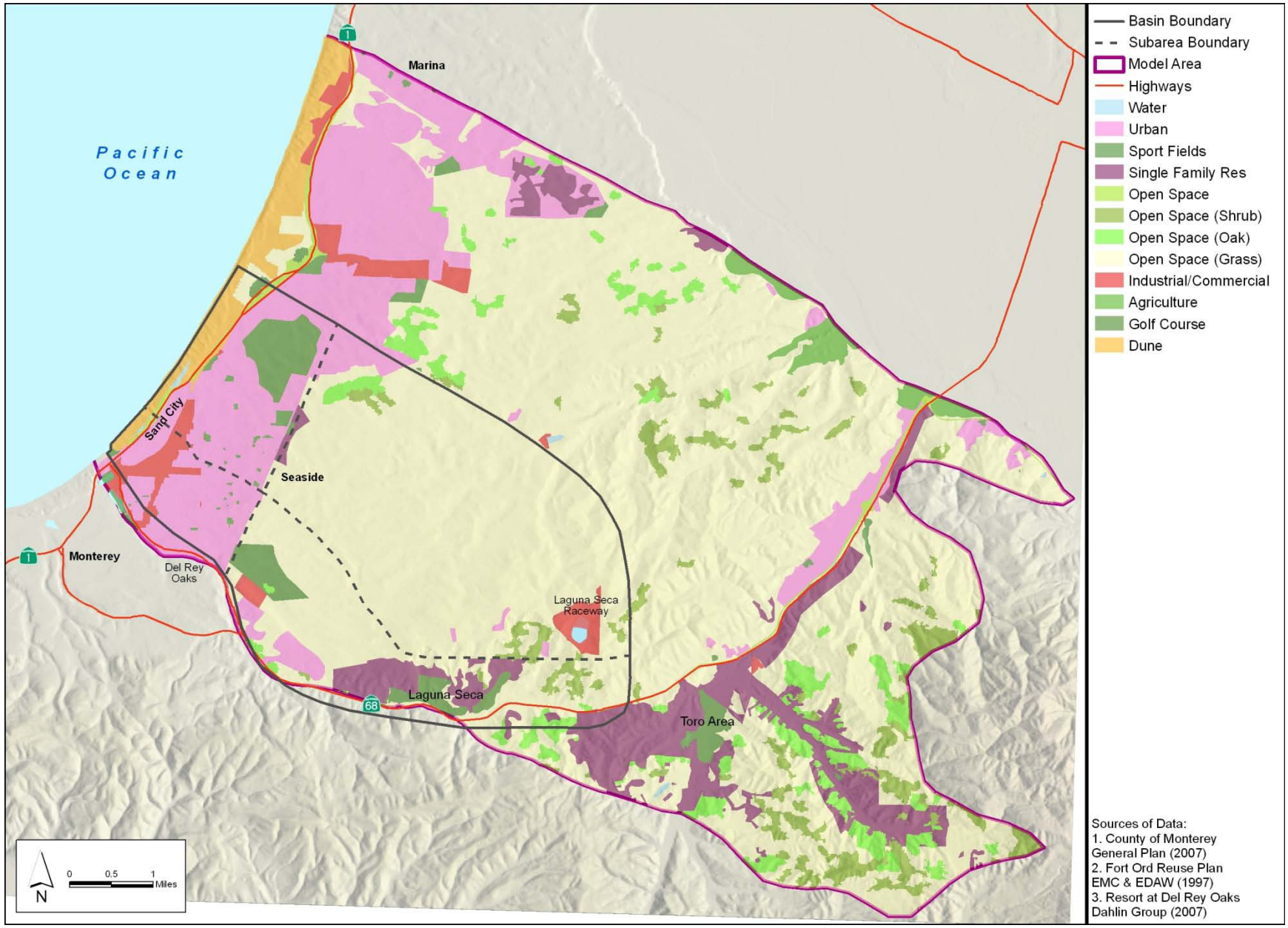


Figure 55: 2014 Land Use

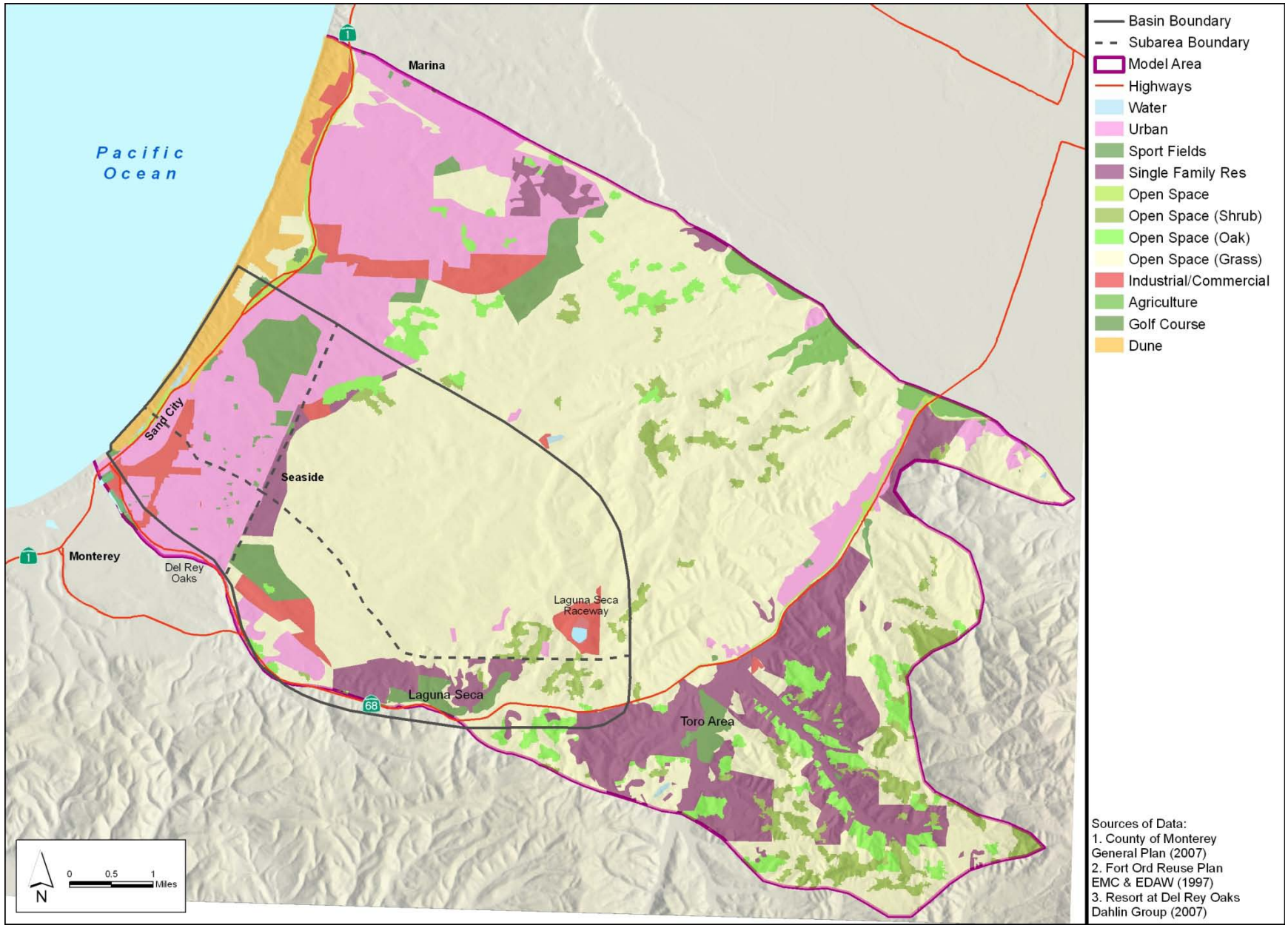


Figure 56: 2019 Land Use

Table 14: Baseline Scenario Production for Standard Producers in the Coastal Subareas (units in acre-feet)

	California American Water								City of Seaside				
Water Year	**Darwin**	**La Salle**	**Luzern**	**Military**	**Ord Grove**	**Paralta**	**Plumas #4**	**Playa #3**	**Well 3**	**Well 4**	**Target**	**Granite**	**Total**
2009 (9 months)	4.6	14.6	241.2	7.4	785.7	1007.9	105.2	161.8	8.4	165.4	29.8	16.3	2548.2
2010	6.1	19.5	322.4	9.9	1050.4	1347.6	140.6	216.4	11.3	221.1	39.9	21.8	3407.0
2011	6.1	19.5	322.4	9.9	1050.4	1347.6	140.6	216.4	11.3	221.1	39.9	21.8	3407.0
2012	5.3	16.9	278.8	8.5	908.3	1165.2	121.6	187.1	9.8	191.2	34.5	18.9	2945.9
2013	5.3	16.9	278.8	8.5	908.3	1165.2	121.6	187.1	9.8	191.2	34.5	18.9	2945.9
2014	5.3	16.9	278.8	8.5	908.3	1165.2	121.6	187.1	9.8	191.2	34.5	18.9	2945.9
2015	4.4	14.2	235.1	7.2	766.1	982.8	102.6	157.8	8.2	161.3	29.1	15.9	2484.8
2016	4.4	14.2	235.1	7.2	766.1	982.8	102.6	157.8	8.2	161.3	29.1	15.9	2484.8
2017	4.4	14.2	235.1	7.2	766.1	982.8	102.6	157.8	8.2	161.3	29.1	15.9	2484.8
2018	3.5	11.3	186.7	5.7	608.3	780.4	81.4	125.3	6.5	128.0	23.1	12.6	1973.0
2019	3.5	11.3	186.7	5.7	608.3	780.4	81.4	125.3	6.5	128.0	23.1	12.6	1973.0
2020	3.5	11.3	186.7	5.7	608.3	780.4	81.4	125.3	6.5	128.0	23.1	12.6	1973.0
2021	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2022	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2023	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2024	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2025	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2026	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2027	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2028	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2029	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2030	2.9	9.2	152.7	4.7	497.3	638.0	66.6	102.4	5.4	104.7	18.9	10.3	1613.0
2031 (3 months)	0.1	0.2	34.2	0.1	152.7	218.1	13.9	29.2	1.1	25.1	4.7	2.6	481.8

Table 15: Baseline Scenario Production for Standard Producers in the Laguna Seca Subarea (units in acre-feet)

Water Year	California American Water						Total
	RR 7	RR 11	Bishop 1	Bishop 2	Paddock 1	Bay Ridge	
2009 (9 months)	14.5	7.6	31.5	41.0	13.2	76.2	184.0
2010	19.5	10.1	42.1	54.8	17.7	101.9	246.1
2011	19.5	10.1	42.1	54.8	17.7	101.9	246.1
2012	11.6	6.1	25.2	32.8	10.6	60.9	147.2
2013	11.6	6.1	25.2	32.8	10.6	60.9	147.2
2014	11.6	6.1	25.2	32.8	10.6	60.9	147.2
2015	3.8	2.0	8.3	10.7	3.5	20.0	48.3
2016	3.8	2.0	8.3	10.7	3.5	20.0	48.3
2017	3.8	2.0	8.3	10.7	3.5	20.0	48.3
2018	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2019	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2021	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2022	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2023	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2031 (3 months)	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 16: Baseline Scenario Production for Alternative Producers in the Coastal Subareas (units in acre-feet)

Water Year	City of Seaside		Security Nat Guard	Calabrese	Mission Memorial Park	Sand City		Total
	Reservoir (BB)	Coe Ave.				Public Works	Robinette	
2009 (9 months)	209.3	194.1	109.5	10.5	23.5	6.7	0.0	553.6
2010	279.9	262.5	149.8	14.0	30.5	8.9	0.1	745.6
2011	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2012	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2013	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2014	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2015	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2016	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2017	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2018	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2019	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2020	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2021	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2022	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2023	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2024	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2025	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2026	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2027	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2028	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2029	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2030	279.9	262.5	149.7	14.0	30.5	8.8	0.1	745.4
2031 (3 months)	43.7	37.9	20.1	2.3	4.7	1.3	0.0	110.0

Table 17: Baseline Scenario Production for Alternative Producers in the Laguna Seca Subarea (units in acre-feet)

	Pasadera Resort		Bishop			County Park		
Water Year	**New Paddock**	**Old Main Gate**	**LS GC 12 new**	**LS GC Racetrack**	**York School**	**LS County Park 1**	**LS County Park 2**	**Total**
2009 (9 months)	114.7	73.0	188.8	50.5	23.9	19.1	11.5	481.7
2010	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2011	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2012	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2013	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2014	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2015	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2016	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2017	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2018	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2019	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2020	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2021	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2022	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2023	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2024	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2025	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2026	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2027	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2028	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2029	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2030	97.6	153.4	252.4	67.6	32.0	25.6	15.4	644.0
2031 (3 months)	16.2	27.5	42.8	12.2	5.1	3.2	3.6	110.5

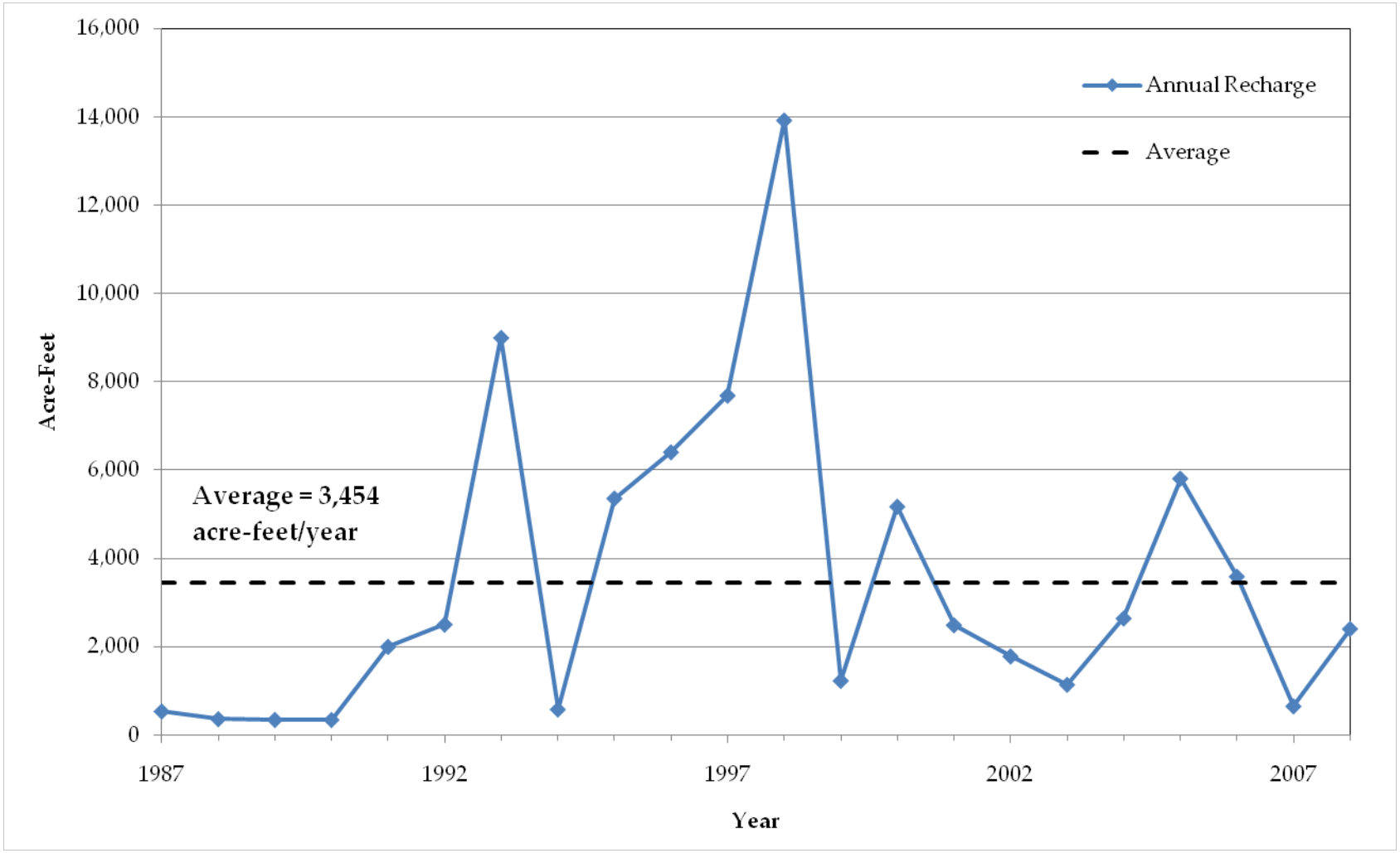


Figure 57: Estimated Annual Recharge for Predictive Scenarios

6.2 SCENARIO 1: IN-LIEU RECHARGE

Scenario 1 estimates the benefits from California American Water (CAW) stopping all pumping from the Seaside Groundwater Basin to obtain credit against its accumulated pumping deficit. The accumulated pumping deficit would eventually be erased through in-lieu recharge. Scenario 1 simulates a reasonable plan for repaying CAW's pumping deficit, evaluating its impact on basin groundwater levels, and estimating when protective groundwater elevations will be met.

The model assumed that up until October 2015, the scheduled triennial ten percent reduction will take place as per the baseline scenario. Beginning in October 2015, all of CAW's pumping was eliminated from the model as a supplemental supply becomes available. Based on the terms of the Replenishment Credit Memorandum of Understanding (MOU) the estimated amount of water CAW will be required to replenish after October of 2015 is approximately 16,865 acre-feet (MPWMD, personal communication).

Turning off all of their wells allows CAW to both eliminate their current overproduction of approximately 2,100 acre-feet per year, and forgo pumping their share of the Basin's Natural Safe Yield (1,474 acre-feet per year). The portion of the Natural Safe Yield that is not pumped effectively increases the amount of groundwater in the Basin by 1,474 acre-feet per year. Therefore, CAW's pumping deficit is reduced by 1,474 acre-feet per year for every year they import all of their water needs. Dividing the deficit of 16,865 acre-feet by 1,474 acre-feet per year suggests that CAW will need to forgo pumping in the Seaside Groundwater Basin for approximately 11 years and 5 months to repay their pumping deficit. Thus, the cumulative over-pumping would be repaid by March 2027.

Other producers were allowed to pump groundwater at full Decision-allocated rates without any triennial reduction during the time that CAW pumped nothing. This was because total annual pumping without CAW's production is less than 3,000 acre-feet, which is below the Basin's Natural Safe Yield. After March 2027, all Standard Producers, including CAW, pump at reduced rates as per the triennial reductions detailed in the Amended Decision.

6.3 SCENARIO 2: IN-LIEU RECHARGE AND INJECTION

Scenario 2 is similar to Scenario 1, with an added 2,000 acre-feet of injected water per year used to restore groundwater to protective elevations. The purpose is to assess how much quicker protective groundwater elevations are reached with supplemental injected water, compared to the 3,600 acre-feet per year in-lieu recharge only. The 2,000 acre-feet of injected water is intended to stay in the Seaside Groundwater Basin, and is not counted as additional supply that can be pumped from the Basin.

The pumping schedule in Scenario 2 is identical to the pumping schedule in Scenario 1. Three new injection wells were added along General Jim Moore Boulevard for injecting the 2,000 acre-feet per year. The locations of these three wells is shown on Figure 58. Injection was split equally among all three new wells. Assuming that the source of the 2,000 acre-feet is not seasonal, the injection was constant throughout the year. The injection was stopped in March 2027, to coincide with CAW resuming pumping.

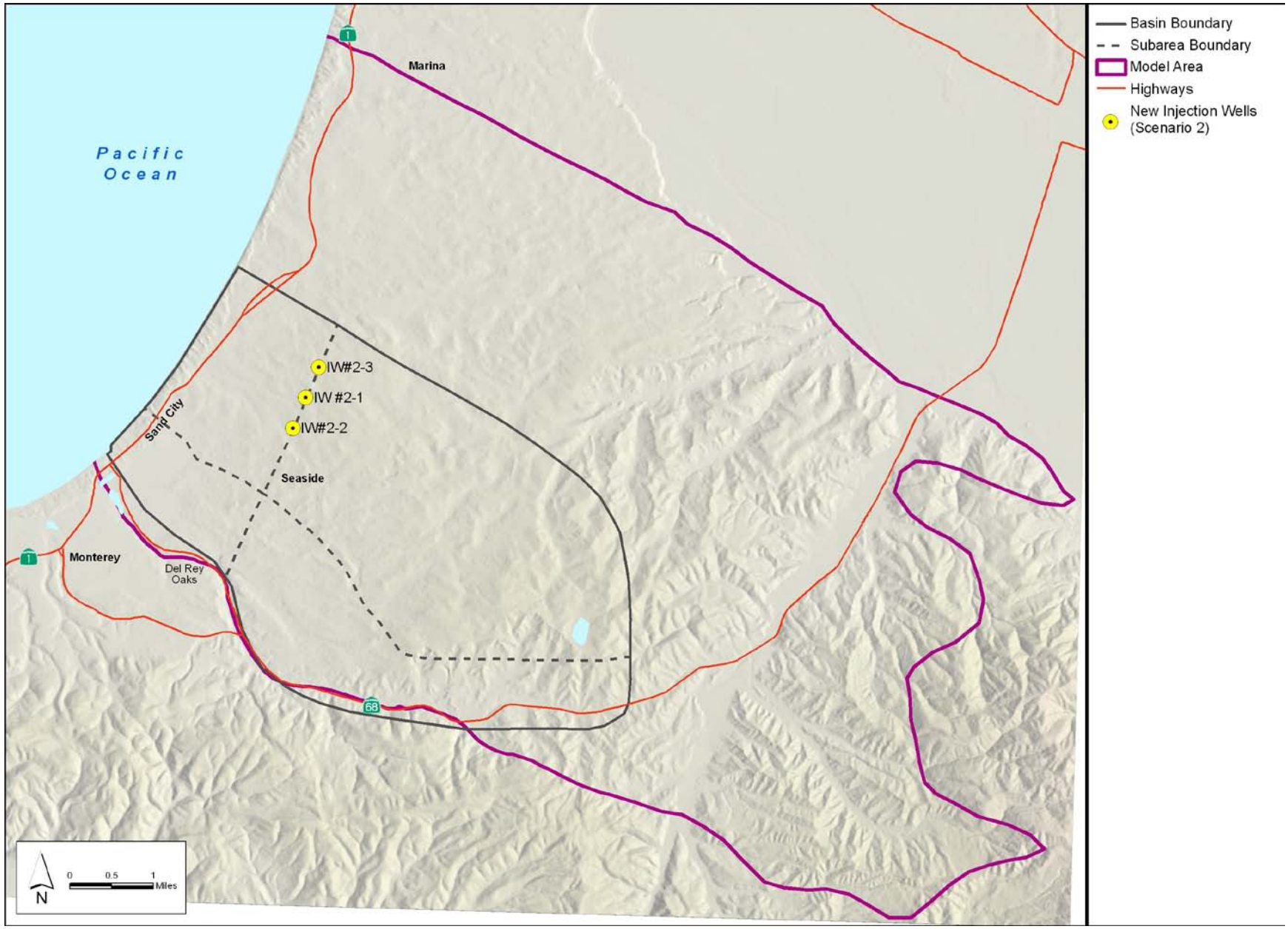


Figure 58: Injection Wells for Scenario 2

6.4 SCENARIO 3: GROUNDWATER REPLENISHMENT PROJECT

Scenario 3 simulates MRWPCA's proposed Groundwater Replenishment Project (GWRP). The model assumes that the start date for the GWRP is October 2015; which is the same date that supplemental supplies become available in Scenarios 1 and 2. Recharge continued for the remainder of the predictive period.

Recycled water was recharged through eight wells: six vadose zone wells and two deep recharge wells. The locations of the wells were provided by Todd Engineers (2009) and are shown in Figure 59. The six vadose zone wells inject water directly into the upper Paso Robles aquifer (model layer 2). The two injection wells will inject water into the Santa Margarita aquifer (model layer 5). Pumping rates were set such that the six vadose zone wells inject approximately 1,530 acre-feet per year, and the two deep injection wells inject approximately 1,270 acre-feet per year, for a total of 2,800 acre-feet per year of injection.

Baseline scenario pumping, which includes the triennial ten percent reduction for Standard Producers, was assumed for this scenario.

6.5 SCENARIO 4: COASTAL INJECTION BARRIER

Scenario 4 estimates the effects of a coastal injection barrier. The purpose of this barrier is to rapidly raise groundwater elevations at the coast to protective elevations, allowing inland pumping to continue without the threat of seawater intrusion. The model assumes that 2,600 acre-feet per year are imported from outside the Seaside Groundwater Basin and injected into a series of wells positioned close to the coastline. The locations of the injection wells are shown on Figure 60. As with the other model scenarios, injection starts in October 2015.

Adding 2,600 acre-feet per year of injected water to the Natural Safe Yield of 3,000 acre-feet per year will bring the Operating Yield up to 5,600 acre-feet per year. Therefore, the model assumed that pumping can remain at the full Decision-allocated rates without any triennial reduction throughout the simulation.

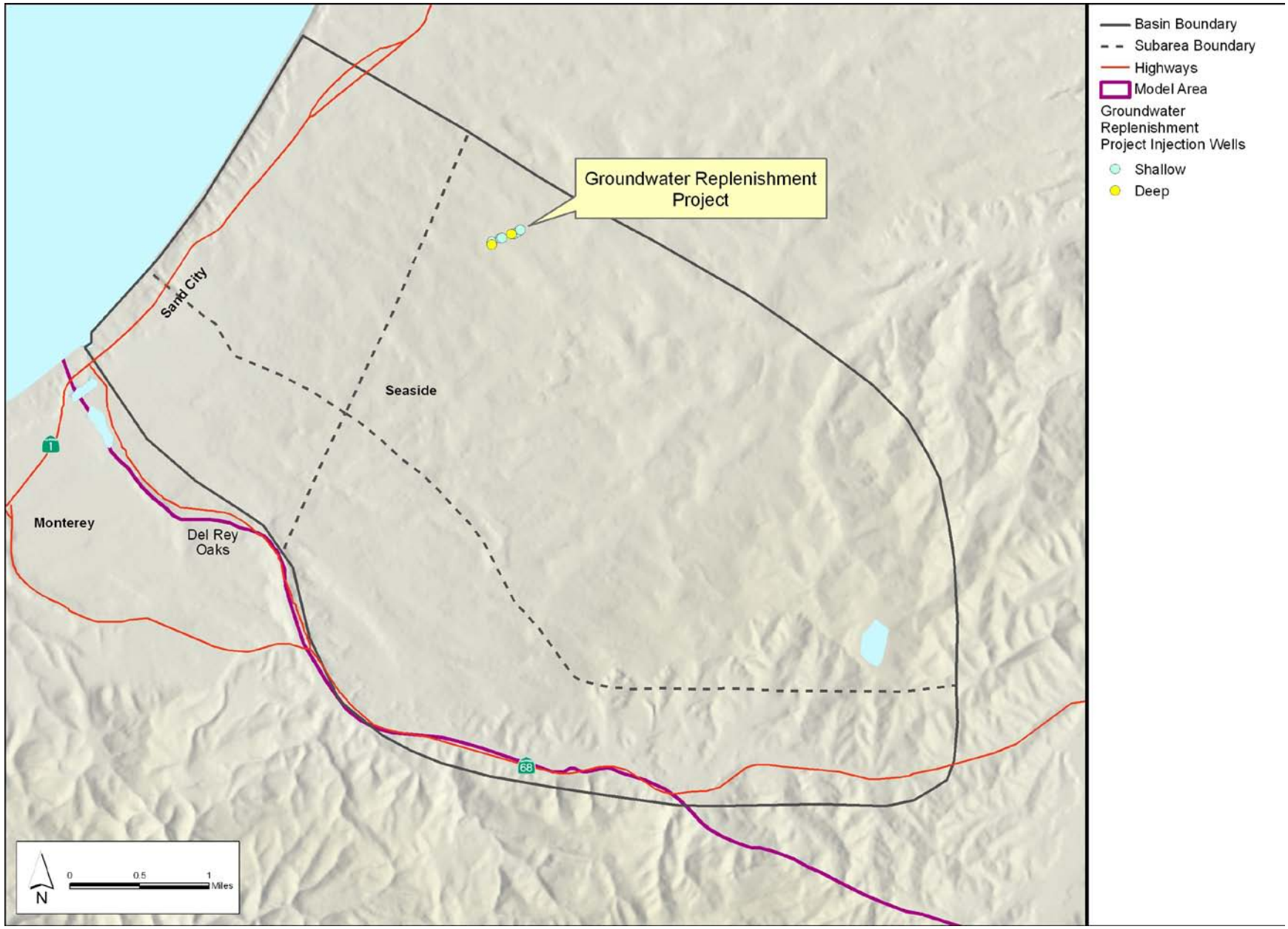


Figure 59: Location of GWRP Wells

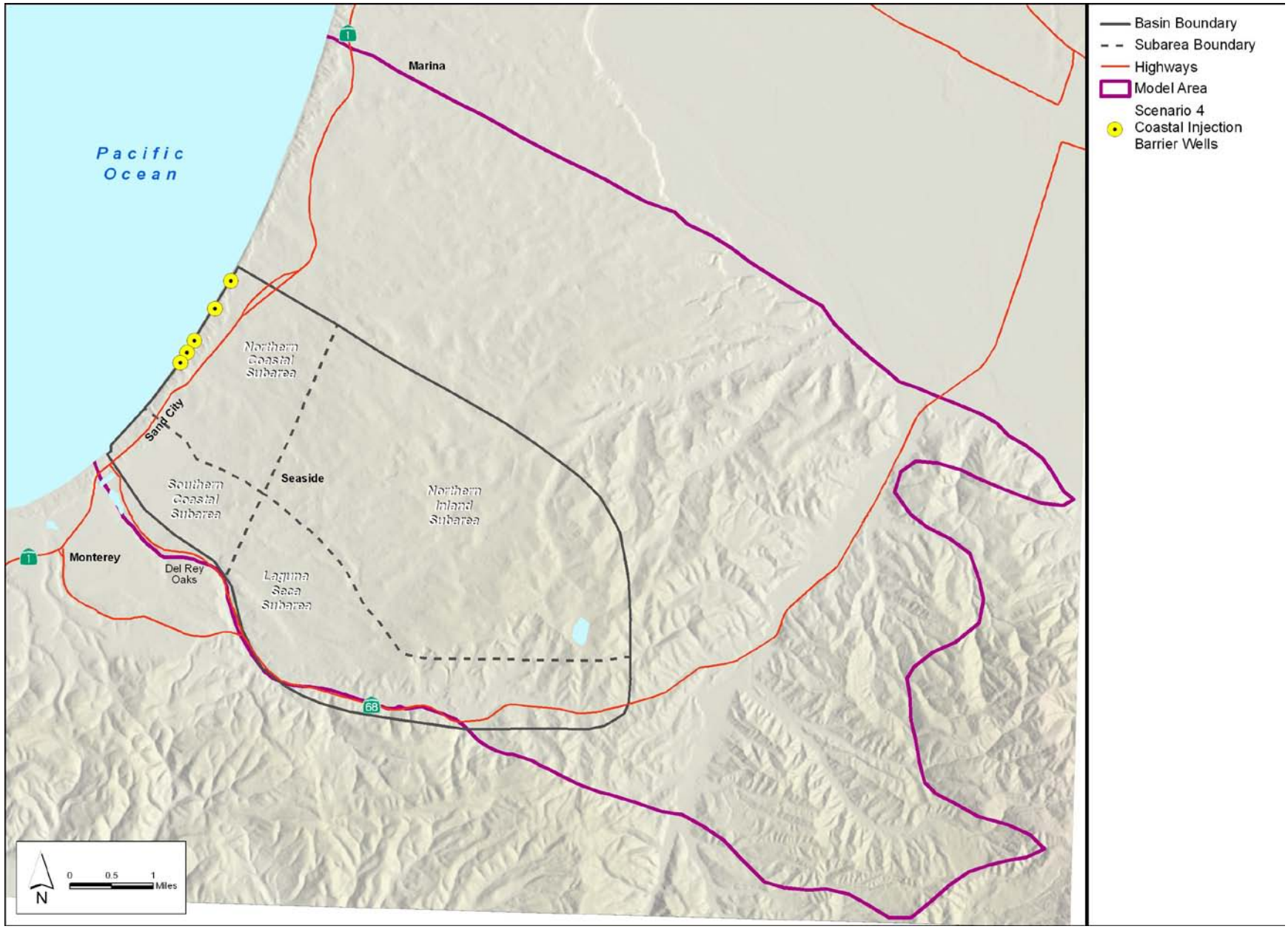


Figure 60: Coastal Injection Barrier Well Locations

6.6 SCENARIO 5: PUMPING REDISTRIBUTION

Scenario 5 evaluates the benefits from redistributing pumping in the Seaside Groundwater Basin. The purpose of this scenario is to estimate whether the benefits of redistributing pumping justify the costs that may be incurred. The major objective of pumping redistribution will be to achieve protective groundwater elevations at the coast.

To test the idea of moving pumping inland, CAW's Paralta well and Ord Grove 2 well were moved eastwards into the former Fort Ord. These two wells were chosen because they are CAW's largest producing wells. The new locations of the Paralta and Ord Grove well are shown on Figure 61. Both new wells pump only from the Santa Margarita aquifer, which is different than the baseline scenario where the wells are also screened in the Paso Robles aquifer. No changes were made to the pumping rates of these or any other wells. The triennial pumping reductions included in the baseline scenario were used in this scenario.

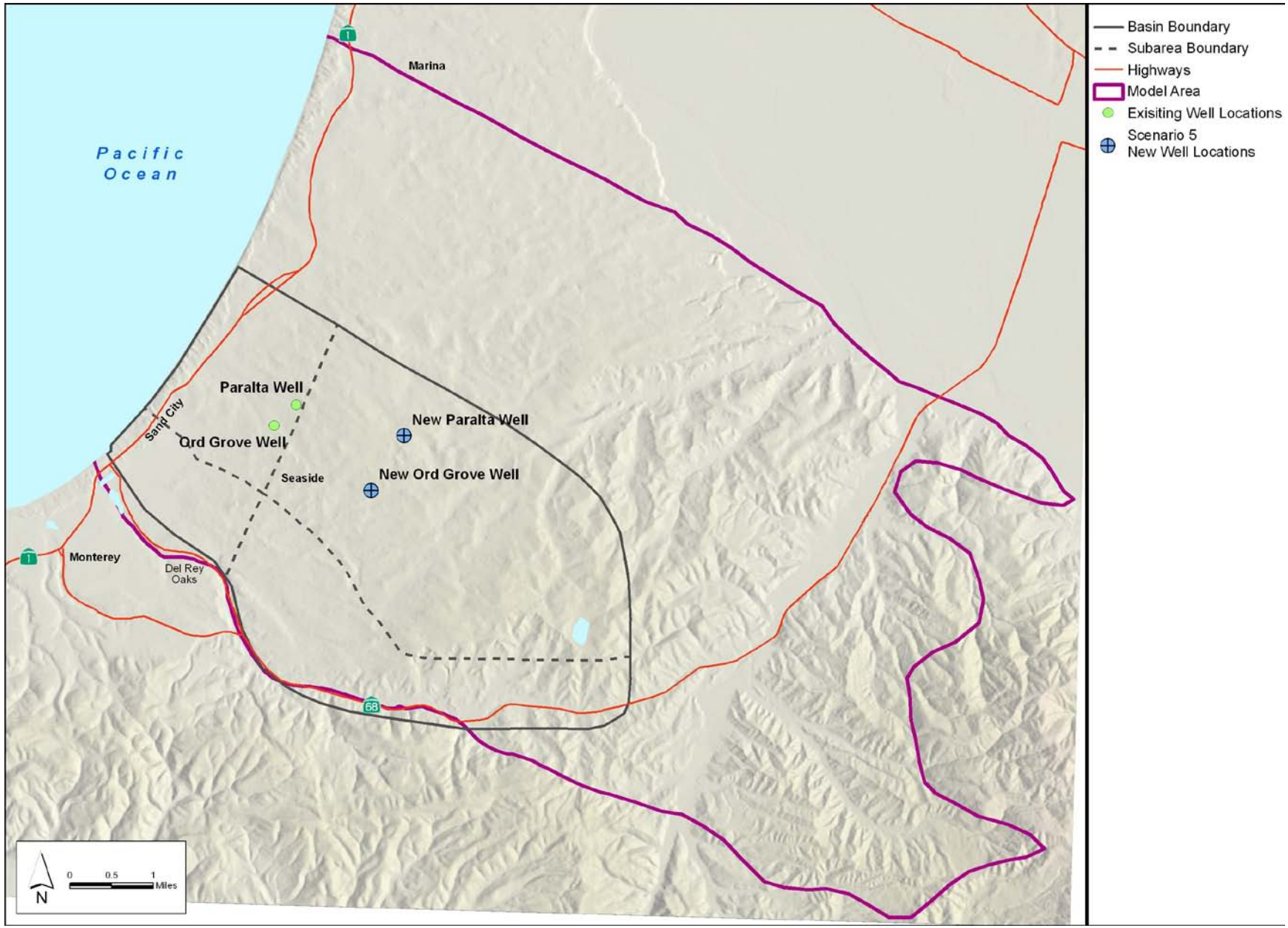


Figure 61: Locations of Moved Paralta and Ord Grove Wells

6.7 MODEL SCENARIO RESULTS

A baseline scenario and five groundwater management scenarios were simulated with the calibrated regional groundwater model. The five scenarios included the following:

- Scenario 1: CAW forgoes all pumping between October 2015 and March 2027. All other Standard Producers pump at the full Decision-allocated rates between October 2015 and March 2027. After March 2027, all Standard Producers, including CAW, pump at Decision-allocated rates with triennial 10% reduction.
- Scenario 2: Similar to Scenario 1, with an additional 2,000 acre-feet per year of recharge along General Jim Moore Boulevard.
- Scenario 3: Both shallow and deep recharge of 2,800 acre-feet per year from the MRWPCA groundwater replenishment project. Pumping includes the triennial 10% reductions.
- Scenario 4: Inject 2,600 acre-feet per year into a line of wells along the coast. All Standard and Alternative Producers pump at the full Decision-allocated rates, totaling 5,600 acre-feet per year.
- Scenario 5: Move CAW's largest pumping wells inland to reduce stress on coastal groundwater levels. Pumping includes the triennial 10% reductions.

Graphical results from all of the scenarios are presented on the following pages. A short analysis of each scenario is provided with graphical and tabular results.

6.7.1 GRAPHICAL RESULTS

6.7.1.1 GROUNDWATER IN STORAGE

The cumulative quantity of groundwater water stored in the Seaside Groundwater Basin under the baseline and five optional scenarios is shown in Figure 62. Cumulative stored water is plotted to demonstrate how much additional water is in the Basin at any one time, rather than how much water is put in the Basin in any one year. Figure 62 shows that the amount of water in storage is highly dependent on rainfall: all simulations begin with a series of dry years where the basin loses storage due to declining groundwater levels. The Basin gains storage in subsequent wet years. Because of these climatic effects on groundwater storage, the graph is most informative for comparing various scenarios rather than estimating absolute quantities of groundwater in storage.

The two scenarios with inland artificial recharge, Scenario 2 and Scenario 3, provide the Seaside Groundwater Basin with the most water in storage. Scenario 4 (Coastal Injection Barrier) provides little water for storage. This is because pumping was held at the full Decision-allocated quantity of 5,600 acre-feet per year in this scenario. Therefore, even with significant injection, there is a little benefit to the amount of groundwater in storage.

It is worth noting that the quantity of groundwater in storage does not necessarily equate with recoverable groundwater. The GWRP (Scenario 3) provides the most groundwater storage. However groundwater stored in the shallow Paso Robles aquifer in some scenarios may not be easily recovered with existing wells, which mostly extract from the underlying Santa Margarita aquifer. New wells will be required in the Paso Robles aquifer to recover more of the stored water.

Figure 62: Estimated Groundwater in Storage for Predictive Scenarios

6.7.1.2 Ocean Outflow and Inflow

Net outflow to the ocean for the baseline and five optional scenarios is shown on Figure 63. This figure plots monthly net ocean outflows, rather than cumulative volumes as were shown in Figure 62. Monthly outflows were chosen rather than cumulative because the total volume of inflow or outflow is less important than whether water is flowing from the ocean or towards the ocean at any time.

Beginning in 2020, both Scenario 2 and Scenario 3 predict a continuous net outflow of groundwater to the ocean. The other scenarios all show a combination of net groundwater flow from the ocean and to the ocean after 2020. Of the scenarios that do not include inland artificial recharge, Scenario 1 has the most net outflow to the ocean.

It is worth noting that Figure 63 shows the total outflow for all aquifers in the Seaside Groundwater Basin. Further analysis of the model results could be done to show which aquifers are discharging to the ocean, and which aquifers continue to be recharged from water beneath the ocean.

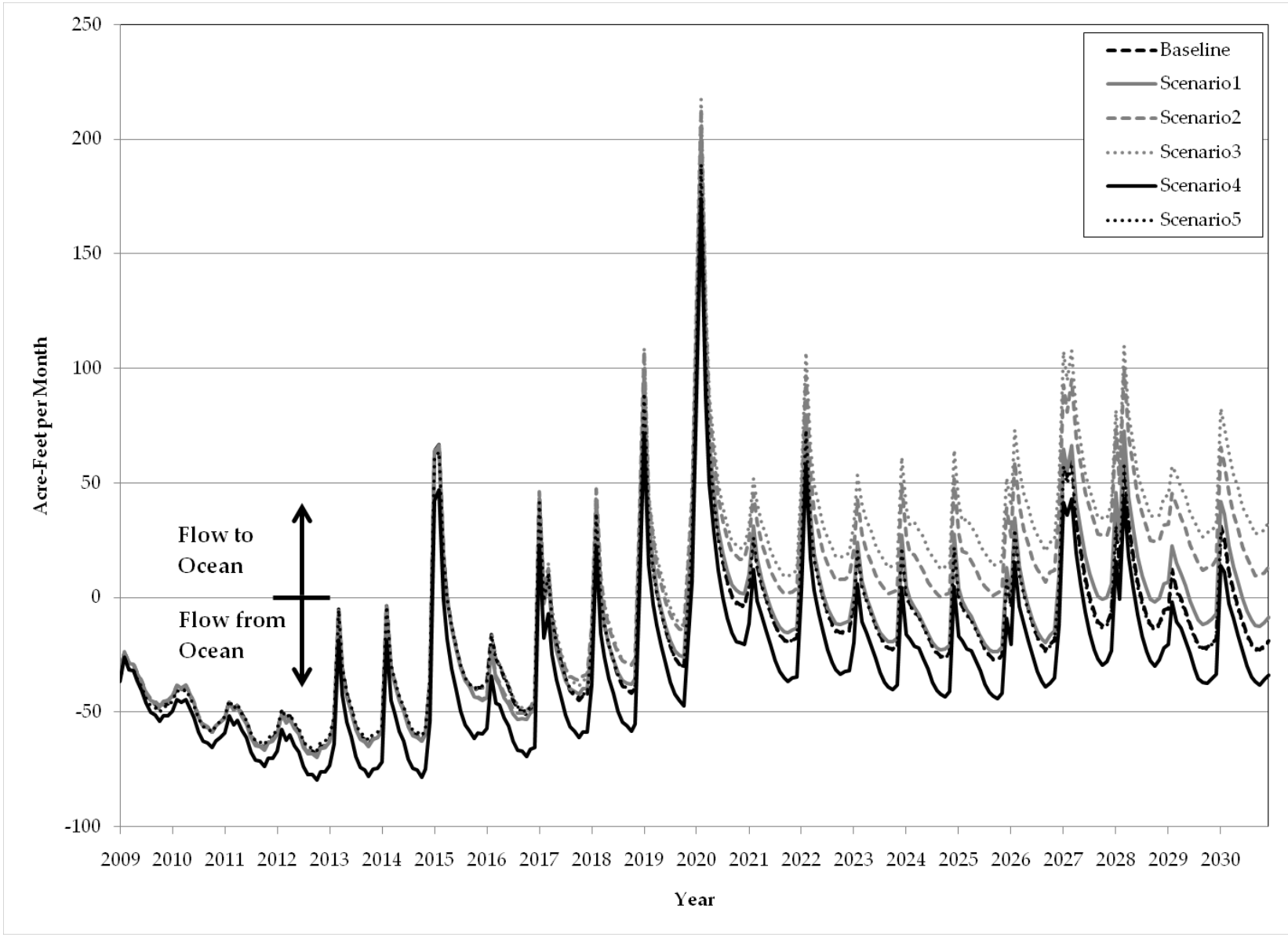


Figure 63: Monthly Estimated Outflow to the Ocean for Predictive Scenarios

6.7.1.3 Salinas Basin Outflow and Inflow

Net groundwater flow into and out of the Salinas Basin for the baseline and five optional scenarios is shown on Figure 64. This figure plots monthly net inflow and outflows, rather than cumulative volumes as were shown in Figure 62. Monthly flows were chosen rather than cumulative because the total volume of inflow or outflow is less important than whether water is flowing into or out of the Salinas Basin at any time.

The quantity of groundwater flowing in and out of the Salinas Basin is highly dependent on groundwater elevations in the Salinas Basin. Because future groundwater elevations in the Salinas Basin are uncertain, the graph is most informative for comparing various scenarios rather than estimating absolute quantities of groundwater in storage. Figure 64 shows that there is very little difference between predictive scenarios in flows in and out of the Salinas Basin. It is likely there is little difference between scenarios due to the fact that all operational changes in the scenarios occur south of the groundwater divide that separates the Seaside Groundwater Basin with the Salinas Basin to the north (Figure 34).

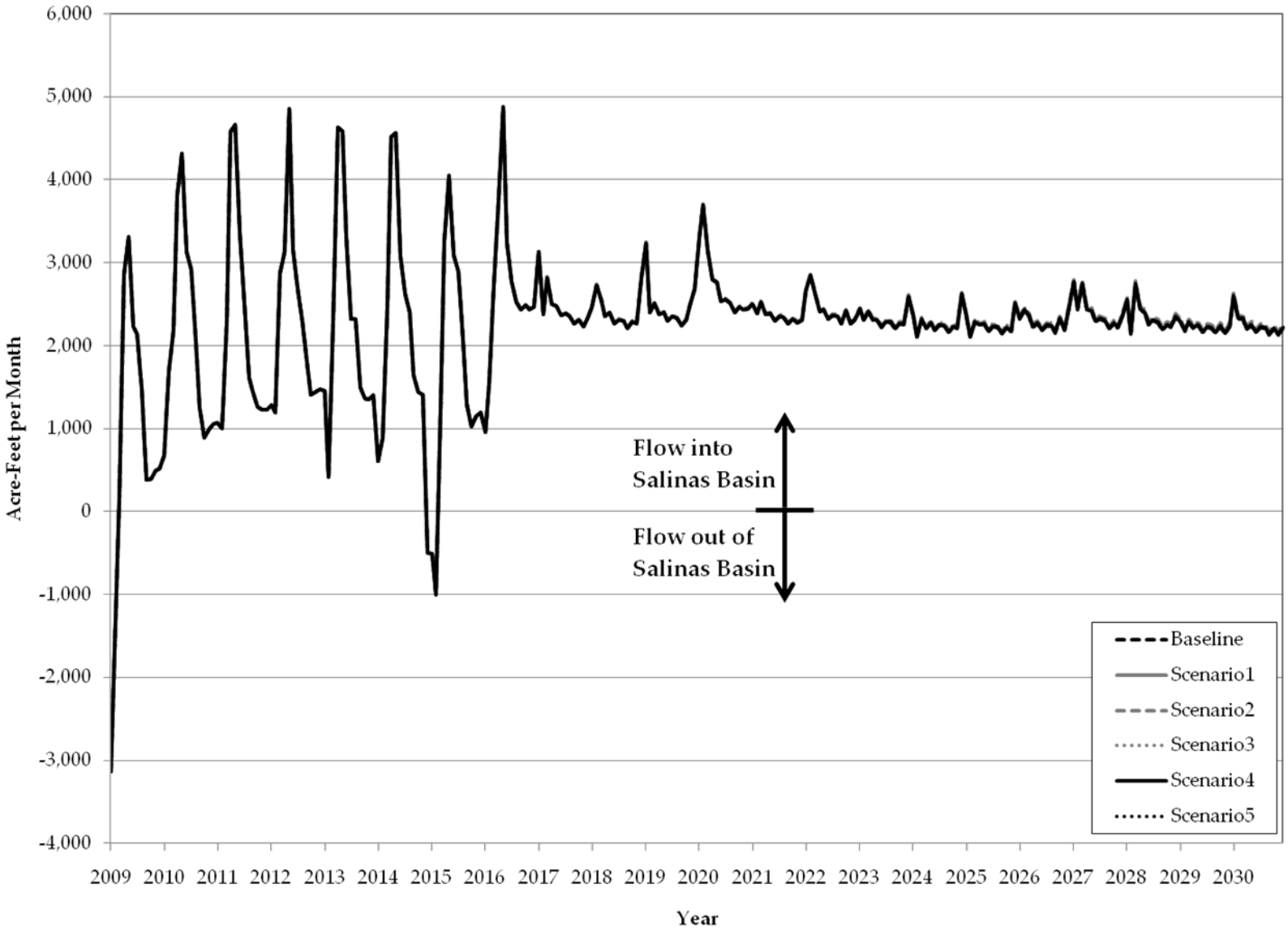


Figure 64: Monthly Estimated Flow Into and Out of the Salinas Basin for Predictive Scenarios

6.7.1.4 PROTECTIVE GROUNDWATER ELEVATIONS

Predicted groundwater elevations are compared with the protective elevations estimated for the four anchor wells used in the protective groundwater elevation models (Figure 65 through Figure 67). These graphs show, as expected, that the scenarios with significant injections are most successful at raising groundwater levels to protective elevations. Because the Santa Margarita aquifer is highly confined beneath thick clay beds near the ocean, it does not receive significant in-lieu recharge near the ocean. Therefore, it takes a long time for wells in the Santa Margarita aquifer to reach protective elevations without artificial recharge.

The MSC deep well hydrographs (Figure 65) show that only Scenario 2 is able to meet the protective elevation towards the end of the period when CAW has repaid its deficit. For the MSC shallow well, none of the scenarios reach protective elevations. The jump in shallow groundwater elevations predicted for Scenarios 1 and 2 occurs in March 2027 when all non-CAW producers switch from full Decision-allocated rates without the triennial reduction to reduced triennial rates. The fact that this jump is most noticeable in the shallow or Paso Robles aquifer indicates that many non-CAW producers have wells extracting from the Paso Robles aquifer.

Figure 66 shows that simulated groundwater elevations at the deep PCA West well meets protective groundwater elevations only in Scenario 2. The decline in groundwater elevation after March 2028 seen in Scenario 2 in the deep well is due to both injection stopping and CAW pumping starting up again. Simulated groundwater elevations at the shallow PCA West well start off above protective elevations, and remain so for all model scenarios. The increased simulated PCA West shallow groundwater elevation in March 2027 result from the same reasons described above for the MSC shallow well.

Only the injection scenarios meet and exceed Santa Margarita aquifer protective groundwater elevations in sentinel well SBWM-3 (Figure 67).

It is worth noting that well CDM-MW4's historical groundwater elevation has been between 3 and 4 feet MSL. As this well was not used for model calibration it appears that its groundwater elevation has been slightly under predicted in the model. Given a higher simulated groundwater elevation by only a foot or two, the predicted groundwater elevations would be above the protective elevation for all scenarios at this well.

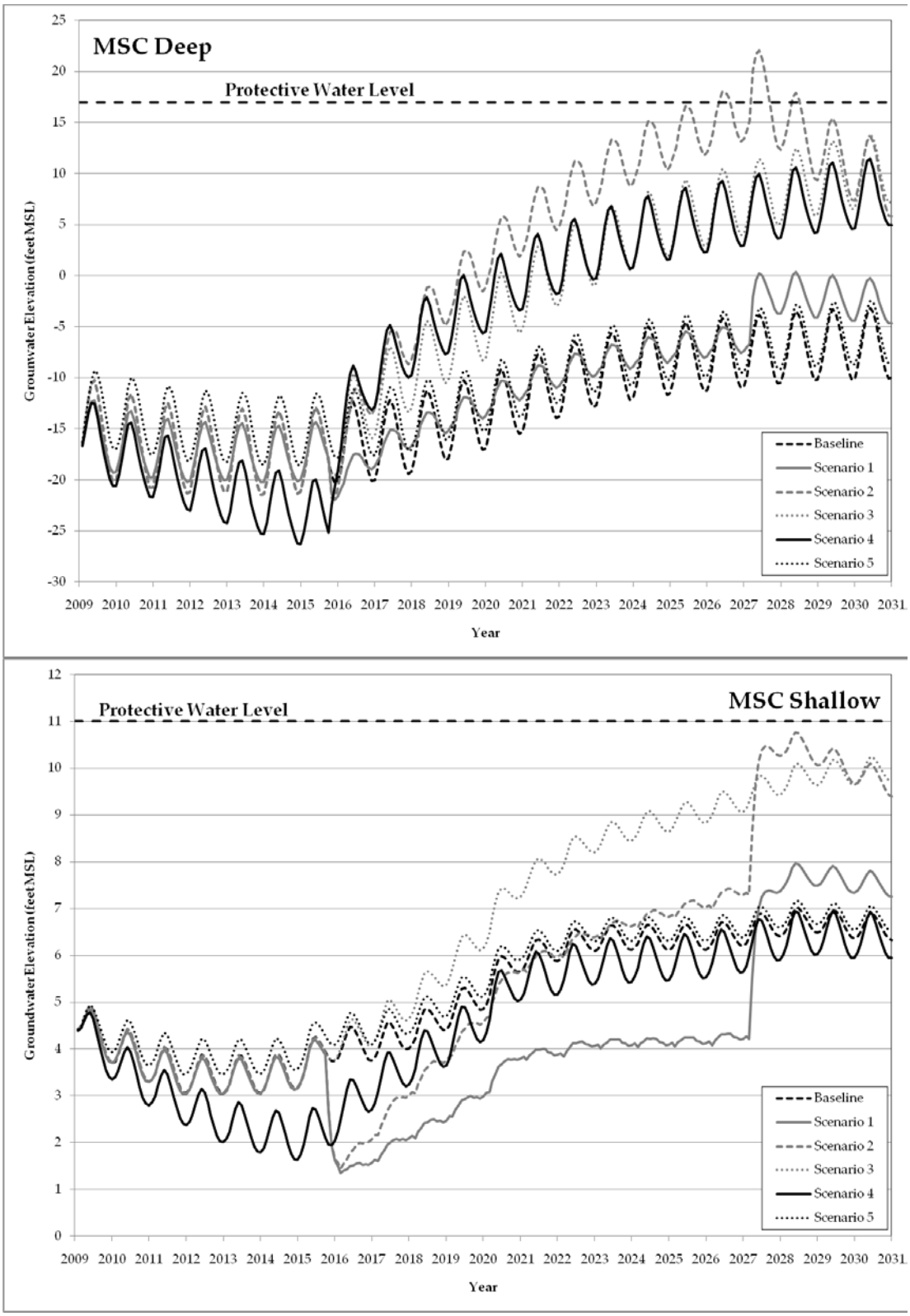


Figure 65: Predicted Groundwater Elevations and Protective Groundwater Elevations for the MSC Wells

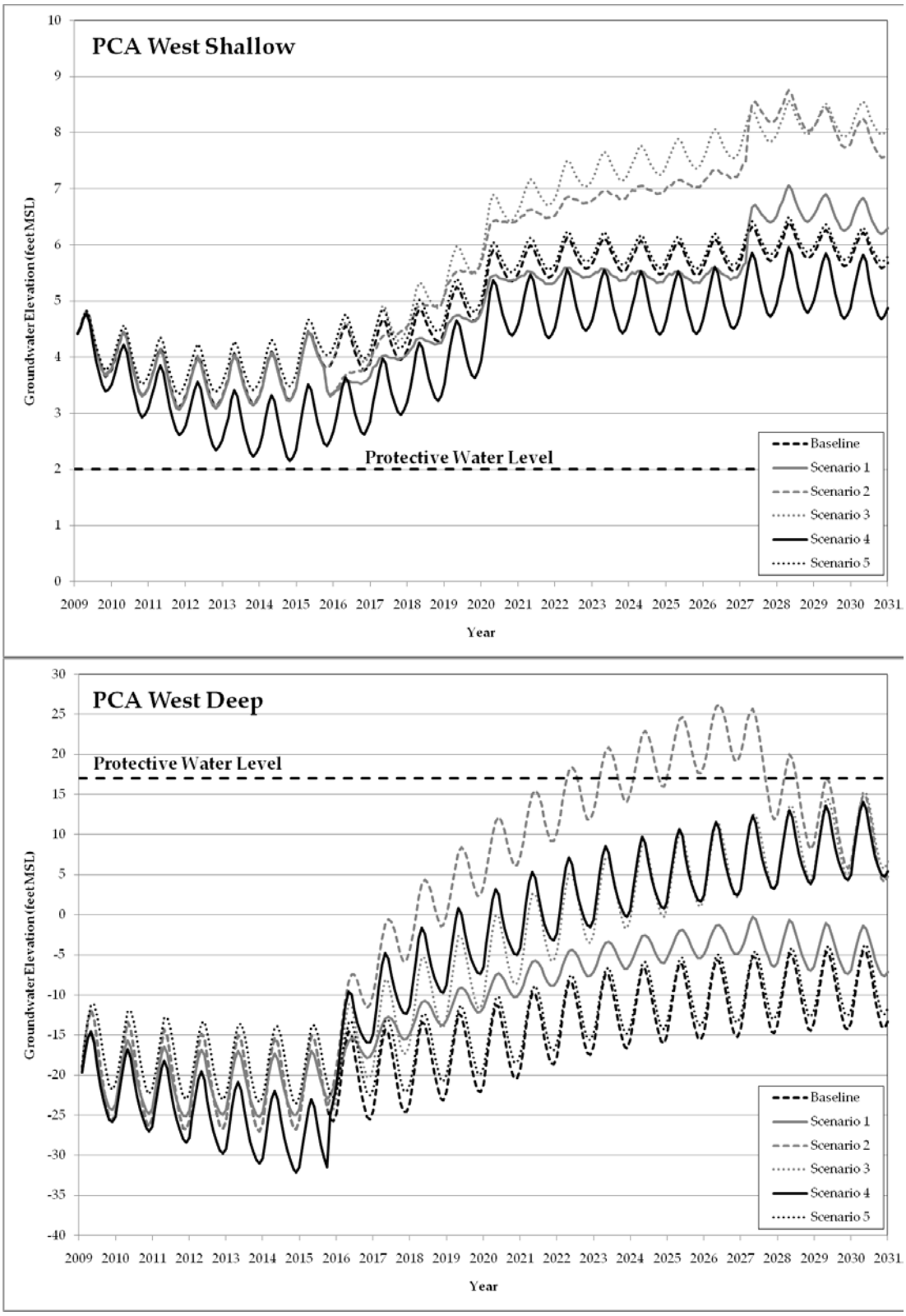


Figure 66: Predicted Groundwater Elevations and Protective Groundwater Elevations for the PCA West Wells

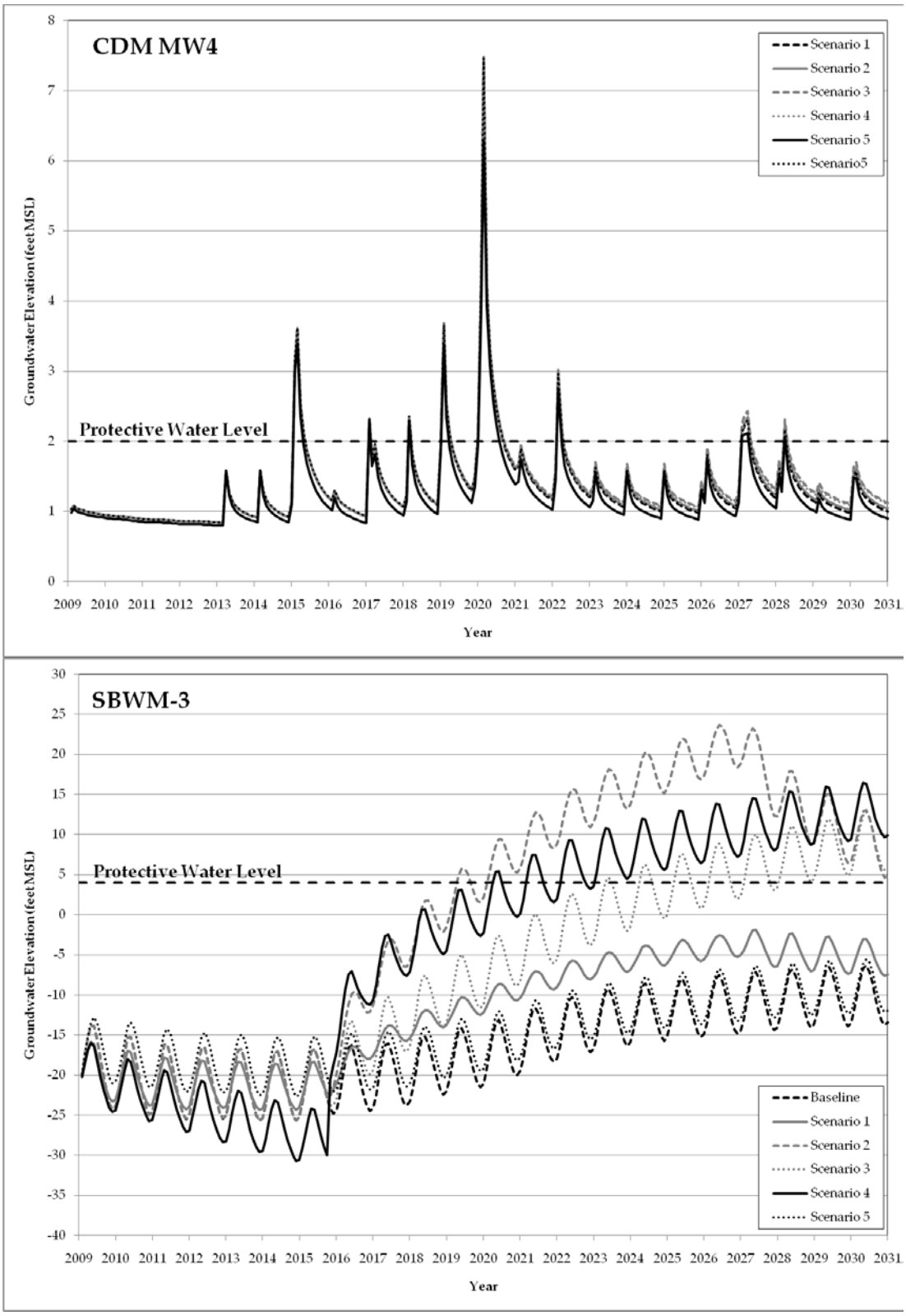


Figure 67: Predicted Groundwater Elevations and Protective Groundwater Elevations for Sentinel Well 3 and CDM Well MW-4

6.7.2 SCENARIO ANALYSIS

Based on the graphical results shown above, the following conclusions can be drawn from a comparison between the baseline scenario and five predictive scenarios.

- The mandated triennial pumping reduction will result in a slow increase in most groundwater elevations. Additionally, the mandated pumping reduction decreases does not completely eliminate inflow from the ocean

- Scenario 1 results in higher groundwater elevations than the baseline scenario. More significantly, Scenario 1 adds approximately 5,000 more acre-feet of water in the Seaside Groundwater Basin by the end of the simulation.

- All scenarios raise groundwater elevations significantly, and add significant amounts of water to the Seaside Groundwater Basin. It is unclear if all of the water added to the Basin is easily recoverable by existing wells. Additional analysis of the model results will show how much stored water is recoverable.

- Scenario 4 shows a significant benefit towards achieving protective groundwater elevations, but is worse than the baseline scenario at storing additional water in the Seaside Groundwater Basin. This is because the increased recharge from artificial injection is offset by high pumping rates in this scenario. The injection will likely show much greater benefits if it accompanied by the mandated triennial pumping reduction. Scenario 4 shows an example of how groundwater elevations near the coast can be increased to near protective elevations while the annual yield remains close to 5,600 acre-feet per year.

- Scenario 5 shows that moving pumping inland has limited benefit. The simulated groundwater elevation rise is similar to the rise observed in the baseline scenario. Scenario 5 adds the least amount of water to basin storage. It seems doubtful that the cost of moving wells inland would be justified.

Table 18 provides a summary of the model scenarios including their results.

Table 18: Summary of Model Scenario Assumptions and Results

Scenario	Assumptions	Results	Observations and Analyses
Baseline	Future land use changes phased in 25% of build-out by 2014, remainder by 2019*	Coastal groundwater levels in both the shallow and deep aquifers show a modest rise in response to the reduced pumping. Most groundwater elevations level off below the protective groundwater elevation around 2028.	This scenario has insufficient water to restore the Basin and raise groundwater levels above protective elevations. Additional actions are needed.
	Water for new developments is obtained from outside of Basin*		
	MPWMD ASR program included*		
	Standard Allocation pumping reduced triennially (every three years) in proportion to pumping rates		
	Alternative Allocation pumping set at Decision-allocated rates		
1	CAW forgoes all pumping between October 2015 and March 2027	Deep groundwater levels rise more quickly than in the Baseline simulation, but the rise is limited. Shallow groundwater elevations decline compared to the Baseline simulation during the time other Standard Allocators are producing the same amount they produced in 2005. Approximately 3,600 acre-feet of additional water are stored compared to the baseline scenario.	The limited pumping in the deep aquifer does not result in groundwater elevations above protective elevations because deep percolation is limited by overlying clay layers. 60% of the additional stored groundwater is in the deep aquifer.
	All other Standard Producers pump at 2005 rates between October 2015 and March 2027		
	Pumping continues at Decision-allocated rate with triennial 10% reduction after March 2027		
2	As in Scenario 1, CAW forgoes all pumping between October 2015 and March 2027	This scenario shows the highest coastal water elevations in the deep aquifer out of all the scenarios. Approximately 11,100 acre-feet of additional water are stored compared to the baseline scenario.	Injection along General Jim Moore Blvd can raise groundwater levels significantly at the coast when combined with limited pumping. 70% of additional stored groundwater is in the deep aquifer.
	2,000 acre-feet per year of injection well recharge is added along General Jim Moore Boulevard		

Table 18: Summary of Model Scenario Assumptions and Results (continued)

Scenario	Assumptions	Results	Observations and Analyses
3	The MRWPCA GWRP recharges 2,800 acre-feet of water per year, split between the shallow and deep aquifers Pumping is the same as in the baseline scenario.	This scenario shows significant groundwater elevation rises in the deep aquifer, although not as great as Scenario 2. Groundwater elevation rises in the shallow aquifer are similar to those observed in Scenario 2. This scenario stores the most water in the Basin: approximately 17,800 acre-feet more than are stored in the baseline scenario.	Deep aquifer groundwater level rises are not as great as in Scenario 2 because the amount of deep injection is less and the deep aquifer pumping is greater in this scenario. Shallow coastal groundwater elevations are approximately equal to those in Scenario 2, suggesting a maximum level these shallow groundwater levels can rise to. Unlike Scenario 1 and Scenario 2, 62% of the additional stored groundwater is in the shallow aquifer.
4	Inject 2,600 acre-feet per year into a line of wells along the coast All Standard and Alternative Producers pump at the 2005 rates (5,600 AFY)	Groundwater elevation rises in the deep aquifer are similar to those seen in Scenario 3. Groundwater elevation rises in the shallow aquifer are small. No water is stored in the Basin.	The coastal injection raises water at the coast, but stores no water because of the aggressive pumping.
5	Move CAW's largest pumping wells inland to reduce stress on coastal groundwater levels Pumping includes the triennial 10% reductions	This scenario shows very little impact on either groundwater elevations or groundwater in storage.	Moving pumping wells inland has little advantage, and is not a useful management strategy.

This page left
intentionally blank

SECTION 7
REFERENCES

Anderson, M.P., and W.W. Woessner. 1992. *Applied groundwater modeling, simulation of flow and advective transport,* Academic Press, Inc., San Diego, California, 381 p.

Association of Monterey Bay Area Governments (AMBAG). Land Cover 1990/93 - Central Coast. Accessed from http://gis.ca.gov/catalog/BrowseRecord.epl?id=1790

California Department of Water Resources. 1989-91 - North Monterey County and Salinas Valley. Accessed from: http://ceic.resources.ca.gov/catalog/CoastalCommWATERWatershedAnalysisTool/LandUse198991NorthMontereyCoAndSalinasValley.html

California Department of Water Resources. 1997 Monterey County land use survey data. Accessed from: http://www.water.ca.gov/landwateruse/lusrvymain.cfm

CH2M HILL, 2004. H*ydrogeologic assessment of the Seaside groundwater basin, draft report* :prepared for Somach, Simmons & Dunne, LLP and California American Water Company. Oakland, CA. January.

City of Seaside. 2009. GIS format land use.

County of Monterey. 2007. Draft 2007 Monterey County general plan, November 6, 2007. Accessed at http://www.co.monterey.ca.us/planning/gpu/draftNov2007

Creegan & D'Angelo Consulting Civil and Structural Engineers. 2005. *Fort Ord Reuse Authority storm water master plan:* prepared for Fort Ord Reuse Authority, March.

Dahlin Group. 2007. Land use plan, The Resort at Del Rey Oaks, Del Rey Oaks, CA. Accessed at http://www.delreyoaksresort.com/pdf/landuse.pdf , October 20, 2009.

Doherty, J. 2002. *Guidelines for pilot point selection.* Watermark Numerical Computing, June.

Doherty, J. 2003. Groundwater model calibration using pilot points and regularisation. *Ground Water*. 41 (2): 170-177.

———. 2007. *PEST groundwater data utilities*. Watermark Numerical Computing, Australia, August.

———. 2008. *Addendum to the PEST Manual.* Watermark Numerical Computing, February 2008.

Durbin, T.J. 2007. *Groundwater flow and transport model, Seaside groundwater basin, Monterey County, California – Technical Advisory Committee Draft:* prepared for RBF Consultants. October 1.

EMC Planning Group, Inc. and EDAW, Inc. 1997. *Fort Ord reuse plan*: prepared for the Fort Ord Reuse Authority, June 13. Accessed at http://www.basereuse.org/reuseplan/HomePage/HomePage.htm

Feeney, M.B. 2007. *Seaside groundwater basin watermaster, Seaside Basin monitoring and management program: groundwater modeling component – report on groundwater modeling meeting and recommended approach*: prepared for Seaside Groundwater Basin Watermaster, January.

———. 2007. *Seaside groundwater basin watermaster, seawater sentinel wells project, summary of operations*: prepared for Seaside Groundwater Basin Watermaster, October.

Feeney, M.B. and L.I. Rosenberg. 2003. *Deep aquifer investigative study:* prepared for Marina Coast Water District. Sacramento, CA. May.

Fugro West, Inc. 1997. *Hydrogeologic assessment, Seaside coastal groundwater Subareas*, Phase III update, Monterey County, California: prepared for Monterey Peninsula Water Management District, September.

Geosyntec Consultants. 2007. *El Toro groundwater study, Monterey County, California*: prepared for Monterey County Water Resources Agency. July.

Guo, W. and C.D. Langevin. 2002. *User's guide to SEAWAT*: A computer program for simulation of three-dimensional variable-density ground-water flow, U.S. Geological Survey TWRI Book 6 Chapter A7.

Harbaugh, A.W. 2005. *MODFLOW-2005, the U.S. Geological Survey modular ground-water model -- the Ground-Water Flow Process:* U.S. Geological Survey

Techniques and Methods 6-A16, U.S. Geological Survey, Reston, VA, variously p.

Harris & Associates. 2006. *City of Marina percolation pond feasibility study*: prepared for City of Marina, March.

HydroMetrics LLC. 2008. *Seawater intrusion analysis report, Seaside groundwater basin, Monterey County, California,* prepared for Seaside groundwater basin watermaster.October.

——— 2009a. *Basin management and action plan*: prepared for Seaside groundwater basin watermaster. February 5.

——— 2009b. *Seawater intrusion analysis report, Seaside groundwater basin, Monterey County, California,* prepared for Seaside groundwater basin watermaster. October.

Langevin, C.D., W.B. Shoemaker, and W. Guo. 2003. *MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model–Documentation of the SEAWAT-2000 Version with the Variable-Density Flow Process (VDF) and the Integrated MT3DMS Transport Process (IMT)*, U.S. Geological Survey Open-File Report 03-426.

Logan, J. 1982. *Hydrogeology of the Seaside area.* Prepared for Monterey Peninsula Water Management District, June 1982.

Monterey County Water Resources Agency. Undated. Isohyetal map originally developed by the Santa Clara Valley Water District and published as the Mean Annual Precipitation Map, San Francisco & Monterey Bay Region, 1988. Edited by MCWRA using unpublished data from Monterey County's ALERT system.

Rosenberg, L.I. 2001. *Digital geologic map of Monterey County, California*. Version 1.0. http://www.co.monterey.ca.us/gpu

———. 2009. Personal communication.

Schaaf & Wheeler, 2004. *Draft California State University Monterey Bay master plan update - water supply/distribution, sewer system, and hydrologic and drainage impact assessments*, prepared for Denise Duffy& Associates, July 2004.

———. 2006. *California State University Monterey Bay stormwater master plan*, prepared for California State University Monterey Bay, March 2006.

———. 2008. Memo entitled *CSUMB Draft EIR stormwater comment response*, prepared for California State University Monterey Bay, October 2008.

Staal, Gardner & Dunne, Inc. 1990. *Hydrogeologic update, Seaside coastal groundwater basin, Monterey County, California*. Prepared for MPWMD, Monterey, CA, August 1990.

Todd Engineers. 2009. *Technical memorandum on description of model scenario for the Seaside Groundwater Basin Watermaster Groundwater Replenishment (GWR) Project - Monterey Regional Water Pollution Control Agency*, prepared for Georgina King, HydroMetrics LLC.

USDA - Natural Resources Conservation Service. 1978. Soil Survey of Monterey County, CA. Accessed online at http://gis.ca.gov/catalog/BrowseRecord.epl?id=2305

Watermark Numerical Computing, 2004, PEST Model-Independent Parameter Estimation User Manual, 5th Edition, July 2004.

Yates, E.B., Feeney, M.B., and Rosenberg, L. I. 2002. *Laguna Seca Subarea phase III hydrogeologic update.* Prepared for Monterey Peninsula Water Management District. November 2002.

———. April 14, 2005. *Seaside groundwater basin: update on water resource conditions*. Prepared for Monterey Peninsula Water Management District, Monterey, CA.

APPENDIX A: ESTIMATATION OF DEEP GROUNDWATER RECHARGE

Estimate of Deep Groundwater Recharge

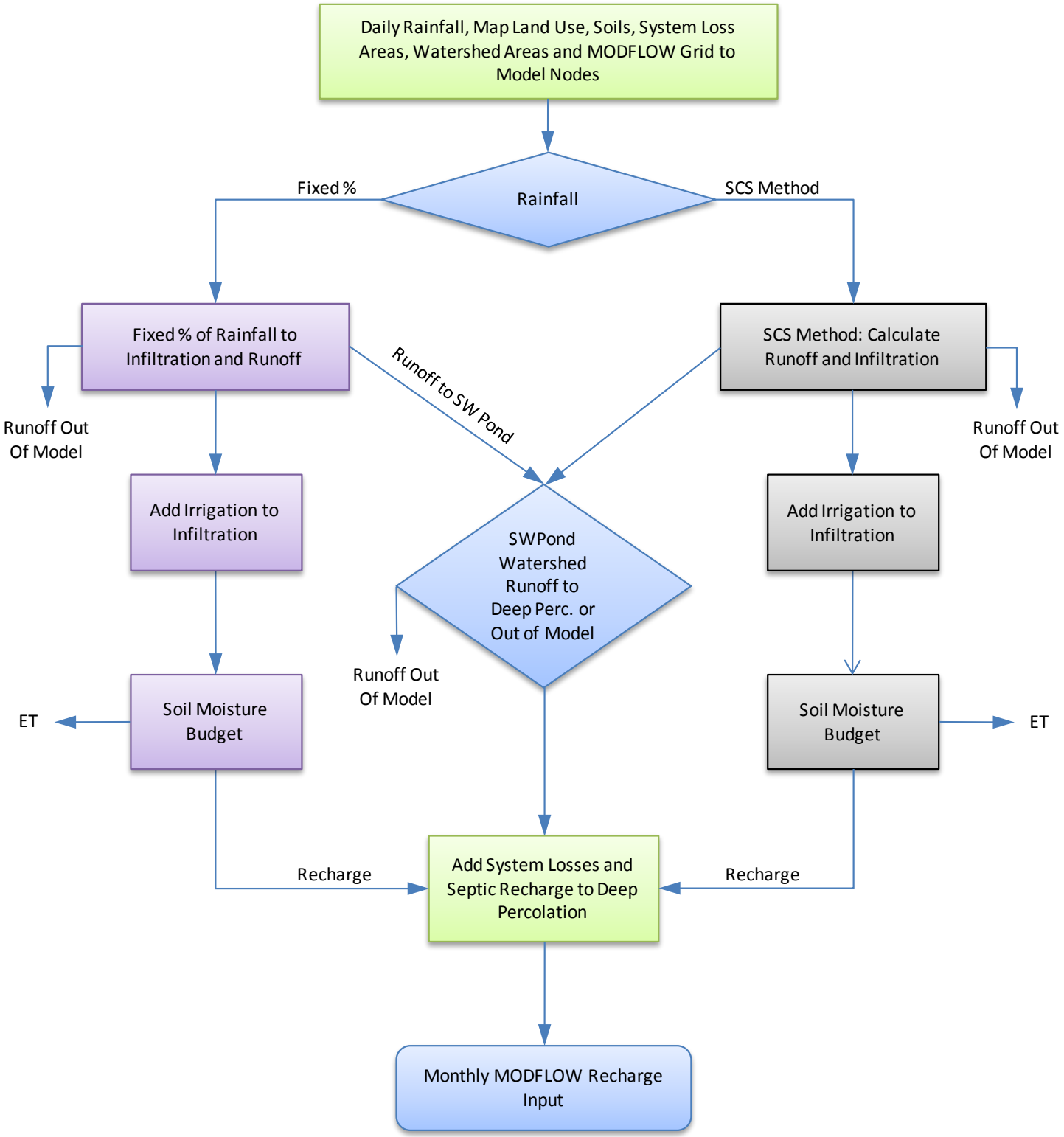
The approach to estimating recharge from the various sources of water is diagramed in Figure A- 1. A FORTRAN program was developed that follows the logic shown on Figure A- 1. The important steps implemented by the FORTRAN program are described below.

Spatial data were first mapped to each model cell in the top model layer. Spatial data included daily rainfall, monthly evapotranspiration, soil type, land use, extents of water distribution systems, and the boundaries of watersheds where runoff is routed to infiltration ponds. The daily rainfall was distributed to each model cell based on the map shown on Figure 9. Monthly evapotranspiration was distributed to each model cell based on distance from each cell's distance from the coast as described in Section 2.5.2.

The initial runoff from rainfall is estimated in one of two ways. For most of the model area, the Soil Conservation Service (SCS) curve number method was used to estimate runoff and recharge. The curve number method assigns a value to each soil type, and combines the soil type with the slope of the land to estimate runoff. The curve numbers used by Yates (2002) were assigned to the various soil types in the model. In certain areas of the model, the runoff was set at either 0% or 100%. Inland areas of Fort Ord with no well developed streams were assigned a runoff of 0%. Surface water bodies such as Roberts lake and the Laguna Grande were assigned a runoff of 100%, effectively removing any rain that falls on these lakes.

Runoff that occurs in percolation pond watersheds is routed to the appropriate percolation pond. All of the runoff that enters the percolation pond is added to the deep percolation. Runoff that occurs outside percolation pond watersheds is routed to ocean outfalls, outside of the model.

Irrigation water is treated similarly to rainfall, with a few modifications. A percentage of delivered water is used for irrigation. In the current model, 25% of water delivered during summer months is used for irrigation. If the irrigation practices are monitored, it is reasonable to assume that none of the irrigation water results in runoff.



SW = stormwater
SCS = Soil Conservation Service

Figure A- 1: Deep Recharge Estimating Technique

The sum of the shallow infiltration from rainfall and shallow infiltration from irrigation provides the input to a soil moisture budget calculation. The soil moisture budget is calculated for every month of the simulation. The soil moisture budget is described by equation 1. This equation states that the water entering the soil root zone (infiltration) minus the water leaving (deep percolation and ET) equals the change in soil moisture stored in the root zone.

$$(1) \qquad I_i - AET_i - DP_i = \Delta SM_i$$

I_i = infiltration during time period i
AET_i = actual evapotranspiration during time period i
DP_i = deep percolation during time period i
ΔSM_i = change in soil moisture during time period i

Infiltration is the amount of shallow recharge from rainfall and shallow recharge from irrigation calculated previously. The actual evapotranspiration used in the calculation is based on a reference evapotranspiration, ETo. The reference evapotranspiration represents the amount of water used by tall grass when water is freely available. The equation used to calculate the AET is presented in equation 2. The crop coefficient in equation 2, Kc, is a factor that adjusts ETo for differences between the reference crop (tall grass) and other types of vegetation. The available water capacity (AWC) in equation 2 is a soil specific value of the maximum soil moisture any of water a particular soil can hold. When the soil moisture falls below 50% of the capacity of the soil, the AET begins to decrease linearly to zero.

$$(2) \qquad AET = 2 * \frac{\theta_r}{AWC} * Kc * ETo \quad \text{for } 0 \leq \frac{\theta_r}{AWC} \leq 0.5$$

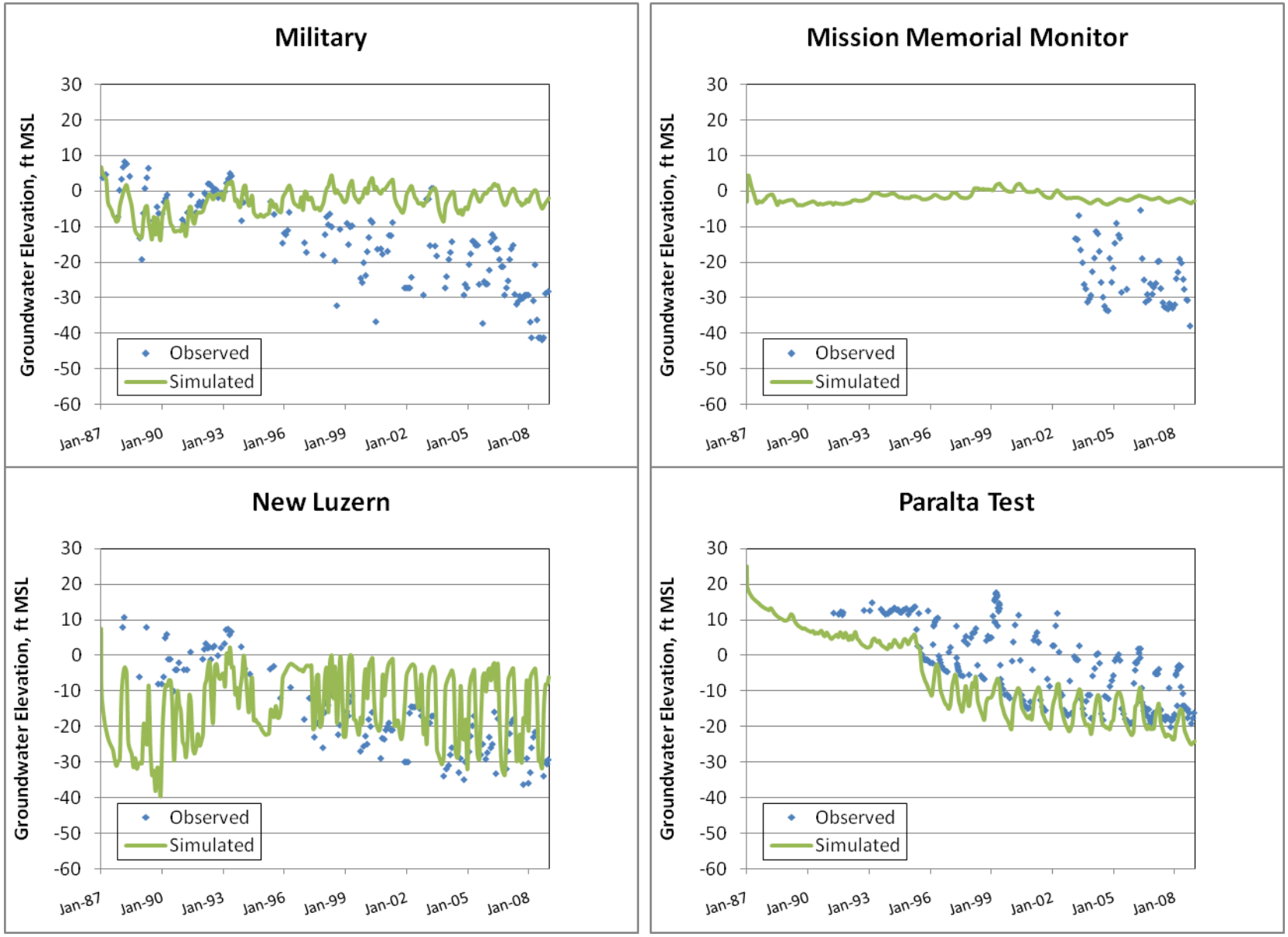
$AET = Kc*ETo$ for $\frac{\theta_r}{AWC} \geq 0.5$
Kc = crop coefficient
AWC = Available Water Capacity; storage capacity of water available to plants
θ_r = Soil Moisture in Root Zone

After subtracting AET, any remaining water in excess of the available water capacity becomes deep percolation. Additional deep percolation comes from system losses and septic system recharge. Septic system recharge of 401 acre-feet per year was added directly to the estimates of deep recharge. Recharge from

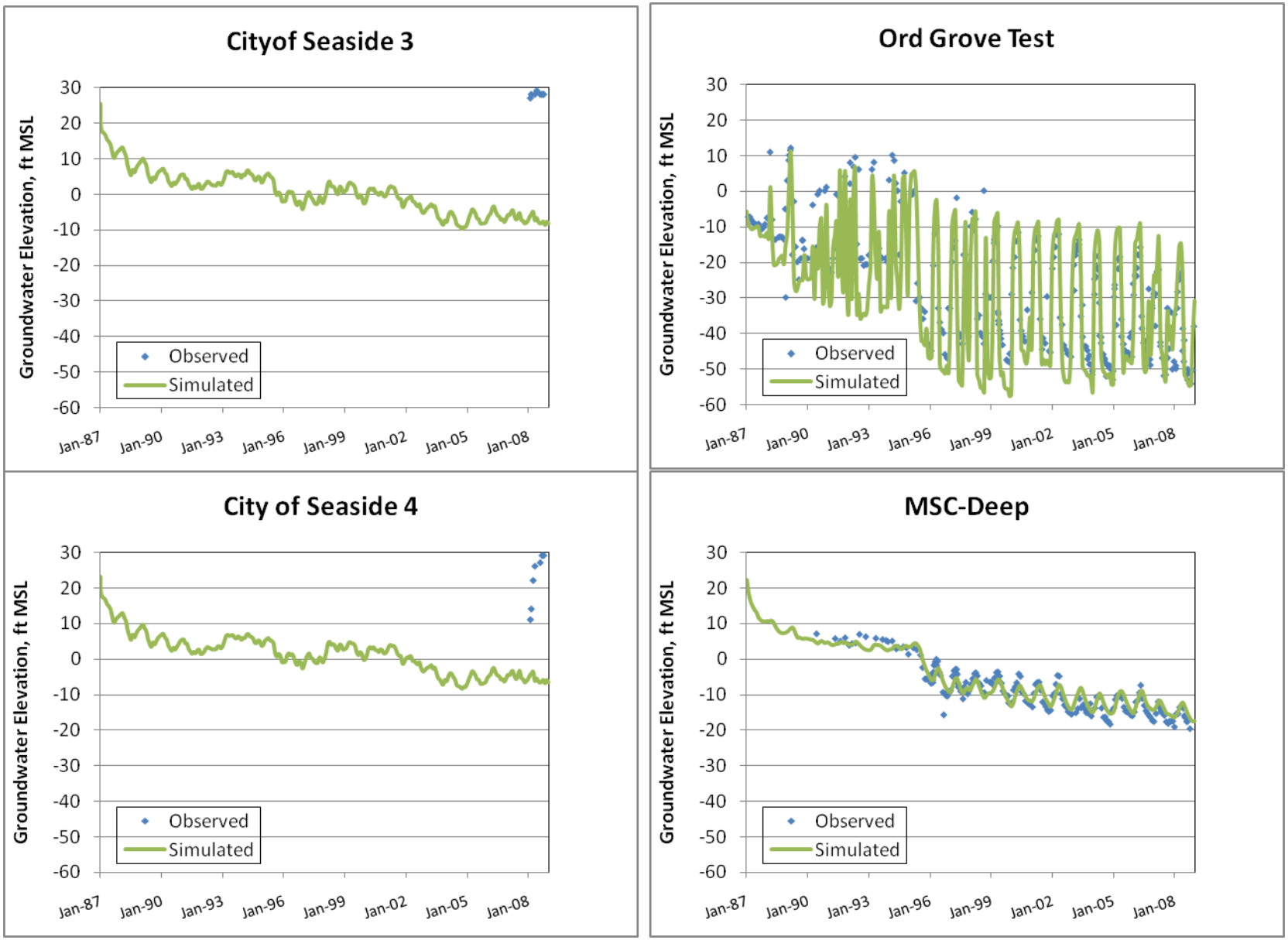
system losses was calculated as 8.5% of all water delivered to the Basin. These system losses were added directly to estimates of deep recharge in the developed portions of the Basin.

This page left
intentionally blank

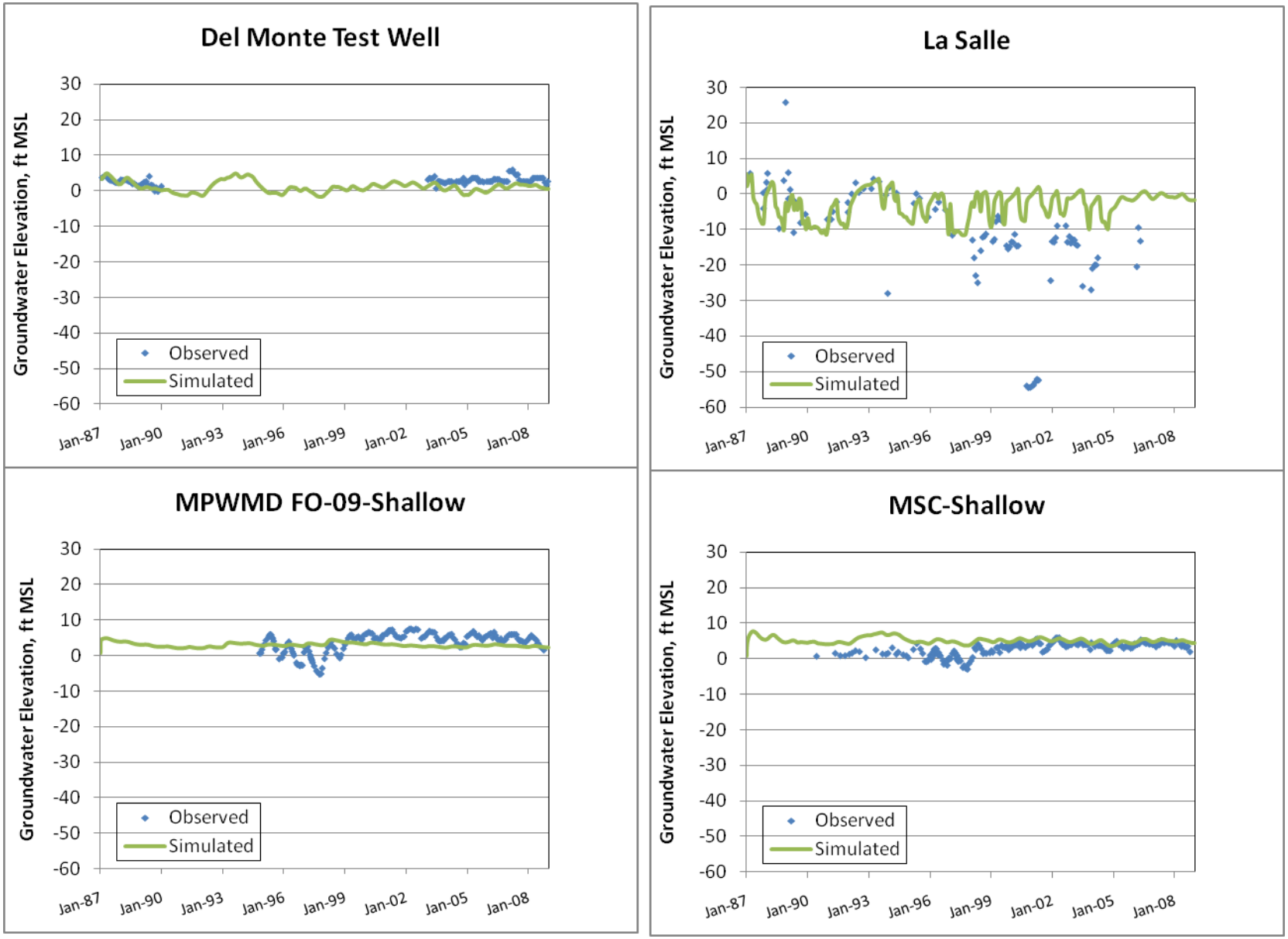
APPENDIX B: CALIBRATION HYDROGRAPHS



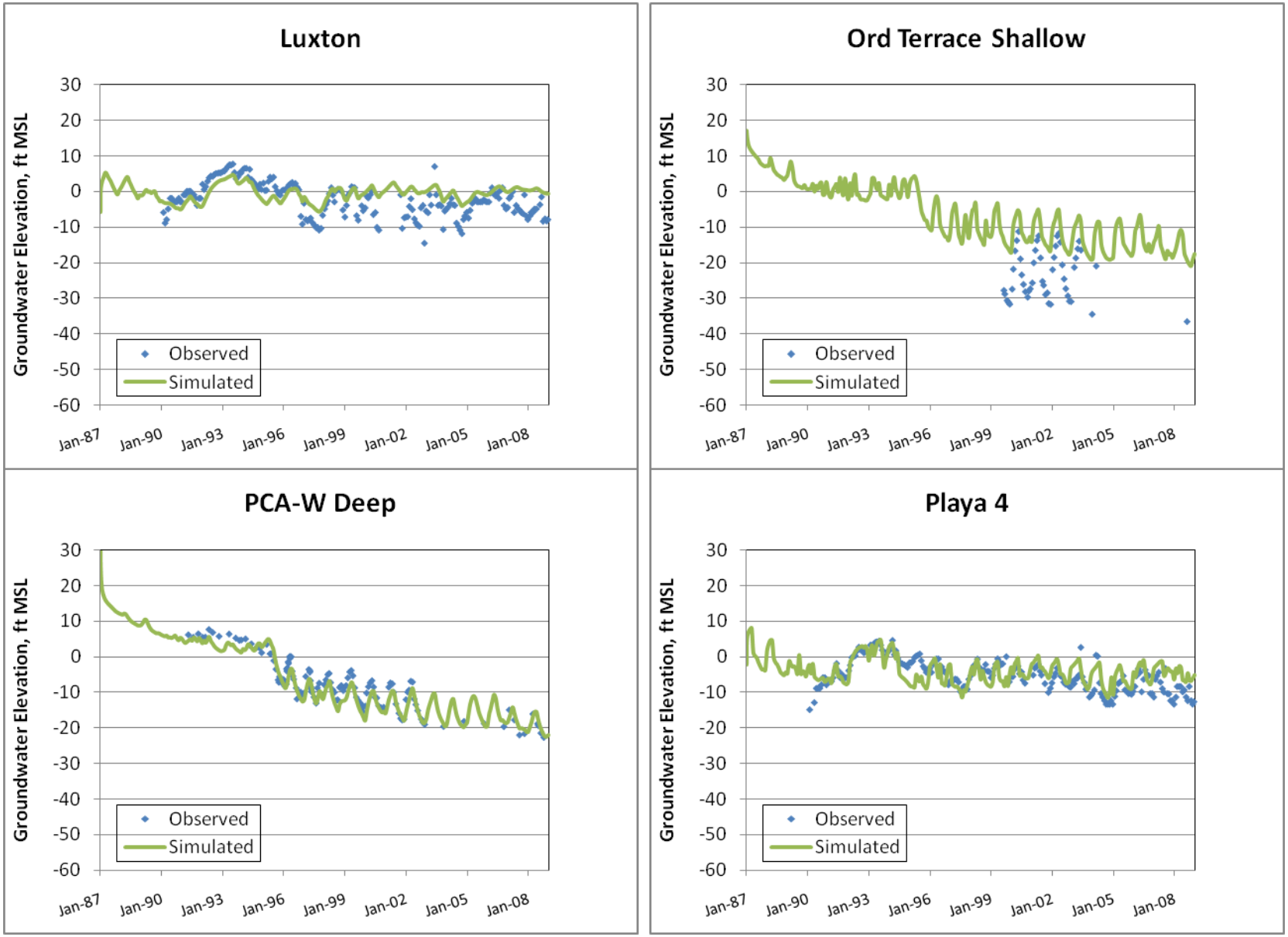
Northern Coastal Subarea Hydrographs



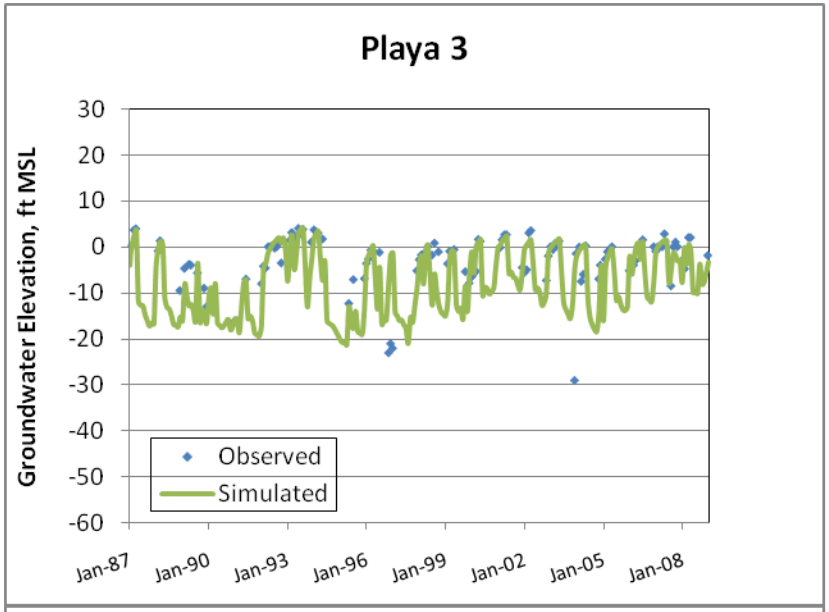
Northern Coastal Subarea Hydrographs

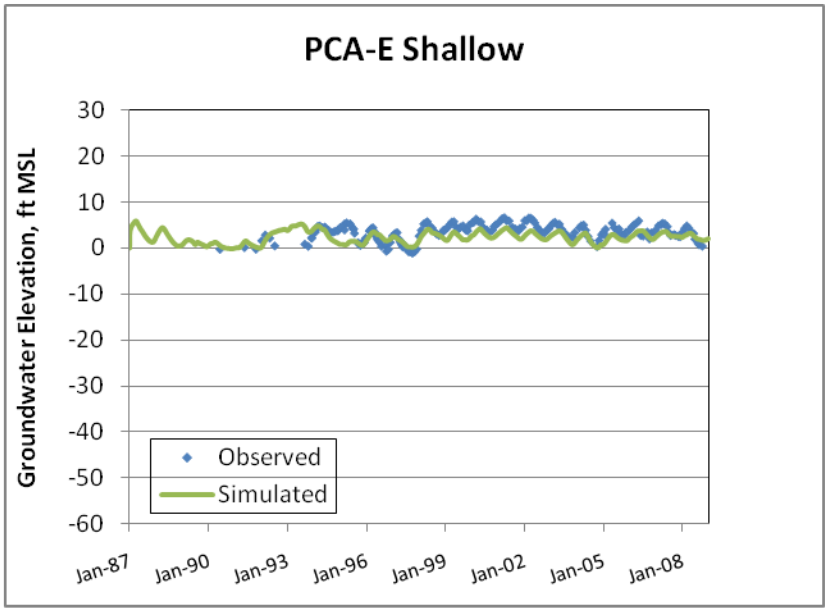


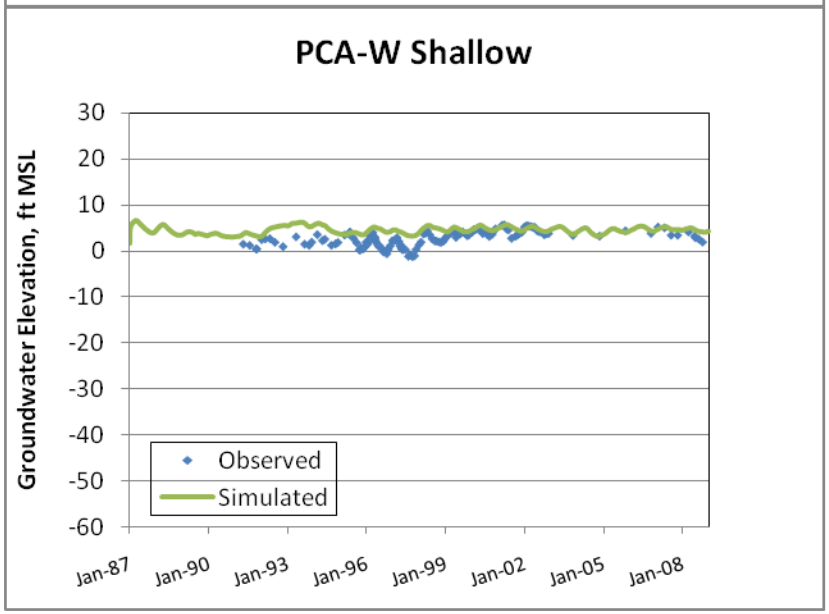
Northern Coastal Subarea Hydrographs



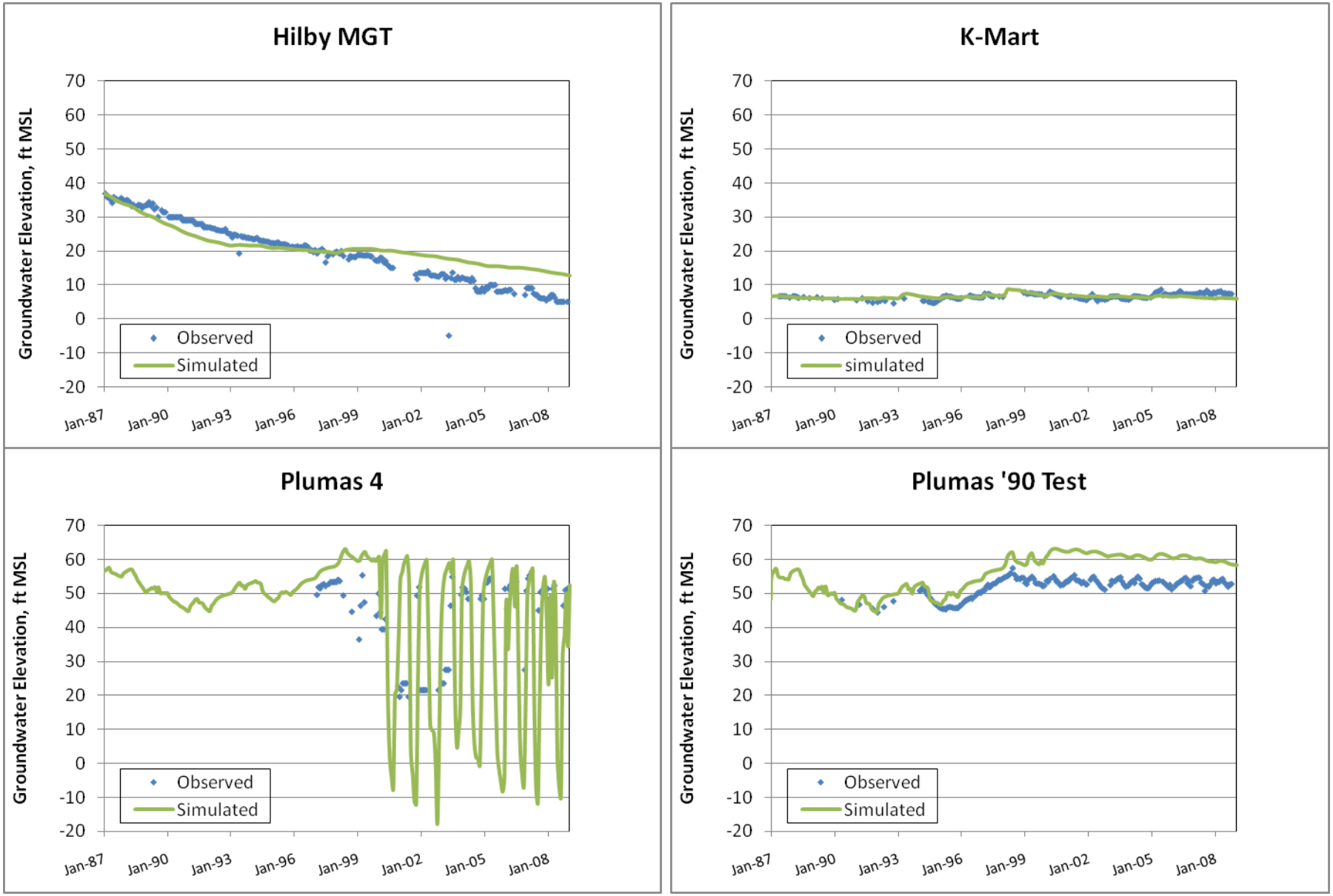
Northern Coastal Subarea Hydrographs



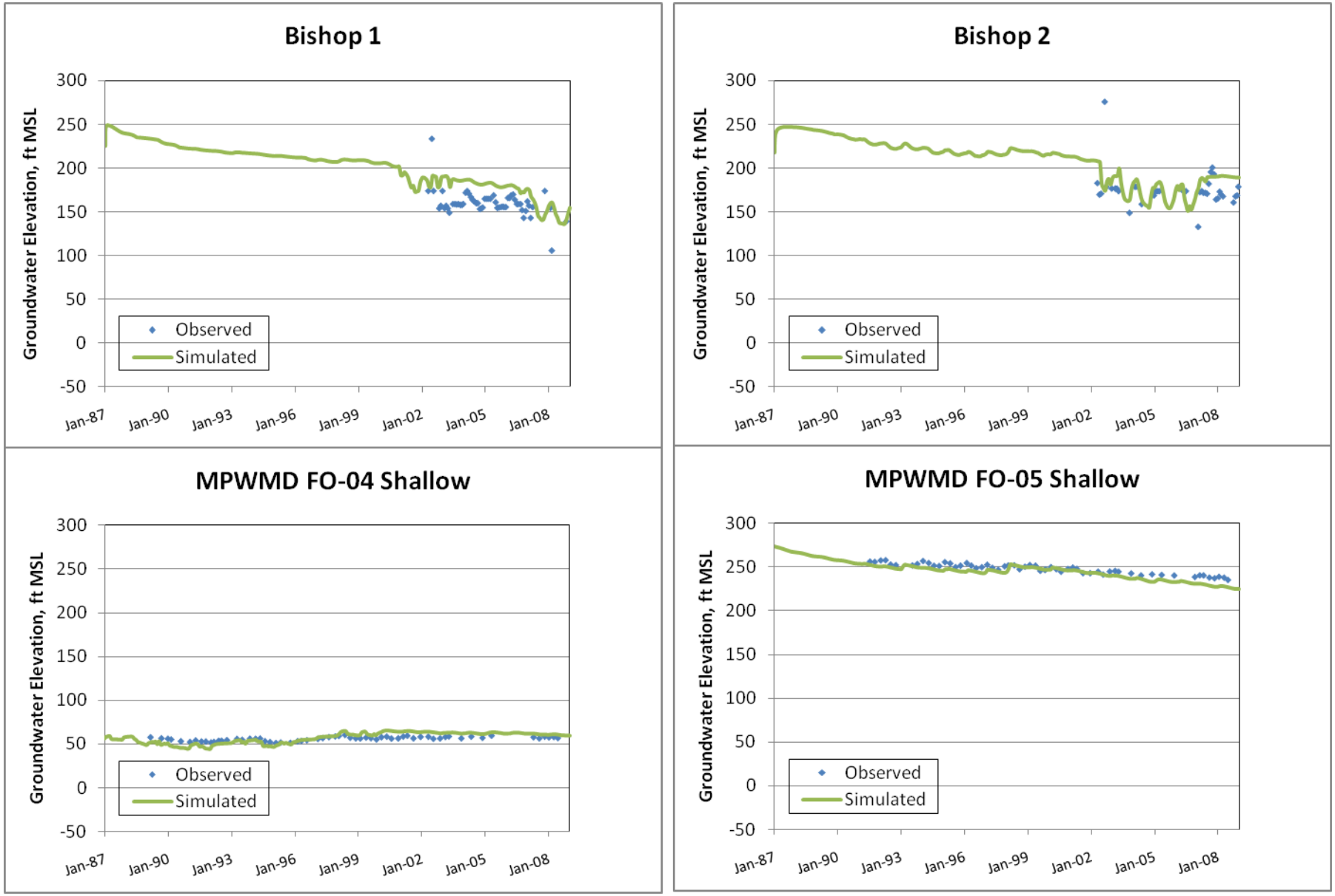




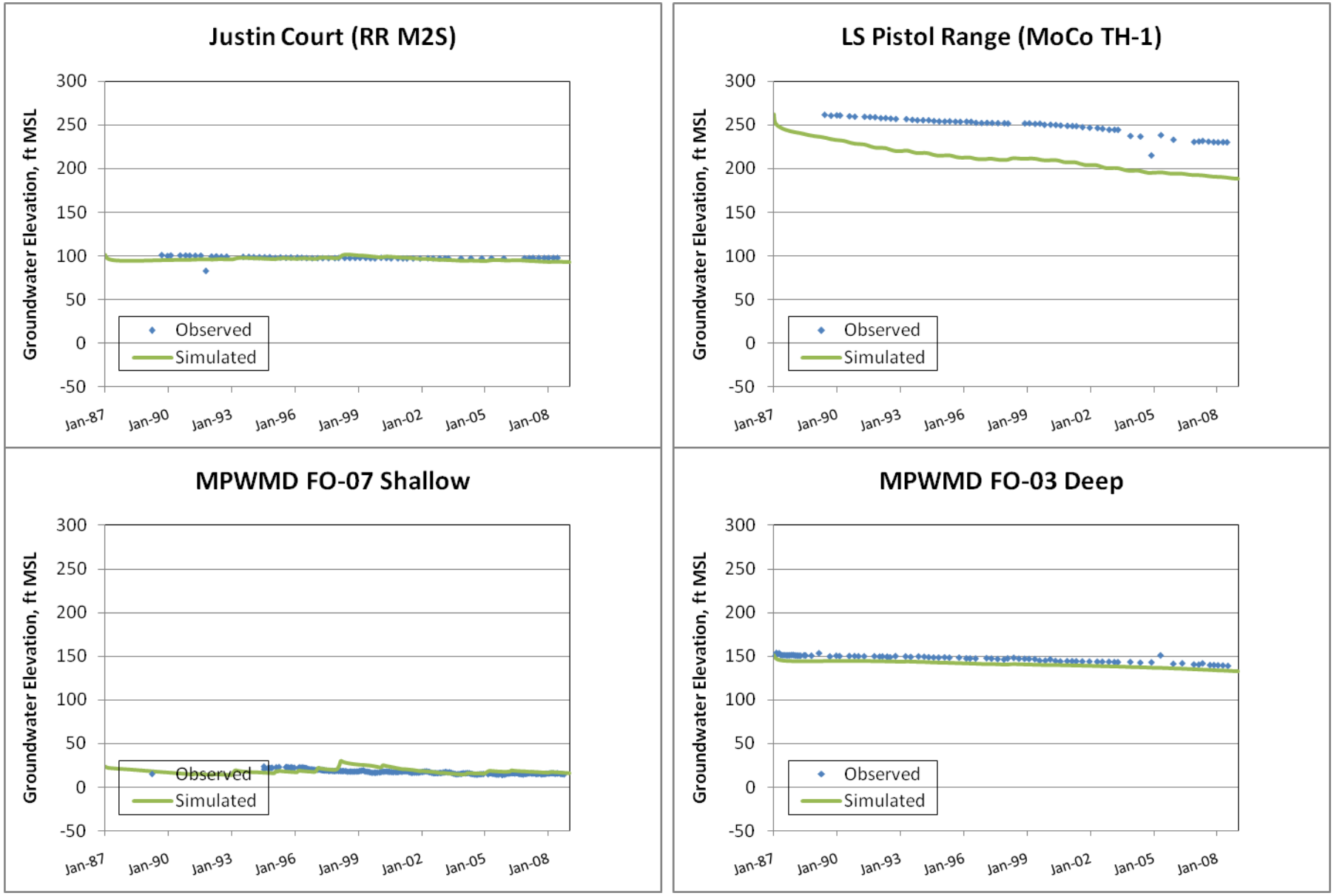
Northern Coastal Subarea Hydrographs



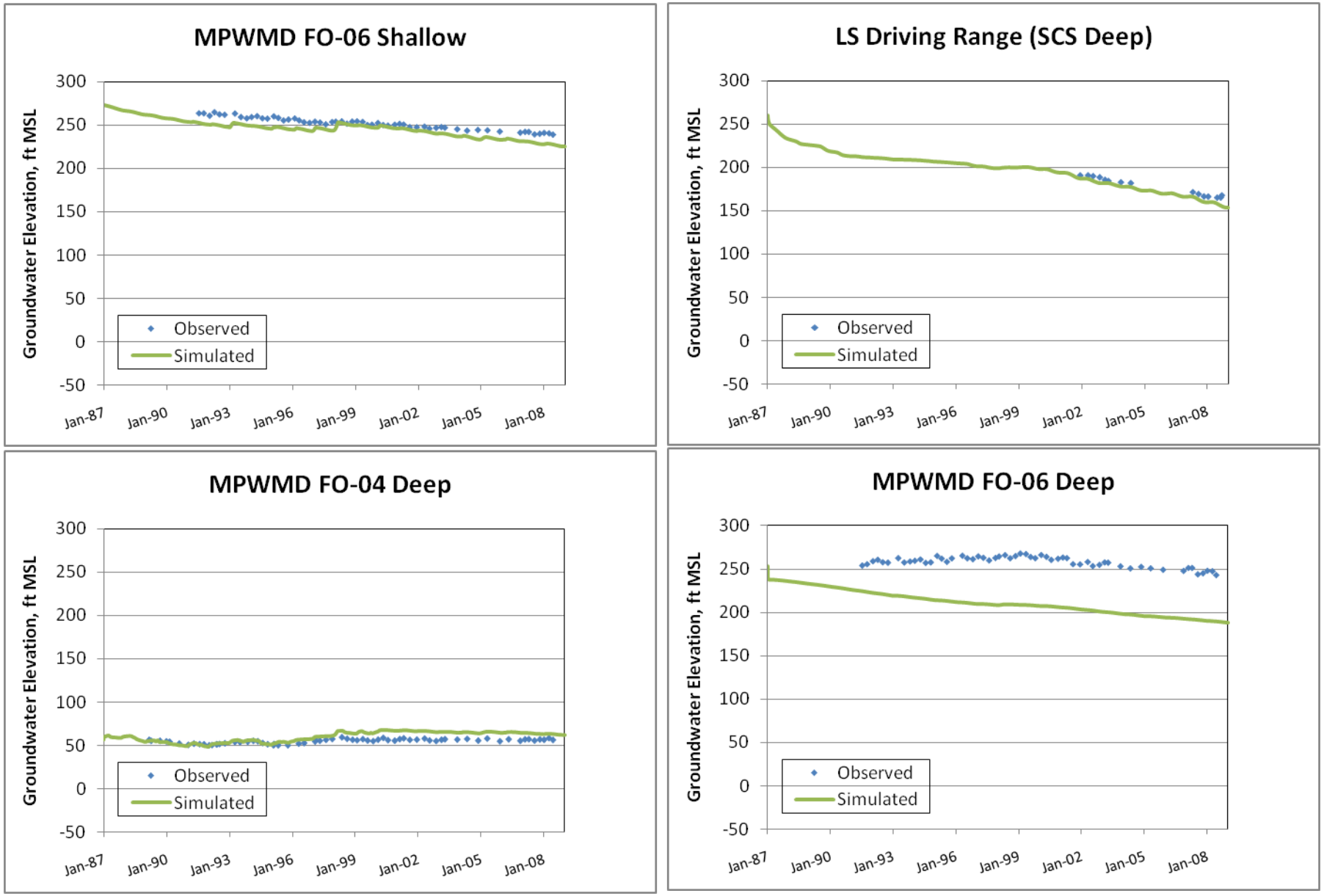
Southern Coastal Subarea Hydrographs



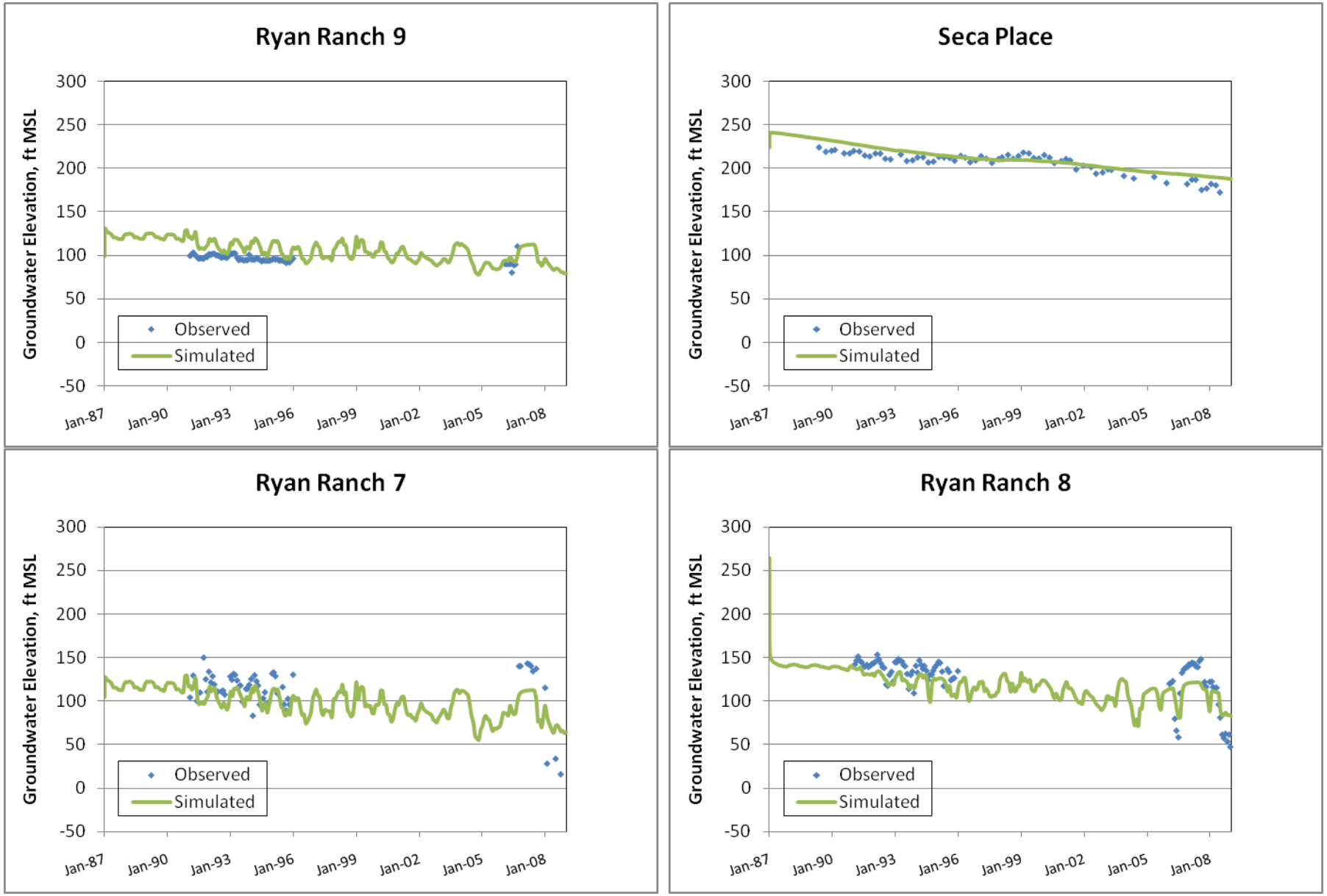
Laguna Sea Subarea Hydrograph



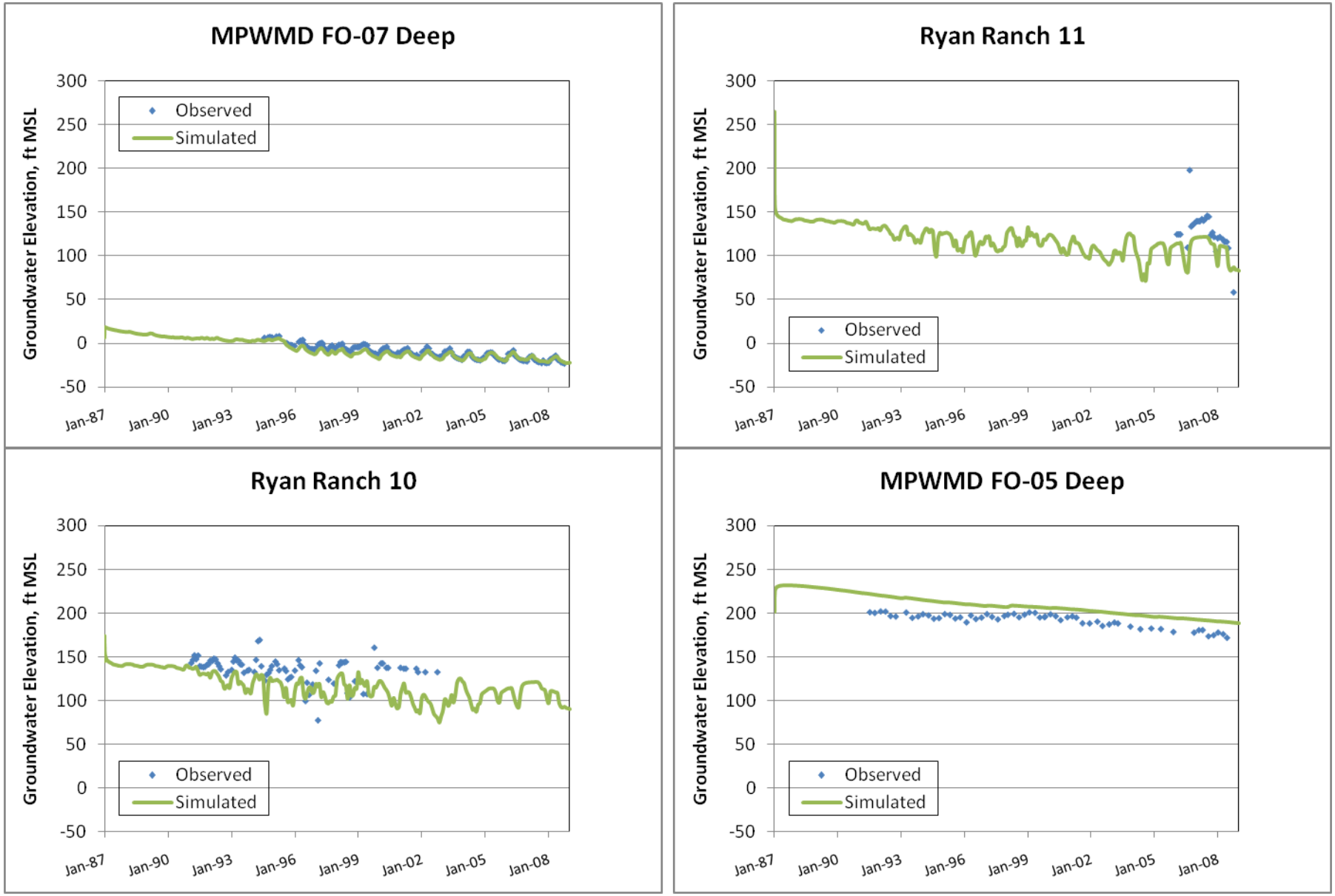
Laguna Sea Subarea Hydrographs



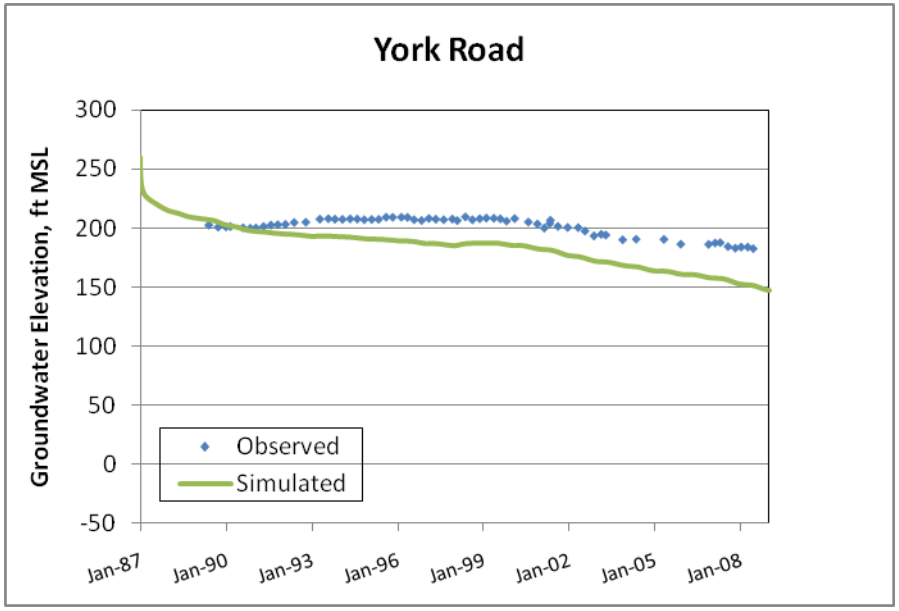
Laguna Seca Subarea Hydrographs

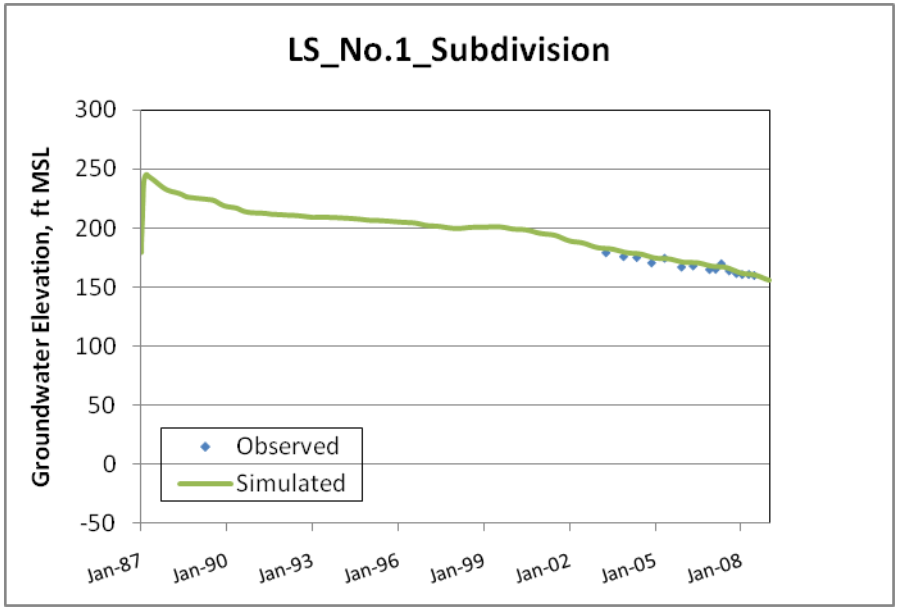


Laguna Seca Subarea Hydrographs

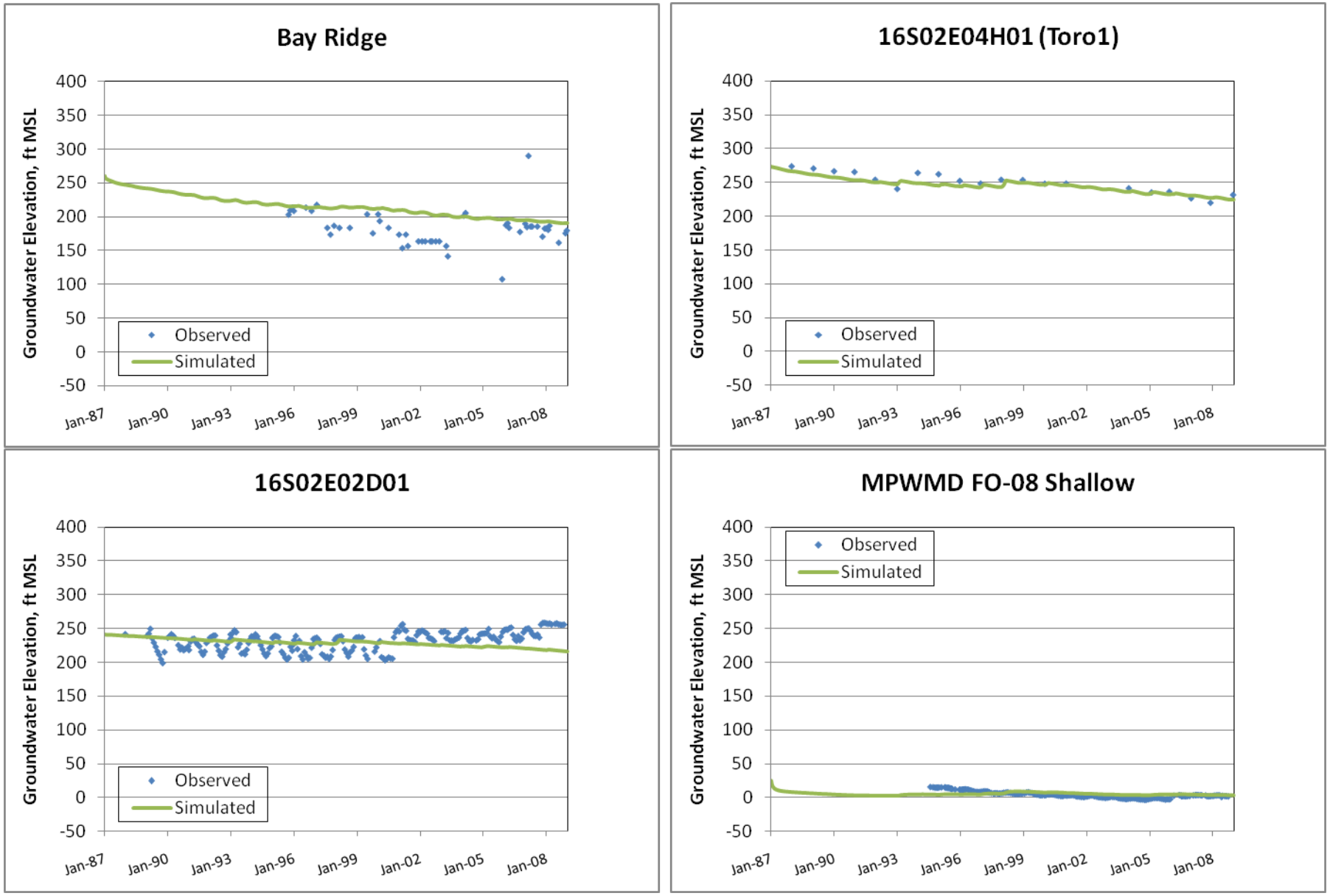


Laguna Seca Subarea Hydrographs

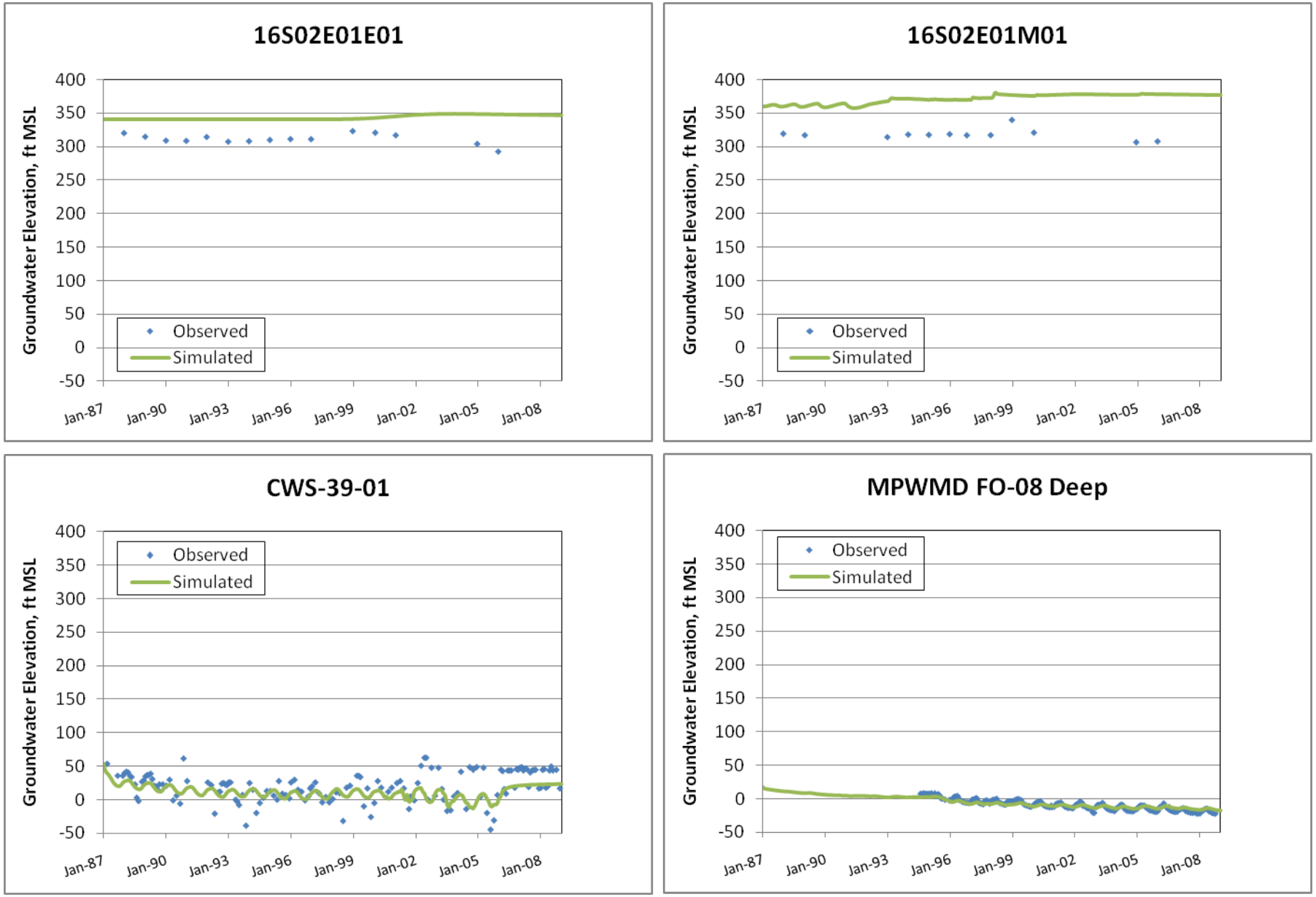




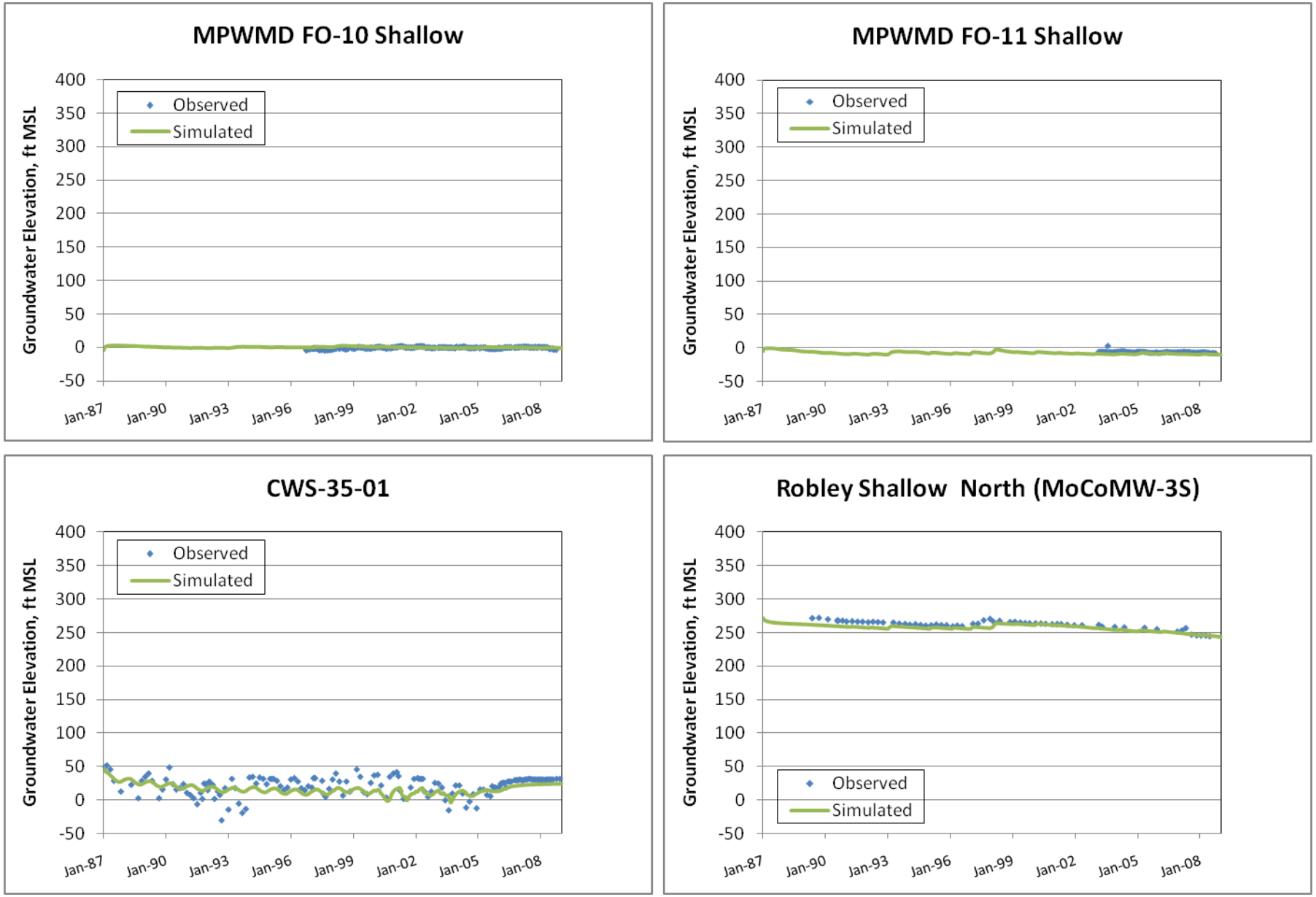
Laguna Seca Subarea Hydrographs



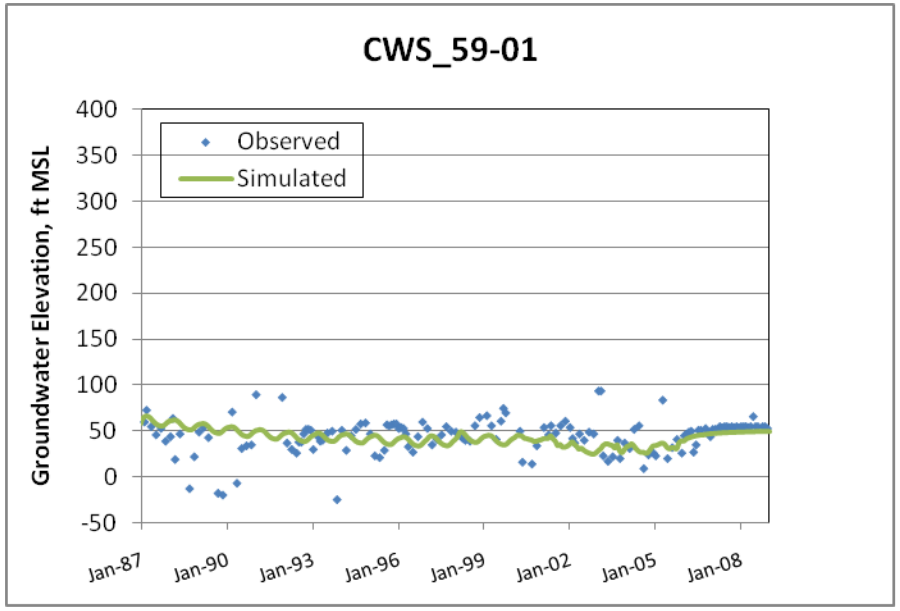
Hydrographs from Wells Outside of the Seaside Groundwater Basin

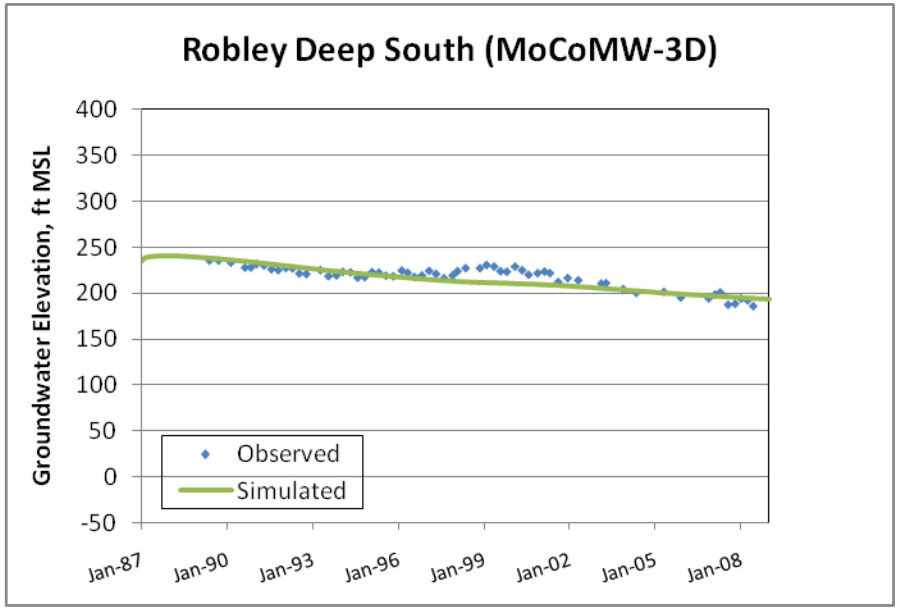


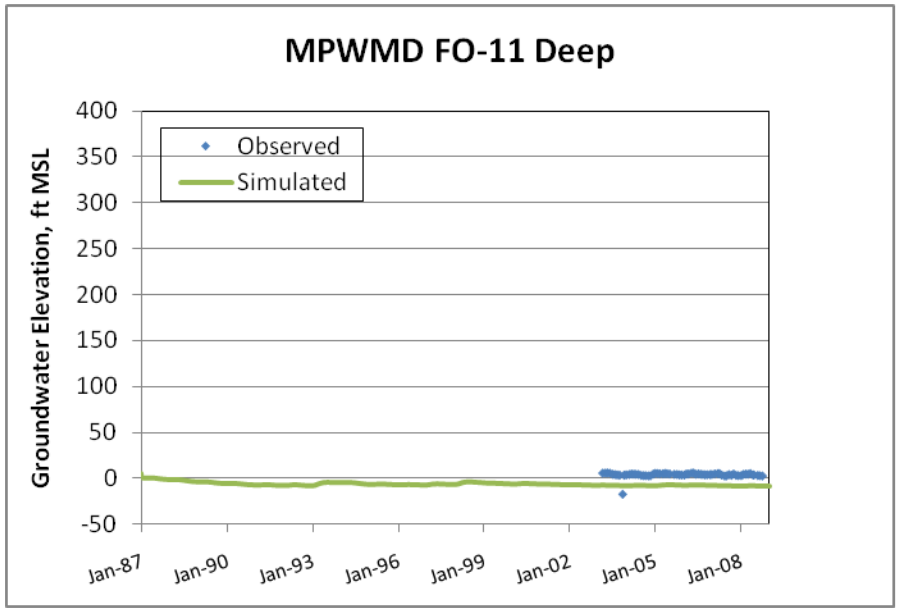
Hydrographs from Wells Outside of the Seaside Groundwater Basin



Hydrographs from Wells Outside of the Seaside Groundwater Basin







Hydrographs from Outside of the Seaside Groundwater Basin

This page left
intentionally blank

APPENDIX C: PROTECTIVE GROUNDWATER ELEVATION SENSITIVITIES TO AQUIFER PARAMETER VALUES

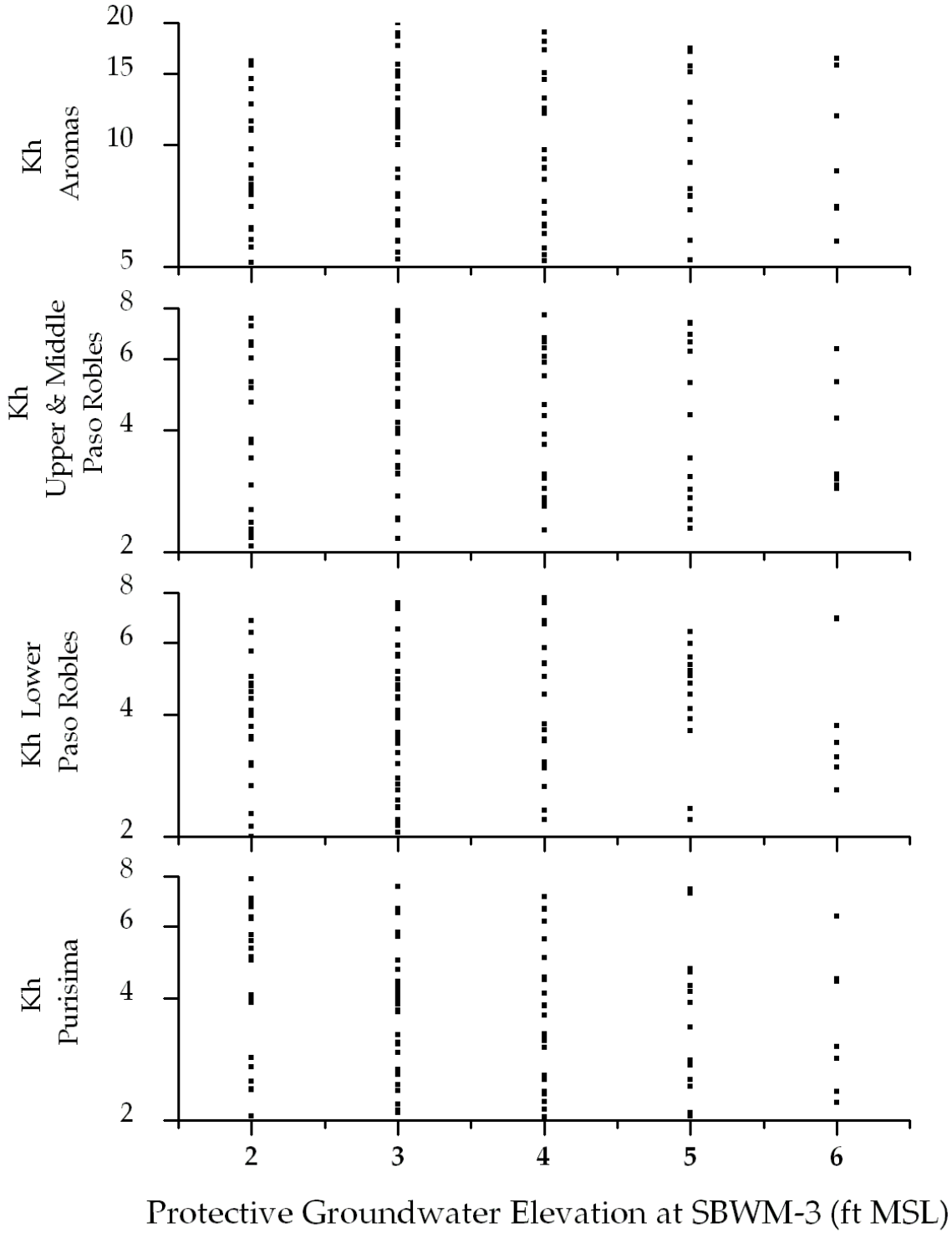


Figure C- 1: Protective Groundwater Elevation at SBWM-3 vs. Horizontal Hydraulic Conductivities

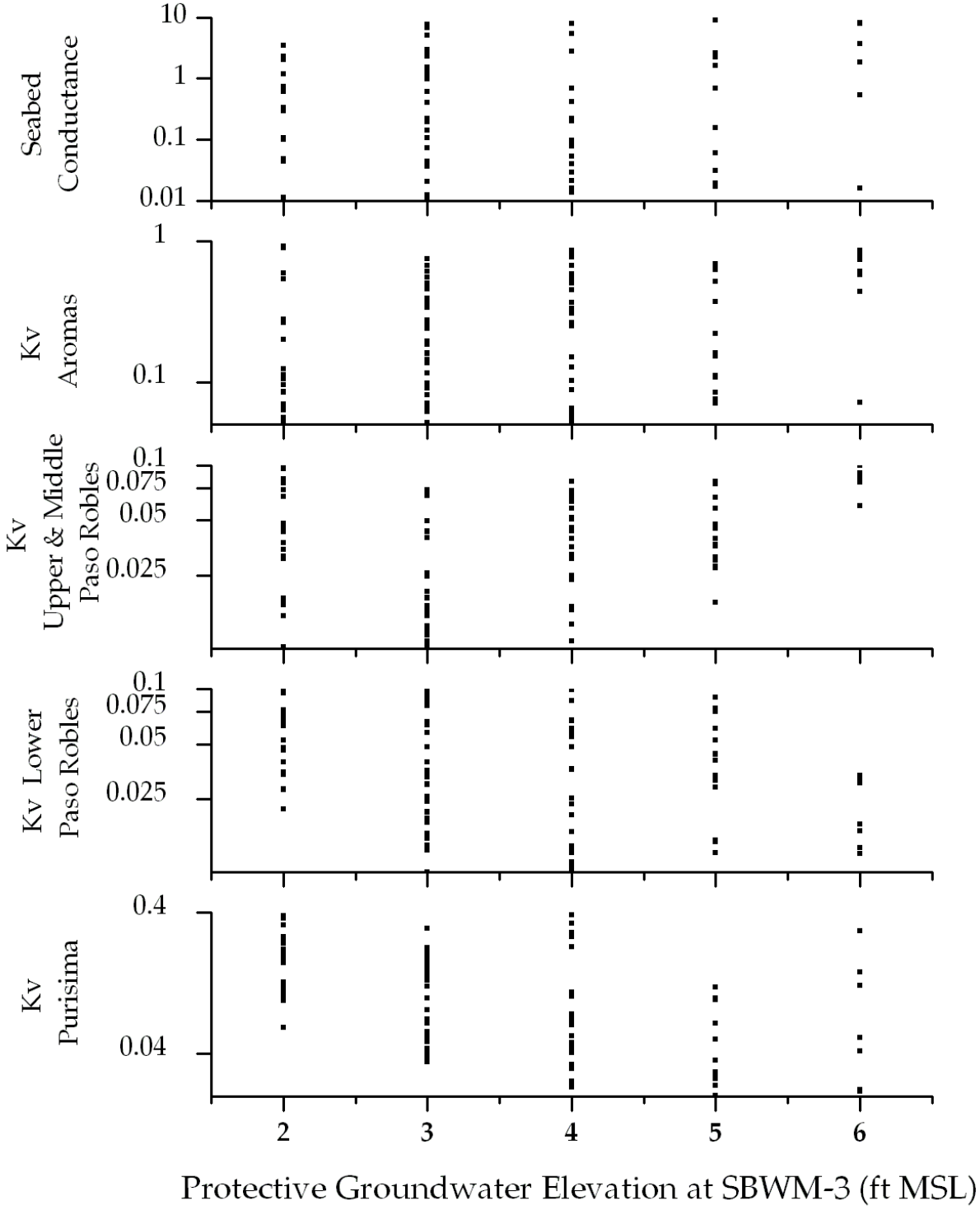


Figure C- 2: Protective Groundwater Elevation at SBWM-3 vs. Vertical Hydraulic Conductivities and Seabed Conductance

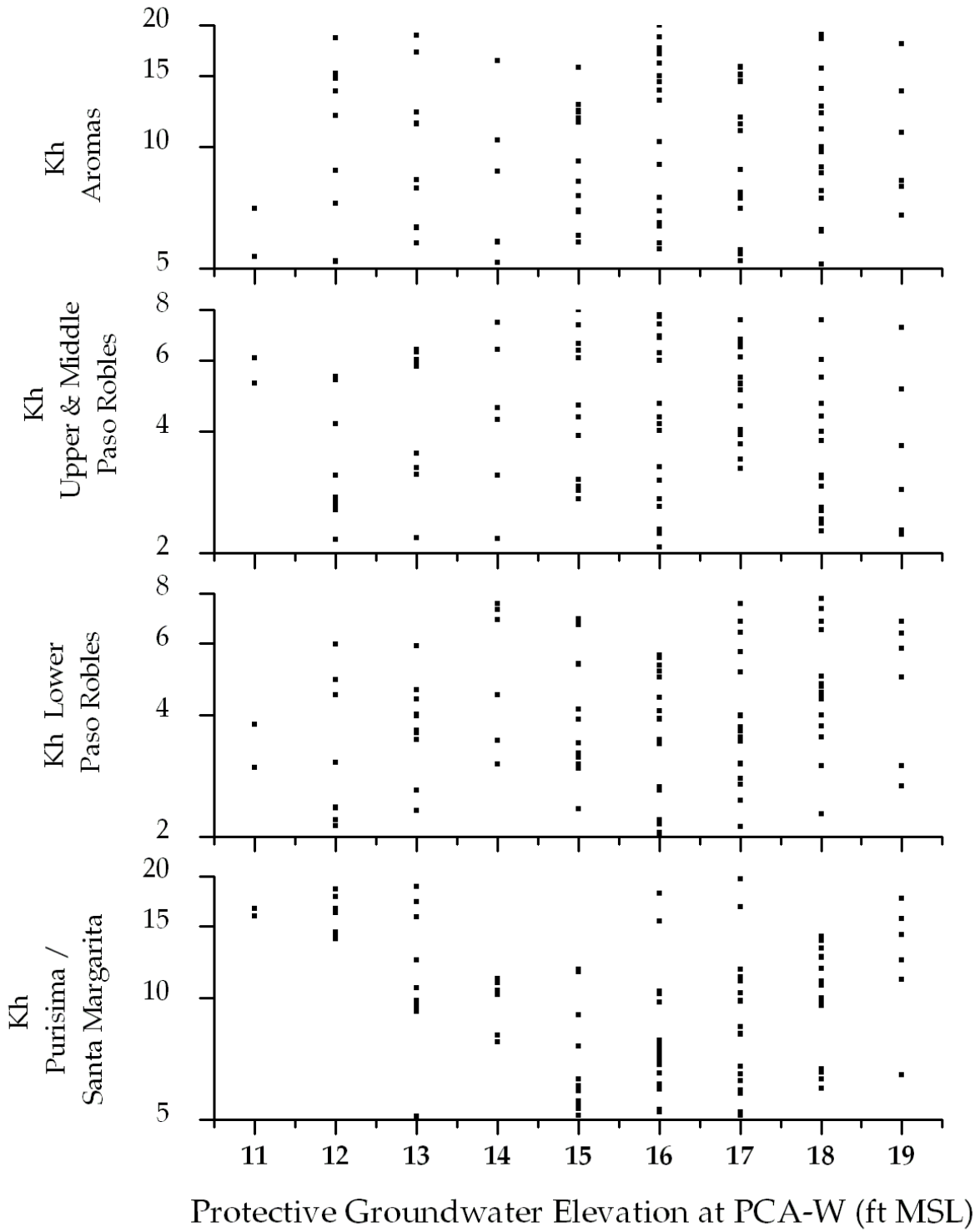


Figure C- 3: Protective Groundwater Elevation at PCA-W vs. Horizontal Hydraulic Conductivities

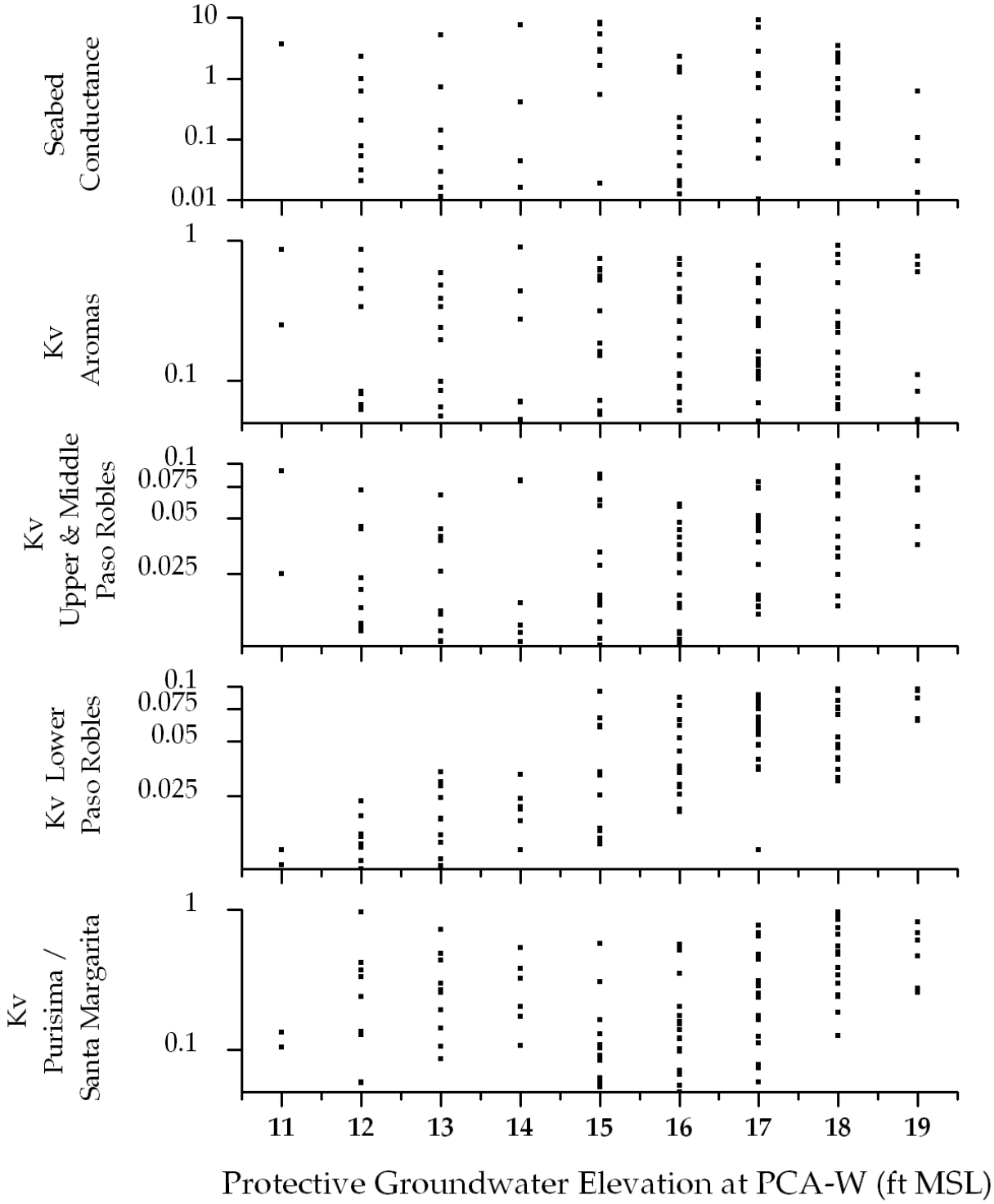


Figure C- 4: Protective Groundwater Elevation at PCA-W vs. Vertical Hydraulic Conductivities and Seabed Conductance

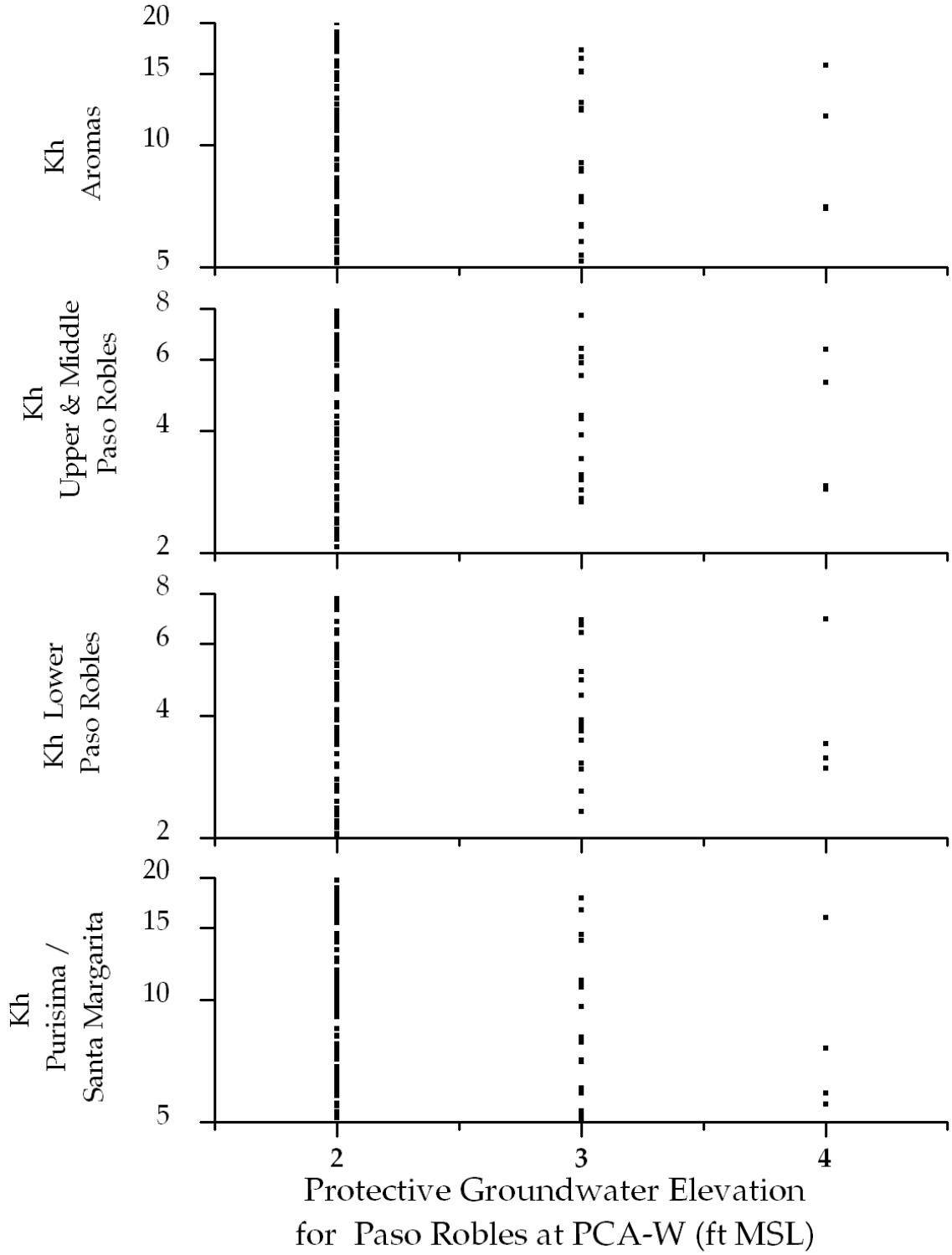


Figure C- 5: Protective Groundwater Elevation for Paso Robles at PCA-W vs. Horizontal Hydraulic Conductivities

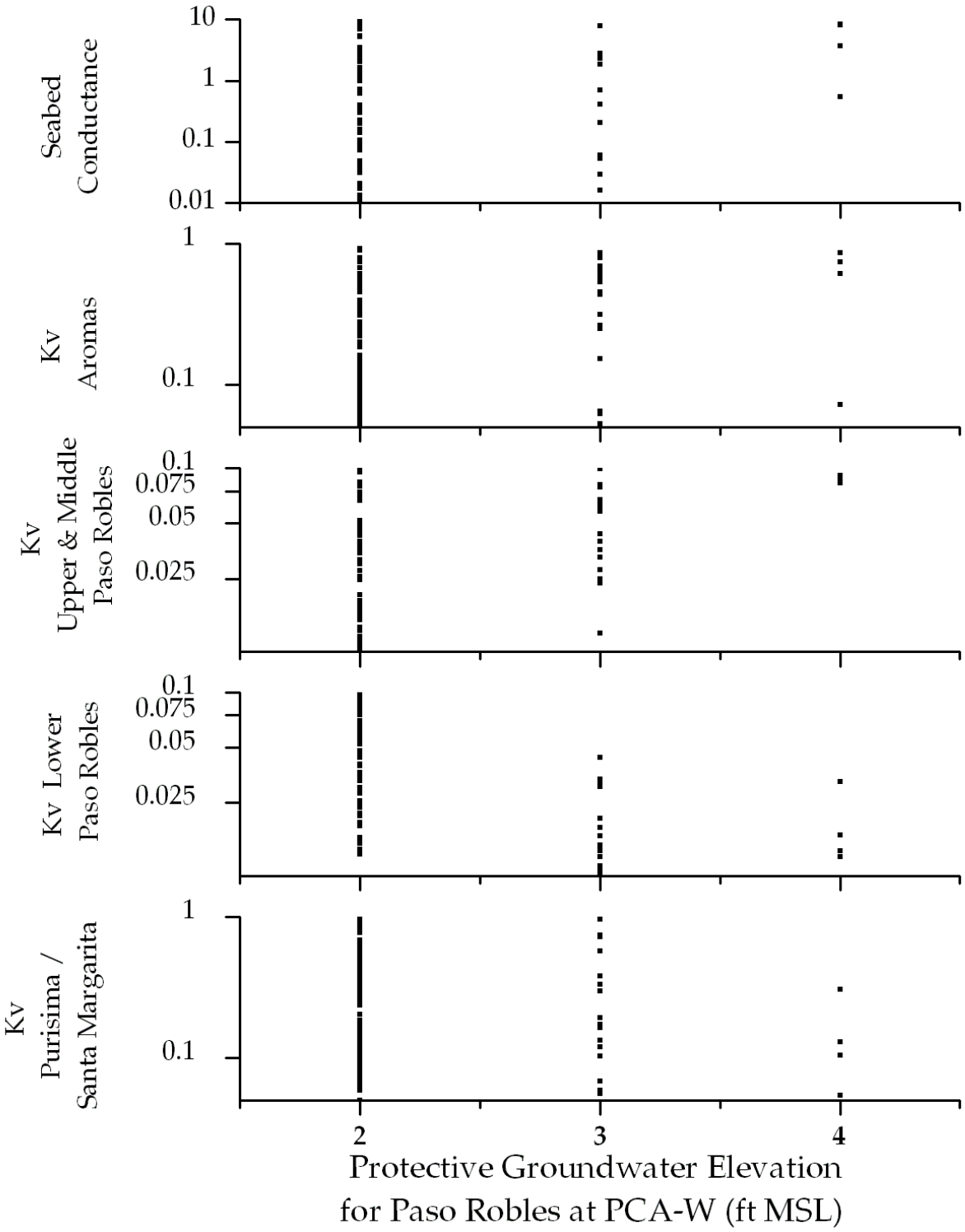


Figure C- 6: Protective Groundwater Elevation for Paso Robles at PCA-W vs. Vertical Hydraulic Conductivities and Seabed Conductance

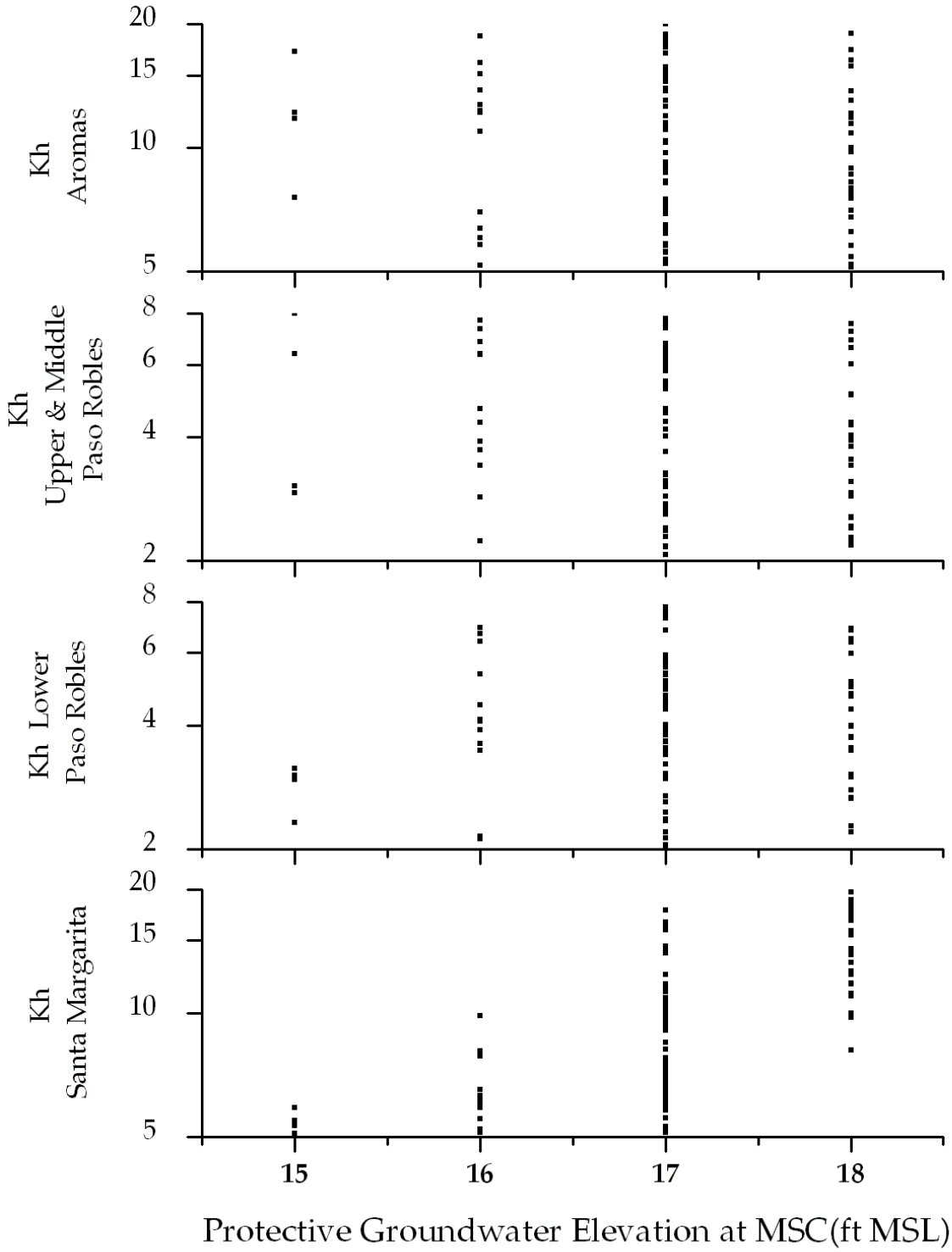


Figure C- 7: Protective Groundwater Elevation at MSC vs. Horizontal Hydraulic Conductivities

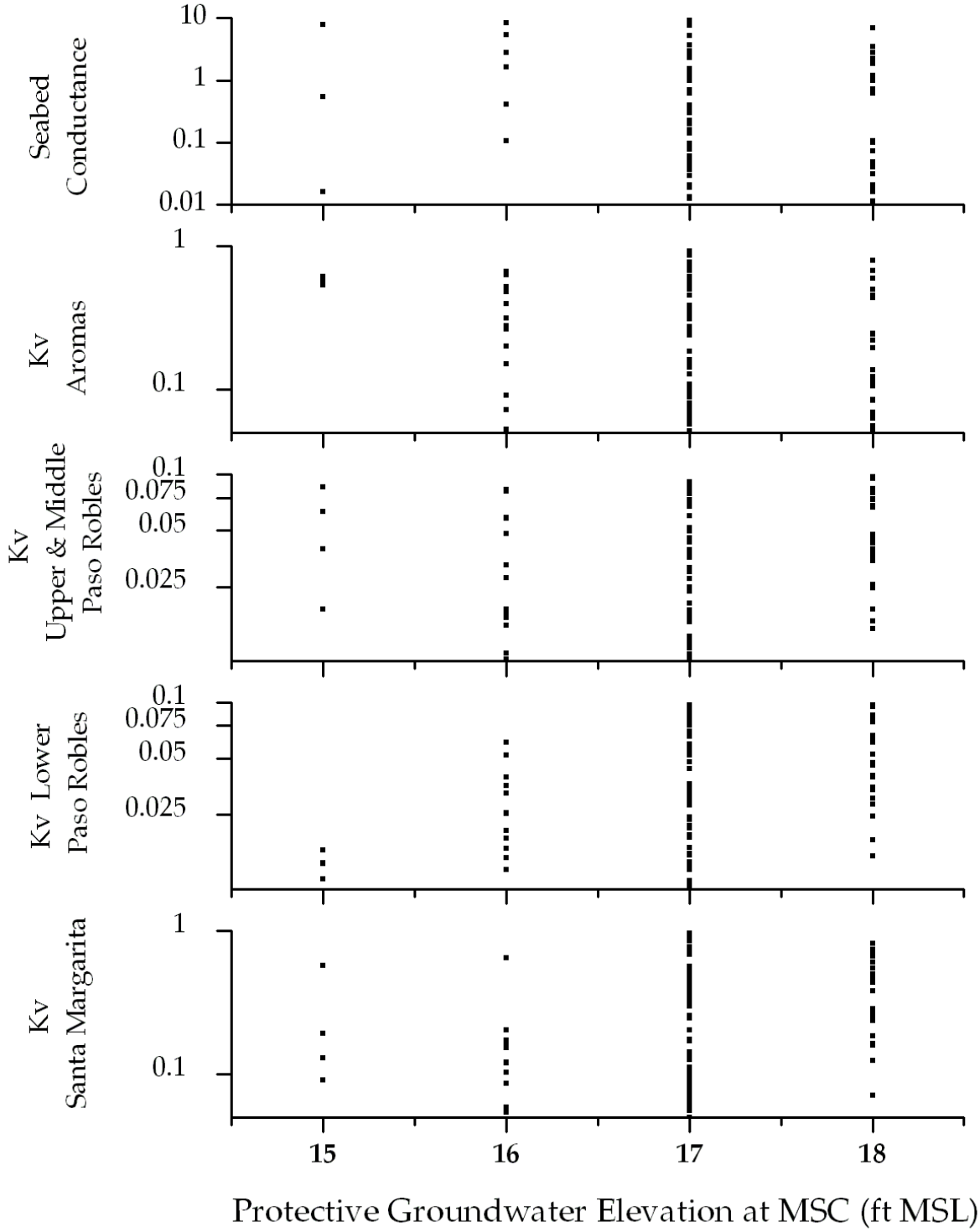


Figure C- 8: Protective Groundwater Elevation at MSC vs. Vertical Hydraulic Conductivities and Seabed Conductance

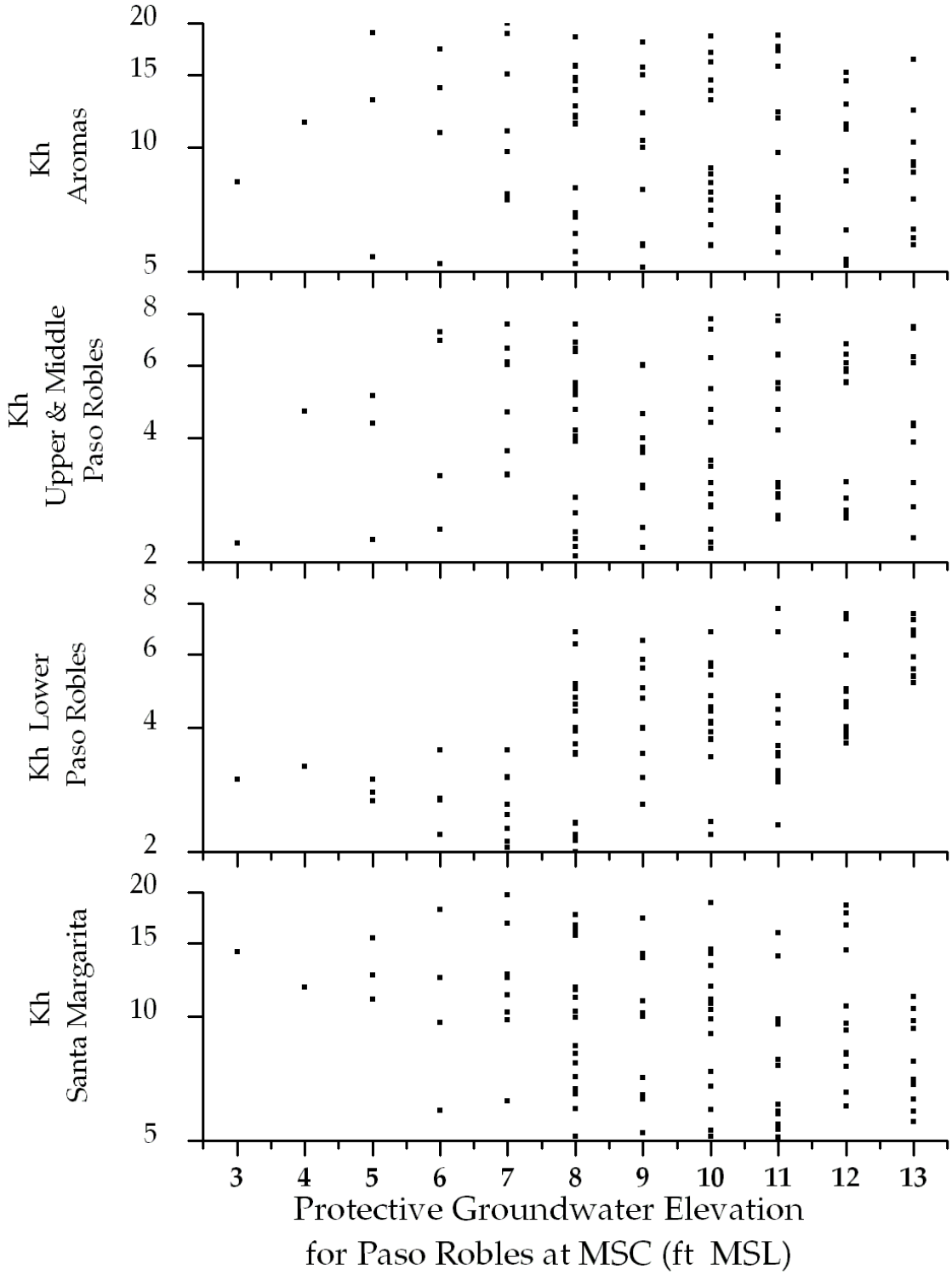


Figure C- 9: Protective Groundwater Elevation for Paso Robles at MSC vs. Horizontal Hydraulic Conductivities

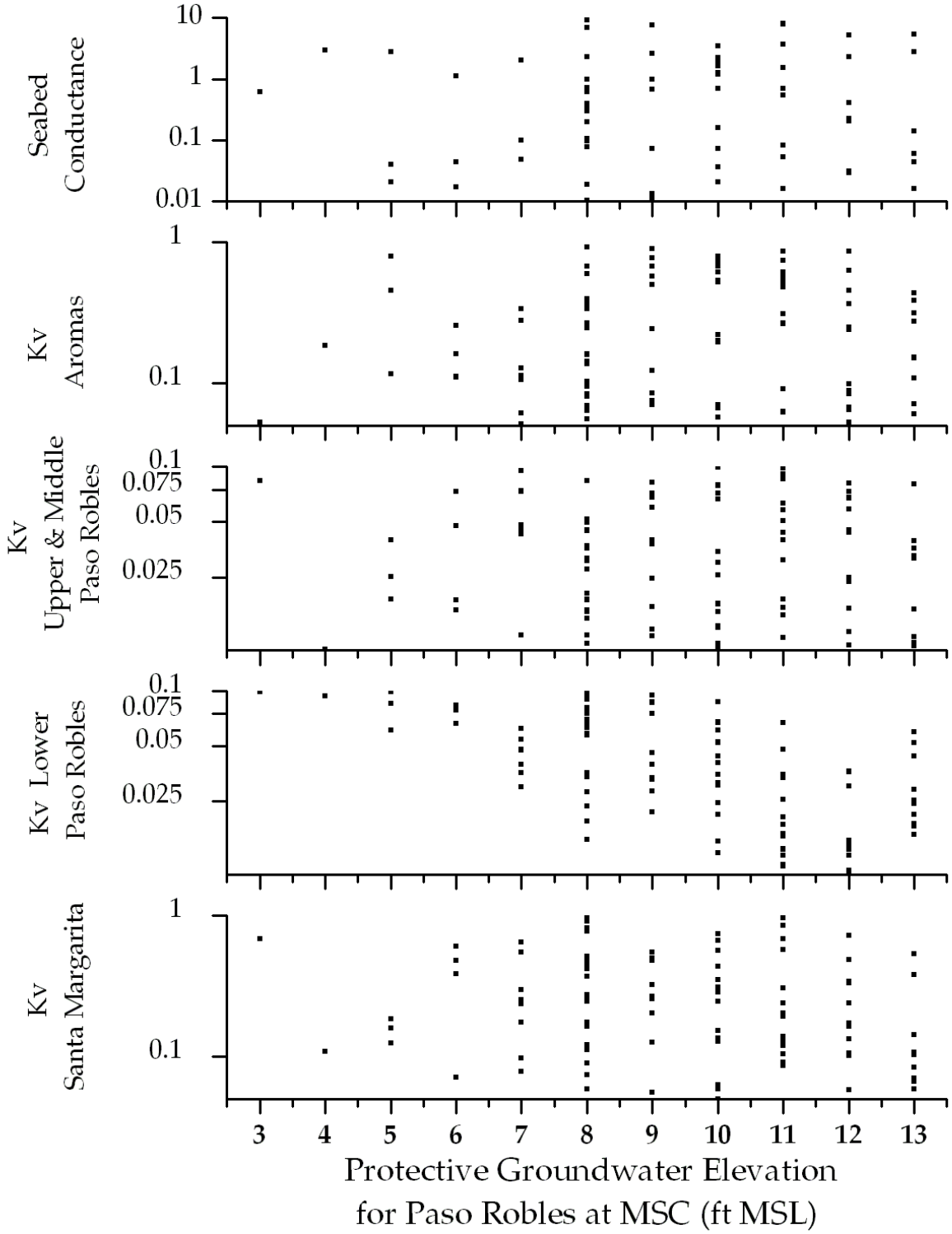


Figure C- 10: Protective Groundwater Elevation for Paso Robles at MSC vs. Vertical Hydraulic Conductivities and Seabed Conductance

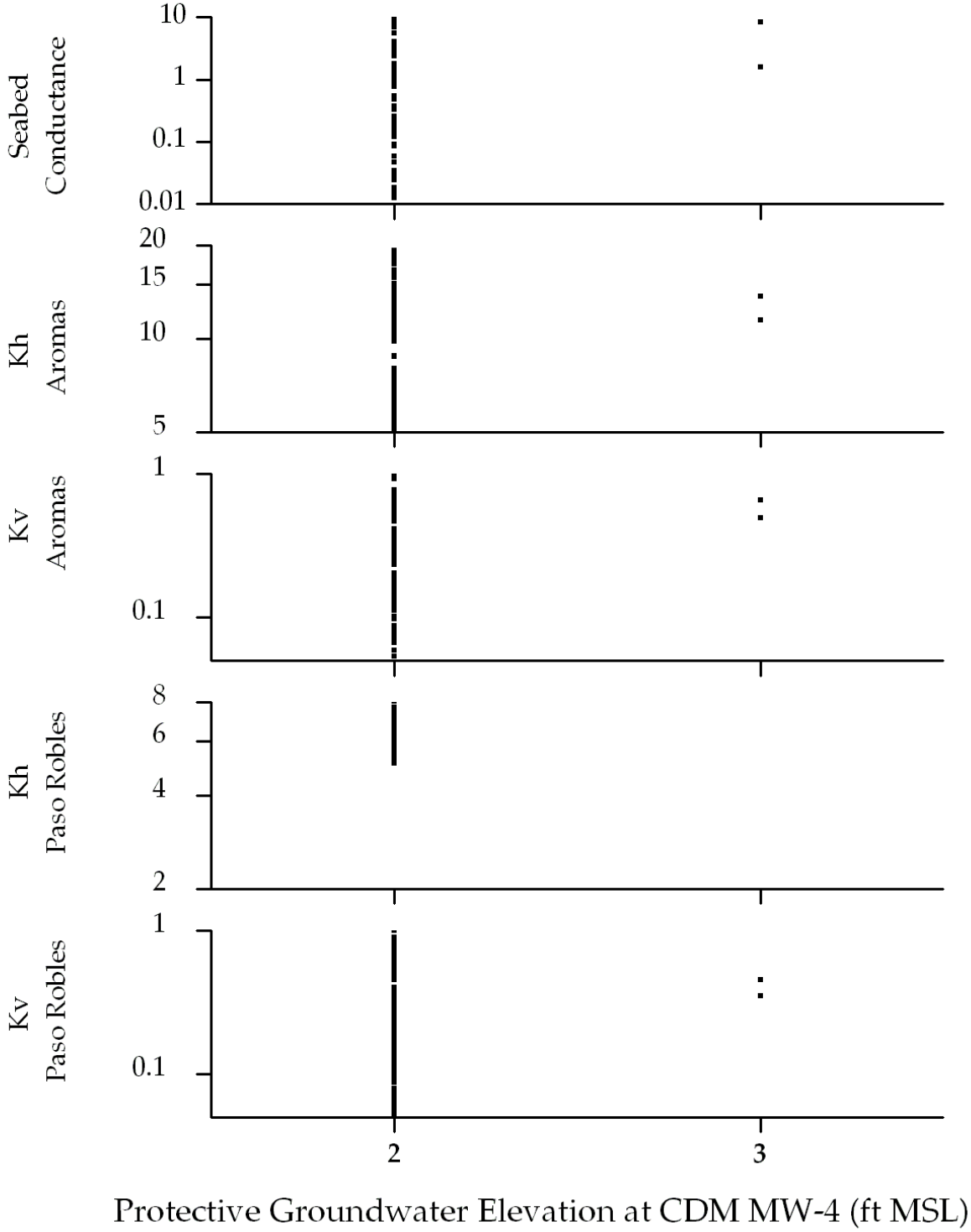


Figure C- 11: Protective Groundwater Elevation at CDM MW-4 vs. Horizontal and Vertical Hydraulic Conductivities and Seabed Conductance