APPENDIX E

UWCD Model Peer Review

Peer Review of the United Water Conservation District and Calleguas Municipal Water District Models for the Oxnard Subbasin, Pleasant Valley Basin, and Las Posas Valley Basin

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Acronyms and Abbreviations

Acronym/Abbreviation	Definition	Units
S_s	Specific Storage	$Feet^{-1}$
S	Storage Coefficient	Unitless
K_h	Horizontal Hydraulic Conductivity	Feet/day
K_Z	Vertical Hydraulic Conductivity	Feet/day
RMSE	Root Mean Squared Error	Feet
ARM	Absolute Residual Mean	Feet

1 INTRODUCTION

1.1 Background

The FCGMA Board of Directors (Board) is relying on the numerical groundwater models developed by the United Water Conservation District (UWCD) and the Calleguas Municipal Water District (CMWD) to estimate the sustainable yield, understand potential undesirable results, and prepare Groundwater Sustainability Plans (GSPs) for the Oxnard Subbasin, Pleasant Valley Basin, and Las Posas Valley Basin. This review was conducted to provide an independent look at the models in order to give the Board confidence in their reliability. The goal of this review was to quantify the uncertainty associated with the modeling estimates of the sustainable yield for these basins.

UWCD conducted a *local* sensitivity analysis of its model prior to this review, in order to evaluate how the model input parameters obtained via the model calibration affect the model outputs. We conducted an additional *global* sensitivity analysis that keys off of their local sensitivity analysis, and allows for a quantitative assessment of uncertainty in seawater flux and sustainable yield.

CMWD has not completed a sensitivity analysis of their model at the time of this review. As a result, our review of the CMWD model is less quantitative than it is for the UWCD model. The review of the CMWD model found potential areas of uncertainty based primarily in areas with less data available to constrain the model results, and assessed the qualitative effects of these data gaps on the model estimates of the sustainable yield.

Results of both models indicate that changes to groundwater production rates and/or to extraction locations are needed to avoid undesirable results in the DWR required analysis of the 30-year sustaining period from 2040 to 2070. Understanding the uncertainties in the model predictions underscores the desirability of making gradual changes in production rates while additional monitoring and studies help to reduce these uncertainties.

1.2 General Considerations

The content of this model review generally follows the U.S. Geological Survey (USGS) guidelines for evaluating groundwater flow models (USGS, 2004). First, the two models were evaluated for whether the mathematical model implemented in the computer program is appropriate, i.e., whether the model program adequately simulates the physical processes needed to represent the system. Then the mathematical representation of the physical processes was compared to the hydrogeological conceptual model to confirm that the two are consistent. Last, the model uncertainties were assessed, quantitatively for the UWCD model and qualitatively for the CMWD model.

Both models are being used to estimate the sustainable yield of the basins they incorporate. In the case of the Oxnard Subbasin, Pleasant Valley Basin, and West Las Posas Management Area of the Las Posas Basin in the UWCD model, sustainable yield is driven by minimizing future net seawater flux. Consequently, our review of the UWCD model focused on identifying those model parameters that had the greatest effect on model calculations of flux along the ocean boundary. In the case of the CMWD model, sustainable yield is driven by changes in groundwater extraction rates and recharge through Arroyo Las Posas. Therefore, our review of the CMWD model focused on the model replication of the field studies of flow in Arroyo Las Posas and recharge to the Fox Canyon Aquifer, the primary aquifer in the East Las Posas Management Area (ELPMA).

2 UWCD MODEL

2.1 Model Software

The UWCD model uses the MODFLOW software, which solves the groundwater flow equation. The latter is used to model single-phase flow of liquids with constant viscosity and density (e.g., fresh water). Seawater intrusion, which is the overriding concern in the Oxnard Subbasin, is a prime example of variable-density flow because salt concentration appreciably affects groundwater density as seawater invades a freshwater aquifer (Dentz et al., 2006). Software packages that are typically used to model the impact of seawater intrusion on sustainable groundwater management include SUTRA, FEFLOW, MOCDENSE, MODFLOW-SWI2, and SEAWAT.

Rather than using MODFLOW with the SWI2 package, the UWCD model adjusts general head boundaries at the ocean interface to reflect the hydrostatic head plus the density difference between fresh and sea water. Consequently, this model correctly represents the boundary conditions but cannot be relied upon to forecast seawater intrusion in all of its relevant detail. Instead, the model aims to estimate the total amount of seawater entering the coastal aquifers through their boundary with the ocean rather than seawater migration within the aquifer. All the conclusions drawn from these models are subject to this caveat.

2.2 Mathematical Representation of the Conceptual Model

Overall, the mathematical representation of the Oxnard Subbasin, Pleasant Valley Basin, and West Las Posas Management Area (WLPMA) of the Las Posas Valley Basin, is consistent with the conceptual model presented in the documentation and literature. Where possible, the mathematical representation is based on measured physical properties and documented assumptions from field observations. These assumptions are necessary in all groundwater models as the exact properties of the subsurface cannot be known over the geographic extent of the model domain, and not all physical properties can be measured in the field. For example, the UWCD model incorporates offshore faulting that limits direct flux from the ocean into the lower aquifer system (LAS) in the southern portion of the model. The hydraulic properties of the fault plane have not been measured and cannot be measured, therefore the UWCD model relies on reasonable values from the literature to characterize the fault in the model.

An example of one of the critical parameters affecting groundwater movement in the model domain that should be based on field tests is horizontal hydraulic conductivity. Horizontal hydraulic conductivity values assigned in the model are based on field tests, although the majority of these tests were slug tests. Slug tests provide information on a limited area of aquifer, adjacent to the location of the well in which the test was performed.

Hydraulic conductivity is the main parameter that was adjusted to match observed heads and calibrate the model; the final values of hydraulic conductivity in the model are in general agreement with the measured values of hydraulic conductivity from the field tests. There are few test results constraining horizontal hydraulic conductivity in the Oxnard and Mugu aquifers, which combined compose the Upper Aquifer System (UAS). However, the horizontal hydraulic conductivity assigned to the Oxnard and Mugu aquifers in the Forebay area are 250 and 200 feet per day, which is consistent with the estimated horizontal hydraulic conductivity based on aquifer tests in wells 02N21W07L07S and 02N22W23G04S, both of which are located in the Forebay.

Representation of the Upper San Pedro Formation (USP), in the WLPMA is an area for potential further examination in the model over the next 5 years. Hydraulic conductivity values assigned to the USP in WLPMA in the UCWD model are approximately 10 times greater than values assigned to the USP in adjacent areas in the CMWD model (Table 1). In contrast, hydraulic conductivity values assigned to the Fox Canyon and Grimes Canyon aquifers in the two models are comparable (i.e., have the same order of magnitude). The aquitard between the USP (Layer 7) and the Fox Canyon aquifer (Layer 9), referred to as Layer 8, has a very low hydraulic conductivity (10^{-3} ft/d horizontal, 10^{-5} vertical). This hydraulic conductivity is lower than anything else in the model. The basis for this value is not evident.

2.2.1 Parameterization

The UWCD model comprises 75 rows, 137 columns and 13 layers (i.e., the Oxnard Subbasin, the Pleasant Valley Basin, and the West Las Posas Management area of the Las Posas Basin is subdivided into 133,575 “grid blocks”). Figure 3-14 in Appendix A shows the relationship between aquifers and model layers. Numerical values of the subsurface hydraulic properties (horizontal hydraulic conductivity K_h, the ratio of vertical and hydraulic conductivities K_h/K_z, and storage coefficient S) have to be assigned to each of these blocks. Additionally, numerical values of the boundary functions, recharge, stream bed conductivity, and conductance of general head boundaries must be assigned to each block. Many of these parameters are time-dependent so that specification of a single parameter in a given grid block over 372 “stress periods” requires 372 parameter values. Consequently, the UWCD model has more than half a million parameters, which are not just unknown but unknowable. Estimates of these parameters are obtained by comparing the model’s predictions of hydraulic head with 800 corresponding observations of groundwater elevation collected at wells with multiple screens.

To reduce this large number of parameter values, the authors subdivide the simulation domain into 900 zones within which all grid blocks have the same parameter values. This reduces the required number of parameter values for K_h, K_h/K_z, and S from 133,575 x 3 = 400,725 to 900 x 3 = 2700. It is worthwhile emphasizing that these 900 zones do not represent particular, well defined/delineated geological features; they are introduced primarily for computational convenience.

2.2.2 Calibration

In addition to standard quantitative metrics such as absolute residual mean (ARM), UWCD’s approach to calibration relies on qualitative measures like the current understanding of the site’s geology and “observed” regional hydraulic head gradients. Even if one were to rely solely on minimization of quantitative metrics, such as root mean square error (RMSE) or ARM the calibration procedure would yield parameter values that are neither unique nor optimal. That is because the underlying high-dimensional optimization problem has a large number of local minima and all but defies identification of the global minimum. While somewhat constraining the parameter selection, the introduction of qualitative criteria further exacerbates the non-uniqueness and optimality issues.

This brief overview of the UWCD model parameterization and calibration should not be viewed as a criticism; the approach used is broadly in line with best practices in the industry. It merely serves to highlight the daunting challenge one faces in trying to parameterize or calibrate groundwater models in a deterministic fashion. It also points out the limitations of *local* sensitivity analyses implemented in the USGS software PEST (Welter et al., 2015). This class of sensitivity analyses assumes a given point (locale) in the parameter space (i.e., a particular model parameterization) to be optimal and investigates how a small deviation of a parameter value from this point affects the model’s predictions. An alternative approach is to use *global* sensitivity analyses, which rely on ANOVA (a statistical technique called ANalysis Of VAriance) to quantify the sensitivity of a model’s prediction to possible variability of parameter values (Saltelli et al., 2008). The use of global sensitivity in groundwater literature has become mainstream (e.g., Ciriello et al., 2013; Song et al., 2015; Razavi and Gupta, 2015; La Vigna et al., 2016; and the references therein). We use the global sensitivity analysis approach to quantify the sensitivity of the RMSE and ARM for the UWCD predictions of hydraulic heads to the possible variability of the 28 parameters assigned level IV sensitivity (those parameters that had the greatest effect on simulated water levels and changes in storage) in Table 4-6 of the UWCD model documentation report (UWCD, 2018). The locations of the parameter zones by layer are shown in figures from the UWCD report attached in Appendix A.

2.3 Uncertainty Analysis

The largest sources of uncertainty in groundwater models often derive from the major stresses, pumping and recharge. In the case of the UWCD model, historical pumping is known and roughly half of all recharge is through artificial recharge through spreading basins, which is metered. Thus, the uncertainty associated with these factors is largely eliminated or significantly reduced. There remains uncertainty about the amount of seawater intrusion, as this is not measured. This uncertainty in model predictions of seawater intrusion is quantified below.

Recharge through Arroyo Las Posas, Conejo Creek, and Calleguas Creek in the Pleasant Valley Basin is also uncertain. Although the model assumes infiltration from these surface water bodies to be small, an average of approximately 17,200 AFY compared to artificial recharge from spreading (48,300 AFY) in the Forebay, it constitutes approximately 58% of average total inflows into the Pleasant Valley Basin. Approximately 79% of this infiltration in the model is derived from stream base flows, as estimated using third quarter simulated infiltration. This infiltration is not well constrained by observations because low flows in the creeks are not captured by stream gauges. Infiltration was estimated through calibration by increasing or decreasing streambed conductance to match groundwater levels in nearby wells.

2.3.1 Global Sensitivity Analysis

Our global sensitivity analysis focuses on the 28 parameters that were assigned level IV sensitivity in the UWCD model documentation report (UWCD, 2018). These parameters were found to have high sensitivity in the model calibration and in the flow budget. Eleven of these parameters vary in time over 372 stress periods, so that the total number of parameter values to study is 17 + 11 x 372 = 4109.

To account for the correlations and dependencies built into the UWCD model, we represent each of the 11 time-dependent parameters $Q(t)$ as $\alpha Q(t)$, where $Q(t)$ has the parameter values used in the UWCD model, and the random parameter α has a uniform distribution on an interval [αmin, αmax]. Likewise, the ocean general head boundary conductance defined over the 5 layers representing aquifers that crop out beneath the ocean, $H(z)$, is replaced with $\alpha H(z)$, where $H(z)$

has the boundary head values used in the UCWD model. The range of these multipliers are presented in Table 2.

We defined the RMSE and ARM with respect to hydraulic heads observed in single-node wells in layers 1, 3, 5, 7, 9, 11, and 13. We deployed the software DAKOTA developed by Department of Energy's Sandia National Laboratories to conduct the global sensitivity analysis of this RMSE and ARM to the variations in the 28 parameters assigned level IV sensitivity discussed above. The DAKOTA project has passed through the DOE's rigorous quality assurance process and "delivers both state-of-the-art research and robust, usable software for optimization and UQ [Uncertainty Quantification]. Broadly, the DAKOTA software's advanced parametric analyses enable design exploration, model calibration, risk analysis, and quantification of margins and uncertainty with computational models."[1] We used this software to post process 120 realizations of the UCWD model created in Groundwater Vistas. DAKOTA generated these realizations by treating the 28 input parameters as mutually independent random variables distributed uniformly on their respective intervals of variability (Table 2), and by using Latin Hypercube Monte Carlo (MC) with 4 bins to sample these distributions. This number of MC realizations is determined by the formula (28 + 2) x 4, as described in the DAKOTA manual (Adams et al., 2018; page 1387).

Figures 1 and 2 show that the ARM and Seawater Flux (seawater intrusion) are most sensitive to the values of hydraulic conductivity, which dominate the contributions from other hydrogeologic parameters. The results are presented in terms of the Sobol' indices (Saltelli et al., 2008). The global sensitivity analysis indicates that horizontal hydraulic conductivity values assigned to the Oxnard and Mugu aquifers in the Forebay (Zone 9 and adjacent Zones 10 and 19; see Appendix A for maps of model zones by layer) account for approximately 37% of the variance in the model-wide ARM for groundwater levels and approximately 24% of the variance in calculated seawater flux (these results are presented in the attached Tables 3 and 4 as well). The fact that these parameters accounting for so much variance in model predictions is constrained locally by independent observation, instills confidence in model predictions of head and seawater intrusion. Beneath the Oxnard Plain in Zone 4, the horizontal hydraulic conductivity of the Hueneme and upper Fox aquifers account for approximately 8% of the variance in both ARM and seawater flux. These results come with a caveat; they correspond to the ranges of parametric uncertainty specified in the Table 2 submitted with this report.

In contrast, the general head boundary (GHB) conductance of the ocean outcrop boundary accounted for 2.7% of the variance in ocean flux. This indicates that hydraulic properties of the

[1] See https://dakota.sandia.gov/

aquifers beneath the Forebay and Oxnard Plain, which can be measured through field testing, account for much more variance than the ocean GHB conductance which cannot be tested.

Hydraulic properties in Zone 12, covering most of the WLPMA, area accounted for 26% of the variance in the global ARM (Table 3). The horizontal hydraulic conductivity of Layers 3, 5, 6, 7, and 8 account for approximately 13.4% of the variance in the global ARM, while the storativity in layers 9, 10, and 11 accounts for 10% of the variance in the ARM and the vertical hydraulic conductivity accounts for 2.5% of the variance in the ARM. This area of the model is less well constrained by aquifer test results and should be revisited during the next 5 years.

Horizontal and vertical hydraulic conductivities in West Las Posas Management Area accounted for approximately 18% of the seawater flux variance (Figure 2, Table 4).

Stream infiltration, horizontal hydraulic conductivity in the Semi-Perched zone, and horizontal and vertical hydraulic conductivity of the aquitard separating Layer 5 (Mugu aquifer) from Layer 7 (the Hueneme aquifer) in the Pleasant Valley Basin accounted for 16% of the variance in seawater flux.

Overall, this analysis provides a measure of confidence in the model's ability to match the observed heads by relying on the parameters that are readily measurable, such as horizontal hydraulic conductivity, as opposed to those that are not, such as vertical hydraulic conductivity. At the same time, it is important to emphasize that RMSE and ARM are global metrics that, by construction, average the discrepancy between the observed and predicted hydraulic heads over all locations where the measurements are available. Since a key quantity of interest pertinent to the present study is seawater flux into the aquifer, one might adopt a different strategy moving forward as the model is refined and recalibrated for the 5-year update. The strategy would emphasize matching water levels near the coast by replacing the constant weights in the current calculation of the RMSE and ARM with the weights inversely proportional to the distance between the observation points and the ocean.

Figure 2 exhibits the sensitivity of the predicted seawater flux to the variability of the same 28 parameters that were found to have the highest sensitivity in the model calibration and flow budget. Figure 2 is reported in terms of the Sobol's indices computed from the 120 realizations described above. Results of the global sensitivity analysis indicate that horizontal hydraulic conductivity in the Oxnard and Mugu Aquifers within the Forebay and adjacent regions (Zone 9, 10, and 19) account for over 24% of the variance in seawater flux. Seawater flux is most sensitive to hydraulic conductivity in the Mugu aquifer within the Forebay, which accounts for 14.5% of the variance in flux.

2.3.2 Quantification of Model Uncertainty

We used two complementary approaches to quantify uncertainty in the UWCD model's predictions of seawater flux. First, we compared the difference between simulated and observed water levels at the coast during the historical model period from 1985 to 2015 and determined the amount of seawater flux attributable to that difference. Second, we conducted statistical analysis of the 121 predicted values of seawater flux (calculated by the original UWCD model and 120 realizations created for the GSA) to compute its mean and standard deviation. Then, we deployed the original UWCD model to simulate seawater fluxes resulting from 6 future conditions and the associated pumping; these were used, in conjunction with a linear regression model and the standard deviation of seawater flux, to obtain confidence intervals for sustainable yield.

2.3.2.1 Seawater Flux: Difference between Simulated and Observed Water Levels

In order to estimate the uncertainty in the volume of seawater coming onshore at the coast calculated by the UWCD model, predicted heads at wells were compared to the flux across the coast calculated by the model. In order to better understand the seawater flux, the coast was divided into three segments: 1. Point Mugu to Arnold road, 2. Arnold Road to Channel Islands Harbor, and 3. North of Channel Islands Harbor. Wells that were near these coastal zones and simulated within the model were selected for analysis. For each well, the modeled head for each monthly stress period was compared to the seawater flux for its associated coastal segment to generate a linear regression. The mean residual head error, which is the difference between the simulated elevation and the observed elevation, for each of these wells was then obtained from the UWCD model. The mean residual was multiplied by the slope of the regression for the well to calculate the potential flux uncertainty at each well. The flux from all wells within a coastal segment was then averaged and multiplied by 12 to get the potential annual flux difference for each coastal segment. Results of these calculations are presented in Table 5.

The uncertainty in the average annual seawater flux was compared to the reported seawater flux from the UWCD numerical model for each coastal segment to determine the potential percentage error in the reported flux values. Overall, the average net annual seawater flux in the UAS was 3,700 AFY while the average in the LAS was approximately 6,800AFY. The net seawater flux uncertainty was approximately 1500 AFY in the UAS and 500 AFY in the LAS, or 2000 AFY combined. The model over-predicted heads along the coast and thereby potentially under-predicted seawater flux.

2.3.2.2 Seawater Flux – Variance in Predictions among 121 Realizations of the Model

The RMSEs and ARMs for the 120 realizations of the input parameters are ranked in Table 2. This table also includes the RMSE of 28.23 and ARM of 16.6 for the original UWCD model. The calculated seawater flux for all layers for the entire simulation is also included. Since all of these realizations respect the original conceptual model in their understanding of the structure and hydrogeology (presence of faults/folds, etc.) within the model domain, they are comparable to the original model.

The mean seawater flux from these realizations is 312,064 AF. The mean seawater flux in the UAS was 4031 AFY and 5966 AFY in the LAS. The standard deviation, or uncertainty, in the estimate for seawater flux in the UAS is approximately 2,154 AFY and 840 AFY in the LAS for a total of 2,994 AFY.

These two approaches yield similar uncertainty in calculated net seawater flux.

2.3.2.2 Sustainable Yield

We used the uncertainty in the average annual seawater flux to predict the impact of groundwater withdrawal on the seawater flux. Our analysis starts with a formulation of surrogate models that relate the seawater flux F to the total pumping P. Figure 4, Figure 5, and Figure 6 reveals a linear relationship between the two, $F = a_0 + a_1P$, for UAS, LAS and their total in the Oxnard Subbasin. The values of a_0 and a_1 for the three surrogate models, as well as the corresponding goodness-of-the-fit (R^2 values) are reported in Table 6. These models predict the sustainable yield for UAS in Oxnard (the maximal pumping that precludes seawater intrusion, i.e., results in zero seawater flux) to be 31,600 AFY, and for LAS to be 6,966 AFY analyzing those aquifer systems individually. Figure 7 shows that accounting for pumping within the Oxnard Subbasin, Pleasant Valley Basin, and West Las Posas Management Area leads to the sustainable yield of 63,409 AFY.

Next, we estimate the uncertainty in the predicted values of sustainable yield by treating the seawater fluxes as Gaussian variables whose mean and standard deviation are given, respectively, by the mean and standard deviation of the seawater fluxes calculated with the 121 realizations of the original model. . The linear relationship between F and P indicates that the latter is Gaussian as well, with the standard deviation given by the ratio of the standard deviation of F divided by a_1.

This gives the sustainable yield confidence intervals of ±5,987 for UAS, ±3,578 for LAS, and ±9,171 for the total.

2.4 Conclusions Regarding the UWCD Model

The UWCD numerical model is consistent with the accepted conceptual model of the Oxnard Subbasin, Pleasant Valley Basin, and Western Management Area of the Las Posas Valley Basin.

The largest potential sources of uncertainty were found to be hydraulic properties. But critical areas were constrained by aquifer testing. In particular, the model parameters that accounted for the most variance (approximately 37% of total variance) in minimizing error between observed groundwater levels and model simulated heads throughout the model were the horizontal hydraulic conductivities assigned to the Oxnard and Mugu aquifers in the Forebay. The values assigned in the model were consistent with horizontal hydraulic conductivities determined from aquifer testing in that area. The fact that the most sensitive parameter assignments were well-constrained by observations reduces uncertainty and provides good confidence in model predictions of groundwater levels overall.

Additionally and importantly, these same zones of horizontal hydraulic conductivity accounted for approximately 24% of total variance in model calculations of seawater flux across the ocean boundary. In contrast, the conductance of the ocean general head boundaries only accounted for approximately 3% of the variance in seawater flux. This indicates that the movement of artificially recharged groundwater from the Forebay to the coast is key in seawater flux. Additionally, the amount of Forebay recharge that enters WLPMA rather than moving towards the coast was found to affect the seawater flux more than the conductance of the GHBs representing the ocean outcrops at the model boundary.

Stream infiltration, a parameter that was estimated based on the correlation between predicted and observed water levels accounted for approximately 5% of the variance in seawater flux and horizontal and vertical hydraulic conductivity of the aquitard separating Layer 5 (Mugu aquifer) from Layer 7 (the Hueneme aquifer) in the Pleasant Valley Basin accounted for approximately 3% of the variance in seawater flux. This sensitivity is associated with the flux across the basin boundary and flow between the UAS and LAS. Again, these parameters in Pleasant Valley accounted for more seawater flux than that accounted for by the conductance of the aquifer outcrops beneath the ocean.

We evaluated the uncertainty associated with model simulations of seawater flux by determining the relationship between simulated groundwater levels in wells near the coast and simulated seawater flux at the ocean boundary. Then we looked at the mean errors between observed and simulated groundwater levels and, using the relationship between simulated groundwater levels and seawater flux, determined what the flux would have been had the model exactly reproduced observed groundwater levels. This indicated that there is approximately 2000 AFY uncertainty due to model error in simulated total seawater flux. Using the standard deviation of seawater flux from the Stratified Monte Carlo simulations, along with the results from the linear relationship between seawater flux and pumping, gives a confidence interval for the sustainable yield of ± 5987 AFY for UAS, ± 3578 AFY for LAS, and ± 9171 AFY for the combined UAS and LAS.

Based on this review and the conclusions above, the UCWD model is reliable to use in the initial estimation of the basin wide sustainable yield. This estimate will be refined through data collection and analysis over successive 5 year periods for the GSP updates.

3 CMWD MODEL

3.1 Model Software

The model code selected for the ELPMA model is appropriate for investigating groundwater flow and changes in storage in response to changing pumping and recharge. MODFLOW is a widely accepted open source code used for flow models of basins and appropriate to the ELPMA, which does not experience seawater intrusion.

3.2 Mathematical Representation of the Conceptual Model

The conceptual model presented in the model documentation is consistent with the literature and the draft GSPs, and has been incorporated into the mathematical representation of the model domain (CMWD, 2018). Accurately representing complex stratigraphic relationships that have been influenced by extensive faulting and folding, is a particular challenge for models of the ELPMA. These relationships have been incorporated by adjusting the thickness of layers in the vicinity of anticlines and synclines, to emulate what is known from subsurface investigations in this area.

3.2.1 Hydraulic Conductivity

Hydraulic conductivity in the model is constrained by aquifer tests and numerous specific capacity determinations of productions wells. The model incorporates substantial heterogeneity in hydraulic conductivity parameterization avoiding potential uncertainty from assuming uniform hydraulic conductivity over broad areas.

3.2.2 Groundwater Levels

The model reproduces historical groundwater levels well in the shallow aquifer, USP, Fox Canyon, and Grimes Canyon aquifers in the central and southern portions of the ELPMA (See for example wells 02N20W09Q01S and 2N20W09Q04S on Figure 8-58, Figure 8-60, wells 02N20W09R01S, 02N20W10D02S, 2N20W10G01S, and others in Figure 8-62b, and 03N20W35R02S and 03N20W26R03S in Figure 8-63 – of the CMWD Model Documentation Report; also included as attachments in Appendix B). Simulated groundwater levels in the northern and northwestern area are not reproduced as well. There were fewer historical observations and greater uncertainty regarding well screens and the aquifers tapped by wells in the northwest. Simulated heads in Well 3N20W27B01S are a couple of hundred feet lower than observed (Figure 8-63 from the CMWD Model Documentation Report and included in Appendix B). Consequently, predictions of groundwater levels under future conditions are much less certain in the northwest of the ELPMA than they are in the center of the basin.

3.2.3 Recharge

Inflow from Arroyo Las Posas (ALP) accounts for approximately 50% (10,395 AFY) of inflow, or recharge, to the ELPMA. The model does a reasonable job of replicating the findings of the field investigation of gaining and losing reaches of Arroyo Las Posas and the total average infiltration (CMWD, 2012). Historical groundwater levels near Arroyo Las Posas are well-replicated by the model. These two factors engender confidence in simulations of the future as changes in ALP flow are the most significant anticipated change in inflows in the future.

Estimates of storage coefficients are largely limited to ASR wells. Additional aquifer tests to determine storage coefficients in other areas would reduce uncertainty regarding assumed areal recharge. More measurements of storage coefficients would help constrain estimates of areal recharge in the model.

The model incorporates recharge to the Grimes Canyon aquifer in the outcrop area in the northeastern portion of the model. CMWD Figures 8-6 and 8-7 in Appendix B show parts of the outcrop area where drainage channels receive 30-35 inches per year of recharge. There are no stream gauges in this area, nor wells to constrain this assumption. There is also no data to guide the assumed thickness of the Grimes Canyon aquifer in this area. Simulated heads in this area of the model rise from initial heads of 1,000 to 7,000 ft msl (CMWD, 2018: Fig. 8-55) in January 1970 to 1,000 to 14,500 ft. msl in January 1990 to 1,000 to 22,000 ft msl in January 2015. Simulations of future conditions produce heads of approximately 29,000 ft msl. While these simulated heads are unrealistic, different assumptions about aquifer thickness and specific storage could change them dramatically.

3.2.4 Discharge

Historical pumping discharges are typically unknown when constructing groundwater models and require estimation. However, in the case of this model, pumping rates since 1985 are documented because of reporting to FCGMA. Discharge from wells accounts for 93% of all outflows from the model. Thus uncertainty associated with the largest discharge stress and associated uncertainty about the model parameters selected to match historical groundwater level observations is greatly reduced.

3.3 Uncertainty Analysis

CMWD is currently working on a quantitative sensitivity analysis of the model. This review provides only a qualitative analysis of apparent sensitivity and uncertainty. The discussion here should be evaluated in light of the sensitivity analysis when it is available.

Areal recharge from precipitation accounts for approximately 26% of the inflows to the model. Areal recharge was estimated using the USGS BCM model scaled to Ventura County Watershed Protection District (VCPWD) rain gauges. Daniel B. Stephens and Associates (DBSA) also estimated rainfall infiltration using its distributed parameter model. Comparison of the two approaches indicates that the long term average recharge is comparable between the two approaches (5,119 AFY in the model approach versus 5,302 AFY in the DBSA approach).

Areal recharge is a constant value based on the 50-year average rainfall. The relatively thick vadose zone and lack of clear climatic signal in historical water levels support the decision to use uniform areal recharge based on the 50-year average precipitation. However, this assumption of uniform recharge eliminates the potential impact of drought cycles in the future from model simulations. To investigate the possible effects of this decision, we constructed a 1-D unsaturated zone flow model using the open-source USGS code, VS2DT, and examined the rate at which water is transported through the vadose zone to the water table. The depth to water in the model was <200 feet over 42% of the domain in 1991 and 48% of the domain in 2015. To investigate the difference between constant 50-year average recharge and variable recharge, we generated a homogeneous and isotropic 200-foot-thick domain using the parameters specified for the top layer of Upper San Pedro/Saugus Formation. We used the precipitation record from the Ventura County Water Works facility in Moorpark and assumed 15% of rainfall infiltrated past the root zone and compared the effect of using a uniform average precipitation value versus the observed monthly data.

Results of the simulation indicate that the flux of water reaching the water table is constant when the model is forced using the 50-year average precipitation value and varies from 91% to 120% of that rate when the amount of water entering the vadose zone varies monthly. High-frequency precipitation events that pulse infiltration at the top of the domain are dampened during transport through the vadose zone. Our results suggest a time-lag on the order of 10-15 years between when a pulse of water enters the domain and when there is a spike in the outflow to the water table. The total volume of water reaching the water table was 1% greater using the varied inflow than with the uniform rate. Results from a supplemental simulation using a 500-foot-thick vadose zone with the same properties indicate that variations at the inflow do not affect rates of transport through the vadose zone or the total volume of water delivered to the water table. Because over 50% of the vadose zone within the CMWD model is greater than 200 feet thick, incorporating monthly variable recharge will not likely affect areal recharge rates under the influence of future drought cycles.

Return flows from municipal and agricultural irrigation constitutes 14% of total inflows. Based on long term averages from the annually variable DBSA results, the CMWD model incorporates 8-16% of applied irrigation water as recharge beyond the root zone. By comparison, the UCWD model assumes about 14% of applied irrigation water infiltrates past the root zone. There is uncertainty associated with these recharge components.

Results of zone budget analysis of the model indicate that 10% of all recharge to the model comes from the Grimes Canyon aquifer outcrop area. The zone budget analysis further indicates that flow from the Grimes Canyon aquifer outcrop area to the rest of the Grimes Canyon aquifer constitutes an average of 12% of the recharge to the rest of the Grimes Canyon aquifer. During the historical simulations, the percentage increases through time from 9% to 14% as the heads in the outcrop area increase. This trend undoubtedly persists in the simulations of future conditions. It creates some uncertainty about simulations of future conditions in the Grimes Canyon aquifer. However, average pumping from the Grimes Canyon aquifer historically only constituted 9% of ELPMA pumping in the model.

In contrast, average pumping from the Fox Canyon aquifer constituted 74% of ELPMA pumping in the model. Simulated heads in Well 03N19W33P03S, the easternmost FCA well used as a calibration target, rise steadily in the latter half of the simulation potentially indicating upward flow of groundwater from the GCA in the outcrop area. In order to investigate the influence of the high simulated groundwater elevations in the Grimes Canyon Aquifer on recharge to the Fox Canyon aquifer in the model, the upward flux from Layer 7 (Grimes Canyon aquifer) through Layer 6 to Layer 5 (Fox Canyon aquifer) was compared to the total flow into the Fox Canyon Aquifer from all sources in the model. The upward flux constitutes approximately 1.5% of total flow into the Fox Canyon aquifer. Therefore, the potentially overstated flow from the Grimes Canyon aquifer outcrop area to the rest of the domain does not create significant uncertainty for simulations of future conditions in the Fox Canyon aquifer.

Examining the historical production from the Grimes Canyon Aquifer and the modeled impacts of the excessive predicted heads in the Grimes Canyon Aquifer, the uncertainty regarding modeling of the entire ELPMA is small. Over the next 5 years, hydraulic properties and recharge to the Grimes Canyon aquifer in the outcrop area should be investigated to constrain the estimated recharge. Geochemical evaluations might be useful in this regard.

3.4 Conclusions Regarding the CMWD Model

The CMWD numerical model of the ELPMA is consistent with the accepted conceptual model of the basin, and MODFLOW is an appropriate tool for assessing groundwater flow conditions in the ELPMA. The largest potential sources of uncertainty: hydraulic properties, historical pumping, and recharge from Arroyo Las Posas, are reasonably well-constrained by measurements and historical observations. Recharge in the Grimes Canyon aquifer outcrop area is a source of uncertainty that is not well constrained. However, average pumping from the Grimes Canyon aquifer historically only constituted 9% of basin wide pumping in the model. Therefore, the uncertainty regarding modeling of the basin as a whole is small. Model simulated groundwater levels in the northwestern portion of the ELPMA are uncertain. Additional revisions are necessary to improve the model in this area.

The model is reliable to use in the initial estimation of the basin-wide sustainable yield of the ELPMA, especially as the model simulates recharge from the ALP well and potential changes to the amount of flow in and infiltration from the arroyo represent the most significant likely changes in conditions in the future.

4 RECOMMENDATIONS

Understanding and quantifying model uncertainty is important for decision makers. The results of this peer review suggest that although the models indicate reductions are required to the groundwater extraction rates, there is sufficient uncertainty in the model results to allow for gradual implementation of the reductions if data gaps are filled and the models are refined over the next five years. Additionally, the implementation of future projects and active management of extraction locations should be incorporated into each model to better constrain the future sustainable yield.

As projects and management actions are proposed, their impacts on groundwater elevations and seawater flux should be modeled. Moving forward to the 5-year GSP update process the groundwater models will continue to be relied upon to assess the sustainable yield, and reduce the uncertainty in that assessment. Below we recommend considerations for future refinements to the UWCD and CMWD models.

4.1 Model Validation

In developing these models, neither the UWCD nor the CMWD validated model calibration with data held back from groundwater head matching during the calibration process. The data held back could be from a separate time period, or from wells that were not considered during calibration. Validation entails calculating the difference between observed groundwater levels and simulated groundwater levels without further modification of the model to reduce the differences to provide a measure of model reliability and associated uncertainty. Before the 5-year updates to the GSPs, the models should be validated against data from 2016 to 2017 prior to re-calibration and data from 2018-19 should be reserved for validation post-re-calibration. If there are wells with reasonably long groundwater level records during the 1985-2015 period that were not used during calibration, it might be possible to validate the models with those records.

4.2 UWCD

If it is desired to evaluate water quality impacts from seawater flux, UWCD should consider incorporating a density driven flow module to the existing flow model. This would also require further vertical discretization within the aquifers to capture the vertical heterogeneity in lithology within aquifers that is evident in some geophysical borehole logs.

UWCD should review the parameterization of the WLPMA especially as the sustainable yield of this basin is driven by its hydraulic connection to the Oxnard Subbasin and the way pumping in the WLPMA has apparent impacts on the ability to control sea water intrusion in Oxnard.

4.3 CMWD

CMWD should perform a sensitivity analysis to quantify the uncertainty in the model and guide additional data acquisition and model refinement for the 5-year update.

The parameterization of the GCA outcrop area merits revision.

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Table 1.
Comparison of Las Posas Aquifer Properties Between the UWCD and CMWD Models on Either Side of the Somis Fault

Aquifer/ Formation	Model Parameter		CMWD	UWCD
	Abbreviation	Units		
San Pedro			**Layer 2**	**Layer 7**
	K_h	Feet/day	0.03 - 1	10
	K_Z	Feet/day	0.01-0.1	0.1
	Ss	$Feet^{-1}$	.00005 -0.001	-
	S	unitless	-	0.002
			Layer3	**Layer 7**
	K_h	Feet/day	0.03 -1	10
	K_Z	Feet/day	0.01 - 0.1	0.1
	Ss	$Feet^{-1}$	.00005 -0.001	-
	S	unitless	-	0.002
Aquitard			**Layer 4**	**Layer 8**
	K_h	Feet/day	-	0.0001
	K_Z	Feet/day	1.00E-04	1.00E-06
	Ss	$Feet^{-1}$	.00005 -0.001	
	S	unitless	-	0.002
Fox Canyon Aquifer			**Layer 5**	**Layer 9**
	K_h	Feet/day	3 -10	5
	K_Z	Feet/day	0.1-1	0.05
	Ss	$Feet^{-1}$	.00005 -0.0001	-
	S	unitless	-	0.002
Santa Barbara			**Layer 6**	**Layer 10**
	K_h	Feet/day		0.01
	K_Z	Feet/day	.001 - 0.1	0.001
	Ss	$Feet^{-1}$	0.00005	-
	S	unitless	-	0.002
Grimes Canyon Aquifer			**Layer 7**	**Layer 13**
	K_h	Feet/day	0.3 - 10	5
	K_Z	Feet/day	0.01 - 1	0.5
	Ss	$Feet^{-1}$	0.00005	-
	S	unitless	-	0.002

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	VRGWFM	64	104	68	19	16	17	120	60	92	100
RMSE	28.23	28.67	28.36	29.65	30.45	29.76	30.55	29.79	29.92	29.87	29.87
ARM	16.60	17.19	17.32	17.98	18.00	18.02	18.04	18.13	18.13	18.15	18.15
Seawater Flux	303950	234605	241378	238474	302172	236757	269845	262681	250118	241019	241000
Kh_L3Z9	250	227.956	227.956	227.956	279.377	227.956	1065.541	227.956	227.956	227.956	227.956
Kh_L1Z11	200	1688.009	1688.009	1688.009	390.310	349.629	24.812	1688.009	1688.009	1688.009	1688.009
Kh_L5Z9	200	108.315	108.315	108.315	74.084	108.315	32.539	108.315	108.315	108.315	108.315
Kh_L3Z12	100	133.714	133.714	133.714	531.591	133.714	38.428	133.714	133.714	133.714	133.714
Kh_L5Z10	100	778.031	778.031	778.031	224.002	778.031	40.764	778.031	778.031	778.031	778.031
Kh_L5Z12	100	16.355	16.355	16.355	44.821	16.355	512.917	16.355	16.355	16.355	16.355
Kz_L7Z12	100	445.121	445.121	445.121	18.385	445.121	168.996	445.121	445.121	445.121	445.121
Kh_L7Z4	20	40.508	40.508	40.508	3.211	40.508	12.716	40.508	40.508	40.508	40.508
Kh_L7Z5	20	155.363	155.363	155.363	20.804	155.363	15.519	155.363	155.363	155.363	155.363
Kh_L7Z10	20	17.951	17.951	17.951	30.888	17.951	3.717	17.951	17.951	17.951	17.951
Kh_L7Z12	10	7.783	7.783	7.783	1.233	7.783	46.467	7.783	7.783	7.783	7.783
Kh_L9Z4	10	12.357	12.357	12.357	48.687	12.357	2.824	12.357	12.357	12.357	12.357
Kh_L9Z5	10	78.215	78.215	78.215	4.243	78.215	2.007	78.215	32.266	78.215	78.215
Kz_L6Z4	10	6.230	37.461	37.461	31.560	37.461	4.226	37.461	37.461	37.461	37.461
Kz_L6Z11	10	4.654	4.654	3.092	11.480	4.654	1.917	4.654	4.654	4.654	4.654
Kz_L6Z13	10	22.561	22.561	22.561	4.243	22.561	2.702	22.561	22.561	22.561	22.561
Kh_L6Z12	5	4.071	4.071	4.071	1.416	4.071	8.683	4.071	4.071	4.071	4.071
Kh_L6Z19	0.1	0.383	0.383	0.383	0.030	0.383	0.113	0.383	0.383	0.383	0.383
Kh_L6Z11	0.01	0.008	0.008	0.008	0.010	0.008	0.002	0.008	0.008	0.008	0.008
Kh_L6Z13	0.01	0.008	0.008	0.008	0.001	0.008	0.018	0.008	0.008	0.008	0.008
S_L9Z12	2.00E-03	3.14E-05	3.14E-05	3.14E-05	2.74E-02	3.14E-05	4.99E-03	3.14E-05	3.14E-05	6.98E-05	3.14E-05
S_L10Z12	0.002	0.045	0.045	0.045	0.018	0.045	0.001	0.045	0.045	0.045	0.045
S_L11Z12	2.00E-03	5.13E-05	5.13E-05	5.13E-05	1.17E-02	5.13E-05	4.32E-02	5.13E-05	5.13E-05	5.13E-05	1.86E-04
S_L13Z12	0.0005	0.013	0.000	0.013	0.001	0.013	0.000	0.013	0.013	0.013	0.013
Kh_L8Z12	1.00E-04	2.23E-05	2.23E-05	2.23E-05	2.93E-04	2.23E-05	8.72E-05	2.23E-05	2.23E-05	2.23E-05	2.23E-05
RCH*	1	0.530	0.530	0.530	1.796	0.530	1.186	0.530	0.530	0.530	0.530
STR*	1	0.238	0.238	0.238	0.084	0.238	13.292	0.238	0.238	0.238	0.238
GHB*	1	0.948	0.948	0.948	0.651	0.948	1.915	1.864	0.948	0.948	0.948

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	76	24	112	36	8	32	108	28	52	72	56
RMSE	29.87	29.88	29.88	29.87	29.88	29.88	29.88	29.82	29.89	29.63	29.91
ARM	18.15	18.15	18.15	18.15	18.15	18.15	18.15	18.15	18.16	18.16	18.17
Seawater Flux	241007	241201	241076	241394	241200	241206	241205	247541	241311	234852	240932
Kh_L3Z9	227.956	227.956	227.956	227.956	227.956	227.956	227.956	227.956	227.956	227.956	227.956
Kh_L1Z11	1688.009	1688.009	1688.009	1688.009	1688.009	1688.009	1688.009	1688.009	1688.009	1688.009	1688.009
Kh_L5Z9	108.315	108.315	108.315	108.315	108.315	108.315	108.315	108.315	108.315	108.315	108.315
Kh_L3Z12	133.714	234.793	133.714	133.714	133.714	133.714	133.714	133.714	133.714	133.714	133.714
Kh_L5Z10	778.031	778.031	778.031	778.031	778.031	778.031	778.031	84.721	778.031	778.031	778.031
Kh_L5Z12	16.355	16.355	16.355	16.355	16.355	15.192	16.355	16.355	16.355	16.355	16.355
Kz_L7Z12	445.121	445.121	445.121	59.510	445.121	445.121	445.121	445.121	445.121	445.121	445.121
Kh_L7Z4	40.508	40.508	40.508	40.508	40.508	40.508	40.508	40.508	40.508	40.508	40.508
Kh_L7Z5	155.363	155.363	155.363	155.363	155.363	155.363	155.363	155.363	155.363	155.363	155.363
Kh_L7Z10	17.951	17.951	17.951	17.951	17.951	17.951	17.951	17.951	17.951	17.951	17.951
Kh_L7Z12	7.783	7.783	7.783	7.783	7.783	7.783	7.783	7.783	7.413	7.783	7.783
Kh_L9Z4	12.357	12.357	12.357	12.357	12.357	12.357	12.357	12.357	12.357	12.357	11.285
Kh_L9Z5	78.215	78.215	78.215	78.215	78.215	78.215	78.215	78.215	78.215	78.215	78.215
Kz_L6Z4	37.461	37.461	37.461	37.461	37.461	37.461	37.461	37.461	37.461	37.461	37.461
Kz_L6Z11	4.654	4.654	4.654	4.654	4.654	4.654	4.654	4.654	4.654	4.654	4.654
Kz_L6Z13	22.561	22.561	22.561	22.561	22.561	22.561	22.561	22.561	22.561	3.272	22.561
Kh_L6Z12	21.104	4.071	4.071	4.071	4.071	4.071	4.071	4.071	4.071	4.071	4.071
Kh_L6Z19	0.383	0.383	0.383	0.383	0.383	0.383	0.383	0.383	0.383	0.383	0.383
Kh_L6Z11	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Kh_L6Z13	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
S_L9Z12	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05
S_L10Z12	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
S_L11Z12	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05
S_L13Z12	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Kh_L8Z12	2.23E-05	2.23E-05	2.23E-05	2.23E-05	2.23E-05	2.23E-05	4.86E-04	2.23E-05	2.23E-05	2.23E-05	2.23E-05
RCH*	0.530	0.530	0.922	0.530	0.530	0.530	0.530	0.530	0.530	0.530	0.530
STR*	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238
GHB*	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	48	80	88	40	96	44	116	63	9	115	20
RMSE	29.89	30.03	30.05	30.14	30.32	30.48	30.84	30.35	30.92	31.32	30.32
ARM	18.20	18.24	18.29	18.36	18.38	18.39	18.50	18.50	18.53	18.58	18.69
Seawater Flux	237657	239955	242719	237394	248052	314657	246641	253852	257876	215017	227233
Kh_L3Z9	227.956	227.956	227.956	227.956	227.956	227.956	227.956	279.377	360.557	279.377	227.956
Kh_L1Z11	1688.009	1688.009	1688.009	1688.009	1688.009	1688.009	1688.009	390.310	24.812	390.310	1688.009
Kh_L5Z9	108.315	108.315	108.315	108.315	108.315	108.315	108.315	728.072	599.817	728.072	256.384
Kh_L3Z12	133.714	133.714	133.714	133.714	133.714	133.714	133.714	531.591	38.428	531.591	133.714
Kh_L5Z10	778.031	778.031	778.031	778.031	778.031	778.031	778.031	224.002	40.764	224.002	778.031
Kh_L5Z12	16.355	16.355	16.355	16.355	16.355	16.355	16.355	44.821	512.917	44.821	16.355
Kz_L7Z12	445.121	445.121	445.121	445.121	445.121	445.121	445.121	18.385	168.996	18.385	445.121
Kh_L7Z4	40.508	40.508	40.508	8.757	40.508	40.508	40.508	3.211	12.716	3.211	40.508
Kh_L7Z5	155.363	155.363	155.363	155.363	155.363	14.030	155.363	20.804	15.519	20.804	155.363
Kh_L7Z10	118.218	17.951	17.951	17.951	17.951	17.951	17.951	30.888	3.717	30.888	17.951
Kh_L7Z12	7.783	7.783	7.783	7.783	7.783	7.783	7.783	1.233	46.467	1.233	7.783
Kh_L9Z4	12.357	12.357	12.357	12.357	12.357	12.357	12.357	48.687	2.824	48.687	12.357
Kh_L9Z5	78.215	78.215	78.215	78.215	78.215	78.215	78.215	4.243	2.007	4.243	78.215
Kz_L6Z4	37.461	37.461	37.461	37.461	37.461	37.461	37.461	1.800	4.226	31.560	37.461
Kz_L6Z11	4.654	4.654	4.654	4.654	4.654	4.654	4.654	11.480	1.917	11.480	4.654
Kz_L6Z13	22.561	22.561	22.561	22.561	22.561	22.561	22.561	4.243	2.702	4.243	22.561
Kh_L6Z12	4.071	4.071	4.071	4.071	4.071	4.071	4.071	1.416	8.683	1.416	4.071
Kh_L6Z19	0.383	0.091	0.383	0.383	0.383	0.383	0.383	0.030	0.113	0.030	0.383
Kh_L6Z11	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.010	0.002	0.010	0.008
Kh_L6Z13	0.008	0.008	0.002	0.008	0.008	0.008	0.008	0.001	0.018	0.001	0.008
S_L9Z12	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	2.74E-02	4.99E-03	2.74E-02	3.14E-05
S_L10Z12	0.045	0.045	0.045	0.045	0.000	0.045	0.045	0.018	0.001	0.018	0.045
S_L11Z12	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	5.13E-05	1.17E-02	4.32E-02	1.17E-02	5.13E-05
S_L13Z12	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.001	0.000	0.001	0.013
Kh_L8Z12	2.23E-05	2.23E-05	2.23E-05	2.23E-05	2.23E-05	2.23E-05	2.23E-05	2.93E-04	8.72E-05	2.93E-04	2.23E-05
RCH*	0.530	0.530	0.530	0.530	0.530	0.530	0.530	1.796	1.186	1.796	0.530
STR*	0.238	0.238	0.238	0.238	0.238	0.238	0.085	0.084	13.292	69.329	0.238
GHB*	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.651	1.915	0.651	0.948

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	84	49	11	67	13	27	45	37	77	97	33
RMSE	30.62	31.36	31.27	31.27	31.40	31.56	31.44	31.41	31.52	31.46	31.51
ARM	18.70	18.92	18.94	19.10	19.12	19.13	19.14	19.14	19.20	19.20	19.21
Seawater Flux	246648.969	245988	266705	257812	242013	261115	248185	244886	244638	251382	247313
Kh_L3Z9	227.956	1065.541	33.024	279.377	1065.541	279.377	1065.541	1065.541	1065.541	1065.541	1065.541
Kh_L1Z11	1688.009	24.812	390.310	390.310	720.156	390.310	24.812	24.812	24.812	24.812	24.812
Kh_L5Z9	108.315	599.817	728.072	728.072	599.817	728.072	599.817	599.817	599.817	599.817	599.817
Kh_L3Z12	133.714	38.428	531.591	531.591	38.428	531.591	38.428	38.428	38.428	38.428	38.428
Kh_L5Z10	778.031	40.764	224.002	224.002	40.764	107.795	40.764	40.764	40.764	40.764	40.764
Kh_L5Z12	16.355	512.917	44.821	44.821	512.917	44.821	512.917	512.917	512.917	512.917	512.917
Kz_L7Z12	445.121	168.996	18.385	18.385	168.996	18.385	168.996	168.996	168.996	168.996	286.068
Kh_L7Z4	40.508	12.716	3.211	3.211	12.716	3.211	12.716	3.093	12.716	12.716	12.716
Kh_L7Z5	155.363	15.519	20.804	20.804	15.519	20.804	15.519	15.519	15.519	15.519	15.519
Kh_L7Z10	17.951	3.717	30.888	30.888	3.717	30.888	2.040	3.717	3.717	3.717	3.717
Kh_L7Z12	7.783	1.449	1.233	1.233	46.467	1.233	46.467	46.467	46.467	46.467	46.467
Kh_L9Z4	12.357	2.824	48.687	48.687	2.824	48.687	2.824	2.824	2.824	2.824	2.824
Kh_L9Z5	78.215	2.007	4.243	4.243	2.007	4.243	2.007	2.007	2.007	2.007	2.007
Kz_L6Z4	37.461	4.226	31.560	31.560	4.226	31.560	4.226	4.226	4.226	4.226	4.226
Kz_L6Z11	4.654	1.917	11.480	3.412	1.917	11.480	1.917	1.917	1.917	1.917	1.917
Kz_L6Z13	22.561	2.702	4.243	4.243	2.702	4.243	2.702	2.702	2.702	2.702	2.702
Kh_L6Z12	4.071	8.683	1.416	1.416	8.683	1.416	8.683	8.683	8.683	8.683	8.683
Kh_L6Z19	0.383	0.113	0.030	0.030	0.113	0.030	0.113	0.113	0.022	0.113	0.113
Kh_L6Z11	0.002	0.002	0.010	0.010	0.002	0.010	0.002	0.002	0.002	0.002	0.002
Kh_L6Z13	8.29E-03	0.018	0.001	0.001	0.018	0.001	0.018	0.018	0.018	0.018	0.018
S_L9Z12	0.000	4.99E-03	2.74E-02	2.74E-02	4.99E-03	2.74E-02	4.99E-03	4.99E-03	4.99E-03	4.99E-03	4.99E-03
S_L10Z12	4.45E-02	0.001	0.018	0.018	0.001	0.018	0.001	0.001	0.001	0.001	0.001
S_L11Z12	0.000	4.32E-02	1.17E-02	1.17E-02	4.32E-02	1.17E-02	4.32E-02	4.32E-02	4.32E-02	6.79E-03	4.32E-02
S_L13Z12	1.30E-02	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Kh_L8Z12	0.000	8.72E-05	2.93E-04	2.93E-04	8.72E-05	2.93E-04	8.72E-05	8.72E-05	8.72E-05	8.72E-05	8.72E-05
RCH*	0.530	1.186	1.796	1.796	1.186	1.796	1.186	1.186	1.186	1.186	1.186
STR*	0.238	13.292	0.084	0.084	13.292	0.084	13.292	13.292	13.292	13.292	13.292
GHB*	0.9	1.915	0.651	0.651	1.915	0.651	1.915	1.915	1.915	1.915	1.915

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	53	29	65	93	5	105	109	21	35	57	51
RMSE	31.51	31.53	32.24	31.54	31.54	31.54	31.54	31.55	31.63	31.52	31.37
ARM	19.22	19.24	19.24	19.24	19.24	19.24	19.25	19.25	19.25	19.25	19.26
Seawater Flux	250751	247941	248898	248266	248248	248248	248494	248145	259523	243188	258430
Kh_L3Z9	1065.541	1065.541	1065.541	1065.541	1065.541	1065.541	1065.541	1065.541	279.377	1065.541	279.377
Kh_L1Z11	24.812	24.812	24.812	24.812	24.812	24.812	24.812	24.812	390.310	24.812	390.310
Kh_L5Z9	599.817	599.817	599.817	599.817	599.817	599.817	599.817	599.817	728.072	599.817	728.072
Kh_L3Z12	38.428	38.428	38.428	38.428	38.428	38.428	38.428	10.972	531.591	38.428	531.591
Kh_L5Z10	40.764	40.764	40.764	40.764	40.764	40.764	40.764	40.764	224.002	40.764	224.002
Kh_L5Z12	512.917	240.655	512.917	512.917	512.917	512.917	512.917	512.917	44.821	512.917	44.821
Kz_L7Z12	168.996	168.996	168.996	168.996	168.996	168.996	168.996	168.996	409.315	168.996	18.385
Kh_L7Z4	12.716	12.716	12.716	12.716	12.716	12.716	12.716	12.716	3.211	12.716	3.211
Kh_L7Z5	15.519	15.519	15.519	15.519	15.519	15.519	15.519	15.519	20.804	15.519	20.804
Kh_L7Z10	3.717	3.717	3.717	3.717	3.717	3.717	3.717	3.717	30.888	3.717	30.888
Kh_L7Z12	46.467	46.467	46.467	46.467	46.467	46.467	46.467	46.467	1.233	46.467	20.961
Kh_L9Z4	7.218	2.824	2.824	2.824	2.824	2.824	2.824	2.824	48.687	2.824	48.687
Kh_L9Z5	2.007	2.007	2.007	2.007	2.007	2.007	2.007	2.007	4.243	9.540	4.243
Kz_L6Z4	4.226	4.226	4.226	4.226	4.226	4.226	4.226	4.226	31.560	4.226	31.560
Kz_L6Z11	1.917	1.917	27.864	1.917	1.917	1.917	1.917	1.917	11.480	1.917	11.480
Kz_L6Z13	2.702	2.702	2.702	2.702	2.702	2.702	2.702	2.702	4.243	2.702	4.243
Kh_L6Z12	8.683	8.683	8.683	8.683	8.683	8.683	8.683	8.683	1.416	8.683	1.416
Kh_L6Z19	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.030	0.113	0.030
Kh_L6Z11	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.010	0.002	0.010
Kh_L6Z13	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.001	0.018	0.001
S_L9Z12	4.99E-03	4.99E-03	4.99E-03	4.99E-03	4.99E-03	4.99E-03	4.99E-03	4.99E-03	2.74E-02	4.99E-03	2.74E-02
S_L10Z12	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.018	0.001	0.018
S_L11Z12	4.32E-02	4.32E-02	4.32E-02	4.32E-02	4.32E-02	4.32E-02	4.32E-02	4.32E-02	1.17E-02	4.32E-02	1.17E-02
S_L13Z12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
Kh_L8Z12	8.72E-05	8.72E-05	8.72E-05	8.72E-05	8.72E-05	8.96E-05	8.72E-05	8.72E-05	2.93E-04	8.72E-05	2.93E-04
RCH*	1.186	1.186	1.186	1.186	1.186	1.186	0.575	1.186	1.796	1.186	1.796
STR*	13.292	13.292	13.292	13.292	13.292	13.292	13.292	13.292	0.084	13.292	0.084
GHB*	1.915	1.915	1.915	1.915	1.915	1.915	1.915	1.915	0.651	1.915	0.651

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	117	89	73	87	99	25	101	15	119	95	47
RMSE	31.56	31.60	31.56	31.54	31.65	31.55	31.72	31.70	31.69	31.70	31.71
ARM	19.26	19.26	19.27	19.30	19.32	19.34	19.35	19.36	19.37	19.38	19.39
Seawater Flux	238372	242133	249015	260579	259608	250147	248239	262224	265629	261663	261820
Kh_L3Z9	1065.541	1065.541	1065.541	279.377	279.377	1065.541	1065.541	279.377	279.377	279.377	279.377
Kh_L1Z11	24.812	24.812	24.812	390.310	390.310	24.812	24.812	105.669	390.310	390.310	390.310
Kh_L5Z9	599.817	599.817	599.817	728.072	728.072	599.817	599.817	728.072	728.072	728.072	728.072
Kh_L3Z12	38.428	38.428	38.428	531.591	531.591	38.428	38.428	531.591	531.591	531.591	531.591
Kh_L5Z10	40.764	40.764	40.764	224.002	224.002	11.203	40.764	224.002	224.002	224.002	224.002
Kh_L5Z12	512.917	512.917	512.917	44.821	44.821	512.917	512.917	44.821	44.821	44.821	44.821
Kz_L7Z12	168.996	168.996	168.996	18.385	18.385	168.996	168.996	18.385	18.385	18.385	18.385
Kh_L7Z4	12.716	12.716	12.716	3.211	3.211	12.716	12.716	3.211	3.211	3.211	3.211
Kh_L7Z5	15.519	15.519	15.519	20.804	20.804	15.519	15.519	20.804	20.804	20.804	20.804
Kh_L7Z10	3.717	3.717	3.717	30.888	30.888	3.717	3.717	30.888	30.888	30.888	29.096
Kh_L7Z12	46.467	46.467	46.467	1.233	1.233	46.467	46.467	1.233	1.233	1.233	1.233
Kh_L9Z4	2.824	2.824	2.824	48.687	48.687	2.824	2.824	48.687	48.687	48.687	48.687
Kh_L9Z5	2.007	2.007	2.007	4.243	4.243	2.007	2.007	4.243	4.243	4.243	4.243
Kz_L6Z4	4.226	4.226	4.226	31.560	31.560	4.226	4.226	31.560	31.560	31.560	31.560
Kz_L6Z11	1.917	1.917	1.917	11.480	11.480	1.917	1.917	11.480	11.480	11.480	11.480
Kz_L6Z13	2.702	2.702	2.702	4.243	4.243	2.702	2.702	4.243	4.243	4.243	4.243
Kh_L6Z12	8.683	8.683	13.179	1.416	1.416	8.683	8.683	1.416	1.416	1.416	1.416
Kh_L6Z19	0.113	0.113	0.113	0.030	0.030	0.113	0.113	0.030	0.030	0.030	0.030
Kh_L6Z11	0.002	0.002	0.002	0.010	0.010	0.002	0.002	0.010	0.010	0.010	0.010
Kh_L6Z13	0.018	0.018	0.018	0.004	0.001	0.018	0.018	0.001	0.001	0.001	0.001
S_L9Z12	4.99E-03	5.97E-02	4.99E-03	2.74E-02	2.74E-02	4.99E-03	4.99E-03	2.74E-02	2.74E-02	2.74E-02	2.74E-02
S_L10Z12	0.001	0.001	0.001	0.018	0.018	0.001	0.001	0.018	0.018	0.032	0.018
S_L11Z12	4.32E-02	4.32E-02	4.32E-02	1.17E-02	8.70E-02	4.32E-02	4.32E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02
S_L13Z12	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.001	0.001	0.001
Kh_L8Z12	8.72E-05	8.72E-05	8.72E-05	2.93E-04	2.93E-04	8.72E-05	8.72E-05	2.93E-04	2.93E-04	2.93E-04	2.93E-04
RCH*	1.186	1.186	1.186	1.796	1.796	1.186	1.186	1.796	1.796	1.796	1.796
STR*	13.292	13.292	13.292	0.084	0.084	13.292	13.292	0.084	0.084	0.084	0.084
GHB*	1.312	1.915	1.915	0.651	0.651	1.915	1.915	0.651	0.697	0.651	0.651

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	23	107	7	111	31	59	75	55	39	71	103
RMSE	31.71	31.71	31.71	31.71	31.71	31.73	31.73	31.79	31.79	31.84	31.91
ARM	19.39	19.39	19.39	19.39	19.40	19.41	19.43	19.43	19.48	19.48	19.54
Seawater Flux	261767	261806	261809	261910	261814	262753	262453	260181	265063	262313	261817
Kh_L3Z9	279.377	279.377	279.377	279.377	279.377	279.377	279.377	279.377	279.377	279.377	279.377
Kh_L1Z11	390.310	390.310	390.310	390.310	390.310	390.310	390.310	390.310	390.310	390.310	390.310
Kh_L5Z9	728.072	728.072	728.072	728.072	728.072	728.072	728.072	728.072	728.072	728.072	728.072
Kh_L3Z12	396.469	531.591	531.591	531.591	531.591	531.591	531.591	531.591	531.591	531.591	531.591
Kh_L5Z10	224.002	224.002	224.002	224.002	224.002	224.002	224.002	224.002	224.002	224.002	224.002
Kh_L5Z12	44.821	44.821	44.821	44.821	766.794	44.821	44.821	44.821	44.821	44.821	44.821
Kz_L7Z12	18.385	18.385	18.385	18.385	18.385	18.385	18.385	18.385	18.385	18.385	18.385
Kh_L7Z4	3.211	3.211	3.211	3.211	3.211	3.211	3.211	3.211	133.132	3.211	3.211
Kh_L7Z5	20.804	20.804	20.804	20.804	20.804	20.804	20.804	20.804	20.804	20.804	20.804
Kh_L7Z10	30.888	30.888	30.888	30.888	30.888	30.888	30.888	30.888	30.888	30.888	30.888
Kh_L7Z12	1.233	1.233	1.233	1.233	1.233	1.233	1.233	1.233	1.233	1.233	1.233
Kh_L9Z4	48.687	48.687	48.687	48.687	48.687	48.687	48.687	34.708	48.687	48.687	48.687
Kh_L9Z5	4.243	4.243	4.243	4.243	4.243	2.628	4.243	4.243	4.243	4.243	4.243
Kz_L6Z4	31.560	31.560	31.560	31.560	31.560	31.560	31.560	31.560	31.560	31.560	31.560
Kz_L6Z11	11.480	11.480	11.480	11.480	11.480	11.480	11.480	11.480	11.480	11.480	11.480
Kz_L6Z13	4.243	4.243	4.243	4.243	4.243	4.243	4.243	4.243	4.243	87.279	4.243
Kh_L6Z12	1.416	1.416	1.416	1.416	1.416	1.416	3.680	1.416	1.416	1.416	1.416
Kh_L6Z19	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Kh_L6Z11	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Kh_L6Z13	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
S_L9Z12	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02
S_L10Z12	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
S_L11Z12	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02
S_L13Z12	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
Kh_L8Z12	2.93E-04	1.87E-04	2.93E-04	2.93E-04	2.93E-04	2.93E-04	2.93E-04	2.93E-04	2.93E-04	2.93E-04	2.93E-04
RCH*	1.796	1.796	1.796	1.488	1.796	1.796	1.796	1.796	1.796	1.796	1.796
STR*	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084
GHB*	0.651	0.651	0.651	0.651	0.651	0.651	0.651	0.651	0.651	0.651	0.651

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	83	61	113	69	79	1	81	12	85	91	18
RMSE	31.95	31.98	31.04	32.18	31.82	30.91	33.10	31.91	33.35	33.03	31.47
ARM	19.54	19.59	19.62	19.68	19.70	19.99	20.37	20.40	20.40	20.48	20.48
Seawater Flux	263027	251404	305680	246345	268212	232972	245369	213880	243453	282749	276615
Kh_L3Z9	279.377	1065.541	1065.541	1065.541	279.377	360.557	1065.541	1708.413	1065.541	279.377	27.498
Kh_L1Z11	390.310	24.812	24.812	24.812	390.310	720.156	24.812	1688.009	24.812	390.310	180.612
Kh_L5Z9	728.072	599.817	599.817	599.817	728.072	32.539	599.817	108.315	599.817	728.072	1990.692
Kh_L3Z12	531.591	38.428	38.428	38.428	531.591	10.972	38.428	133.714	38.428	531.591	31.427
Kh_L5Z10	224.002	40.764	40.764	40.764	224.002	11.203	40.764	778.031	40.764	224.002	11.321
Kh_L5Z12	44.821	512.917	512.917	512.917	44.821	240.655	512.917	16.355	512.917	44.821	209.283
Kz_L7Z12	18.385	168.996	168.996	168.996	18.385	286.068	168.996	445.121	168.996	18.385	67.397
Kh_L7Z4	3.211	12.716	12.716	12.716	3.211	3.093	12.716	40.508	12.716	3.211	112.977
Kh_L7Z5	20.804	15.519	15.519	15.519	20.804	192.425	15.519	155.363	15.519	20.804	3.522
Kh_L7Z10	30.888	3.717	3.717	3.717	30.888	2.040	3.717	17.951	3.717	30.888	133.624
Kh_L7Z12	1.233	46.467	46.467	46.467	1.233	1.449	46.467	7.783	46.467	1.233	14.081
Kh_L9Z4	48.687	2.824	2.824	2.824	48.687	7.218	2.824	12.357	2.824	48.687	5.992
Kh_L9Z5	4.243	2.007	2.007	2.007	4.243	9.540	2.007	78.215	2.007	4.243	15.871
Kz_L6Z4	31.560	12.101	4.226	4.226	31.560	12.101	4.226	37.461	4.226	31.560	2.334
Kz_L6Z11	11.480	1.917	1.917	1.917	11.480	27.864	1.917	4.654	1.917	11.480	57.446
Kz_L6Z13	4.243	2.702	2.702	1.571	4.243	1.571	2.702	22.561	2.702	4.243	41.298
Kh_L6Z12	1.416	8.683	8.683	8.683	1.416	13.179	8.683	4.071	8.683	1.416	28.101
Kh_L6Z19	0.030	0.113	0.113	0.113	0.492	0.022	0.113	0.383	0.113	0.030	0.042
Kh_L6Z11	0.005	0.002	0.002	0.002	0.010	0.034	0.034	0.008	0.002	0.010	0.041
Kh_L6Z13	0.001	0.018	0.018	0.018	0.001	0.099	0.018	0.008	0.099	0.001	0.057
S_L9Z12	2.74E-02	4.99E-03	4.99E-03	4.99E-03	2.74E-02	5.97E-02	4.99E-03	3.14E-05	4.99E-03	7.69E-04	4.32E-04
S_L10Z12	0.018	0.001	0.001	0.001	0.018	0.000	0.001	0.045	0.001	0.018	0.000
S_L11Z12	1.17E-02	4.32E-02	4.32E-02	4.32E-02	1.17E-02	6.79E-03	4.32E-02	5.13E-05	4.32E-02	1.17E-02	4.26E-04
S_L13Z12	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.013	0.000	0.001	0.000
Kh_L8Z12	2.93E-04	8.72E-05	8.72E-05	8.72E-05	2.93E-04	8.96E-05	8.72E-05	2.23E-05	8.72E-05	2.93E-04	8.44E-04
RCH*	1.796	1.186	1.186	1.186	1.796	0.575	1.186	0.530	1.186	1.796	0.805
STR*	0.084	13.292	0.113	13.292	0.084	0.113	13.292	0.238	13.292	0.084	2.228
GHB*	0.651	1.915	1.915	1.915	0.651	1.312	1.915	0.948	1.915	0.651	1.166

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	41	4	43	2	10	3	42	26	50	38	86
RMSE	31.89	32.95	33.87	34.18	32.08	35.09	36.48	36.65	37.50	37.81	37.90
ARM	20.49	20.79	21.31	21.54	23.13	23.67	25.50	25.79	27.11	27.21	27.26
Seawater Flux	144131	335241	280662	241314	416594	348341	436575	422565	439134	455501	461910
Kh_L3Z9	1065.541	1708.413	279.377	88.764	88.764	33.024	27.498	27.498	27.498	27.498	27.498
Kh_L1Z11	24.812	349.629	390.310	47.157	180.612	105.669	180.612	180.612	180.612	180.612	180.612
Kh_L5Z9	599.817	256.384	728.072	1990.692	22.177	74.084	22.177	22.177	22.177	22.177	22.177
Kh_L3Z12	38.428	234.793	531.591	47.856	31.427	396.469	31.427	31.427	31.427	31.427	31.427
Kh_L5Z10	40.764	84.721	224.002	813.580	11.321	107.795	11.321	813.580	11.321	11.321	11.321
Kh_L5Z12	512.917	15.192	44.821	33.244	209.283	766.794	209.283	209.283	209.283	209.283	209.283
Kz_L7Z12	168.996	59.510	18.385	12.062	67.397	409.315	67.397	67.397	67.397	67.397	67.397
Kh_L7Z4	12.716	8.757	3.211	52.957	112.977	133.132	112.977	112.977	112.977	52.957	112.977
Kh_L7Z5	192.425	14.030	2.021	20.271	3.522	2.021	20.271	3.522	3.522	3.522	3.522
Kh_L7Z10	3.717	118.218	30.888	19.558	133.624	29.096	133.624	133.624	133.624	133.624	133.624
Kh_L7Z12	46.467	7.413	1.233	68.404	14.081	20.961	14.081	14.081	68.404	14.081	14.081
Kh_L9Z4	2.824	11.285	48.687	1.867	5.992	34.708	5.992	5.992	5.992	5.992	5.992
Kh_L9Z5	2.007	32.266	4.243	12.420	15.871	2.628	15.871	15.871	15.871	15.871	15.871
Kz_L6Z4	4.226	6.230	31.560	62.941	2.334	1.800	2.334	2.334	2.334	2.334	2.334
Kz_L6Z11	1.917	3.092	11.480	58.022	57.446	3.412	57.446	57.446	57.446	57.446	57.446
Kz_L6Z13	2.702	3.272	4.243	26.535	41.298	87.279	41.298	41.298	41.298	41.298	41.298
Kh_L6Z12	8.683	21.104	1.416	0.578	28.101	3.680	28.101	28.101	28.101	28.101	28.101
Kh_L6Z19	0.113	0.091	0.030	0.223	0.042	0.492	0.042	0.042	0.042	0.042	0.042
Kh_L6Z11	0.002	0.002	0.010	0.028	0.041	0.005	0.041	0.041	0.041	0.041	0.041
Kh_L6Z13	0.018	0.002	0.001	0.032	0.057	0.004	0.057	0.057	0.057	0.057	0.032
S_L9Z12	4.99E-03	6.98E-05	2.74E-02	2.58E-03	4.32E-04	7.69E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04
S_L10Z12	0.001	0.000	0.018	0.004	0.000	0.032	0.000	0.000	0.000	0.000	0.000
S_L11Z12	4.32E-02	1.86E-04	1.17E-02	1.09E-03	4.26E-04	8.70E-02	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04
S_L13Z12	0.000	0.000	0.001	0.015	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Kh_L8Z12	8.72E-05	4.86E-04	2.93E-04	2.16E-05	8.44E-04	1.87E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04
RCH*	1.186	0.922	1.796	1.328	0.805	1.488	0.805	0.805	0.805	0.805	0.805
STR*	13.292	0.085	0.084	4.490	2.228	69.329	2.228	2.228	2.228	2.228	2.228
GHB*	1.915	1.864	0.651	0.973	1.166	0.697	1.166	1.166	1.166	1.166	1.166

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	78	82	34	22	110	66	6	106	94	98	30
RMSE	37.82	38.03	37.97	37.97	37.99	38.00	38.00	38.00	38.02	38.08	38.06
ARM	27.40	27.44	27.44	27.44	27.44	27.45	27.45	27.45	27.45	27.48	27.48
Seawater Flux	456390	459372	456898	458431	458331	458557	458532	458532	457575	457828	459276
Kh_L3Z9	27.498	27.498	27.498	27.498	27.498	27.498	27.498	27.498	27.498	27.498	27.498
Kh_L1Z11	180.612	180.612	180.612	180.612	180.612	180.612	180.612	180.612	180.612	180.612	180.612
Kh_L5Z9	22.177	22.177	22.177	22.177	22.177	22.177	22.177	22.177	22.177	22.177	22.177
Kh_L3Z12	31.427	31.427	31.427	47.856	31.427	31.427	31.427	31.427	31.427	31.427	31.427
Kh_L5Z10	11.321	11.321	11.321	11.321	11.321	11.321	11.321	11.321	11.321	11.321	11.321
Kh_L5Z12	209.283	209.283	209.283	209.283	209.283	209.283	209.283	209.283	209.283	209.283	33.244
Kz_L7Z12	67.397	67.397	12.062	67.397	67.397	67.397	67.397	67.397	67.397	67.397	67.397
Kh_L7Z4	112.977	112.977	112.977	112.977	112.977	112.977	112.977	112.977	112.977	112.977	112.977
Kh_L7Z5	3.522	3.522	3.522	3.522	3.522	3.522	3.522	3.522	3.522	3.522	3.522
Kh_L7Z10	133.624	133.624	133.624	133.624	133.624	133.624	133.624	133.624	133.624	133.624	133.624
Kh_L7Z12	14.081	14.081	14.081	14.081	14.081	14.081	14.081	14.081	14.081	14.081	14.081
Kh_L9Z4	5.992	5.992	5.992	5.992	5.992	5.992	5.992	5.992	5.992	5.992	5.992
Kh_L9Z5	15.871	15.871	15.871	15.871	15.871	15.871	15.871	15.871	15.871	15.871	15.871
Kz_L6Z4	2.334	2.334	2.334	2.334	2.334	2.334	2.334	2.334	2.334	2.334	2.334
Kz_L6Z11	57.446	57.446	57.446	57.446	57.446	58.022	57.446	57.446	57.446	57.446	57.446
Kz_L6Z13	41.298	41.298	41.298	41.298	41.298	41.298	41.298	41.298	41.298	41.298	41.298
Kh_L6Z12	28.101	28.101	28.101	28.101	28.101	28.101	28.101	28.101	28.101	28.101	28.101
Kh_L6Z19	0.223	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
Kh_L6Z11	0.041	0.028	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
Kh_L6Z13	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
S_L9Z12	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04
S_L10Z12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
S_L11Z12	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	1.09E-03	4.26E-04
S_L13Z12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kh_L8Z12	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	2.16E-05	8.44E-04	8.44E-04	8.44E-04
RCH*	0.805	0.805	0.805	0.805	1.328	0.805	0.805	0.805	0.805	0.805	0.805
STR*	2.228	2.228	2.228	2.228	2.228	2.228	2.228	2.228	2.228	2.228	2.228
GHB*	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	114	54	58	118	46	14	70	90	74	62	102
RMSE	38.31	38.09	38.10	38.09	38.16	38.11	38.14	38.42	38.55	39.31	39.10
ARM	27.51	27.54	27.58	27.59	27.60	27.62	27.64	27.73	27.78	28.04	28.24
Seawater Flux	455275	457155	461018	442835	471360	462699	455274	454074	467744	465647	459121
Kh_L3Z9	27.498	27.498	27.498	27.498	27.498	27.498	27.498	27.498	27.498	27.498	27.498
Kh_L1Z11	180.612	180.612	180.612	180.612	180.612	47.157	180.612	180.612	180.612	180.612	180.612
Kh_L5Z9	22.177	22.177	22.177	22.177	22.177	22.177	22.177	22.177	22.177	22.177	22.177
Kh_L3Z12	31.427	31.427	31.427	31.427	31.427	31.427	31.427	31.427	31.427	31.427	31.427
Kh_L5Z10	11.321	11.321	11.321	11.321	11.321	11.321	11.321	11.321	11.321	11.321	11.321
Kh_L5Z12	209.283	209.283	209.283	209.283	209.283	209.283	209.283	209.283	209.283	209.283	209.283
Kz_L7Z12	67.397	67.397	67.397	67.397	67.397	67.397	67.397	67.397	67.397	67.397	67.397
Kh_L7Z4	112.977	112.977	112.977	112.977	112.977	112.977	112.977	112.977	112.977	112.977	112.977
Kh_L7Z5	3.522	3.522	3.522	3.522	3.522	3.522	3.522	3.522	3.522	3.522	3.522
Kh_L7Z10	133.624	133.624	133.624	133.624	19.558	133.624	133.624	133.624	133.624	133.624	133.624
Kh_L7Z12	14.081	14.081	14.081	14.081	14.081	14.081	14.081	14.081	14.081	14.081	14.081
Kh_L9Z4	5.992	1.867	5.992	5.992	5.992	5.992	5.992	5.992	5.992	5.992	5.992
Kh_L9Z5	15.871	15.871	12.420	15.871	15.871	15.871	15.871	15.871	15.871	15.871	15.871
Kz_L6Z4	2.334	2.334	2.334	2.334	2.334	2.334	2.334	2.334	2.334	62.941	2.334
Kz_L6Z11	57.446	57.446	57.446	57.446	57.446	57.446	57.446	57.446	57.446	57.446	57.446
Kz_L6Z13	41.298	41.298	41.298	41.298	41.298	41.298	26.535	41.298	41.298	41.298	41.298
Kh_L6Z12	28.101	28.101	28.101	28.101	28.101	28.101	28.101	28.101	0.578	28.101	28.101
Kh_L6Z19	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
Kh_L6Z11	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
Kh_L6Z13	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
S_L9Z12	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	4.32E-04	2.58E-03	4.32E-04	4.32E-04	4.32E-04
S_L10Z12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_L11Z12	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04
S_L13Z12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015
Kh_L8Z12	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04	8.44E-04
RCH*	0.805	0.805	0.805	0.805	0.805	0.805	0.805	0.805	0.805	0.805	0.805
STR*	4.490	2.228	2.228	2.228	2.228	2.228	2.228	2.228	2.228	2.228	2.228
GHB*	1.166	1.166	1.166	0.973	1.166	1.166	1.166	1.166	1.166	1.166	1.166

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 2
Parameterization for 120 realizations of the UWCD groundwater flow model

Realization/ Parameter	Range Min.	Min.	Max.	Range Max.
RMSE	--	28.23	39.31	--
ARM	--	16.60	28.24	--
Seawater Flux	--	144131	471360	--
Kh_L3Z9	25.000	27.498	1708.413	2500.000
Kh_L1Z11	20.000	24.812	1688.009	2000.000
Kh_L5Z9	20.000	22.177	1990.692	2000.000
Kh_L3Z12	10.000	10.972	531.591	1000.000
Kh_L5Z10	10.000	11.203	813.580	1000.000
Kh_L5Z12	10.000	15.192	766.794	1000.000
Kz_L7Z12	10.000	12.062	445.121	1000.000
Kh_L7Z4	2.000	3.093	133.132	200.000
Kh_L7Z5	2.000	2.021	192.425	200.000
Kh_L7Z10	2.000	2.040	133.624	200.000
Kh_L7Z12	1.000	1.233	68.404	100.000
Kh_L9Z4	1.000	1.867	48.687	100.000
Kh_L9Z5	1.000	2.007	78.215	100.000
Kz_L6Z4	1.000	1.800	62.941	100.000
Kz_L6Z11	1.000	1.917	58.022	100.000
Kz_L6Z13	1.000	1.571	87.279	100.000
Kh_L6Z12	0.500	0.578	28.101	50.000
Kh_L6Z19	0.010	0.022	0.492	1.000
Kh_L6Z11	0.001	0.002	0.041	0.100
Kh_L6Z13	0.001	0.001	0.099	0.100
S_L9Z12	2.00E-05	3.14E-05	5.97E-02	2.00E-01
S_L10Z12	0.000	0.000	0.045	0.200
S_L11Z12	2.00E-05	5.13E-05	8.70E-02	2.00E-01
S_L13Z12	0.000	0.000	0.015	0.050
Kh_L8Z12	1.00E-05	2.16E-05	8.44E-04	1.00E-03
RCH*	0.500	0.530	1.796	2.000
STR*	0.010	0.084	69.329	100.000
GHB*	0.500	0.651	1.915	2.000

* numbers in these rows represent factors that were multiplied to initial parameter values

Table 3
Contribution of level IV sensitivity parameters to ARM variance

Parameter	Percentage of Variance
Kh_L3Z9	9.40%
Kh_L1Z11	0.07%
Kh_L5Z9	21.29%
Kh_L3Z12	1.58%
Kh_L5Z10	3.50%
Kh_L5Z12	2.48%
Kz_L7Z12	2.49%
Kh_L7Z4	2.51%
Kh_L7Z5	5.33%
Kh_L7Z10	2.07%
Kh_L7Z12	2.48%
Kh_L9Z4	2.48%
Kh_L9Z5	2.46%
Kz_L6Z4	2.98%
Kz_L6Z11	4.66%
Kz_L6Z13	2.90%
Kh_L6Z12	2.51%
Kh_L6Z19	2.53%
Kh_L6Z11	2.79%
Kh_L6Z13	2.06%
STORL9Z12	2.68%
STORL10Z12	2.50%
STORL11Z12	2.08%
STORL13Z12	2.73%
Kh_L8Z12	4.30%
RCH	2.49%
STR	2.78%
GHB	1.88%

Notes:
L denotes model layer
Z denotes model zone
GHB denotes ocean general head boundary conductance
STR denotes streambed conductance

Table 4
Contribution of level IV sensitivity parameters to seawater flux variance

Parameter	Percentage of Variance
Kh_L5Z9	14.56%
Kh_L7Z5	6.93%
Kh_L1Z11	4.89%
STR	4.67%
Kh_L3Z12	3.84%
Kh_L3Z9	3.52%
Kh_L6Z12	3.34%
Kh_L5Z10	3.34%
Kz_L6Z11	3.32%
Kh_L7Z12	3.26%
Kz_L6Z13	3.09%
Kh_L6Z11	2.99%
S_L9Z12	2.98%
Kh_L6Z19	2.94%
Kh_L9Z5	2.94%
S_L13Z12	2.93%
S_L10Z12	2.93%
Kz_L7Z12	2.92%
RCH	2.91%
Kh_L7Z4	2.91%
Kh_L9Z4	2.91%
Kh_L8Z12	2.90%
GHB	2.72%
Kh_L6Z13	2.60%
Kh_L5Z12	2.52%
S_L11Z12	2.51%
Kz_L6Z4	2.43%
Kh_L7Z10	0.20%

Notes:
L denotes model layer
Z denotes model zone
GHB denotes ocean general head boundary conductance
STR denotes streambed conductance

Table 5.
Estimated seawater flux uncertainty based on residuals at wells in UWCD model

		Uncertainty in average annual residual flux (AF)	***Simulated annual seawater flux (AF)***	***Uncertainty in (% of) simulated seawater flux***
UAS	Channel Islands Harbor North	-455	1009	- 45%
	Arnold Road to Channel Islands Harbor	306	1107	28%
	Point Mugu to Arnold Road	1661	1785	93%
	Total UAS	*1513*	*3900*	*39%*
LAS	Channel Islands Harbor North	287	2854	10%
	Arnold Road to Channel Islands Harbor	71	1735	4%
	Point Mugu to Arnold Road	93	908	10%
	Total LAS	*450*	*5498*	*8%*
Total		**1963**	**9398**	**21%**

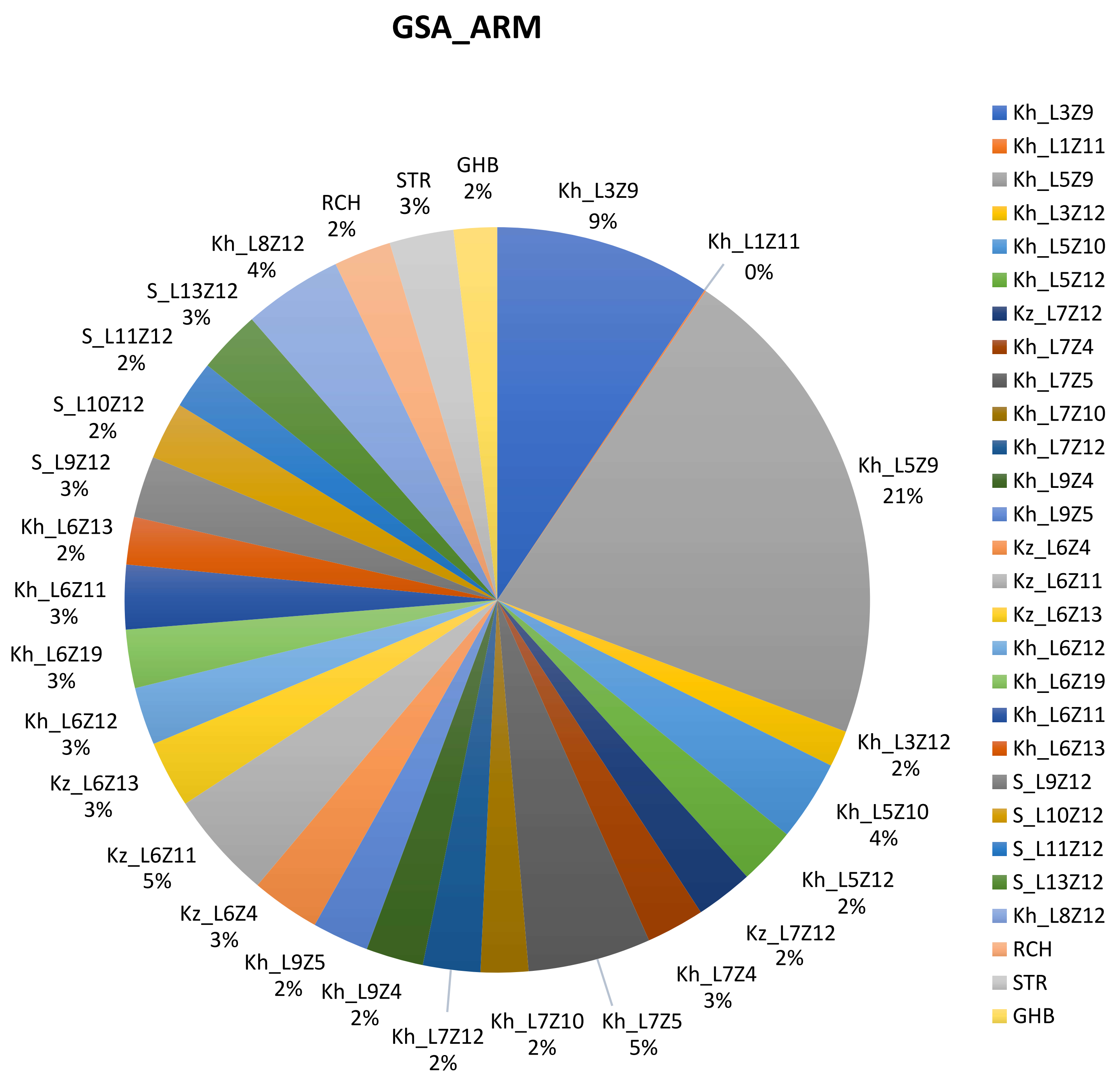
Notes: *Negative values represent offshore flux, while positive values reflect onshore flux.*

Table 6.
Parameters and goodness-of-fit for surrogate models relating pumping, *P*, and seawater flux, *F*

Scenario	a_o	a_1	R^2
Pumping from UAS in Oxnard Subbasin	-11357	0.3598	0.892
Pumping from LAS in Oxnard Subbasin	-1635	0.2348	0.994
Combined pumping from UAS and LAS in Oxnard Subbasin	-13300	0.3195	0.966
Pumping from UAS and LAS in Oxnard, Pleasant Valley, and Western Las Posas	-18655	0.2942	0.996

Table 7
Simulated seawater Flux under future pumping scenarios

Future Scenarios (2040-2070)	Seawater Flux (AFY)			Annual Oxnard Production (AFY)			WLPMA Production (AFY)			PV Production (AFY)			
	UAS	LAS	Total	UAS	LAS	Total Pumping	Shallow	LAS	Total Pumping	Semi-Perched	UAS	LAS	Total Pumping
Baseline	4375	5286	9661	39,116	29423	68538	932	12,720	13,652	159	5,646	7,345	13,150
Projects	3007	4163	7170	41317	24761	66078	940	11,197	12,137	112	4,445	5,898	10,455
Projects + 35% Ox, 20% WLPMA, 20% PV	-3253	1180	-2073	26497	12760	39257	746	8,615	9,361	1	2,348	5,250	7,600
Baseline + 55%Ox, 20%PV, 20% WLPMA Reduction	-4674	911	-3762	17629	11488	29117	749	10,367	11,117	7	3,102	6,502	9,611
Baseline + 55%Ox, 0%PV, 0% WLPMA Reduction	-3676	1433	-2243	18145	12320	30465	936	12,962	13,898	49	4,641	8,518	13,208
Baseline + 25%45%60%Ox, 25% PV & WLPMA Reduction	-2795	1254	-1541	27192	11648	38840	700	9,718	10,418	22	2,878	5,154	8,054

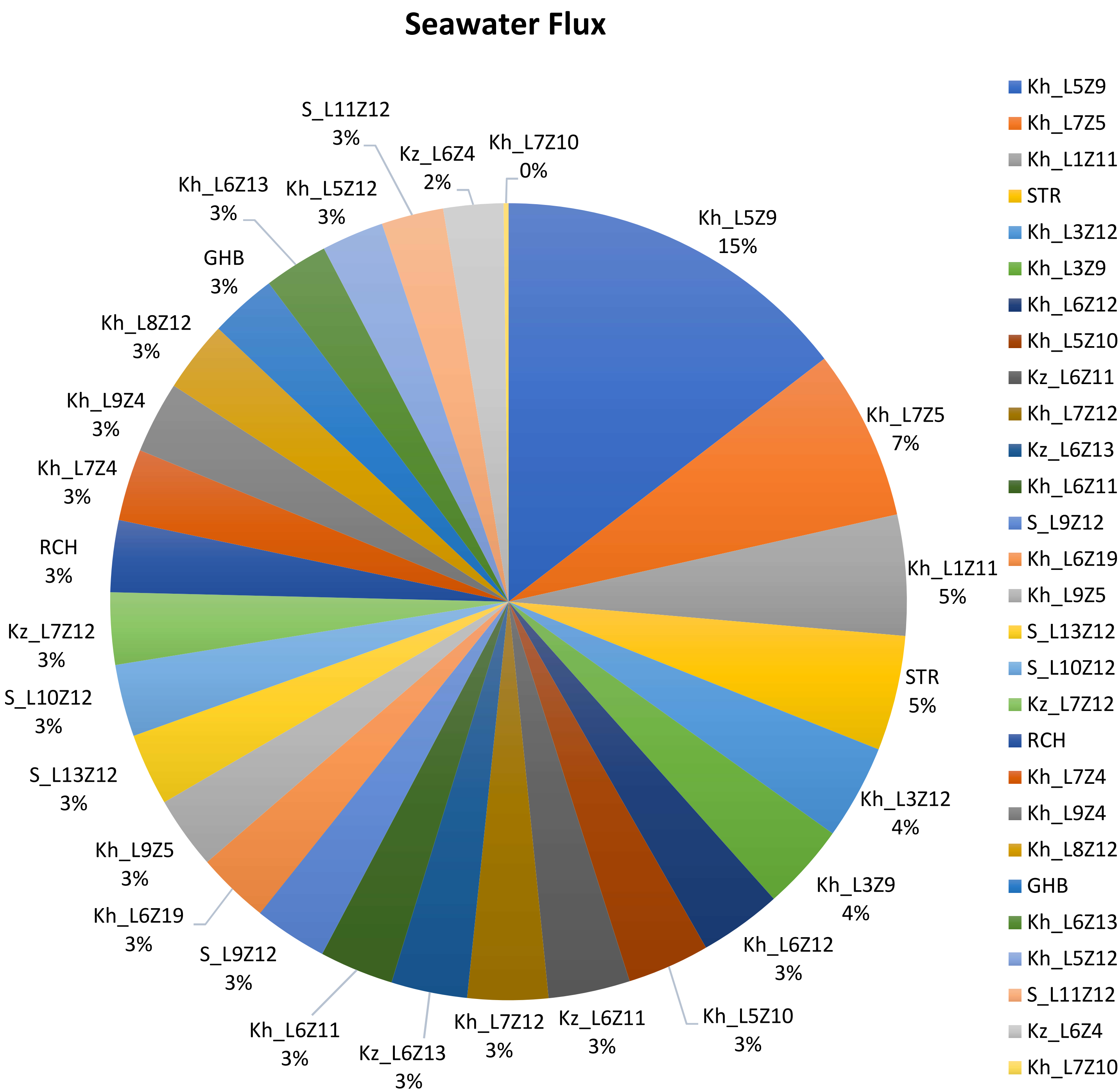


Notes:
L denotes model layer
Z denotes model zone
GHB denotes ocean general head boundary conductance
STR denotes streambed conductance

SOURCE:

FIGURE 1

Contribution of level IV sensitivty parameters to ARM variance

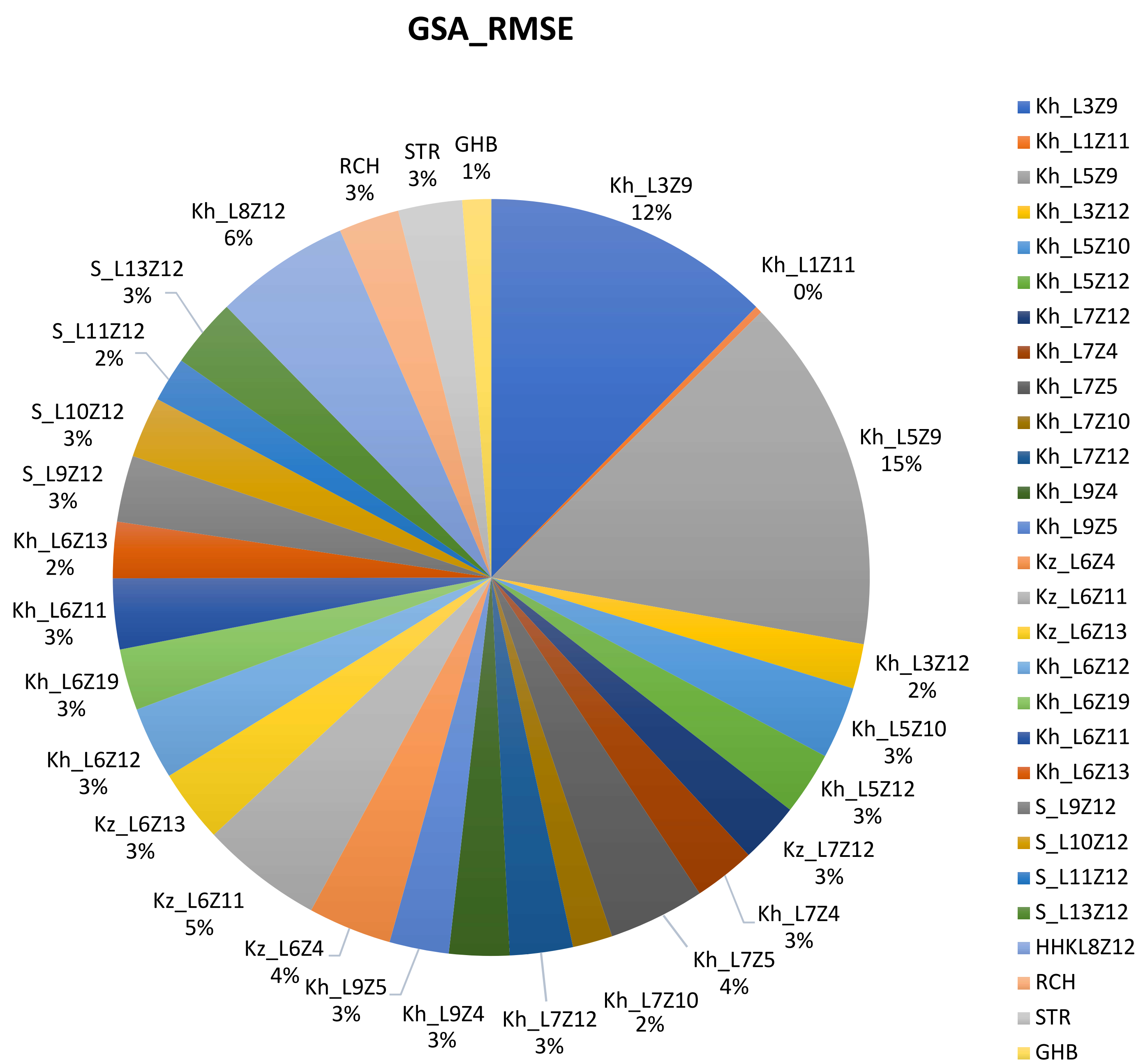


Notes:
L denotes model layer
Z denotes model zone
GHB denotes ocean general head boundary conductance
STR denotes streambed conductance

SOURCE:

FIGURE 2

Contribution of level IV sensitivty parameters to variance in seawater flux

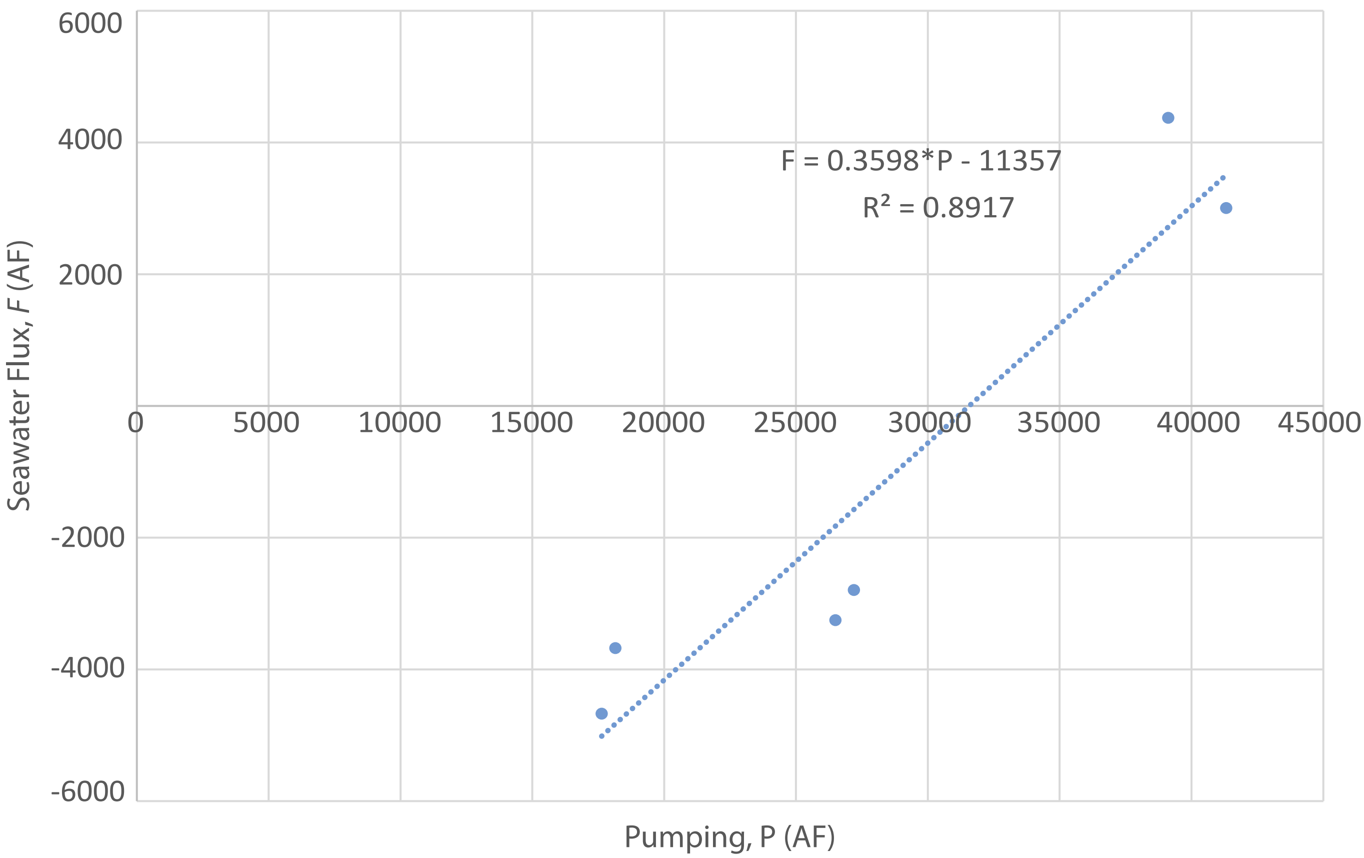


Notes:
L denotes model layer
Z denotes model zone
GHB denotes ocean general head boundary conductance
STR denotes streambed conductance

SOURCE:

FIGURE 3

Contribution of level IV sensitivty parameters to RMSE Variance

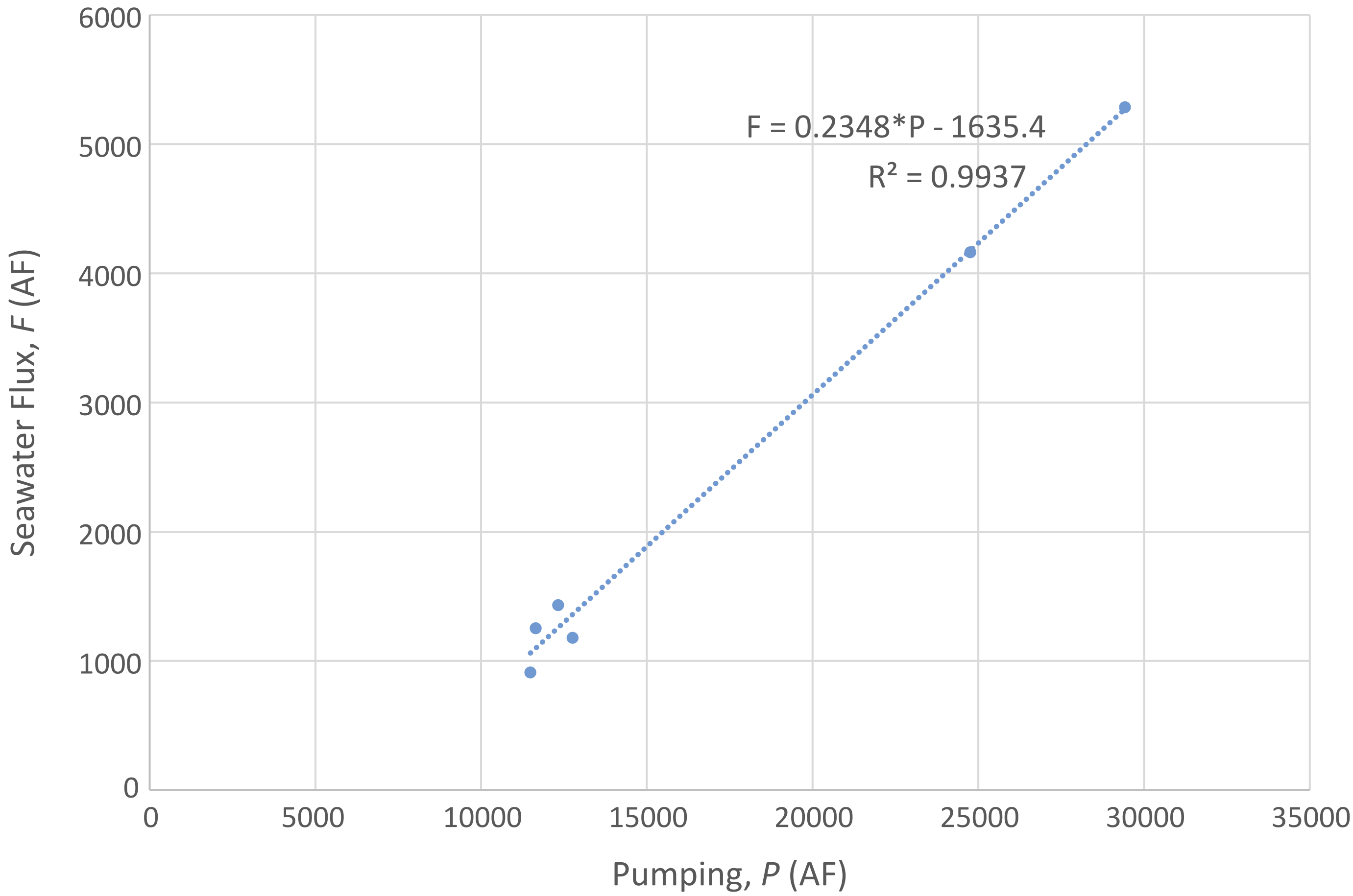


Path: Z:\Projects\

SOURCE:

Figure 4

Relationship between pumping in the UAS of the Oxnard Subbasin and seawater flux

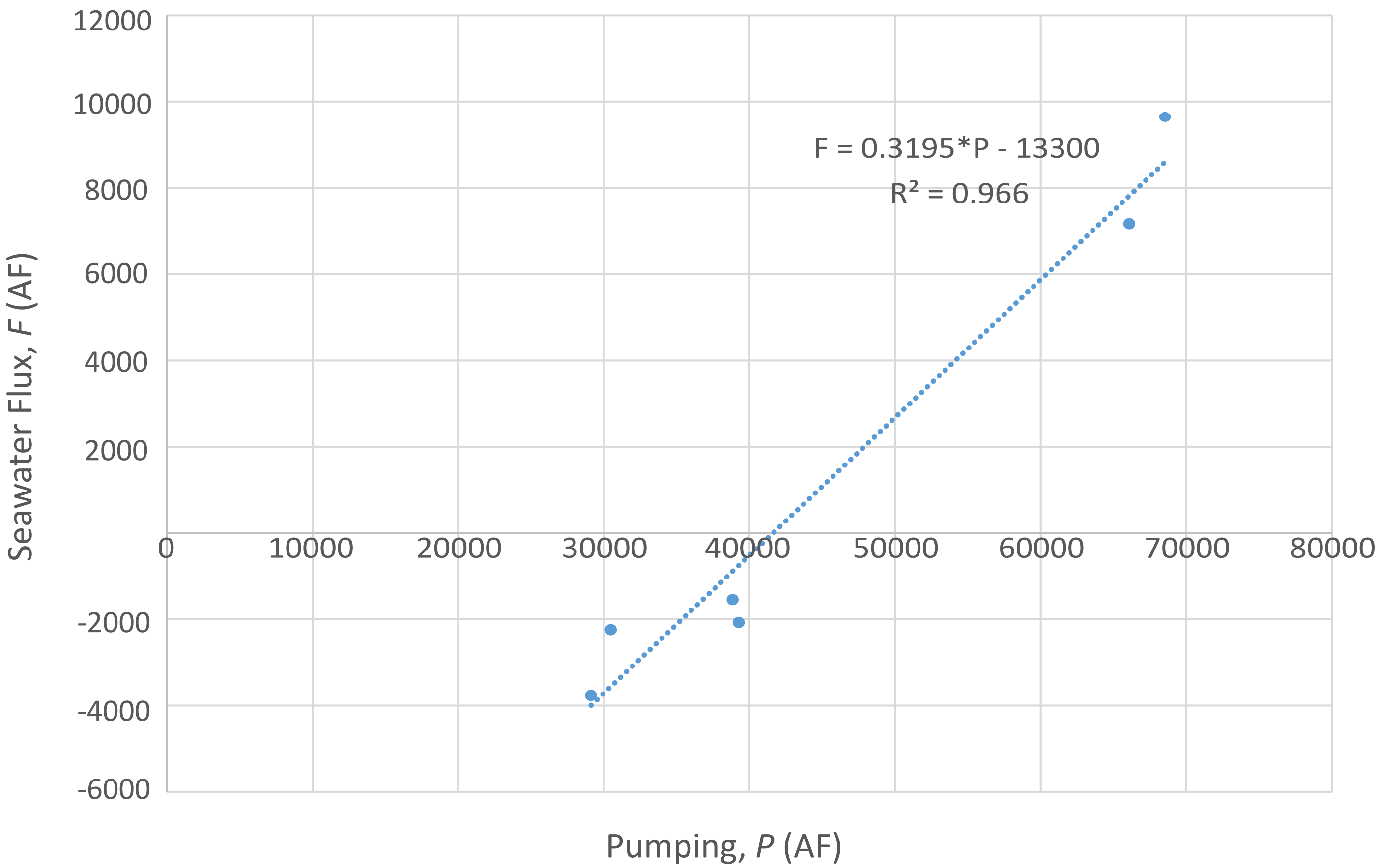


Path: Z:\Projects\

SOURCE:

Figure 5

Relationship between pumping in the LAS of the Oxnard Subbasin and seawater flux

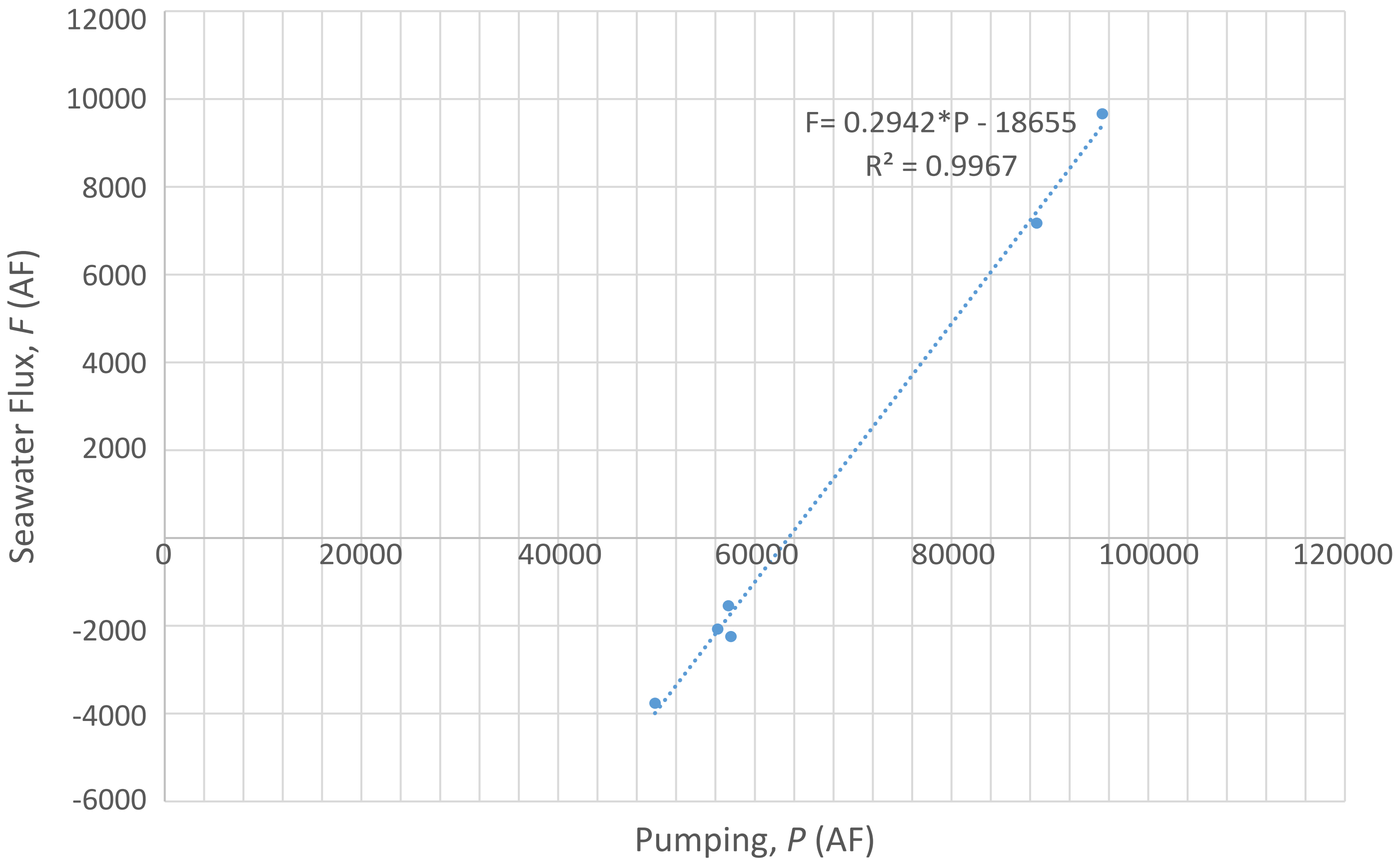


Path: Z:\Projects\

SOURCE:

Figure 6

Relationship between combined pumping in the LAS and UAS of the Oxnard Subbasin and seawater flux



Path: Z:\Projects\

SOURCE:

Figure 7

Relationship between combined pumping in Oxnard Subbasin, PV, and WLPMA and seawater flux

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Appendix A

UWCD Model Layers and Parameters by Zone

Model Layer	Mound Basin	Forebay area	Oxnard Plain Basin	Pleasant Valley Basin	West Las Posas Sub-basin
1	Shallow alluvial aquifer	*layer inactive*	Semi-perched Aquifer	Semi-perched Aquifer	Shallow alluvial aquifer
2	Fine-grained Pleistocene deposits (Layers 2 through 4)	*layer inactive*	Clay Cap	Clay Cap	Layers 2 through 5 are each 1 foot thick in this basin, and assigned similar properties as the shallow alluvial aquifer
3		Oxnard Aquifer	Oxnard Aquifer	Oxnard Aquifer	
4		Oxnard-Mugu Aquitard	Oxnard-Mugu Aquitard	Oxnard-Mugu Aquitard	
5	Mugu Aquifer	Mugu Aquifer	Mugu Aquifer	Mugu Aquifer	
6	Mugu-Hueneme Aquitard	Mugu-Hueneme Aquitard	Mugu-Hueneme Aquitard	Mugu-Hueneme Aquitard	unnamed aquitard
7	Hueneme Aquifer	Hueneme Aquifer	Hueneme Aquifer	Hueneme Aquifer	Upper San Pedro Formation (Layers 7 and 8)
8	Hueneme-Fox Cyn Aquitard	Hueneme-Fox Cyn Aquitard	Hueneme-Fox Cyn Aquitard	Hueneme-Fox Cyn Aquitard	
9	Fox Cyn-main Aquifer	Fox Cyn-main Aquifer	Fox Cyn-main Aquifer	Fox Cyn-main Aquifer	Fox Cyn-main Aquifer
10	Mid-Fox Cyn Aquitard	Mid-Fox Cyn Aquitard	Mid-Fox Cyn Aquitard	Mid-Fox Cyn Aquitard	Mid-Fox Cyn Aquitard
11	Fox Cyn-basal Aquifer	Fox Cyn-basal Aquifer	Fox Cyn-basal Aquifer	Fox Cyn-basal Aquifer	Fox Cyn-basal Aquifer
12	*layer inactive*	*layer inactive*	Fox-Grimes Aquitard	Fox-Grimes Aquitard	Fox-Grimes Aquitard
13	*layer inactive*	*layer inactive*	Grimes Canyon Aquifer	Grimes Canyon Aquifer	Grimes Canyon Aquifer

Note: This diagram is conceptual, and does not reflect all of the details incorporated in the VRGWFM regarding changes in thickness or character of hydrostratigraphic units occurring in each basin or area.

Figure 3-14. Conceptual Diagram Illustrating Relationships between Model Layers and Hydrostratigraphic Units

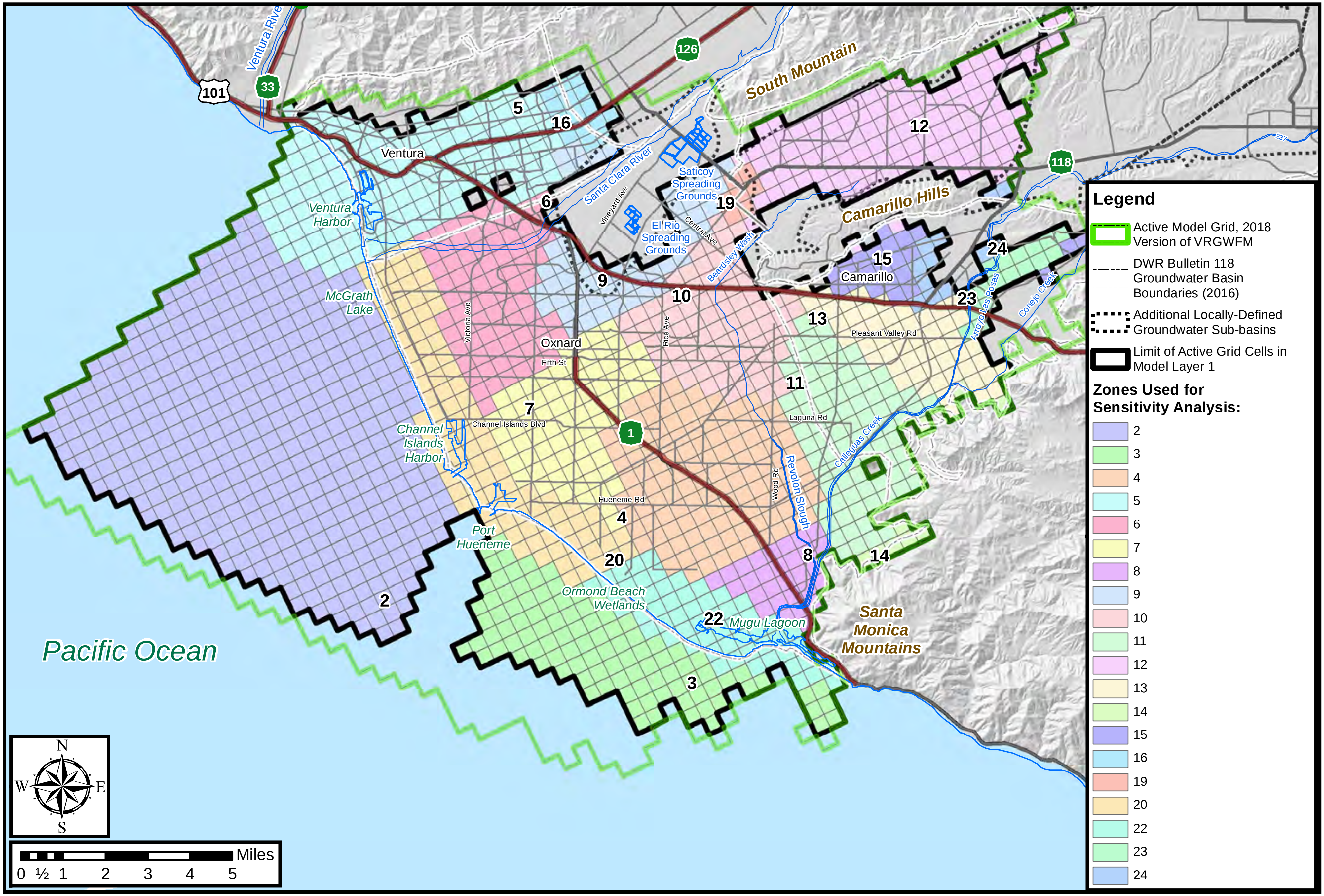

Figure 4-45. Zones Used for Sensitivity Analysis, Model Layer 1

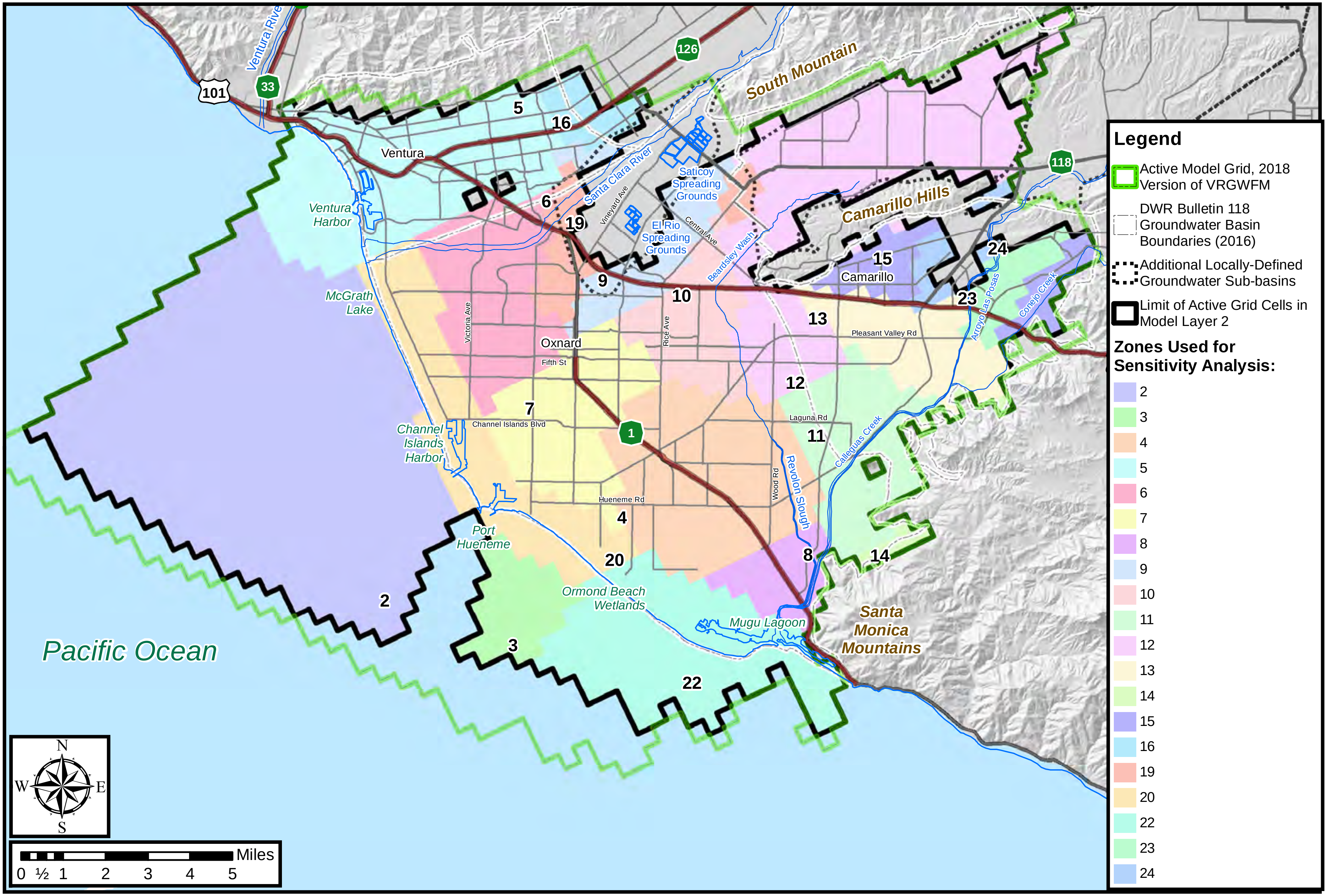

Figure 4-46. Zones Used for Sensitivity Analysis, Model Layer 2

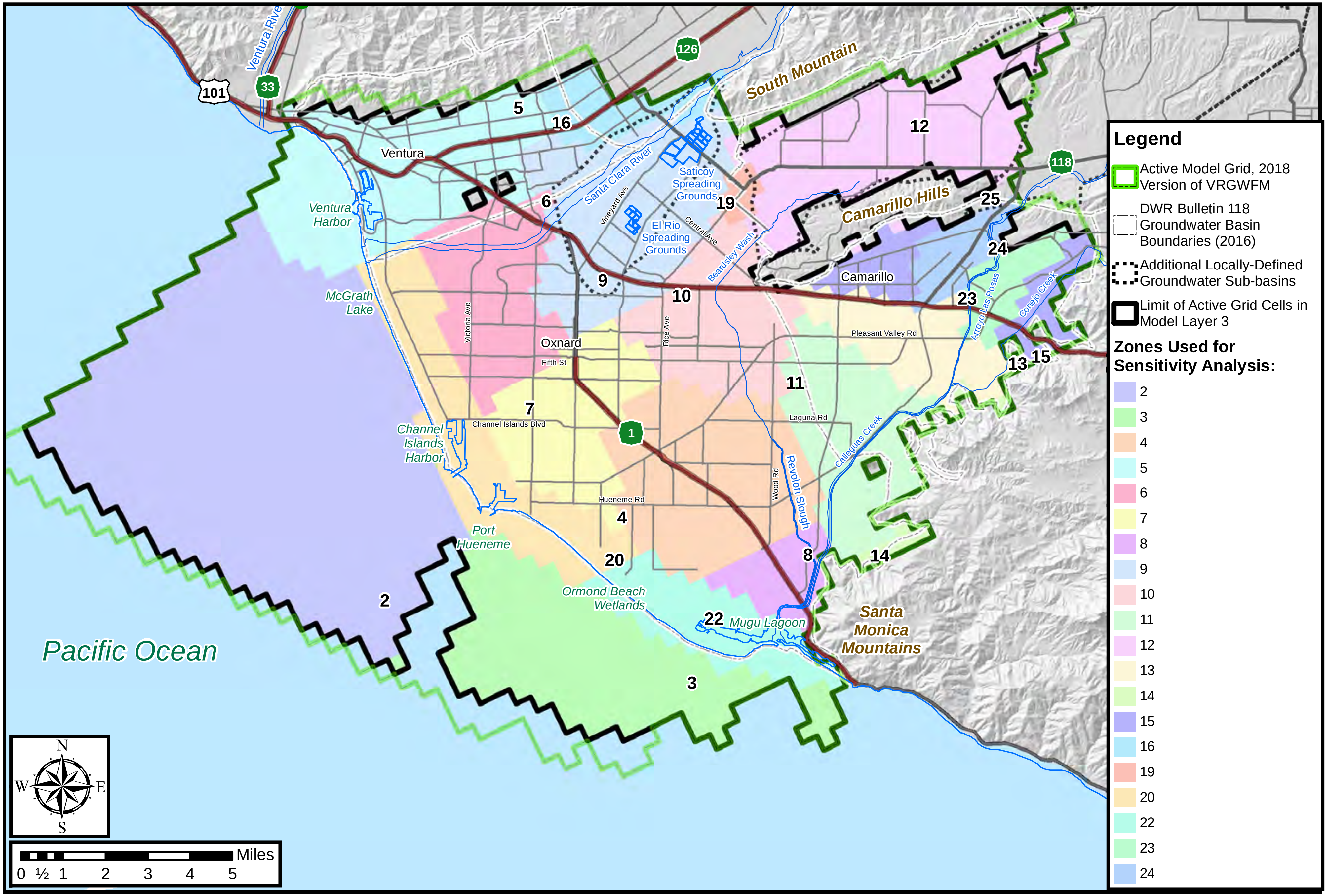

Figure 4-47. Zones Used for Sensitivity Analysis, Model Layer 3

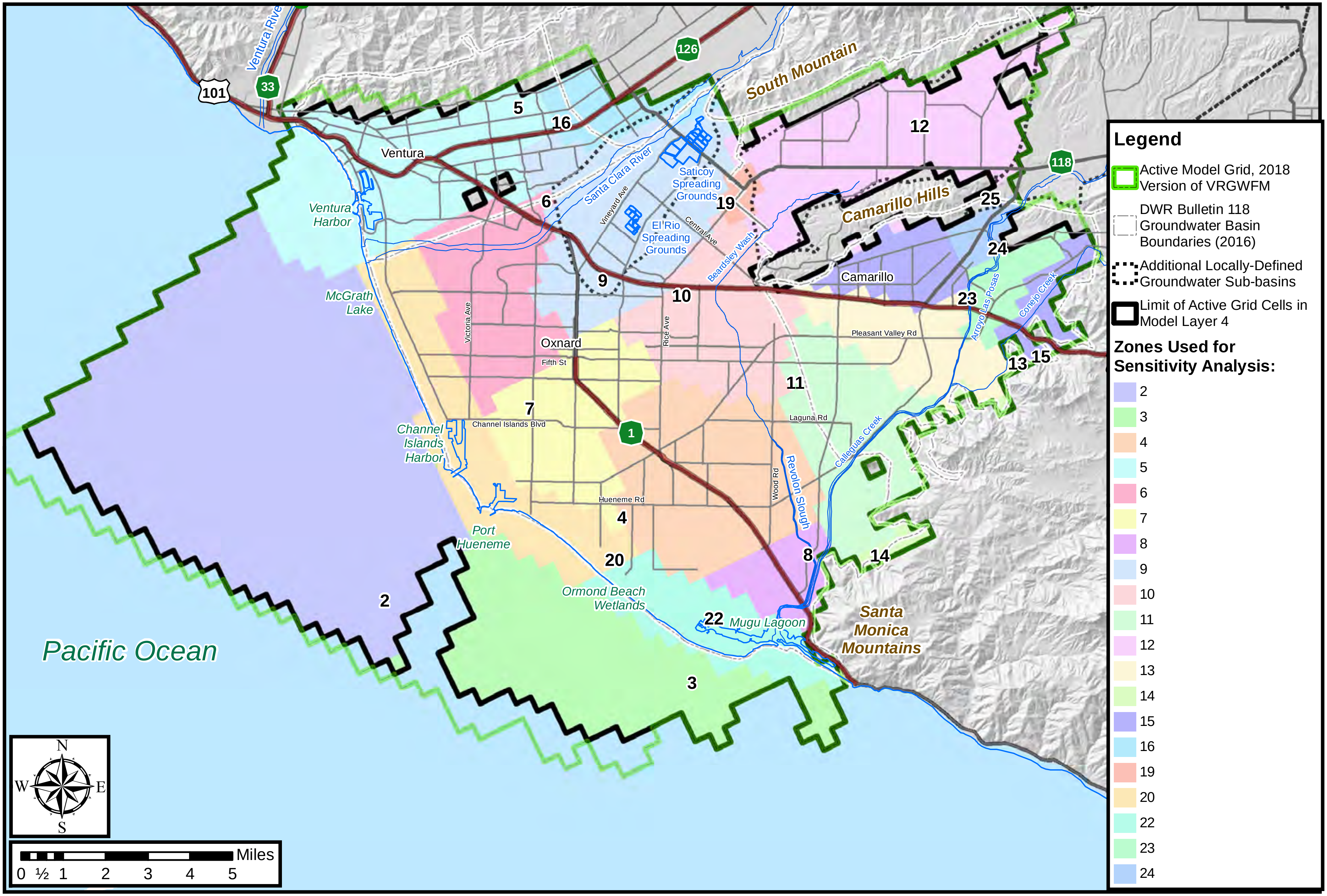

Figure 4-48. Zones Used for Sensitivity Analysis, Model Layer 4

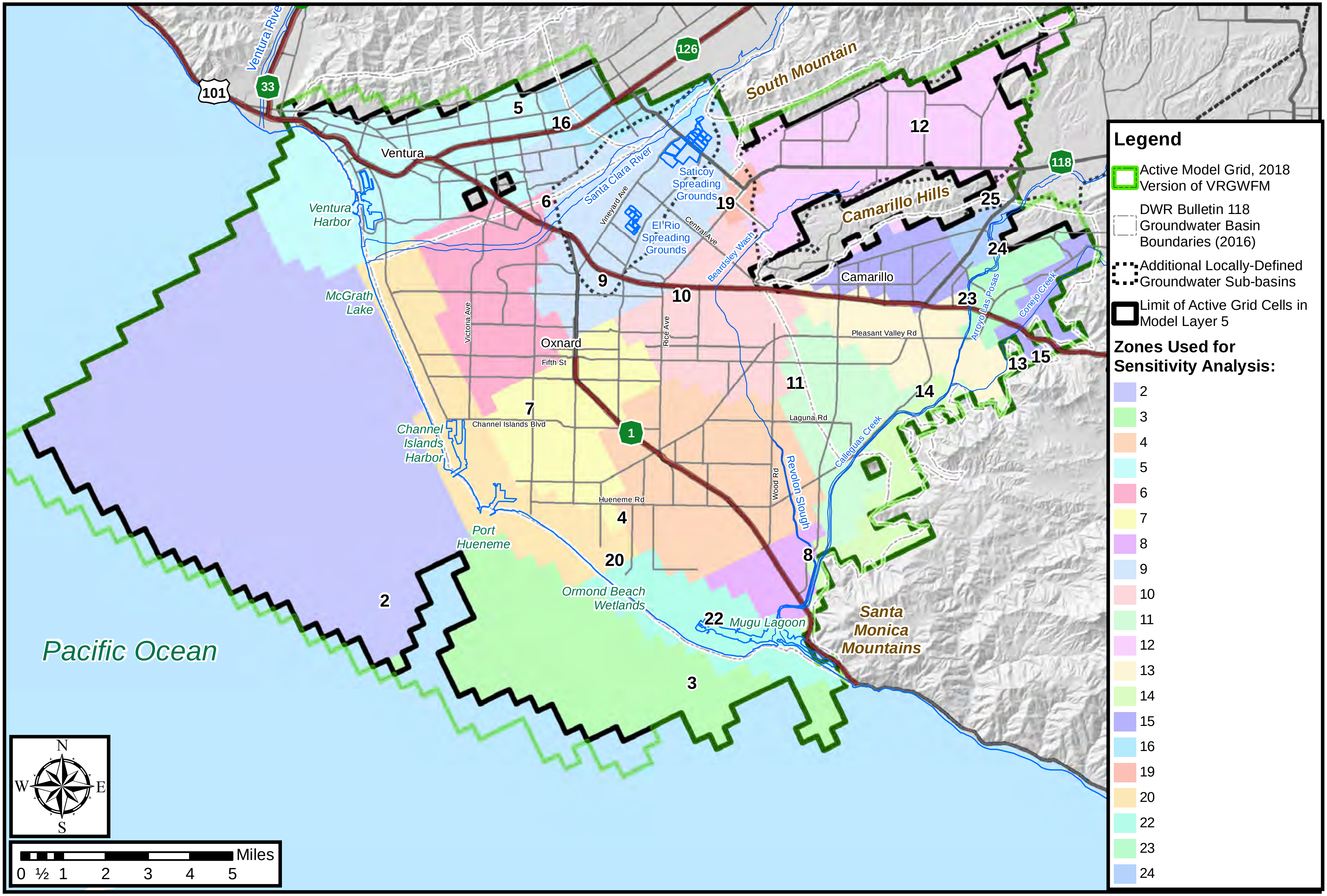

Figure 4-49. Zones Used for Sensitivity Analysis, Model Layer 5

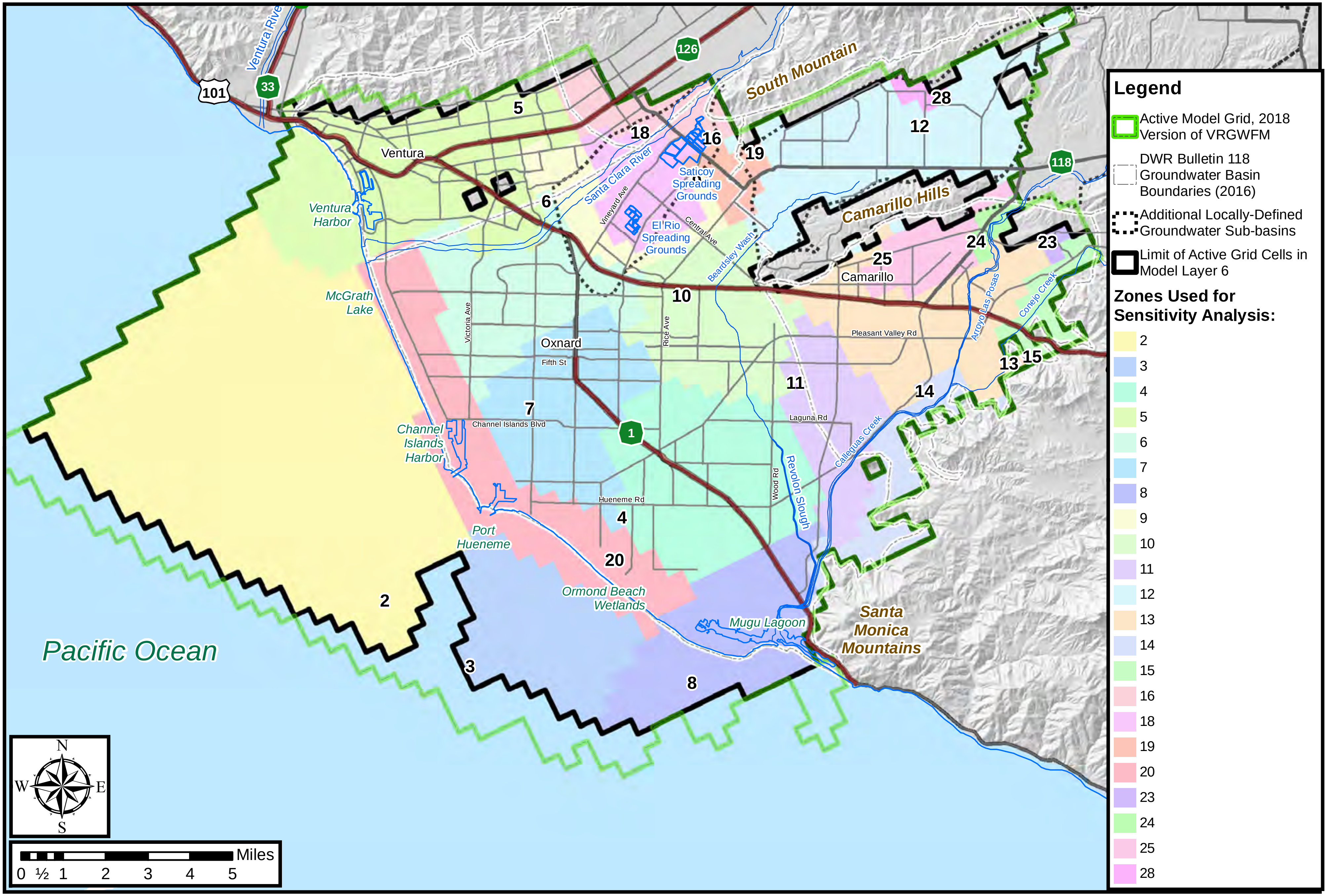

Figure 4-50. Zones Used for Sensitivity Analysis, Model Layer 6

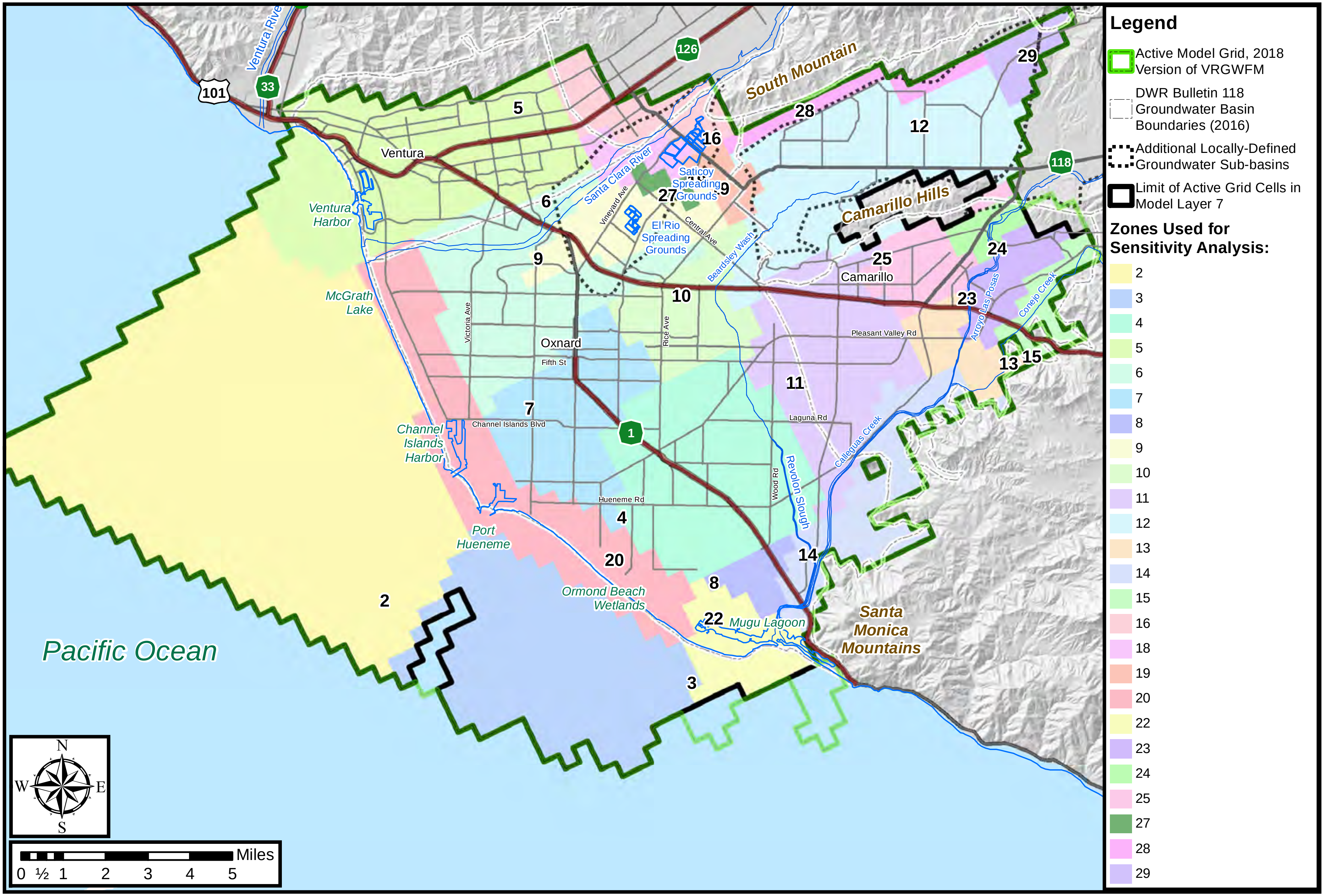

Figure 4-51. Zones Used for Sensitivity Analysis, Model Layer 7

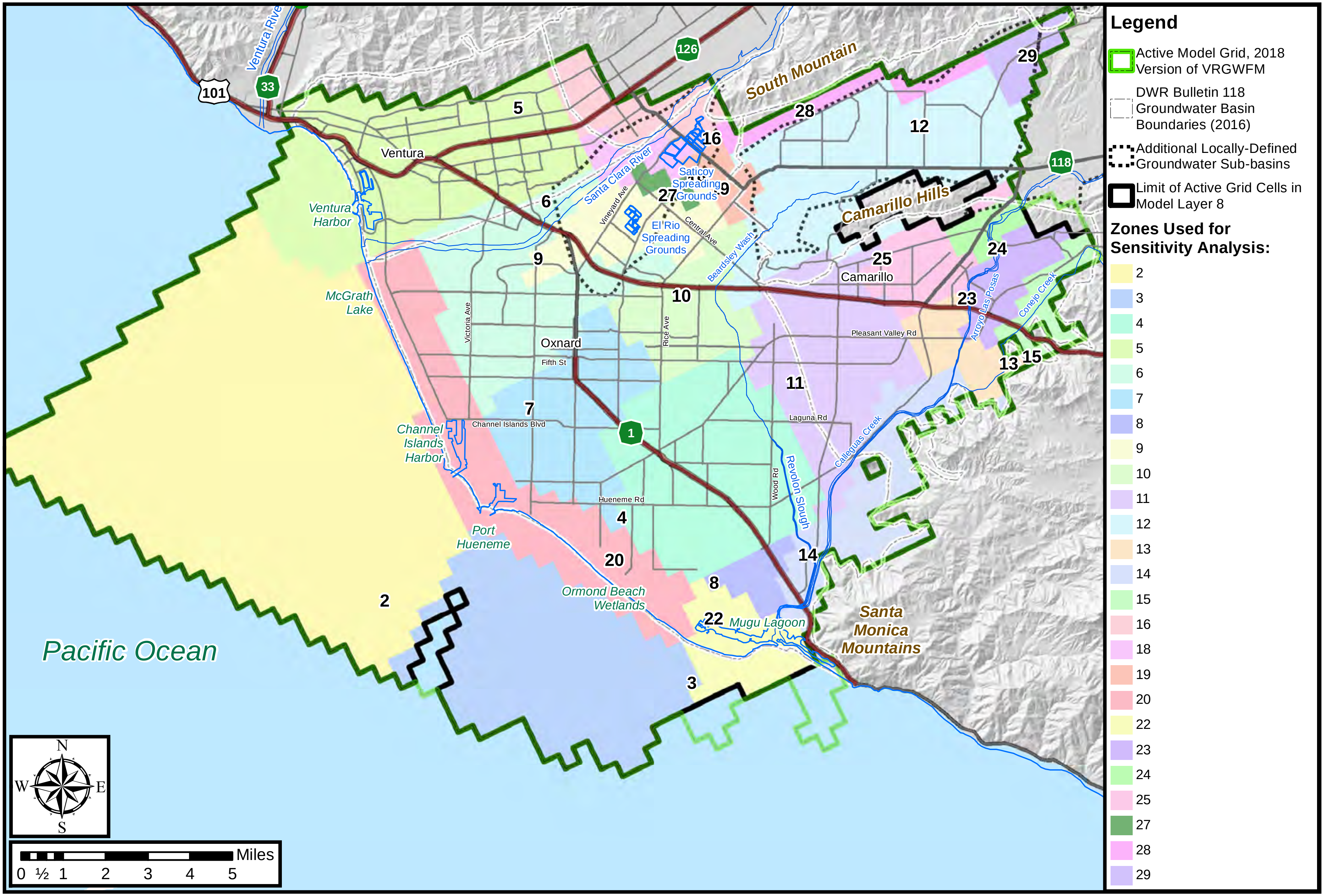

Figure 4-52. Zones Used for Sensitivity Analysis, Model Layer 8

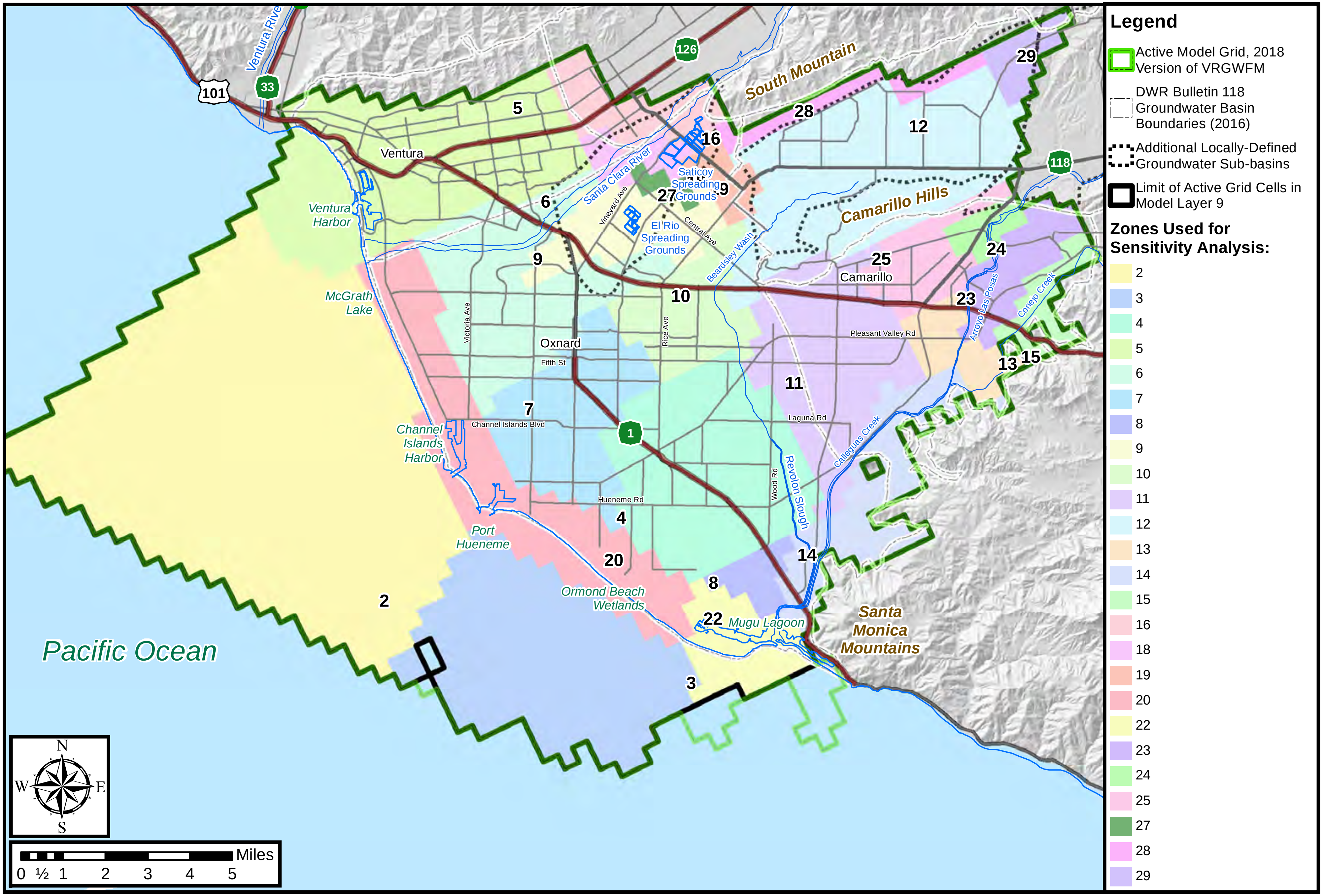

Figure 4-53. Zones Used for Sensitivity Analysis, Model Layer 9

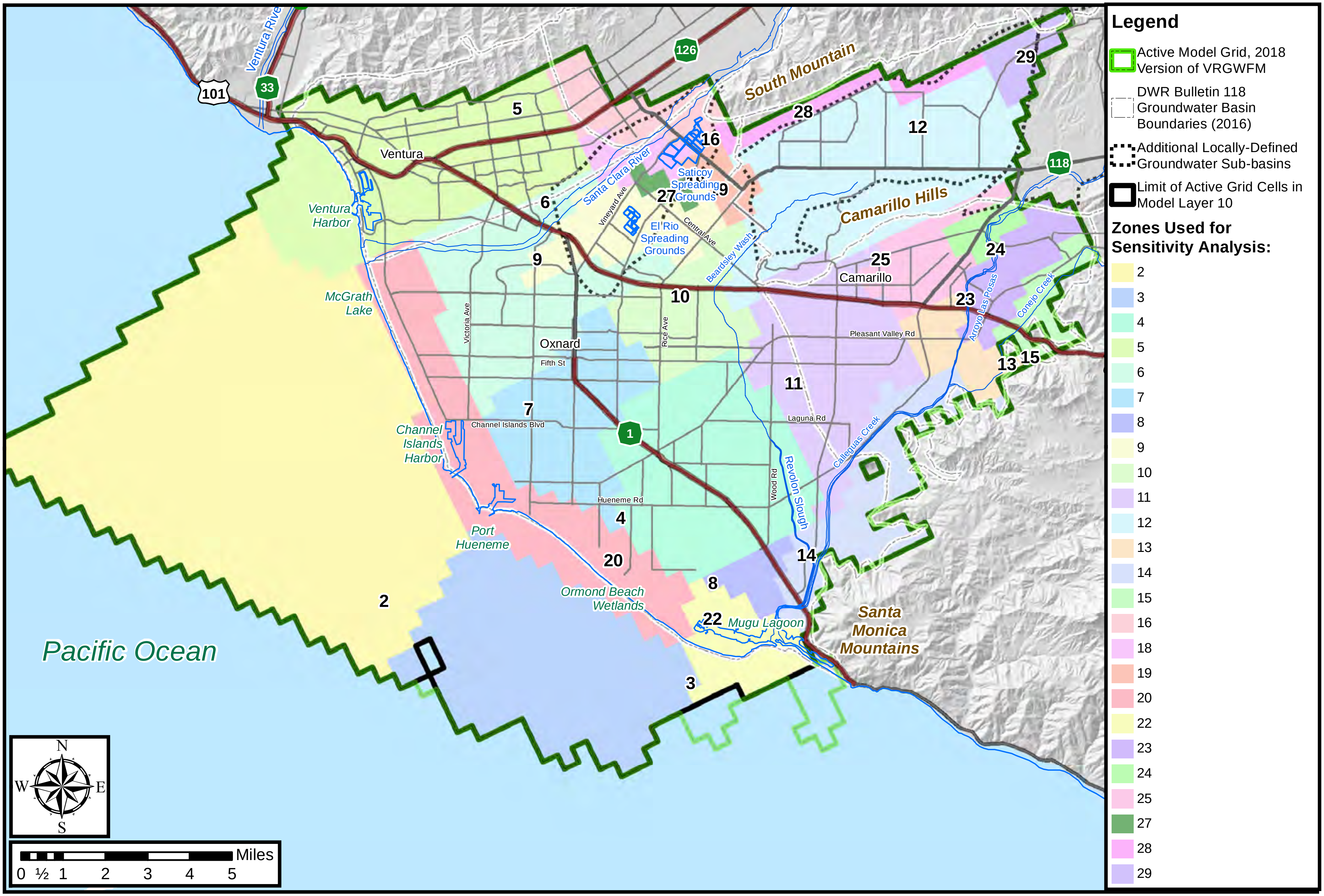

Figure 4-54. Zones Used for Sensitivity Analysis, Model Layer 10

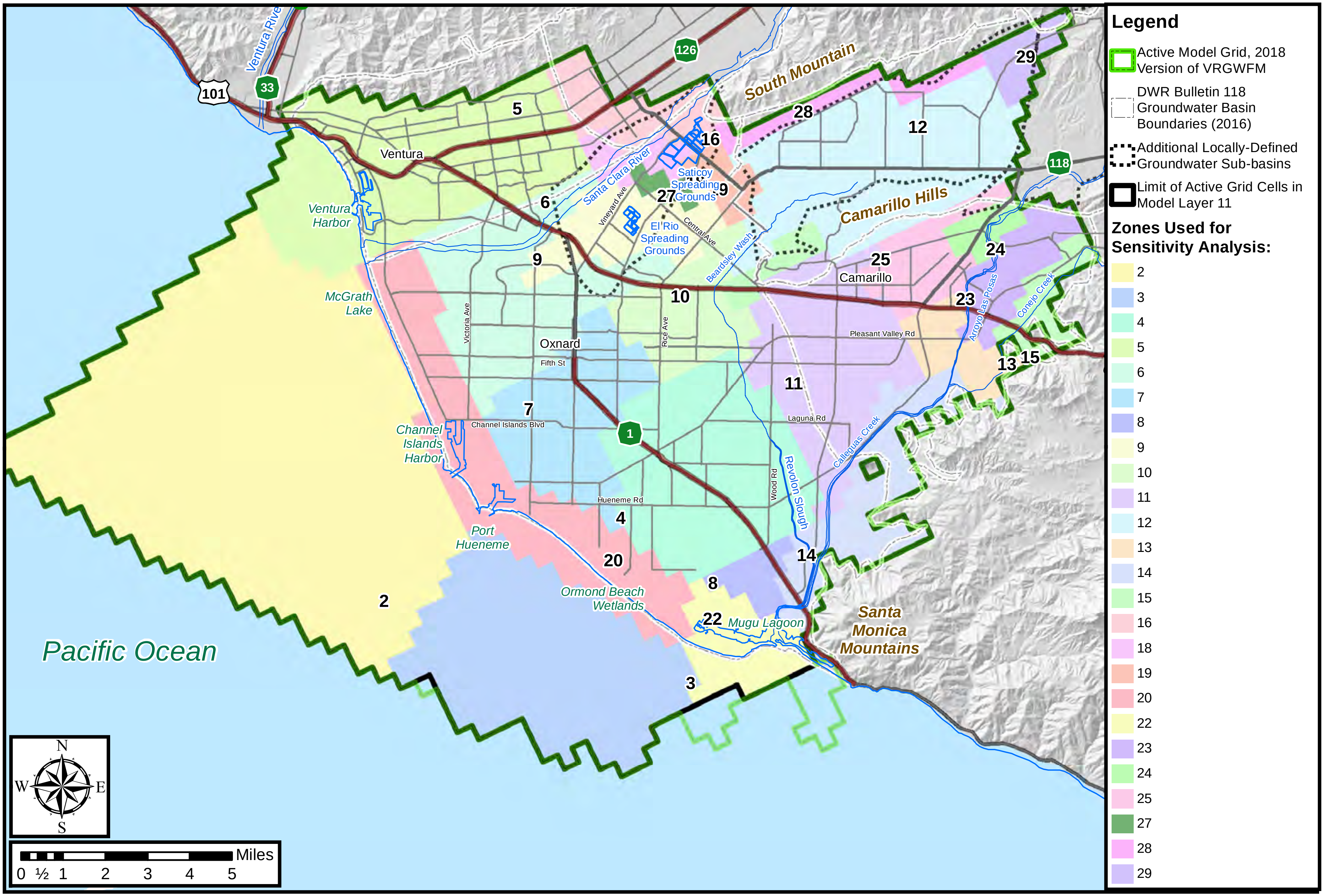

Figure 4-55. Zones Used for Sensitivity Analysis, Model Layer 11

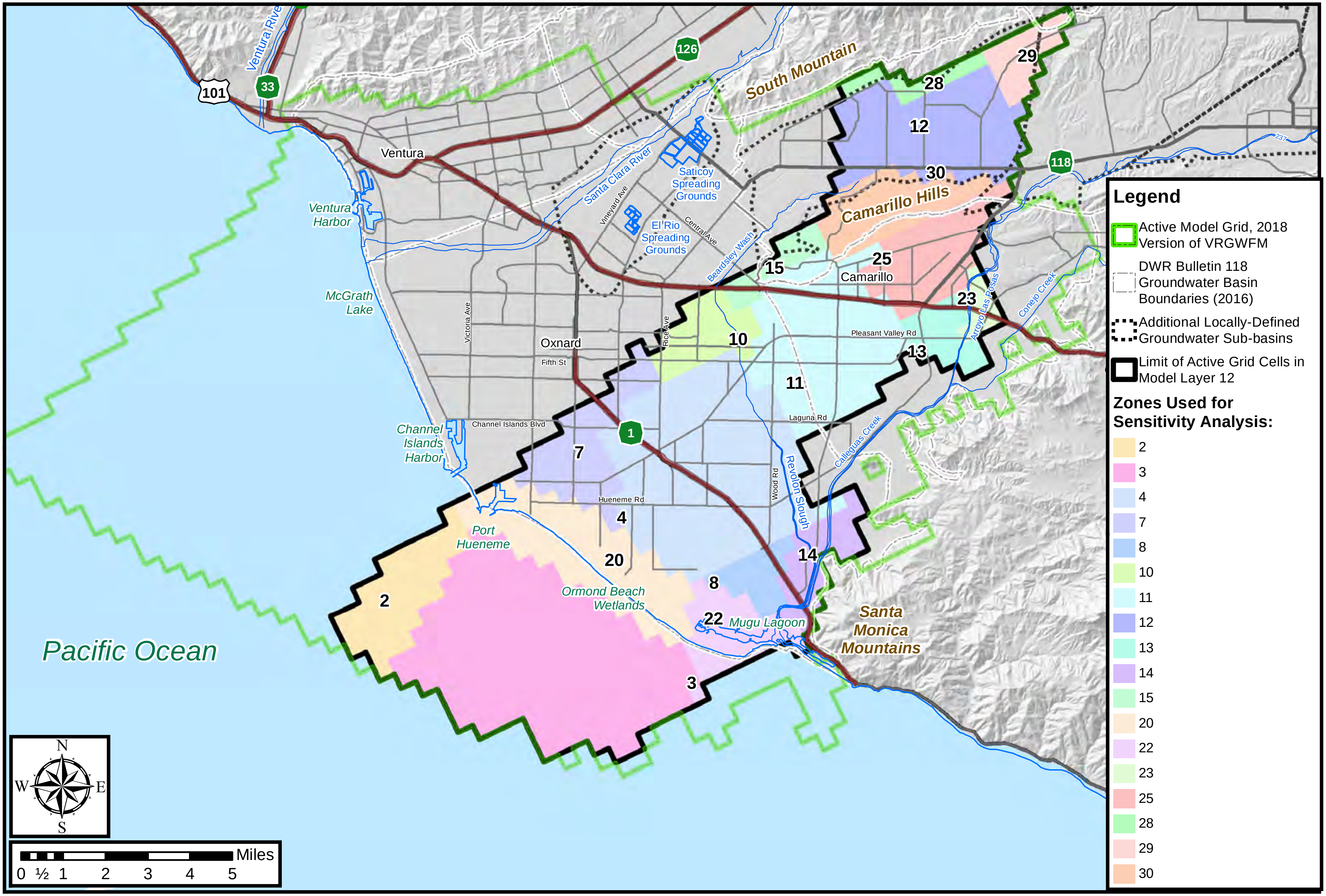

Figure 4-56. Zones Used for Sensitivity Analysis, Model Layer 12

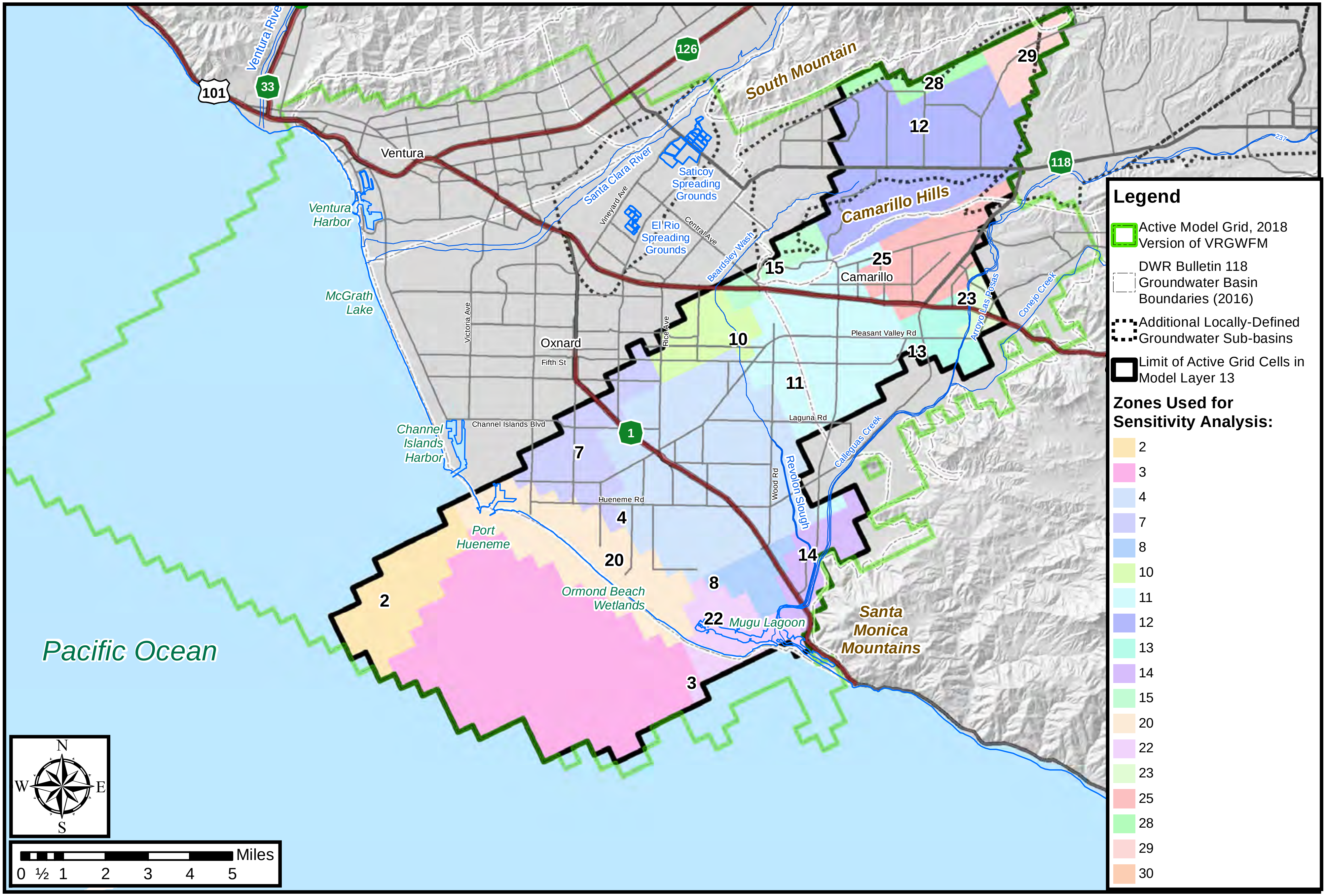

Figure 4-57. Zones Used for Sensitivity Analysis, Model Layer 13

Table 4-6. Values Input for Parameters (by Zone) During Sensitivity Analysis

Horizontal Hydraulic Conductivity in Each Zone (ft/day)

Layer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1.0E-12	200	200	200	200	300	200	200	300	200	200	200	200	50	50	200	0.1	300	200	200	1.0E-12	200	100	100	100	100	1	200	200	200
2	1.0E-12	0.01	0.01	0.01	1.00E-02	0.01	0.01	1.0E-03	0.01	0.01	0.01	100	100	50	50	200	0.01	300	200	0.01	1.0E-12	1.0E-04	100	100	100	0.01	0.01	200	100	100
3	1.0E-12	100	100	100	1.00E-02	300	100	100	250	100	100	100	50	10	10	200	0.05	250	200	100	1.0E-12	100	50	80	1	100	1	200	100	100
4	1.0E-12	0.01	0.01	0.1	1.00E-02	1	1	1	200	1	20	100	20	1	1	200	1.00E-03	250	200	1	1.0E-12	1	20	50	1	1	0.01	200	100	100
5	1.0E-12	100	50	50	100	200	50	50	200	100	20	100	20	1	1	200	20	200	100	100	1.0E-12	50	20	50	1	100	1	200	100	100
6	1.0E-12	1.0E-03	1.0E-03	1.0E-03	1	3.0E-03	0.01	1.0E-03	1.0E-03	5.0E-04	1.0E-02	50	0.01	0.01	0.01	1.00E-03	0.01	1.0E-04	0.1	1.0E-03	0.01	1.0E-03	0.1	1	5.0E-03	1.0E-03	1.0E-03	50	0.1	0.1
7	1.0E-12	20	20	20	20	20	20	20	0.5	20	20	10	10	10	1	20	5	1.0E-04	20	20	1.0E-12	20	10	20	1	100	0.1	20	20	10
8	1.0E-12	0.1	0.1	0.1	1	0.1	0.1	0.1	0.05	0.1	0.1	1.0E-04	0.1	0.1	0.1	0.1	1	1.0E-04	0.1	0.1	1.0E-12	0.1	0.1	0.1	0.1	0.1	0.01	15	0.01	0.01
9	1.0E-12	10	10	10	10	10	10	10	0.5	10	20	5	1	1	1	10	5	1.0E-04	10	10	1.0E-12	10	5	10	1	100	0.1	10	10	5
10	1.0E-12	0.1	0.1	0.1	1	0.1	0.1	0.1	0.05	0.1	0.1	0.01	0.1	0.1	0.1	0.1	1	1.0E-04	0.1	0.1	1.0E-12	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.01
11	1.0E-12	5	5	5	1	5	5	5	0.5	5	5	5	1	1	1	10	1	1.0E-04	5	5	1.0E-12	10	1	5	1	50	0.1	5	5	2
12	1.0E-12	0.1	0.1	0.1	1	0.1	0.1	0.1	0.05	0.1	0.1	0.01	0.1	0.1	0.01	0.1	1	1.0E-04	0.1	0.1	1.0E-12	10	0.1	0.01	0.01	0.1	0.01	0.1	0.1	0.5
13	1.0E-12	1	1	1	1.0E-03	1	1	1	0.1	1	1	5	1	0.5	0.01	1	0.01	1.0E-04	1	1	1.0E-12	1	1	1	0.01	5	0.1	5	5	2

Vertical Anisotropy Ratio in Each Zone (unitless)

Layer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	10	10	10	10	10	10	10	10	10	10	10	100	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2	10	10	10	10	10	10	10	10	10	10	10	100	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
3	10	10	10	10	10	10	10	10	10	10	10	100	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
4	10	10	10	10	10	10	10	10	10	10	10	100	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
5	10	10	10	10	10	10	10	10	10	10	10	100	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	10	10	10	10	100	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
7	10	10	10	10	10	10	10	10	10	10	10	100	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
8	10	10	10	10	10	10	10	10	10	10	10	100	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
12	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
13	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

Storage Coefficient in Each Zone (unitless)

Layer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
6	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.002	0.001	0.0005	0.0005	0.0005	0.001	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.001	0.001	0.002
7	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.002	0.001	0.0005	0.0005	0.0005	0.001	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.001	0.001	0.002
8	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.002	0.001	0.0005	0.0005	0.0005	0.001	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.001	0.001	0.002
9	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.002	0.001	0.0005	0.0005	0.0005	0.001	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.001	0.001	0.002
10	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.002	0.001	0.0005	0.0005	0.0005	0.001	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.001	0.001	0.002
11	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.002	0.001	0.0005	0.0005	0.0005	0.001	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.001	0.001	0.002
12	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.002	0.001	0.0005	0.0005	0.0005	0.001	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.001	0.001	0.002
13	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.002	0.001	0.0005	0.0005	0.0005	0.001	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001	0.001	0.001	0.002

Table 4-6. Values Input for Parameters (by Zone) During Sensitivity Analysis

	Specific Yield in Each Zone (unitless)																													
Layer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1	0.1	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1	0.1	0.15	0.15	0.15	0.15	0.15
2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.15
3	0.15	0.15	0.15	0.15	0.05	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1	0.1	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1	0.1	0.15	0.15	0.15	0.15	0.15
4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.15
5	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1	0.1	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1	0.1	0.15	0.15	0.15	0.15	0.15
6	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
7	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.1	0.1	0.1
8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
9	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.1	0.1	0.1
10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
11	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.1	0.1	0.1
12	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
13	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.1	0.1	0.1

Appendix B

Figures from CMWD Report

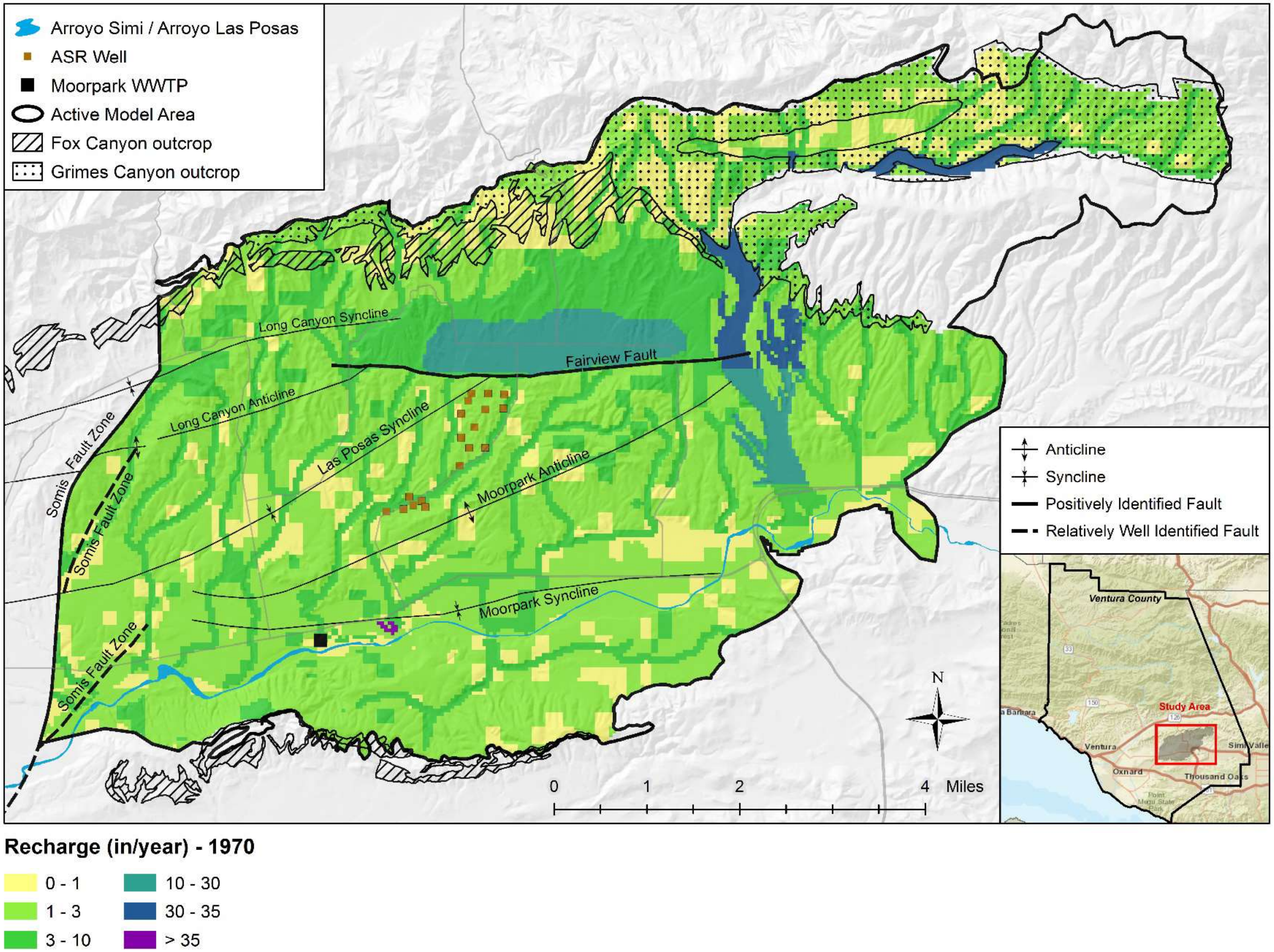

Figure 8-6 Recharge (in/year) for January, 1970

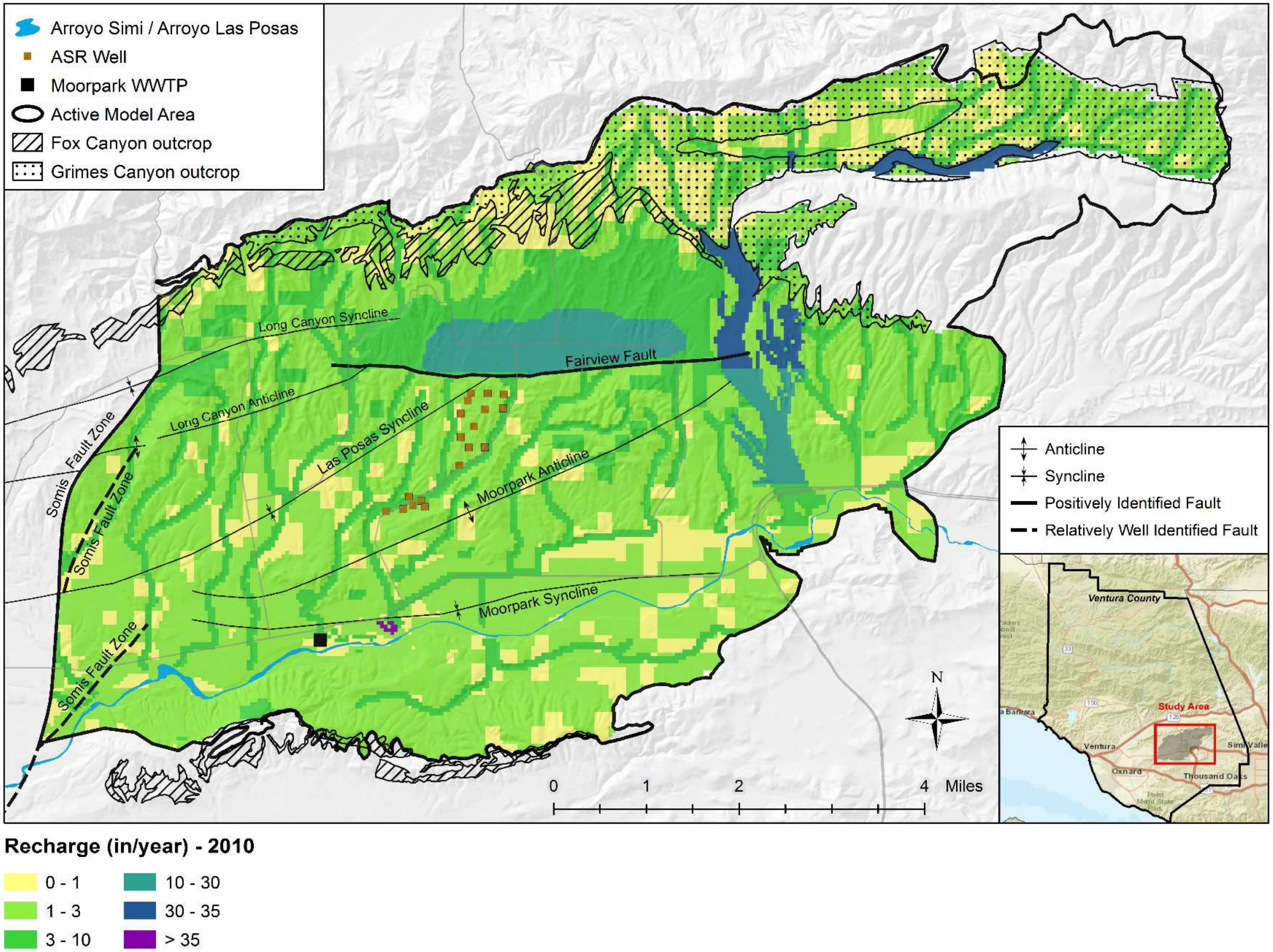

Figure 8-7 Recharge (in/year) for January, 2010

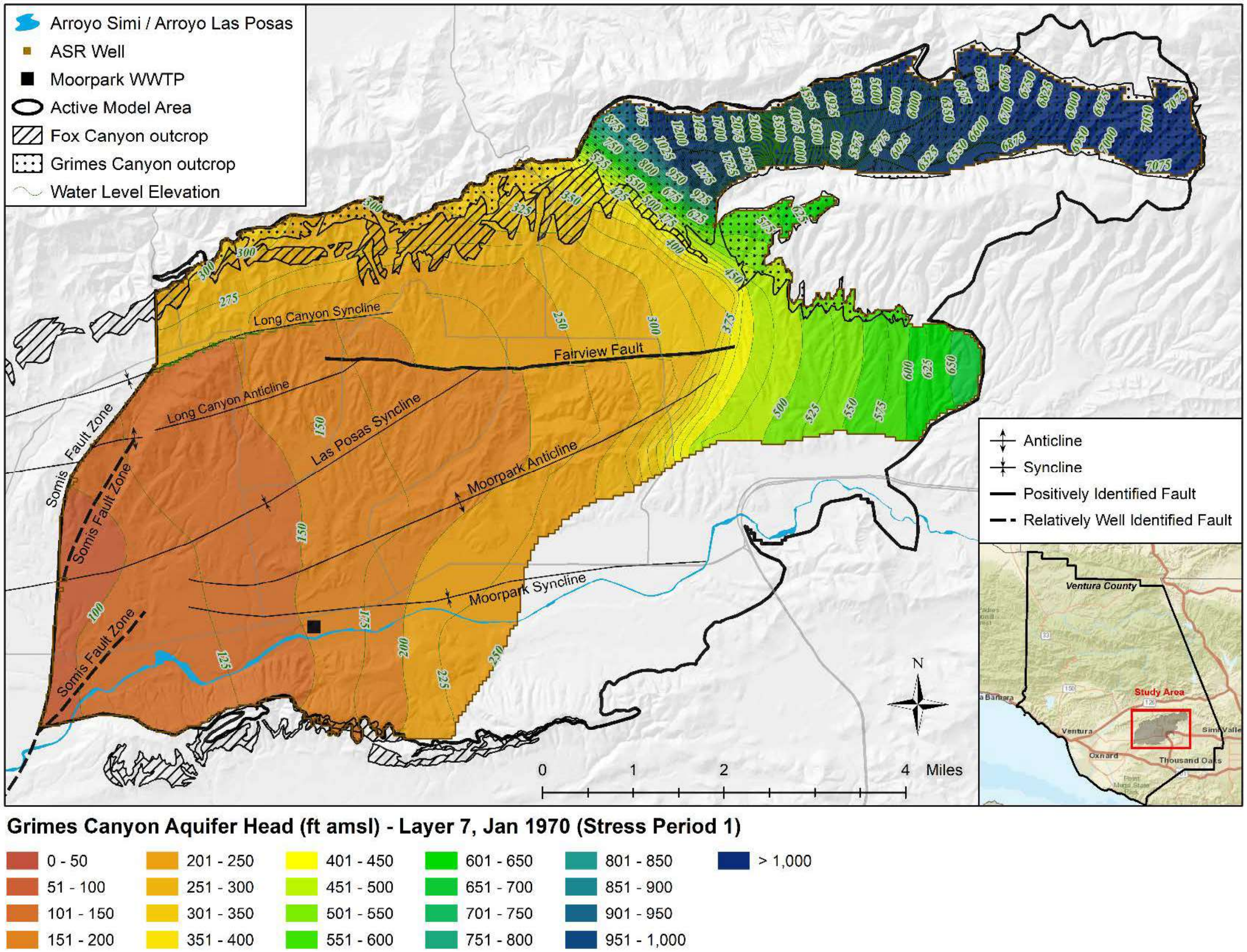

Figure 8-55 Layer 7 (GCA) hydraulic heads (ft amsl) – Jan 1970 (Stress Period 1)

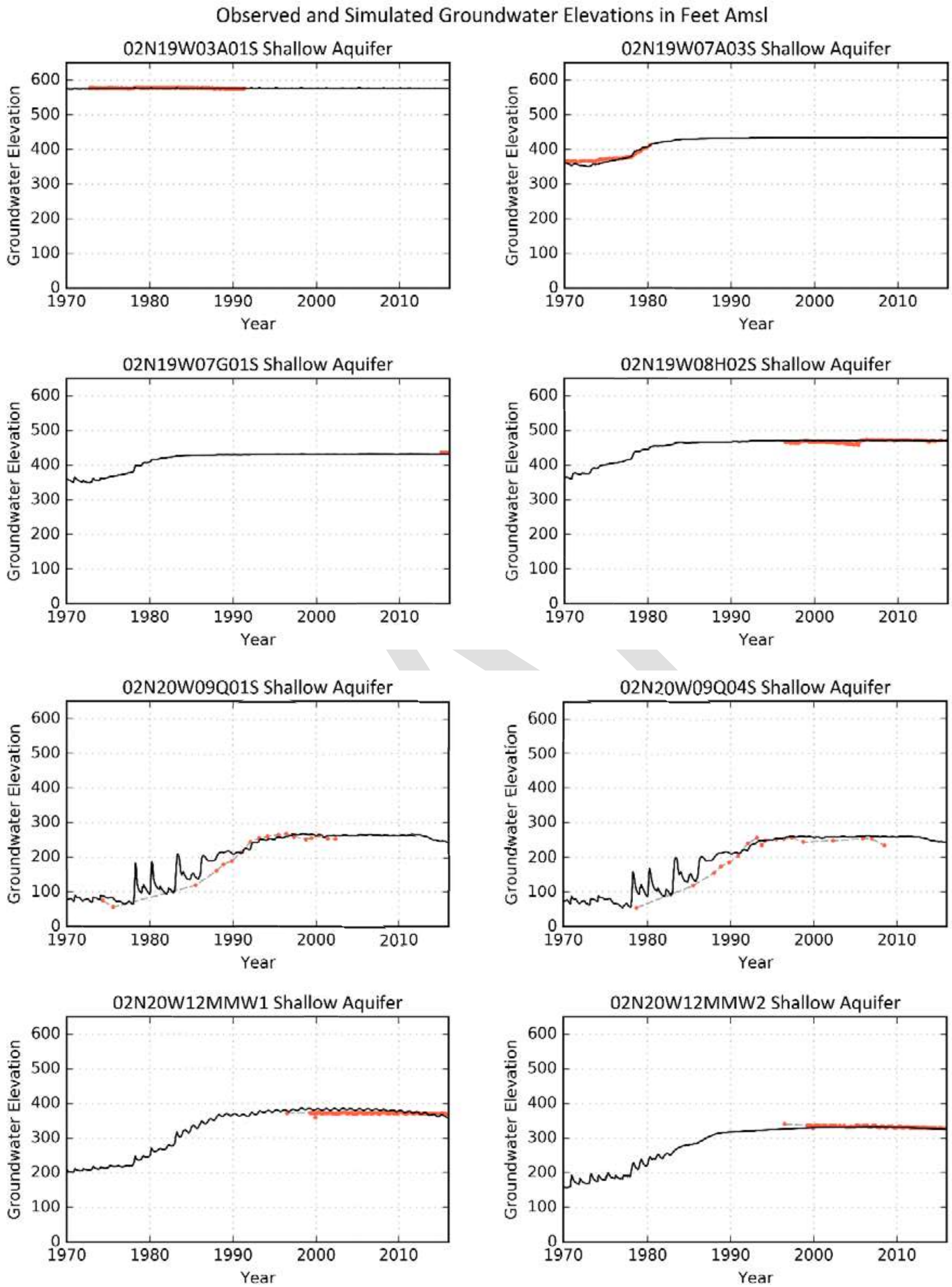

Figure 8-58 Simulated versus observed hydrographs at key wells in the Shallow Aquifer (Layer 1)

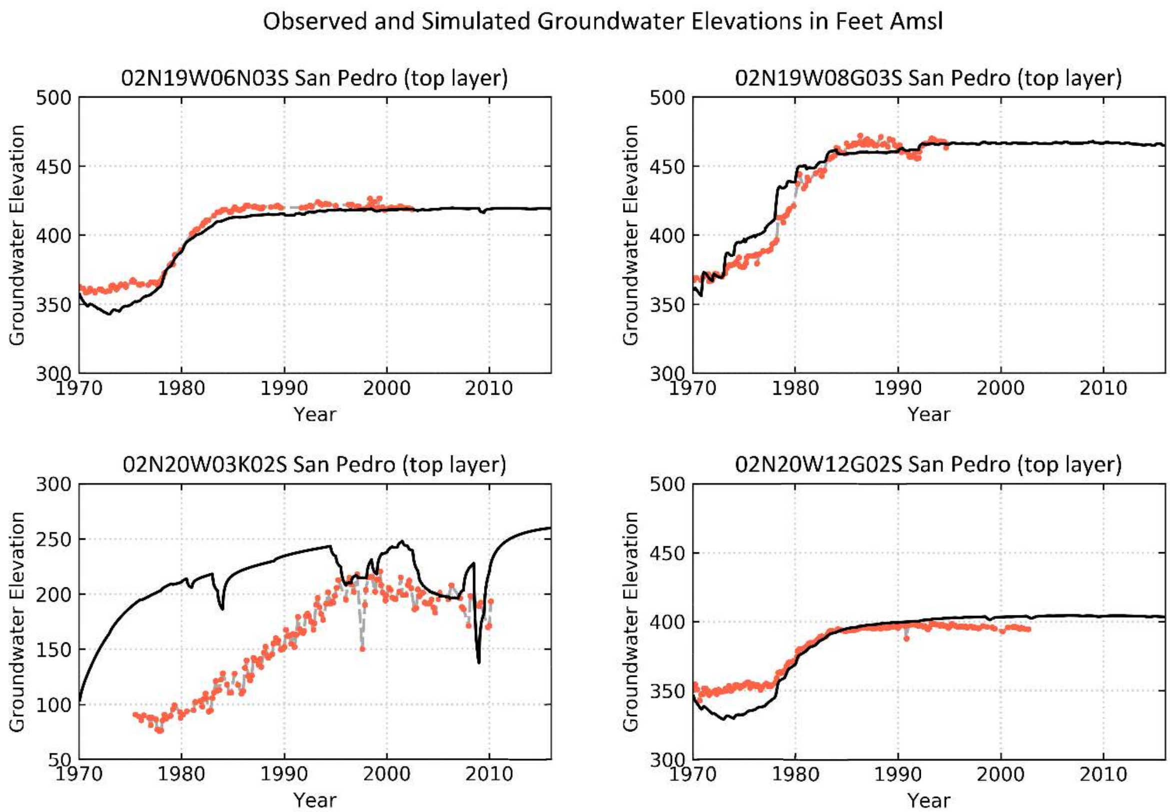

Figure 8-60 Simulated versus observed hydrographs at key wells in the Top Layer of the Upper San Pedro/Saugus Formation (Layer 2)

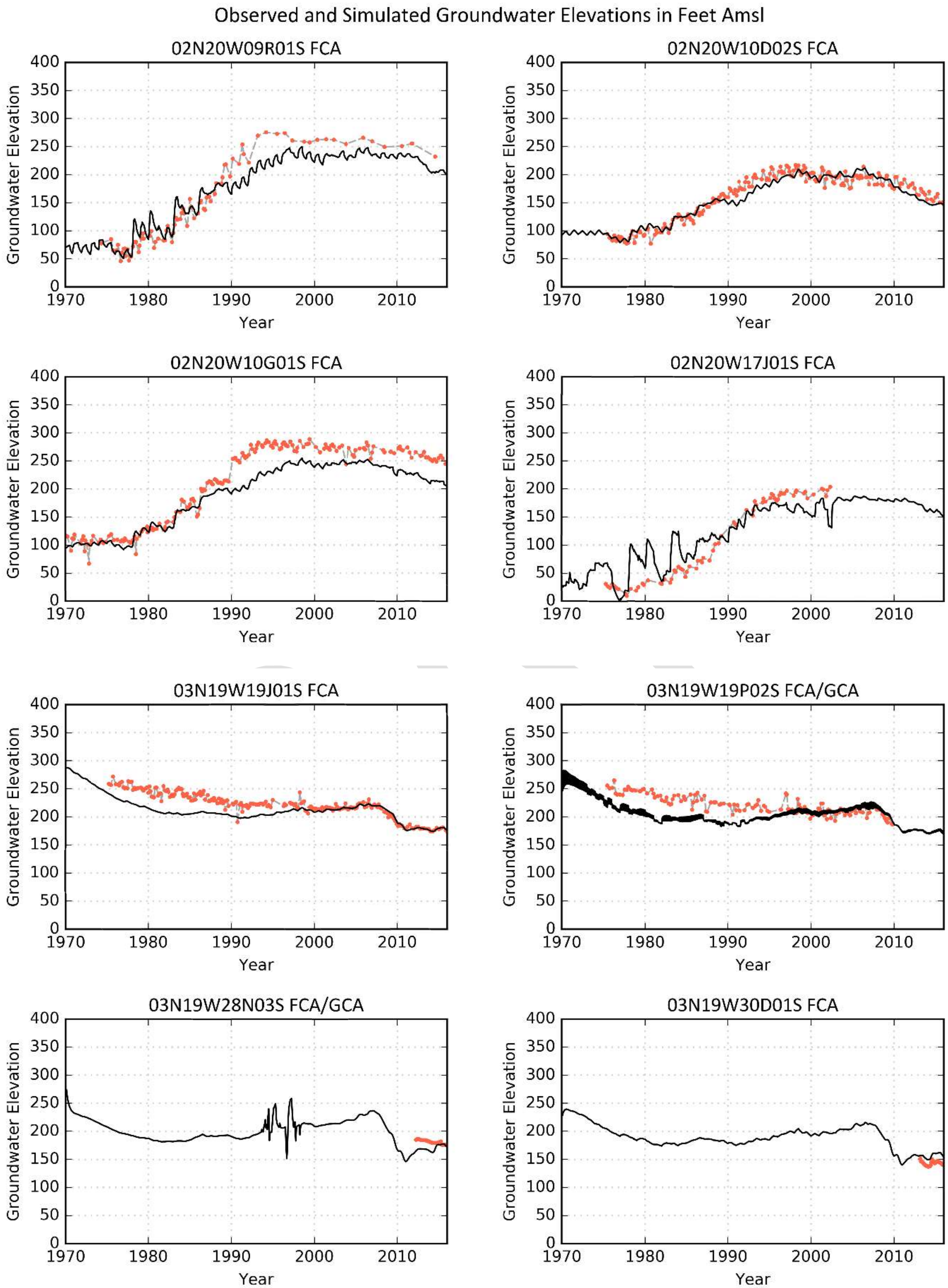

Figure 8-62b Simulated versus observed hydrographs at key wells in the FCA (Layer 5)

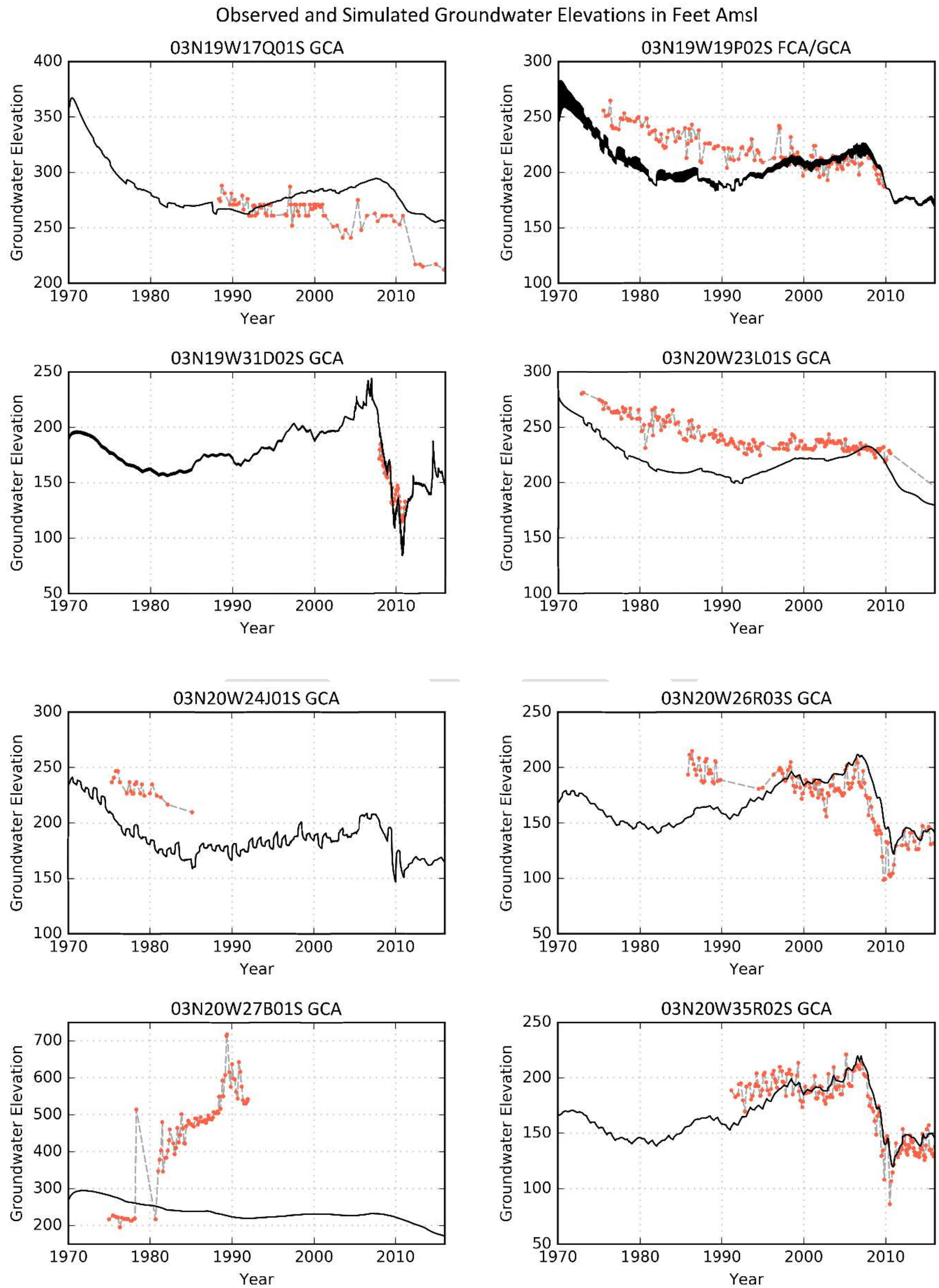

Figure 8-63 Simulated versus observed hydrographs at key wells in the GCA (Layer 7)