HydroMetrics WRI

1814 Franklin St, Suite 501
Oakland, CA 94612

TECHNICAL MEMORANDUM

To:	Seaside Groundwater Basin Watermaster Technical Advisory Committee
From:	Pascual Benito, Georgina King, and Derrik Williams
Date:	June 28, 2018
Subject:	2018 Seaside Groundwater Model Update

Background and Scope

The Watermaster's first Basin Management Action Plan (BMAP) was completed in February 2009 (HydroMetrics LLC, 2009a). The BMAP constitutes the basic plan for managing the Seaside Groundwater Basin. The BMAP identifies both short-term actions and long-term strategies intended to protect the groundwater resource while maximizing the beneficial use of groundwater in the basin. It provides the Seaside Basin Watermaster (Watermaster) a logical set of actions that can be undertaken to manage the basin to its Safe Yield. Over the nine years since the BMAP was completed, the Watermaster has collected much groundwater level and quality data, and conducted various studies to improve the understanding of the basin.

At the time the 2009 BMAP was prepared, a groundwater model had not yet been developed for the basin, and the analysis contained in the BMAP was completed using analytical methods. Following the BMAP recommendation that a groundwater model be constructed to assist with groundwater management decisions, a calibrated model was completed in November 2009 (HydroMetrics LLC, 2009b). The model simulated groundwater conditions in the basin between January 1987 and December 2008. In 2014, the model was updated with data through September 2013 (HydroMetrics WRI, 2014) but not recalibrated because its accuracy was still acceptable. The 2014 update found that the uncalibrated portion of the model (January 2009 – September 2013) tended to simulate higher groundwater levels than measured levels. Periodic recalibration of the model is necessary to ensure the model simulates groundwater levels within an acceptable industry standard accuracy. When simulated groundwater levels are not accurate this reduces the accuracy of all output from the model such as groundwater storage and water budget.

This technical memorandum documents (1) the update of the Seaside Basin groundwater model that extends the model simulation period through 2017, and (2) recalibration of the model using all the groundwater level data that has been added to the model since 2008. In extending the model timeframe, new pumping and recharge input data for the extended period, and new groundwater level data used to measure model calibration were added to the model.

Data Collection and Input to Model

PUMPING

Updated monthly records of groundwater pumping from wells in the model area were provided by Monterey Peninsula Water Management District (MPWMD), Cal Water Service, and Marina Coast Water District (MCWD) for the period between 2014 and 2017.

Figure 1 shows the total monthly pumping for the entire model period of 1987-2017. The pumping pattern of the updated period between 2014 and 2017 is similar to the lower pumping that was observed in the 1992/93 drought. No new wells were added to the model for the updated period as no new municipal production wells were drilled and put into production between 2014 and 2017.

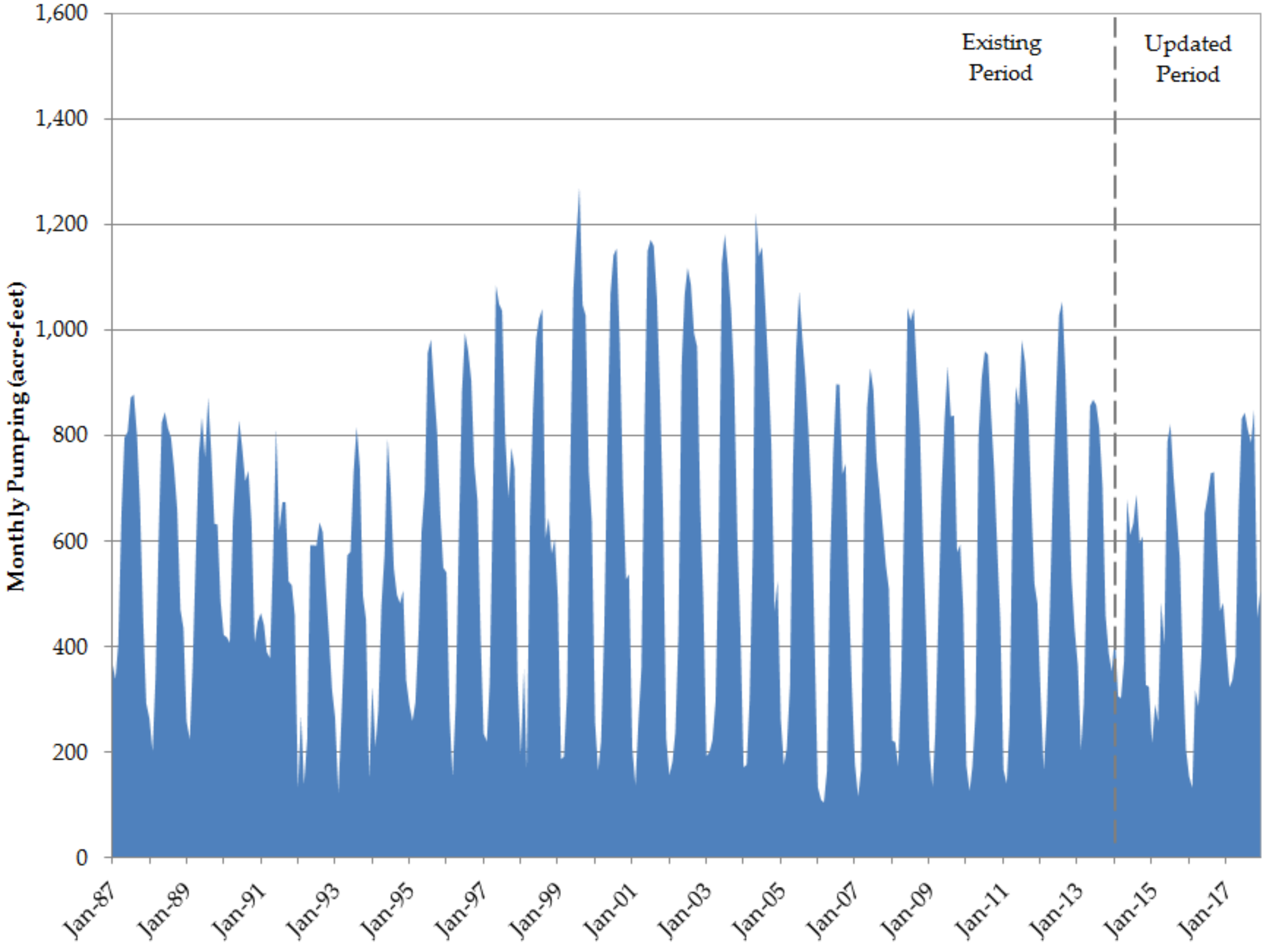


Figure 1: Total Monthly Pumping

DEEP GROUNDWATER RECHARGE

The amount of deep groundwater recharge added to the model each month is estimated by a soil moisture balance model. The documentation of this model can be found in the Seaside Basin Modeling and Protective Groundwater Elevations Report (HydroMetrics, 2009a). The inputs to the soil moisture balance model include:

- Water system deliveries
- Precipitation
- Evapotranspiration
- Land use
- Soil types
- Recharge pond and septic information

The soil moisture balance model was updated by supplying updated input data to extend the model period through the end of 2017. System loss data were obtained from MPWMD for Cal-Am water delivered to customers. Precipitation data were downloaded from the Utah Climate Center to extend the Monterey (Coop No. 45795) and Salinas (Coop No. 47668) station data. Monthly evapotranspiration data were downloaded for the Castroville CIMIS station.

As the soil moisture balance model uses average monthly evapotranspiration rates, 2009-2017 evapotranspiration data for the Castroville CIMIS station was evaluated to determine if it varied from average monthly rates used previously in the model. It was found that average monthly evapotranspiration for the updated period was similar to previous years and thus, average monthly evapotranspiration rates for the updated model were assumed to be the same as for the 1987-2008 original model calibration period.

The number of septic tanks in use and the land use throughout the model domain were assumed to be the same because land use has not changed substantially from the General Plan land use used in the original model. The amount of runoff percolation occurring in the recharge ponds is estimated in the soil moisture balance model as a proportion of precipitation.

Figure 2 shows the estimated total monthly deep groundwater recharge that is input into the model for every month between 1987 and 2017. The greatest recharge takes place during winter months when deep percolation of rainfall occurs. Less recharge takes place during the dry portion of the year when recharge is dependent upon system losses and irrigation return flow. This seasonal pattern is consistent throughout the entire simulation period, including the updated model period.

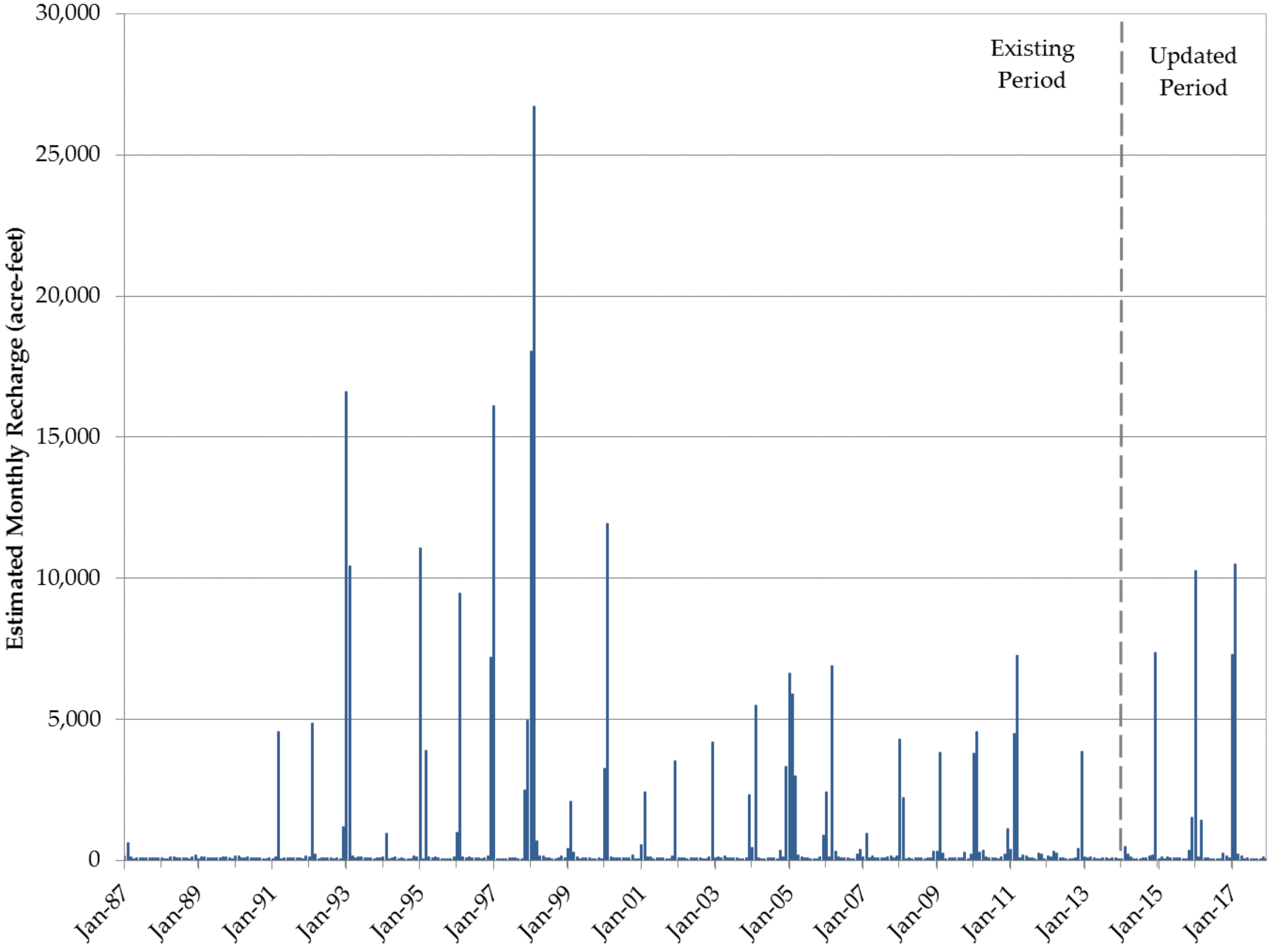


Figure 2: Estimated Monthly Recharge

GROUNDWATER LEVEL OBSERVATIONS

An updated set of groundwater level observations from wells in the Seaside Basin were provided by MPWMD, MCWD, and the Monterey County Water Resources Agency (MCWRA). The dataset covers the updated model period of 2014-2017. Observations collected from wells that were pumping at the time of measurement (pumping temporarily lowers the groundwater level at the well location) and other questionable values were removed from the dataset.

The updated groundwater level data were used to assess the performance of the updated groundwater model. Performance of the model was evaluated by comparing the model's simulated groundwater elevations to the observed groundwater elevations that were provided. This process is described in greater detail in the Model Recalibration section below.

MODEL BOUNDARY WITH SALINAS VALLEY

Groundwater flows freely into and out of the Salinas Valley along the model's northeastern boundary. The boundary with Salinas Valley was simulated as a specified head boundary condition with the MODFLOW Constant Head (CHD) package. This option assigns a set of specified (or known) groundwater elevation heads to each model cell along the northwestern boundary. The specified groundwater elevations vary spatially along the boundary and can also be made to vary with time according to changing conditions. If simulated groundwater elevations in the model are higher than the assigned boundary elevations, water will flow out of the model towards the Salinas Valley. If simulated groundwater elevations in the model are lower than the assigned boundary elevations, water will flow from the Salinas Valley into the model.

For the original model calibration in 2009 (HydroMetrics LLC, 2009b), the groundwater elevations assigned to the model cells along the northeastern boundary were derived from results of the Salinas Valley Integrated Groundwater Surface Water Model (SVIGSM) (Montgomery Watson, 1997). WRIME Inc., the consultant updating the SVIGSM for Monterey County Water Resources Agency, provided estimated groundwater elevations from a number of the SVIGSM nodes that were near the regional model boundary and these were interpolated onto the regional model boundary cells ("the 1997 SVIGSM results"). In 2009, the SVIGSM calibrated results were available only through model year 1994, so the SVIGSM groundwater heads from the last month of 1994 were repeated through the end of the calibration model period, 2008, for each boundary cell.

In 2010, WRIME, Inc. provided updated SVIGSM results ("2010 SVIGSM Results") that covered a longer time period extending to 2004, and these new results were used to update the specified heads along the northeastern boundary as part of a modeling study looking at the impacts from the Regional Project as described in the Final Environmental Impact Report (EIR) for the Coastal Water Project (HydroMetrics Water Resources Inc., 2010).

In the Seaside Basin model's 2014 update, the Seaside Basin model was updated to extend through years 2005-2013. SVIGSM model results were not available for these years, so to approximate the groundwater elevations along the northeastern boundary for this period, the final 12 months of available 2010 SVIGSM results (from year 2004) were applied to each of the remaining years from January 2005 through December 2013. This is illustrated in graph form on Figure 3 as the higher elevation blue line.

At the time of the 2014 Seaside Basin model update, no sensitivity analysis had yet been performed for the northeastern boundary condition to evaluate if and how changes to the specified heads along this boundary might impact model results. Given that the boundary is over four miles away from the nearest Seaside Basin production wells located in the central portion of the Northern Coastal subarea, it was thought that impacts from the boundary would be greatest in areas adjacent to the boundary, and would have less impact on areas further away.

In preparation for the model recalibration described in this Technical Memorandum, a limited sensitivity analysis of the northeastern boundary condition was carried out by applying consecutive changes in specified groundwater heads along the boundary for different durations of time, and assessing how this impacted groundwater levels in different areas of the model. It was found that changes in specified boundary heads of more than 10-20 feet over multi-year periods resulted in changes to groundwater levels and regional gradients in large areas of the model including areas not directly adjacent to the boundary, such as the Northern Coastal subarea. Because of the length and large cross-sectional area of the northeastern boundary, large changes in the specified heads over sustained periods of time can change the regional groundwater levels and gradients, the location of the groundwater divide, and also the spatial and temporal distribution of wet and dry cells in the model.

With this understanding, the original 1997 SVIGSM model and the newer 2010 SVIGSM model head values along the northeastern boundary were compared against one another, as shown for an example model boundary cell in Figure 3. For the same time periods, the newer updated 2010 SVIGSM head values that were used to update the model in 2014 were significantly higher than the earlier 1997 SVGISM model head values, by as much as 35 feet during some periods.

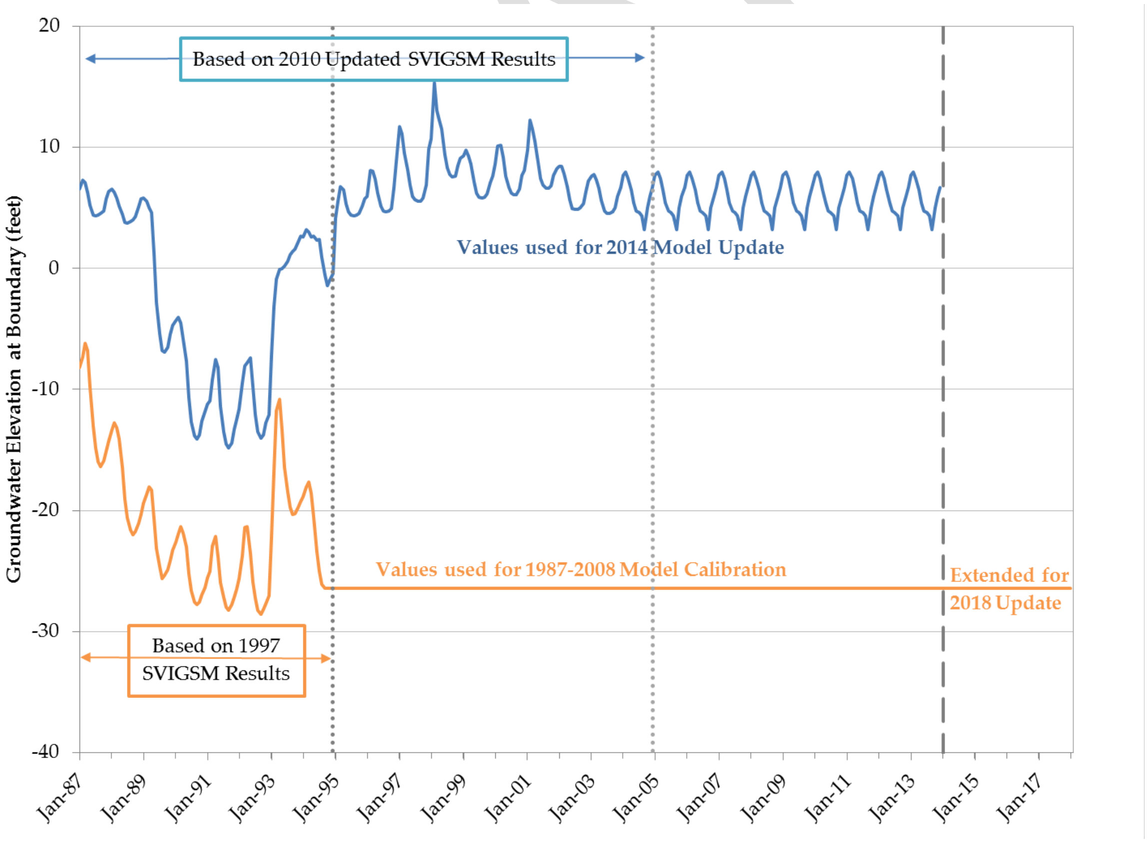


Figure 3: Groundwater Elevations at an Example Northeastern Boundary Cell

The two SVIGSM model results (1997 and 2010) were compared against measured groundwater levels in wells located along and adjacent to the northeastern boundary. Historical and current groundwater level data for these wells were compiled from a number of sources, including the Fort Ord environmental remediation monitoring wells, the California Department of Water Resources CASGEM program, and Marina Coast Water District's production wells.

The comparison of the two SVIGSM model results along the boundary showed that the heads from the earlier 1997 SVIGSM model results used for the original 2009 Seaside Basin model calibration much more closely match observed groundwater levels along the boundary over the extended model period through 2017. Using the 2010 SVIGSM heads did not allow for improvement in model calibration and for this reason, the much higher 2010 SVIGSM heads, used in the groundwater model since 2010, were replaced with the original 1997 SVIGSM heads. The head value for the last month of 1994 in the 1997 SVIGSM model were applied to all subsequent months through December 2017, as shown in Figure 3. Even without the annual seasonal variation in the extended period from 1994 through 2017, it was found matching the overall average head elevations along the boundary was critical to recalibrating the model.

Model Recalibration

CALIBRATION APPROACH

Calibrating the groundwater flow model involved successive attempts to match model output to measured data from the calibration period. Relatively uncertain and sensitive parameters such as horizontal and vertical hydraulic conductivities, were varied over a reasonable range of values. Simulated hydraulic heads were compared against available observed groundwater elevations. The model was considered calibrated when simulated groundwater levels matched the measured groundwater levels within an industry standard acceptable measure of accuracy, and when successive calibration attempts did not notably improve the calibration statistics. Acceptable measures of model accuracy are described on pages 15 and 16.

Prior to varying the 2009 calibrated model parameters such as hydraulic conductivity and storage coefficients, a limited sensitivity analysis was carried out on two model inputs that had not previously undergone calibration, 1) the specified head boundary with the Salinas Valley (as described in the previous section), and 2) the deep groundwater recharge estimated using a soil moisture balance model.

The sensitivity of the groundwater model to changes in applied recharge was evaluated by making incremental changes to the soil properties in the soil moisture balance model. Both the rooting depth and the soil runoff curve numbers (CN) are soil parameters that influence the percentage of rainfall that runs off or infiltrates to become recharge. Rooting depth is the typical depth of the root zone and the soil runoff curve number is a coefficient that reduces precipitation to runoff. The soil balance model was run with a range of soil rooting depth (between 12-80 inches) and a range of CN parameter values to create different groundwater recharge input data sets for the groundwater model, and the sensitivity of the changes on simulated groundwater levels was evaluated. It was found that in general the model was much more sensitive to long-term average groundwater elevations along the Salinas Valley boundary than to changes in the soil runoff properties, and as such, recalibration efforts were focused first on recalibrating the Salinas Valley boundary as described in the previous section.

CALIBRATION RESULTS

After updating the Salinas Valley boundary conditions as described above, the updated groundwater model was re-run and the calibration results improved to the same level of calibration as the original 1987-2008 calibration period. This indicates that the revision of the northern boundary condition provides for better simulation of groundwater levels than the model was able to achieve with the higher 2010 SVIGSM heads. Many of the simulated groundwater levels that had been diverging from the observed values in the 2014 model update better matched observed values. At this stage, a calibration tool called Parameter Estimation (PEST) (Watermark Numerical Computing, 2004) was used to determine if further significant improvements could be made by adjusting model parameters.

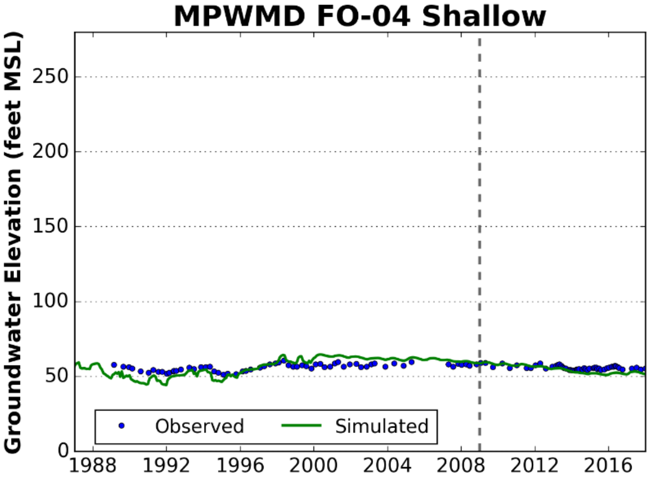
MODEL PARAMETER MODIFICATIONS

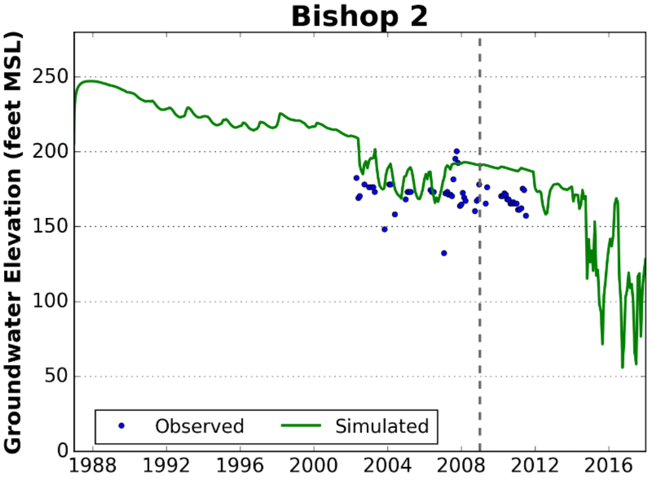
Model hydraulic parameters are adjusted during model calibration to improve the model's ability to simulate known conditions. Calibration runs of the model with PEST consisted of modifying the distribution and magnitude of horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific storage values. This process was conducted in the 2009 model calibration.

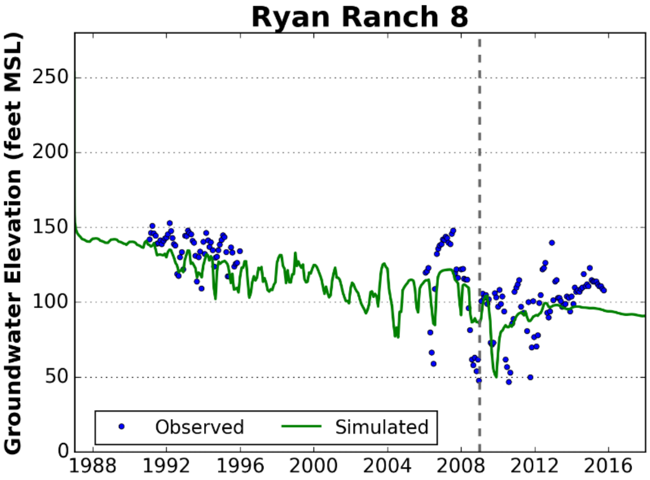
For this 2018 recalibration of the model, hydraulic parameter modifications resulted in measureable, but not significant, improvements in the calibration statistics. In some cases, small improvements were gained in matching groundwater levels of some wells, while other wells showed decreases in accuracy. It was determined that the existing calibrated parameters should be kept and that the recalibration of groundwater elevations at the Salinas Valley boundary was sufficient to return the model to its original performance and accuracy, without the need to modify hydraulic parameters.

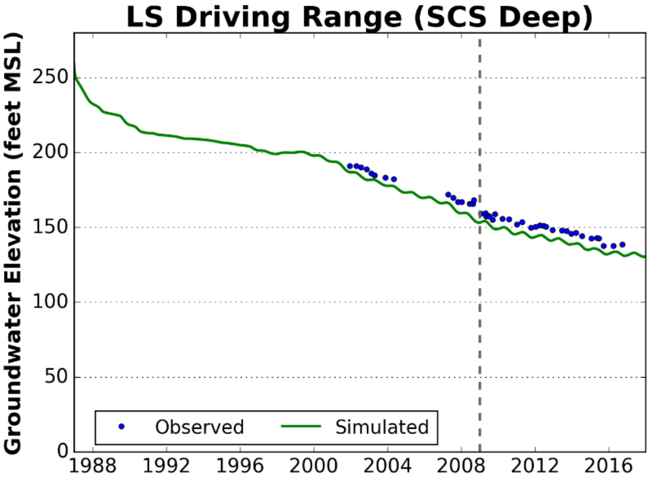
GROUNDWATER ELEVATION CALIBRATION

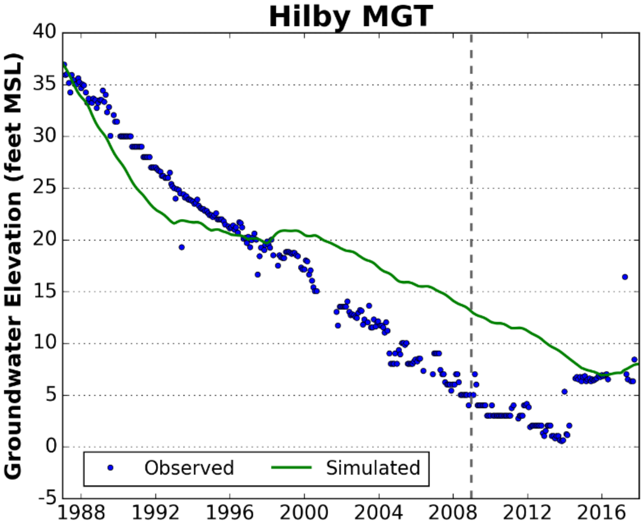
Groundwater flow model calibration is evaluated by comparing simulated groundwater elevations with observed groundwater elevations from monitoring and production wells. Hydrographs of simulated groundwater elevations should generally match the trends and fluctuations observed in measured hydrographs. Furthermore, the average errors between observed and simulated groundwater elevations should be relatively small and unbiased. Unbiased means that simulated groundwater levels should not be either all higher or all lower than the observed values. For wells screened over multiple model layers,


MPWMD FO-04 Shallow


Bishop 2


Ryan Ranch 8


LS Driving Range (SCS Deep)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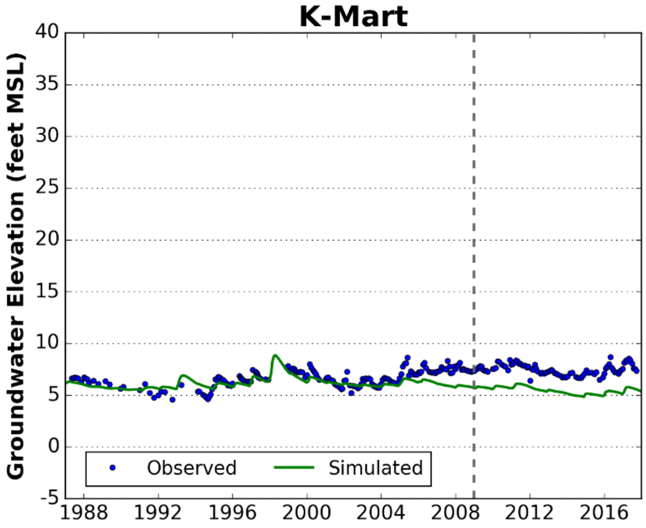
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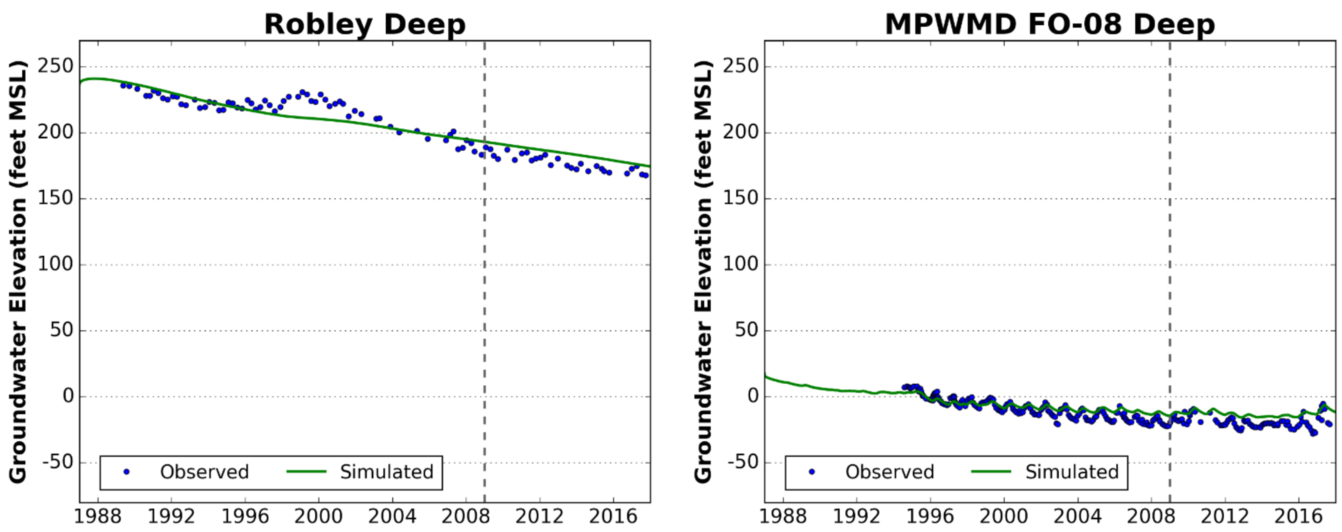
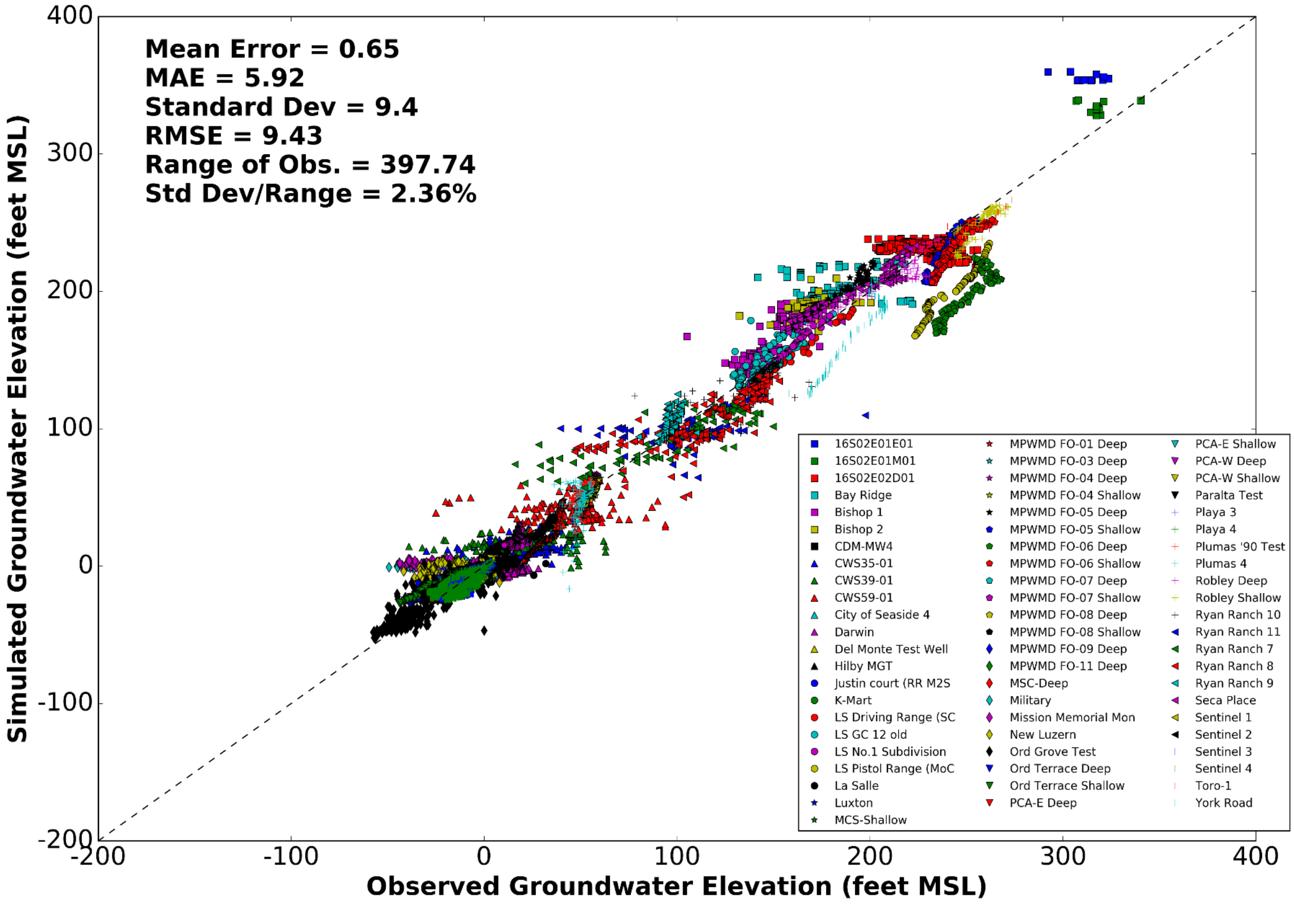
simulated groundwater levels in each of the layers were weighted by layer transmissivity and averaged before comparing with measured data.



Example hydrographs showing both observed and simulated groundwater elevations are shown in Figure 4 through Figure 7. These example hydrographs were selected to demonstrate the model's accuracy in various parts of the Seaside Groundwater Basin.



The hydrographs show that the updated model accurately simulates both the magnitude of groundwater fluctuations and trends observed in monitoring well data throughout the basin. A complete set of hydrographs showing both observed and simulated groundwater elevations are included in Appendix A.

Various graphical and statistical methods can be used to demonstrate the magnitude and potential bias of the calibration errors. Figure 8 shows all simulated groundwater elevations plotted against observed groundwater elevations for each month in the updated calibration period. Results from an unbiased model will scatter around a dashed line with a slope of 45° on Figure 8. If the model has a bias such as consistently exaggerating or underestimating groundwater level differences, the results will diverge from this line. The dashed line drawn on Figure 8 demonstrates that the results suggest that in general the model results are not biased towards overestimating or underestimating average groundwater level differences.

The four statistical measures used to evaluate calibration are the mean error (ME), the mean absolute error (MAE), the standard deviation of the errors (STD), and the root mean squared error (RMSE). These statistical measures are included on Figure 8. These statistical measures take into consideration all wells in the model with groundwater level data.

Figure 4: Hydrographs – Northern Coastal Subarea

Right of the dashed line represents the model period added as part of this model update

Figure 5: Hydrographs – Laguna Seca Subarea

Figure 6: Hydrographs – Southern Coastal Subarea Right of the dashed line represents the model period added as part of this model update

Figure 7: Hydrographs – Outside Seaside Groundwater Basin

Right of the dashed line represents the model period added as part of this model update

Figure 8: Simulated Versus Observed Groundwater Elevations - All Data (1987–2017)

The mean error is the average error between measured and simulated groundwater elevations for data on Figure 8 through **Error! Reference source not found.**.

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

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

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

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

The standard deviation of the errors is one measure of the spread of the errors around the 45° line on Figure 8 through **Error! Reference source not found.**. The population standard deviation is used for these calculations.

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

The RMSE is similar to the standard deviation of the error. It also measures the spread of the errors around the 45° line on Figure 8 through **Error! Reference source not found.**, and is calculated as the square root of the average squared errors.

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

As a measure of successful model calibration, Anderson and Woessner (1992) state that the ratio of the spread of the errors to the total head range in the system should be small to ensure that the errors are only a small part of the overall model response. As a general rule, the RMSE should be less than 10% of the total head range in the model.

The RMSE for the entire simulation period is 9.4 feet. This is approximately 2.4% of the total range of observed groundwater elevations of 397.7 feet. Table 1 provides a comparison of calibration statistics for both the original 2009 model and the 2018 recalibrated model. The table shows that overall, the 2018 updated and recalibrated model simulates groundwater levels better than the 2009 model.

Table 1: Comparison of 2009 Model Calibration and 2018 Recalibration Statistics

Statistical Measure	**2009 Calibration**	**2018 Recalibration**
Mean Error	2.18	0.65
Mean Absolute Error (MAE)	7.4	5.9
Standard Deviation	12.9	9.4
Root Mean Squared Error (RMSE)	12.9	9.4
Standard Deviation/Range	2.9%	2.4%

A second general rule that is occasionally used is that the absolute value of the mean error should be less than 5% of the total head range in the model. The mean error for the entire simulation period is 0.65 feet. This is approximately 0.2% of the range of observed groundwater elevations. These results indicate that the model is in good calibration after the model update and recalibration of the Salinas Valley boundary condition.

A second graph type used to evaluate bias in model results is shown on Figure 9. This figure shows observed groundwater elevations versus model residual (observed elevation minus simulated elevation) for the entire model period. A residual value of zero would indicate the model exactly simulating the observed groundwater elevation. Residual values greater than zero indicate that the model has underestimated observed groundwater levels, and residuals less than zero indicate the model has overestimated the observed groundwater level. Results from a non-biased simulation will appear as a cloud of residual points evenly distributed both above and below zero model residual line. Results that do not cluster around the zero residual line show potential model bias. Results that display a trend instead of a random cloud of points may suggest additional model bias.

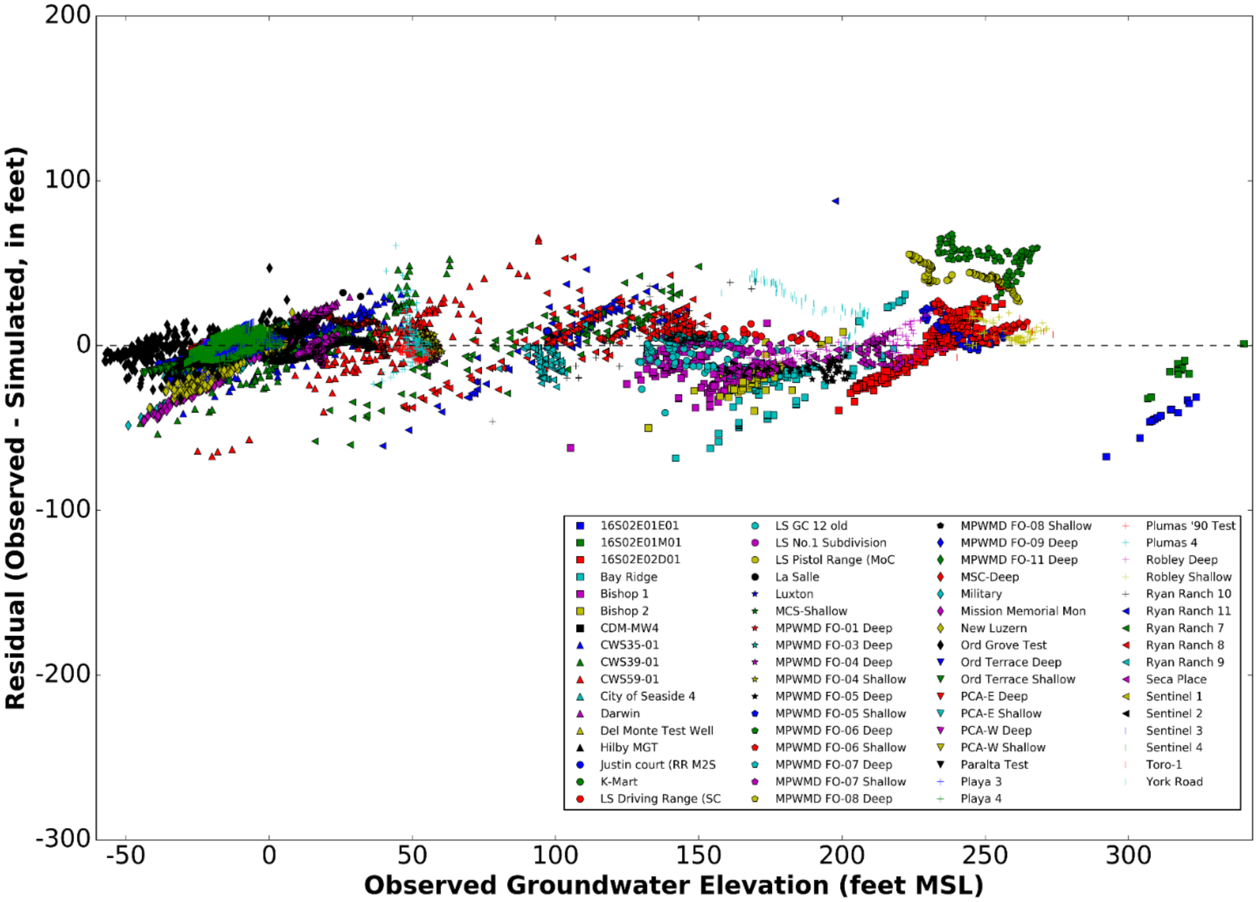


Figure 9: Observed Groundwater Elevations Versus Model Residual - All Data (1987–2013)

The residuals plotted on Figure 9 show that overall the calibrated model is not strongly biased to either overestimating or underestimating observed groundwater levels. There are however, some individual wells that show bias towards overestimation or underestimation, as well as some wells that show trends that may indicate other types of model bias. There are a number of individual well hydrographs in Appendix A with simulated groundwater levels that do not correspond well with observed levels. Generally, these are production wells that are screened in multiple aquifers/model layers, e.g., Northern Coastal Subarea wells: Military, Mission Memorial Monitor (former production well), and City of Seaside 3. Without field spinner (flow) testing to determine how much groundwater each aquifer is contributing to the well, only an estimate of each aquifer's contribution can be simulated by the model. The difference in modeled levels and observed levels can be attributed to this estimate not being correct and/or the model layers in this area requiring refinement. For example, , some production wells, such as City of Seaside 3 and City of Seaside 4, are located in the same model cell, and as such because of the model grid resolution, the model cannot accurately resolve the different groundwater level behavior at both wells.

As there is a mix of well simulated and less well simulated wells in the same area, there is confidence that the model is simulating groundwater levels acceptably in those areas, and that there no locational bias. Monitoring wells such as MSC-Shallow, MSC-Deep, Ord Grove Test, Del Monte Test, show much better correlation between simulated and observed groundwater levels. These wells are screened in a single aquifer/model layer which provides much more certainty in assigning it to a model layer.

Appendix A includes hydrographs for all wells so that it is clear that some wells are less well calibrated than others. It is impossible to simulate every well accurately, and thus the statistical measures described above have ranges of statistics that are considered acceptable. Statistical ranges such as the RMSE should be less than 10% of the total head range in the model, and the absolute value of the mean error should be less than 5% of the total head range in the model acknowledge that some wells will be less well calibrated than others.

Conclusions

1. Simulated groundwater levels are sensitive to the specified heads along the northeastern boundary with the Salinas Valley. The behavior of the boundary was found to impact the calibration of areas of the model at some distance from the boundary. It was found that in the absence of the most recent Salinas Valley Integrated Hydraulic Model (SVIHM), currently being developed by the USGS, assigning boundary head elevations that match the general observed average groundwater levels along the boundary is more important than capturing smaller scale seasonal fluctuations along the boundary. It is recommended that when the SVIHM has been completed, an assessment of how well it simulates historical groundwater conditions in the Seaside Basin be conducted. If it is concluded that the new data improves simulation of groundwater level in the Seaside Basin, the boundary condition can be revised using parts of the SVIHM that improve model calibration of the Seaside Basin model.

2. The model recalibration improved calibration statistics over the original 2009 model calibration. As a result, simulated groundwater levels throughout the model, as a whole, better match observed groundwater levels.

3. The groundwater model should be updated in a maximum of five years and its calibration reevaluated at that time. However, if groundwater related projects are implemented in the basin before that time, the update and calibration reevaluation may need to be performed sooner.

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A. HYDROGRAPHS

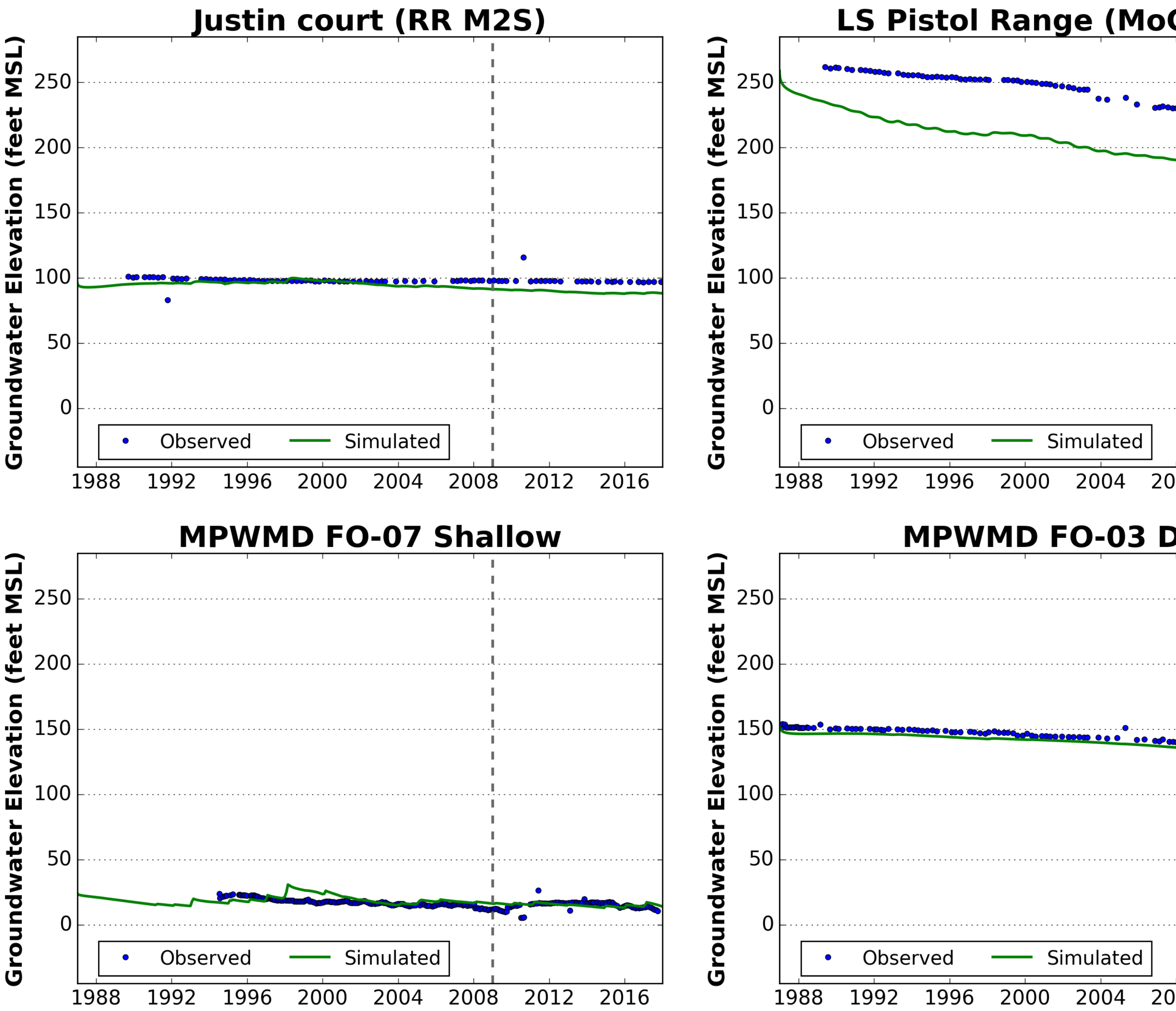


Figure A1: Northern Coastal Subarea Hydrographs

Figure A2: Northern Coastal Subarea Hydrographs

Figure A3: Northern Coastal Subarea Hydrographs

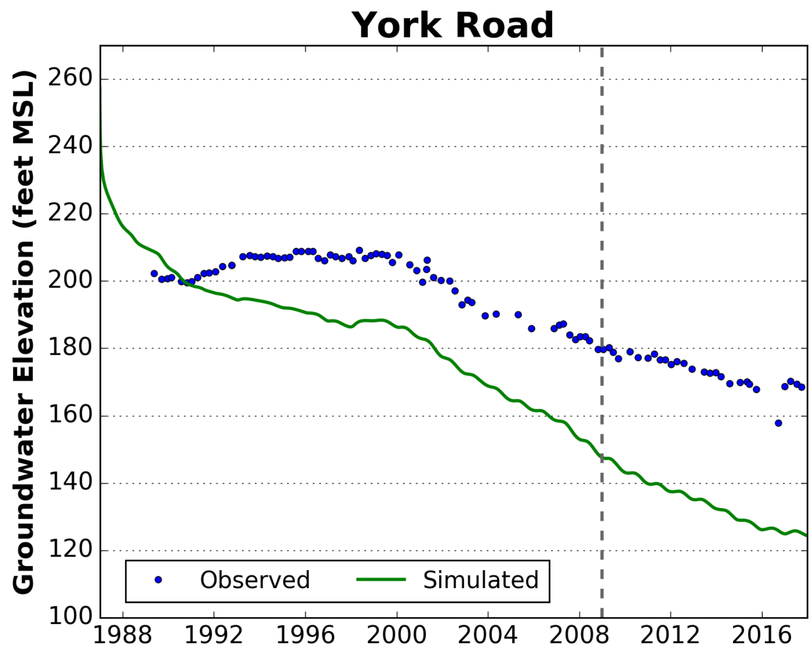
Figure A4: Northern Coastal Subarea Hydrographs

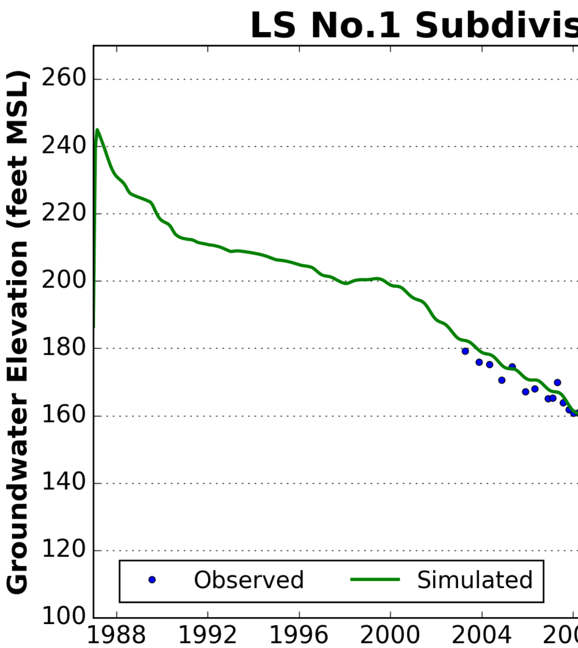
Figure A5: Northern Coastal Subarea Hydrographs

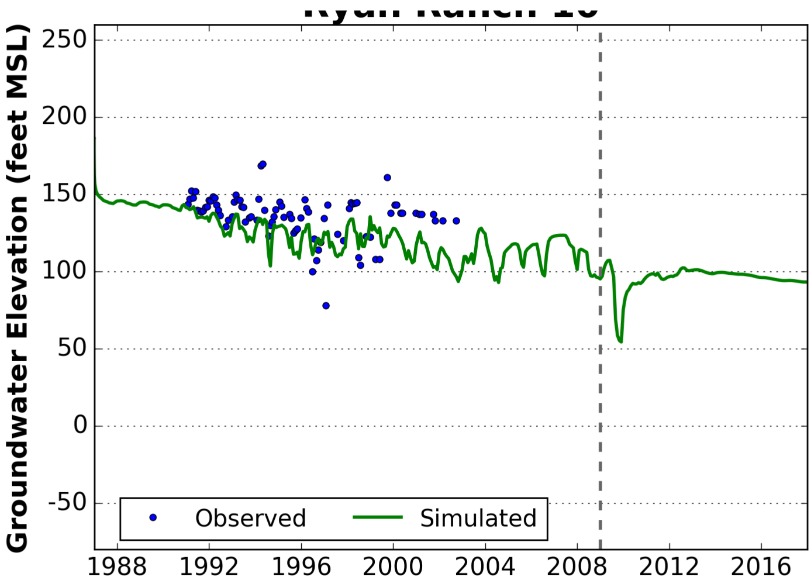
Figure A6: Southern Coastal Subarea Hydrographs

Figure A7: Southern Coastal Subarea Hydrographs

Figure A8: Laguna Seca Subarea Hydrographs







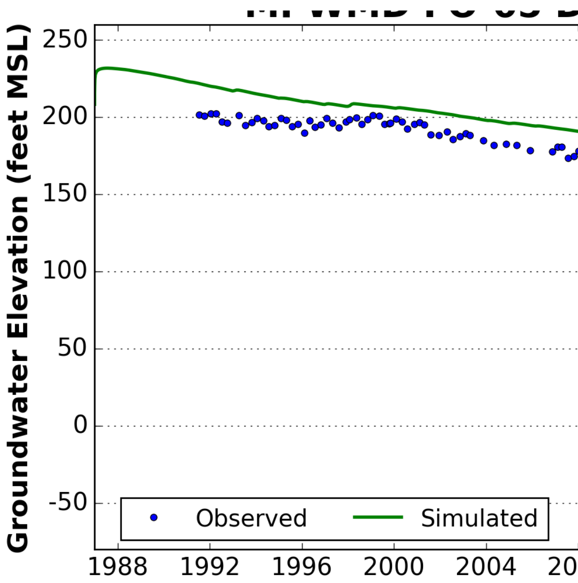


Figure A9: Laguna Seca Subarea Hydrographs

Figure A10: Laguna Seca Subarea Hydrographs

Figure A11: Laguna Seca Subarea Hydrographs

Figure A12: Laguna Seca Subarea Hydrographs

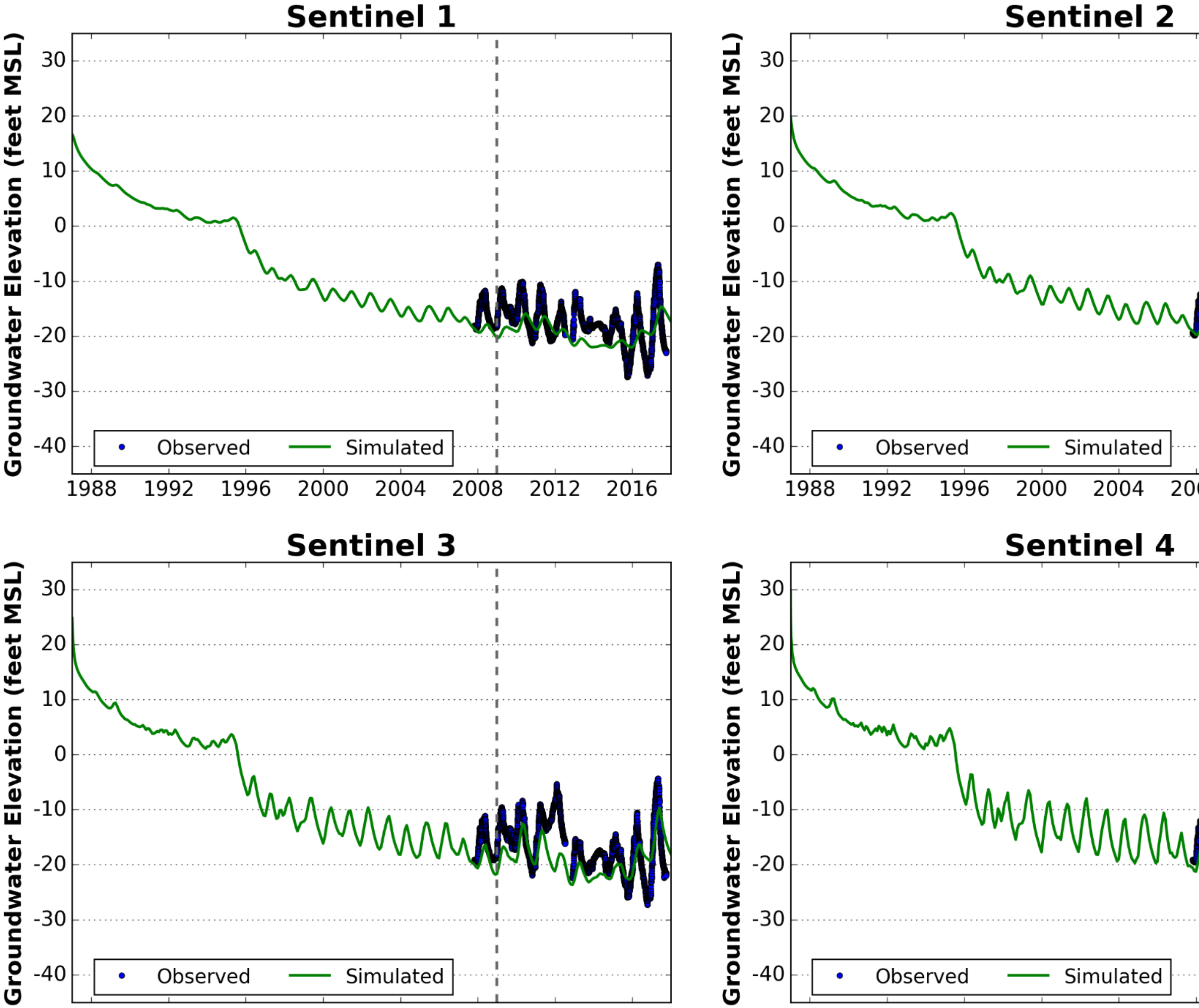


Figure A13: Hydrographs from Wells Outside of the Seaside Groundwater Basin

Figure A14: Hydrographs from Wells Outside of the Seaside Groundwater Basin

Figure A15: Hydrographs from Wells Outside of the Seaside Groundwater Basin

Figure A16: Hydrographs from Wells Outside of the Seaside Groundwater Basin

Figure A17: Hydrographs for Sentinel Wells