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TECHNICAL MEMORANDUM

To: Seaside Groundwater Basin Watermaster
Technical Advisory Committee

From: Stephen Hundt, Derrik Williams, and Georgina King

Date: July 31, 2014

Subject: 2014 Seaside Groundwater Model Update

Background and Scope

This technical memorandum documents a recent update to the Seaside Basin groundwater model that extends the model simulation period to 2013. 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 required. A second part of the model update is to assess the performance of the model for the updated period and determine whether or not a recalibration of the model is needed.

The model was extended from its previous time frame of 1987 through 2008 to simulate conditions between 1987 and 2013. Model simulations were compared to the updated groundwater levels to determine the performance of the model for the entire model period, the original model period, and the updated model period. The model remains in good calibration for the entire model period, but the model appears to have declining accuracy for the updated period. Additional changes are recommended, including a recalibration, to ensure the accuracy of the Seaside Basin groundwater model for future uses.

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 2009 and 2013.

Figure 1 shows the monthly pumping for the entire model period of 1987-2013. It can be seen that the pumping pattern of the updated period is consistent with the preceding years. No new wells were added to the model for the updated period, but the position of the ASR wells 3&4 were moved to correct their former misplacement in the model.

DEEP GROUNDWATER RECHARGE

The amount of deep groundwater recharge that is received by 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, 2009). 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 that extend into the model to 2013. System loss data was obtained from MPWMD for Cal-Am water delivered to customers. Precipitation data was downloaded from the Utah Climate Center to extend the Monterey (Coop No. 45795) and Salinas (Coop No. 47668) station data. Similarly, evapotranspiration data was downloaded from CIMIS for the Castroville station. The number of septic tanks in use was assumed to be the same as in 2008. The amount of runoff percolation occurring in the recharge ponds is estimated in the soil moisture balance model as a proportion of precipitation.

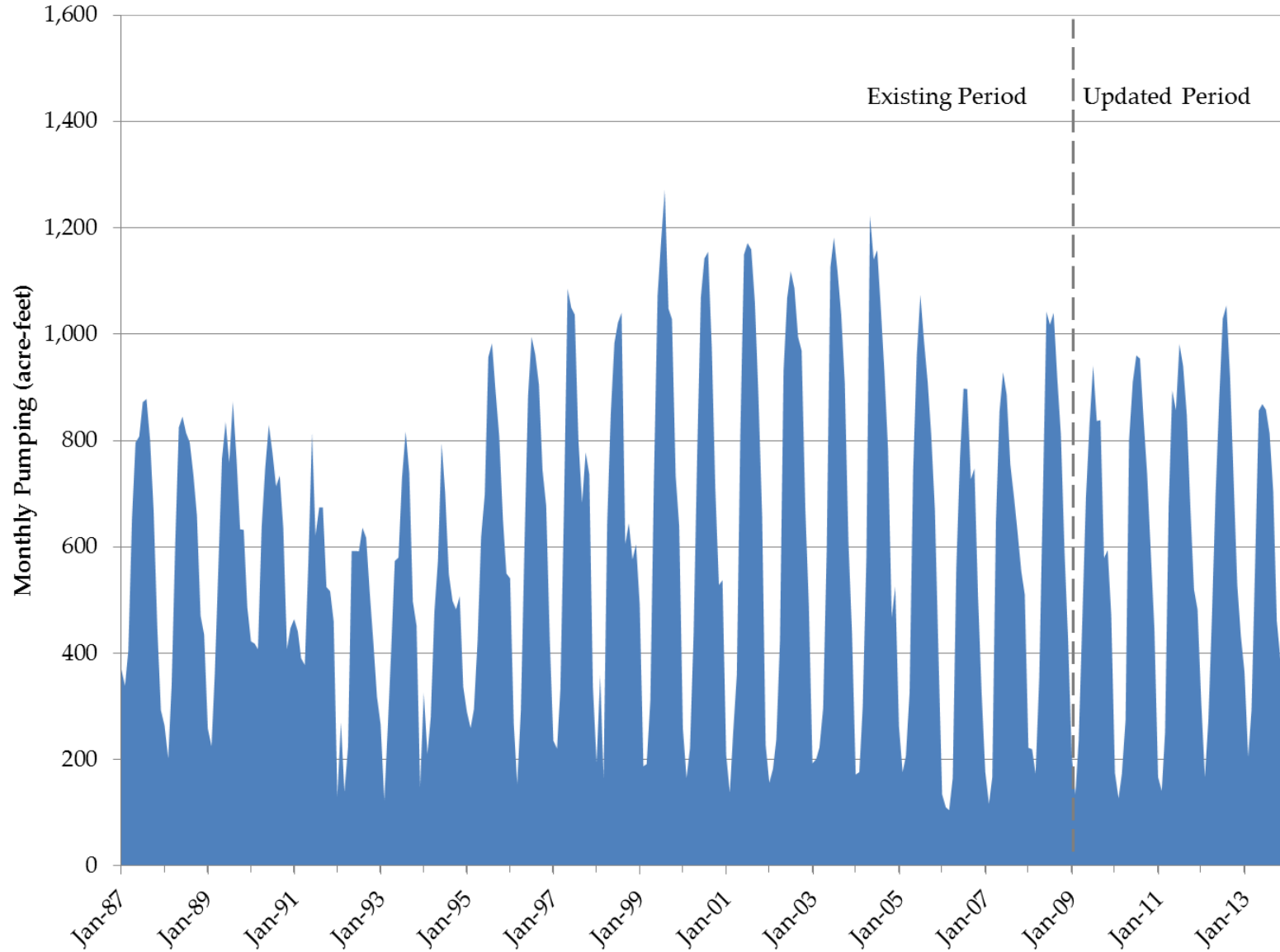


Figure 1: Total Monthly Pumping Rates

Figure 2 shows the total monthly deep groundwater recharge that is received by the model for every month between 1987 and 2013. 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.

GROUNDWATER LEVEL OBSERVATIONS

An updated set of groundwater level observations from wells in the Seaside Groundwater Basin were provided by MPWMD. This dataset covered the updated model period of 2009-2013. Observations collected from wells under operation at the time of measurement and other questionable values were removed from the dataset by MPWMD staff.

The updated groundwater level data were used to judge 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 provided by MPWMD. This process is described in greater detail in the section below.

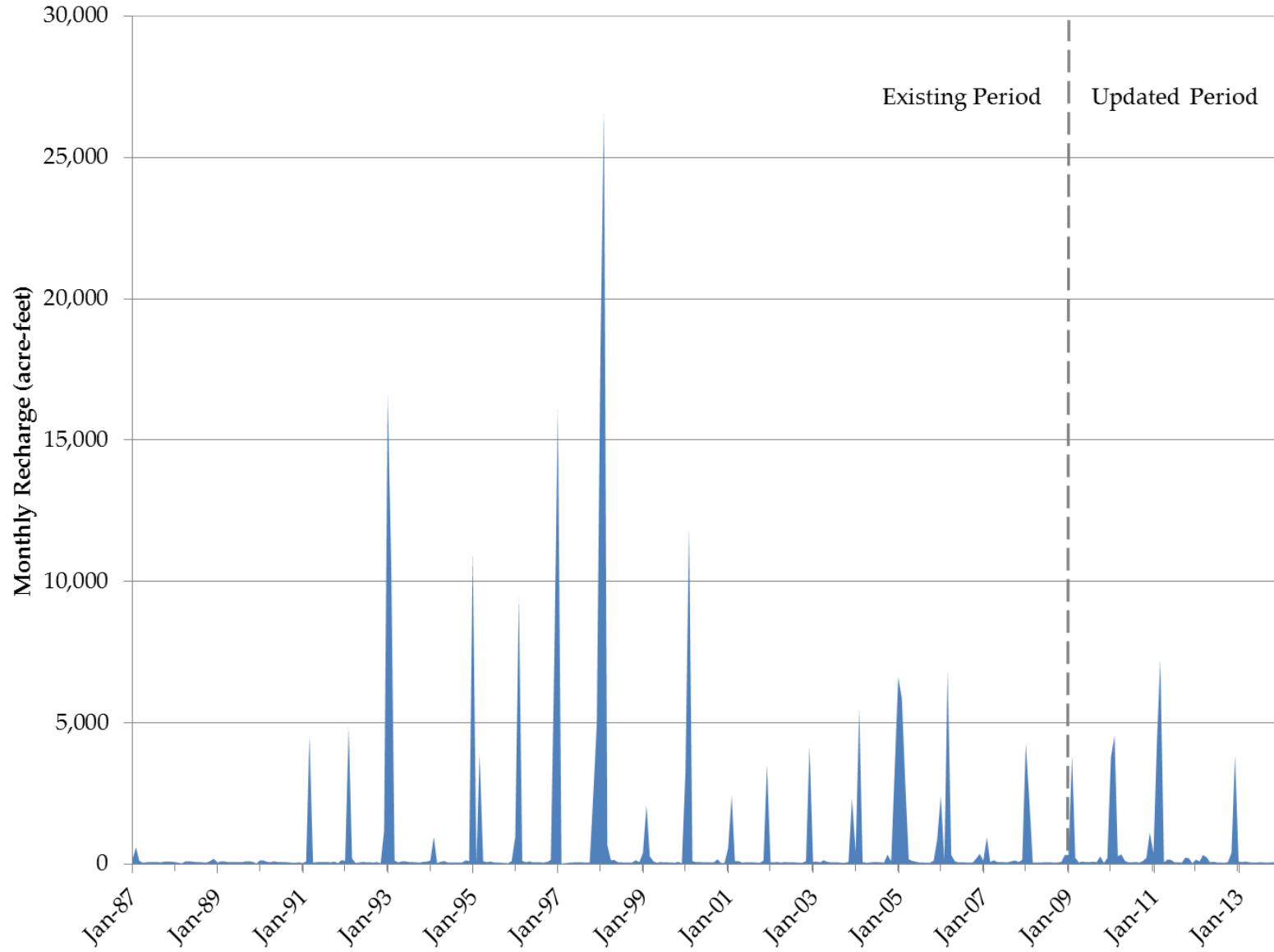


Figure 2: Monthly Recharge

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

For model years 1987-2004, the groundwater elevations assigned to model nodes along the northeastern boundary were derived from the Salinas Valley Integrated Groundwater Surface Water Model (SVIGSM). Wprime Inc. provided estimated groundwater elevations from a number of the SVIGSM nodes that are near the regional model boundary and these were interpolated onto the regional model boundary nodes.

SVIGSM model results were not available for model years 2005-2013. To approximate the groundwater elevations along the northeastern boundary for this period, the final 12 months of available SVIGSM results (from year 2004) were applied to each of the remaining years 2005-2013. As a result, the northeastern boundary repeats the same seasonal cycle for the final ten years of the simulation. Figure 3 shows the groundwater elevations at an example cell along the northeastern model boundary. Because no sensitivity analysis has been performed for this boundary of the model, we cannot say definitively what the impact is on the model. However, the boundary is over four miles away from the nearest Seaside Basin production wells which are located in the central portion of the Northern Coastal subarea. Groundwater flow gradients generated by these production wells have a greater influence on groundwater flow in the Seaside Groundwater Basin than the northern boundary.

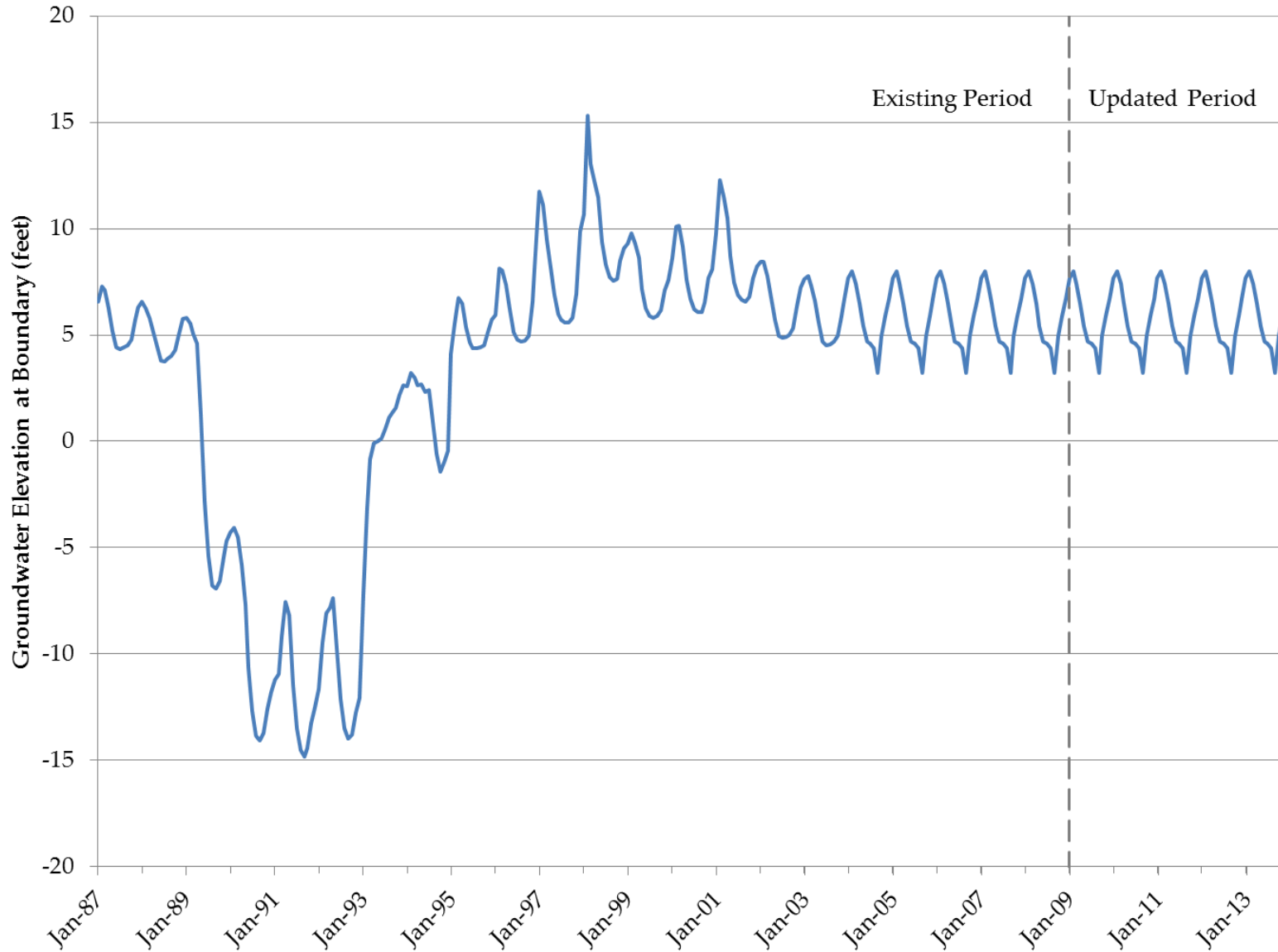


Figure 3: Groundwater Elevations at an Example Northeastern Boundary Cell

Results of Updated Model

The simulated groundwater levels of the updated groundwater model were compared to observed groundwater levels to assess whether a recalibration of the model is required.

The original calibration of the model of the model included data through December 2008. Calibrating the regional groundwater flow model involved successive attempts to match model output to measured data from this calibration period. The model was considered calibrated when simulated results matched the measured data within an acceptable measure of accuracy, and when successive calibration attempts did not notably improve the calibration statistics. However, in the time following the calibration period the groundwater system may experience stresses and observations (such as different pumping rates, new wells, or changing groundwater level trends) that were not included in the original calibration and that the model may not be able to faithfully reproduce. As a result, it is good practice to periodically revisit a groundwater model and adjust the calibration if it is deemed necessary.

The analysis focused on three time periods:

1. The entire period of the updated model; from January 1987 through December 2013
2. The period included before the model update; from January 1987 through December 2008
3. The updated period; January 2009 through December 2013

In the figures and results presented below a comparison was made between these three periods. These periods were singled out to reveal whether the updated period is simulated as well as the original calibrated period, and to determine the overall performance of the updated model.

GROUNDWATER ELEVATION CALIBRATION

Flow model calibration is commonly 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.

A complete set of hydrographs showing both observed and simulated groundwater elevations are included in Appendix A. These hydrographs include wells in the Northern Coastal Subarea, the Southern Coastal Subarea, the Laguna Seca Subarea, and outside of the Seaside Groundwater Basin. The green line shows the groundwater elevations that were simulated by the model, the blue dots show observed groundwater elevations, and the vertical dashed gray line indicates when the newly updated period begins in January 2009.

The following four sets of hydrographs, Figure 4 through Figure 7, demonstrate the accuracy of the model in various parts of the Seaside Basin. These wells generally show the model accurately reproducing the magnitudes of fluctuations and the trends of observed groundwater elevations. However, in several of the wells (MSC-Deep, Playa 4, K-Mart, MPWMD FO-8 Deep) the trends simulated by the model appear to diverge from the observed data during later time periods. This behavior suggests that a recalibration may be required to bring the model back into agreement.

Various graphical and statistical methods can be used to demonstrate the magnitude and potential bias of the calibration errors. Figure 8 through Figure 10 show simulated groundwater elevations plotted against observed groundwater elevations for the entire model period, the original period, and the updated period. Results from an unbiased model will scatter around a 45° line on this graph. If the model has a bias such as exaggerating or underestimating groundwater levels, the results will diverge from this 45° line.

For Figure 8 through Figure 10, the results tend to lie close to the 45° line, with a greater tendency to lie above the line than below. This suggests that model has a minor bias towards overestimating average groundwater levels. A comparison between the original period (Figure 9) and the new period (Figure 10) shows that the model overestimates groundwater elevations more during the updated period than during the original period.

Figure 8 through Figure 10 also include various statistical measures of calibration accuracy. The four statistical measures used to evaluate calibration are the mean error (ME), the mean absolute error (MAE), the standard deviation of the errors (STD), and the root mean squared error (RMSE).

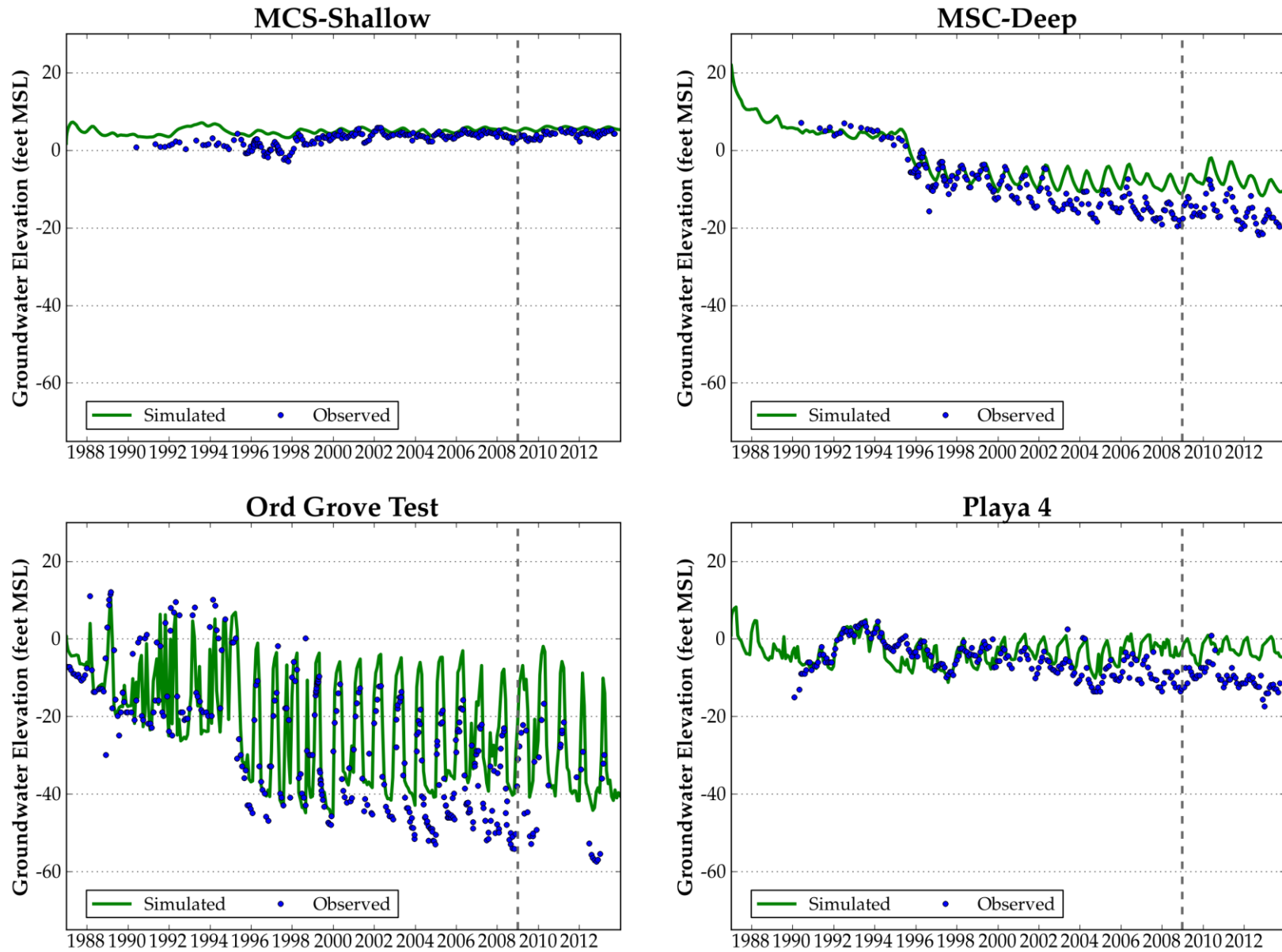


Figure 4: Hydrographs – Northern Coastal Subarea

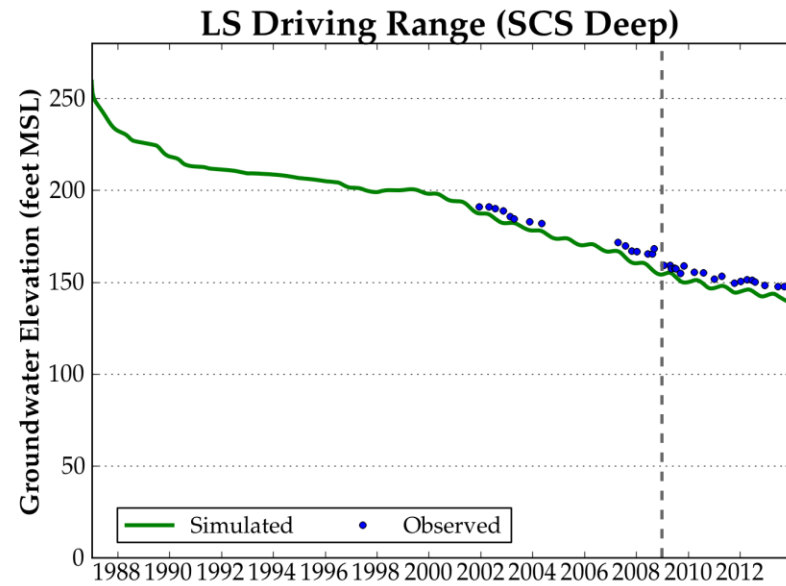
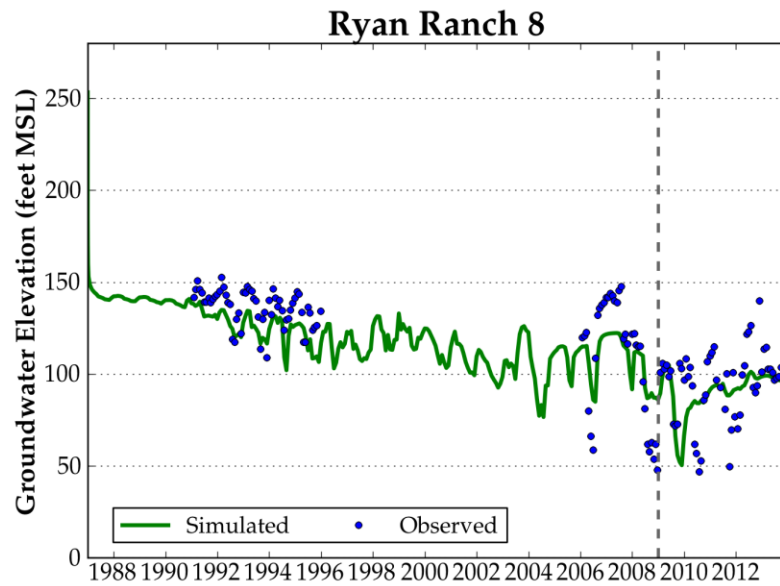
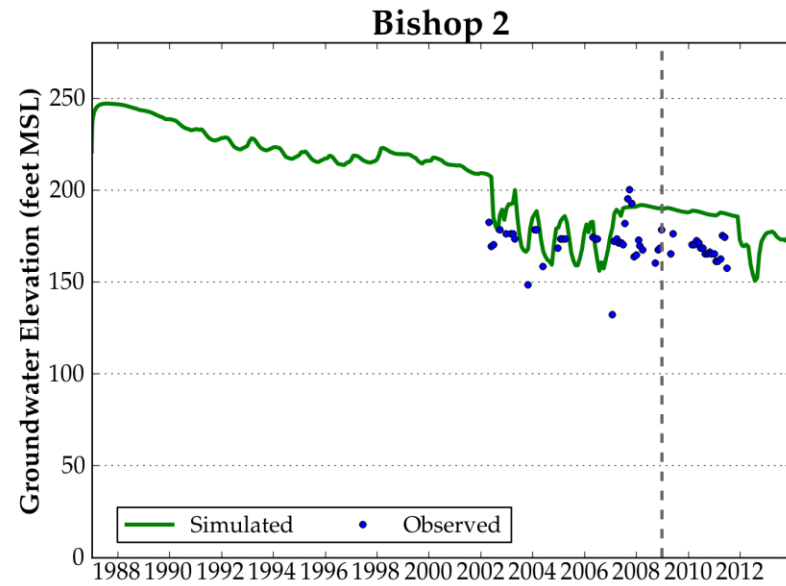
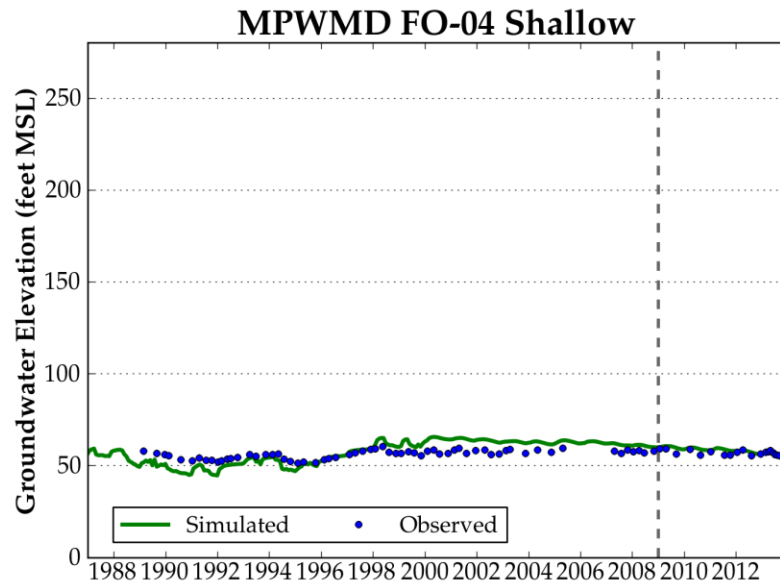


Figure 5: Hydrographs – Laguna Seca Subarea

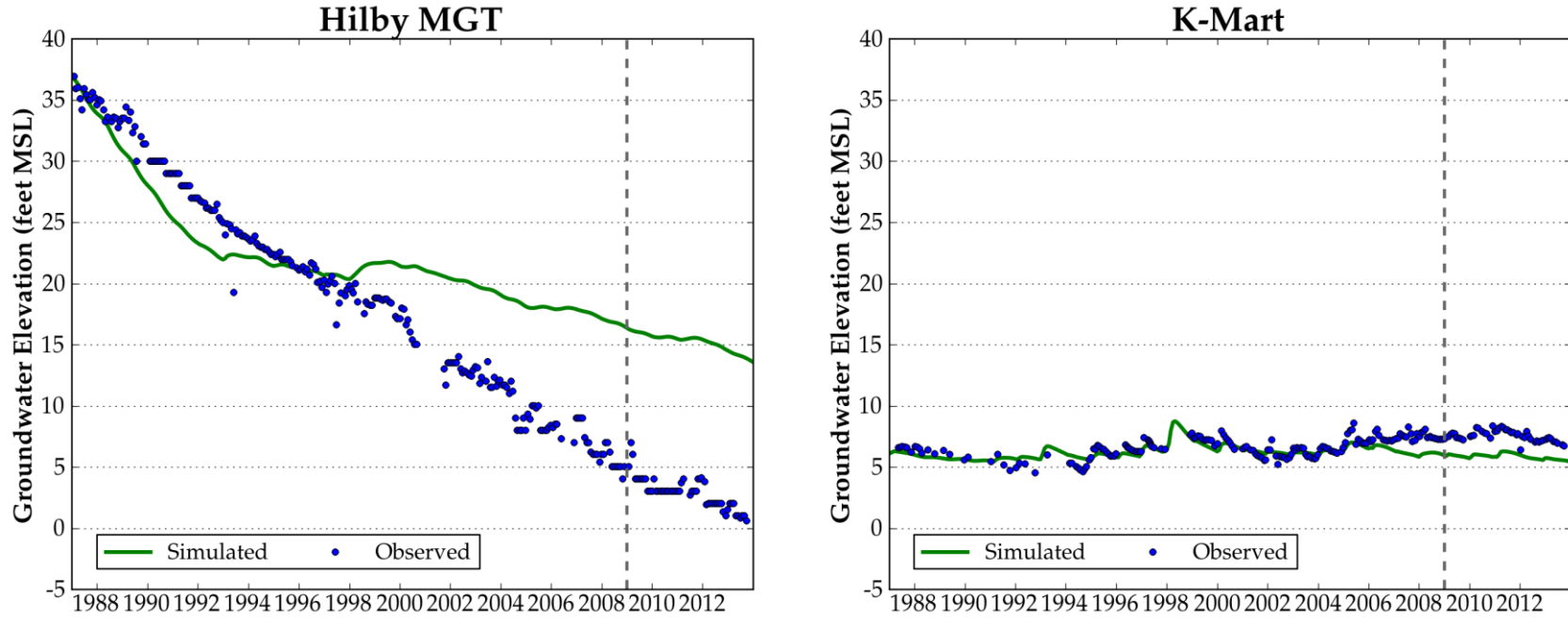


Figure 6: Hydrographs – Southern Coastal Subarea

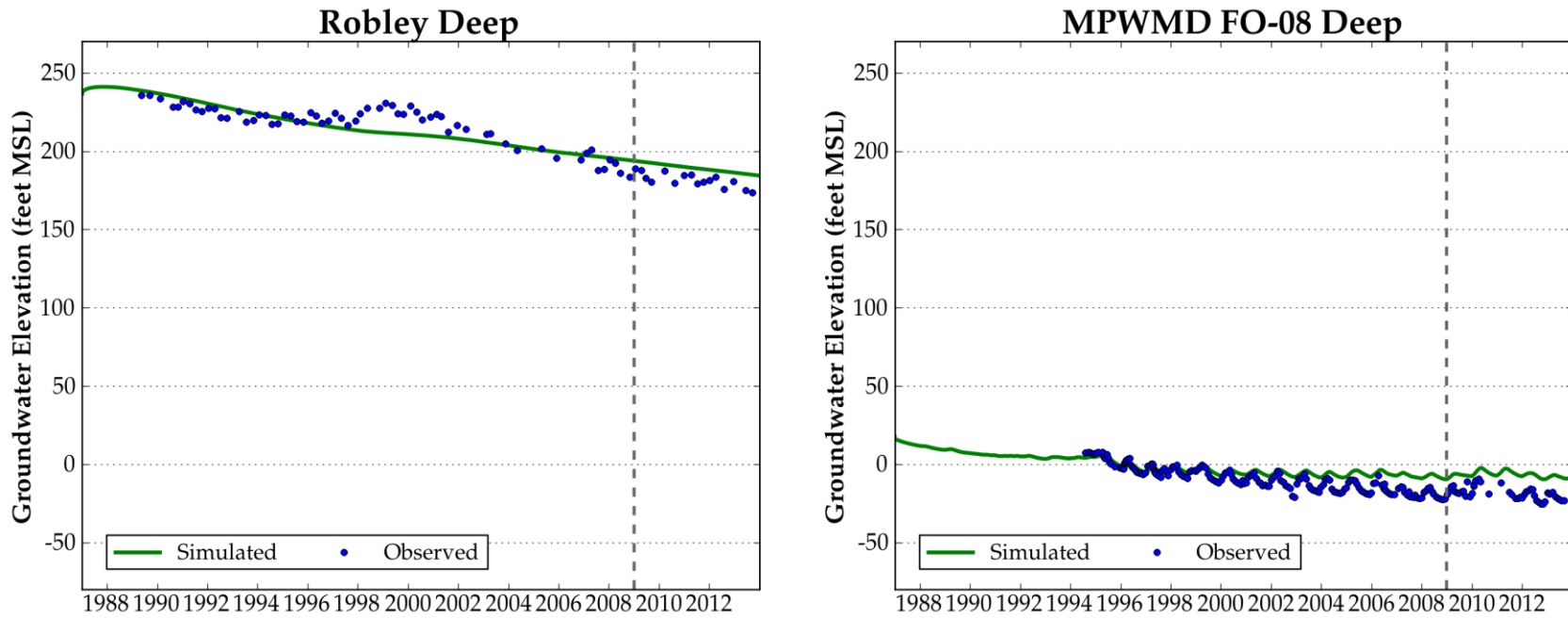


Figure 7: Hydrographs – Outside Seaside Groundwater Basin

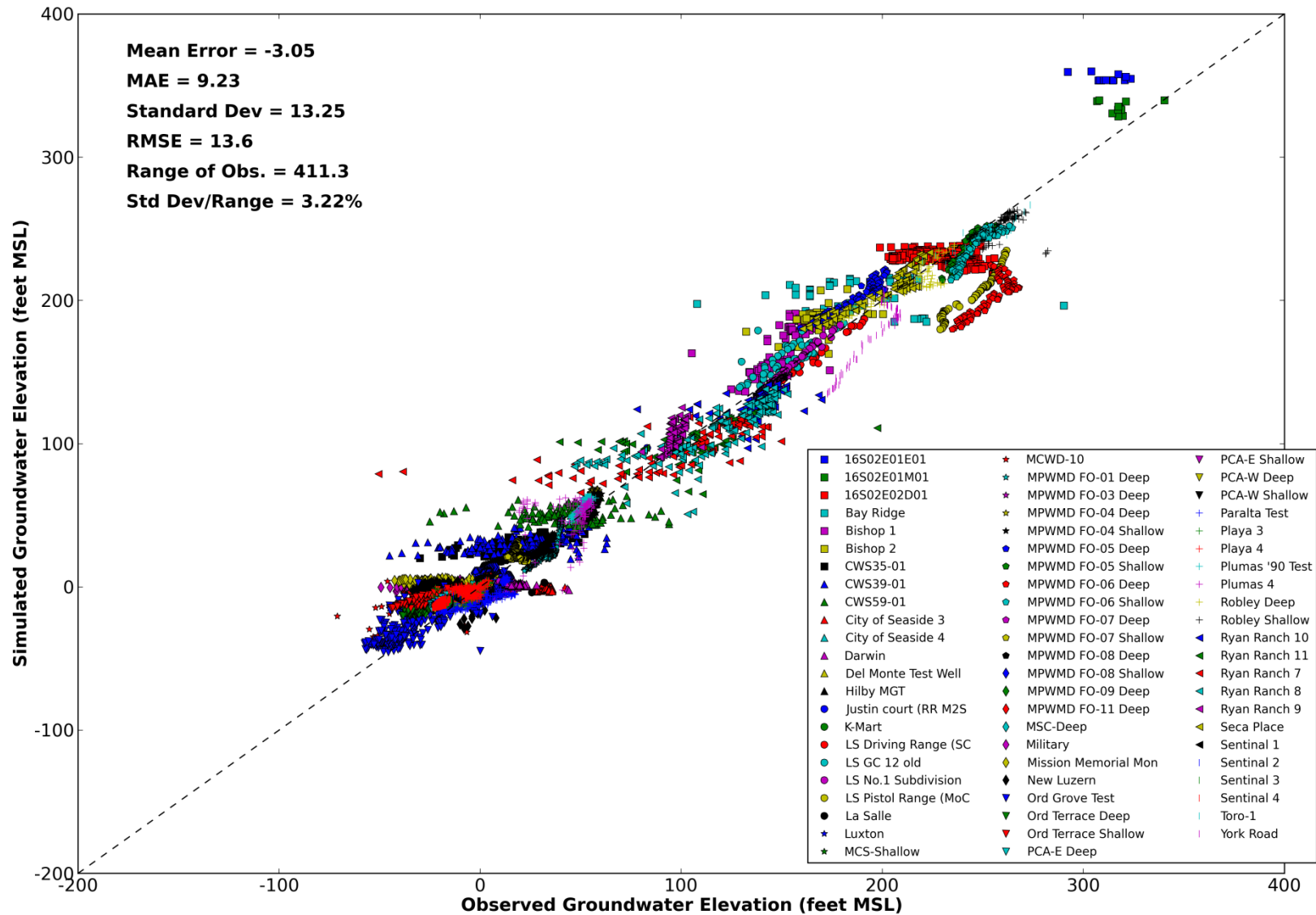


Figure 8: Simulated Versus Observed Groundwater Elevations - All Data (1987–2013)

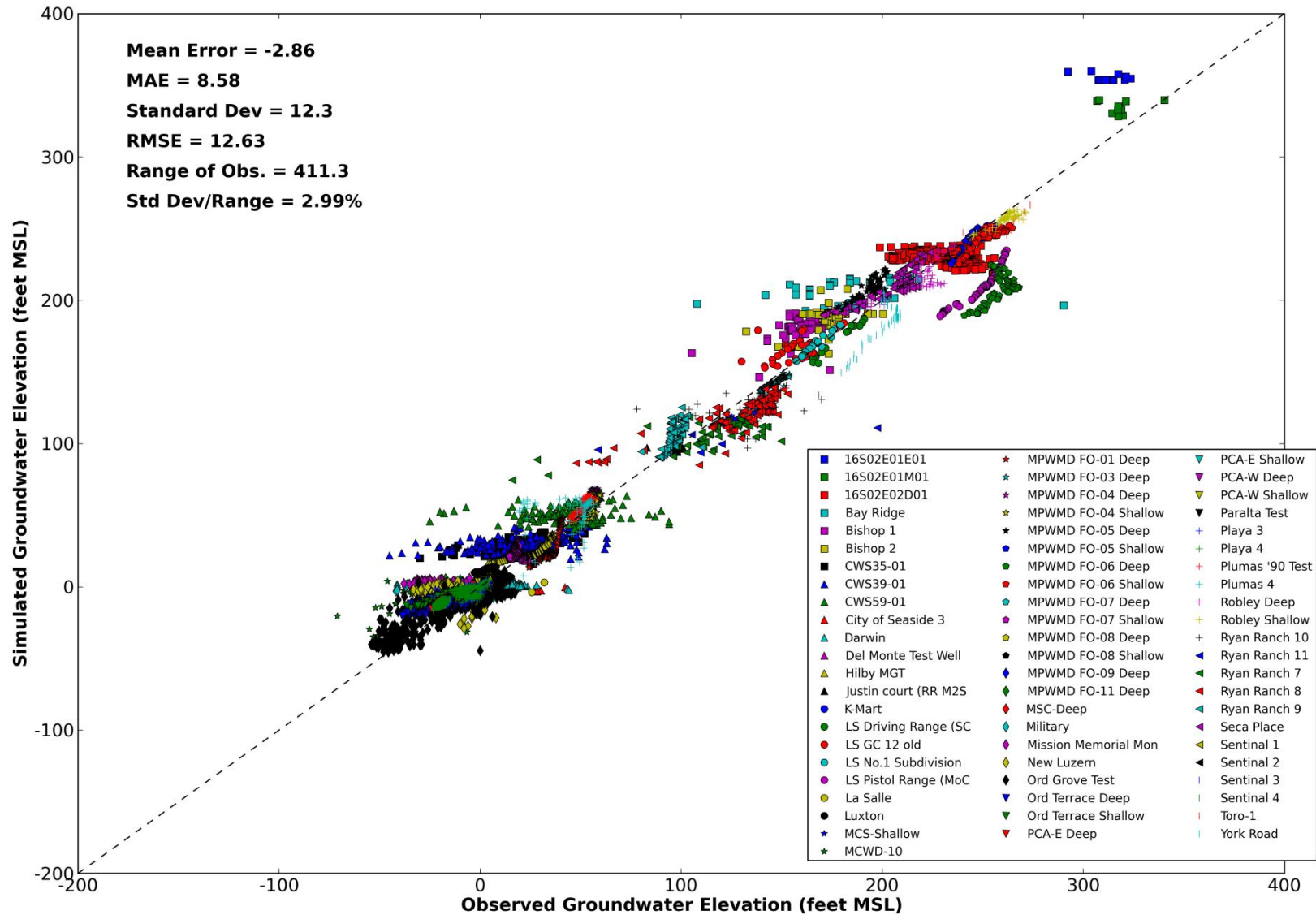


Figure 9: Simulated Versus Observed Groundwater Elevations - Existing Data (1987–2008)

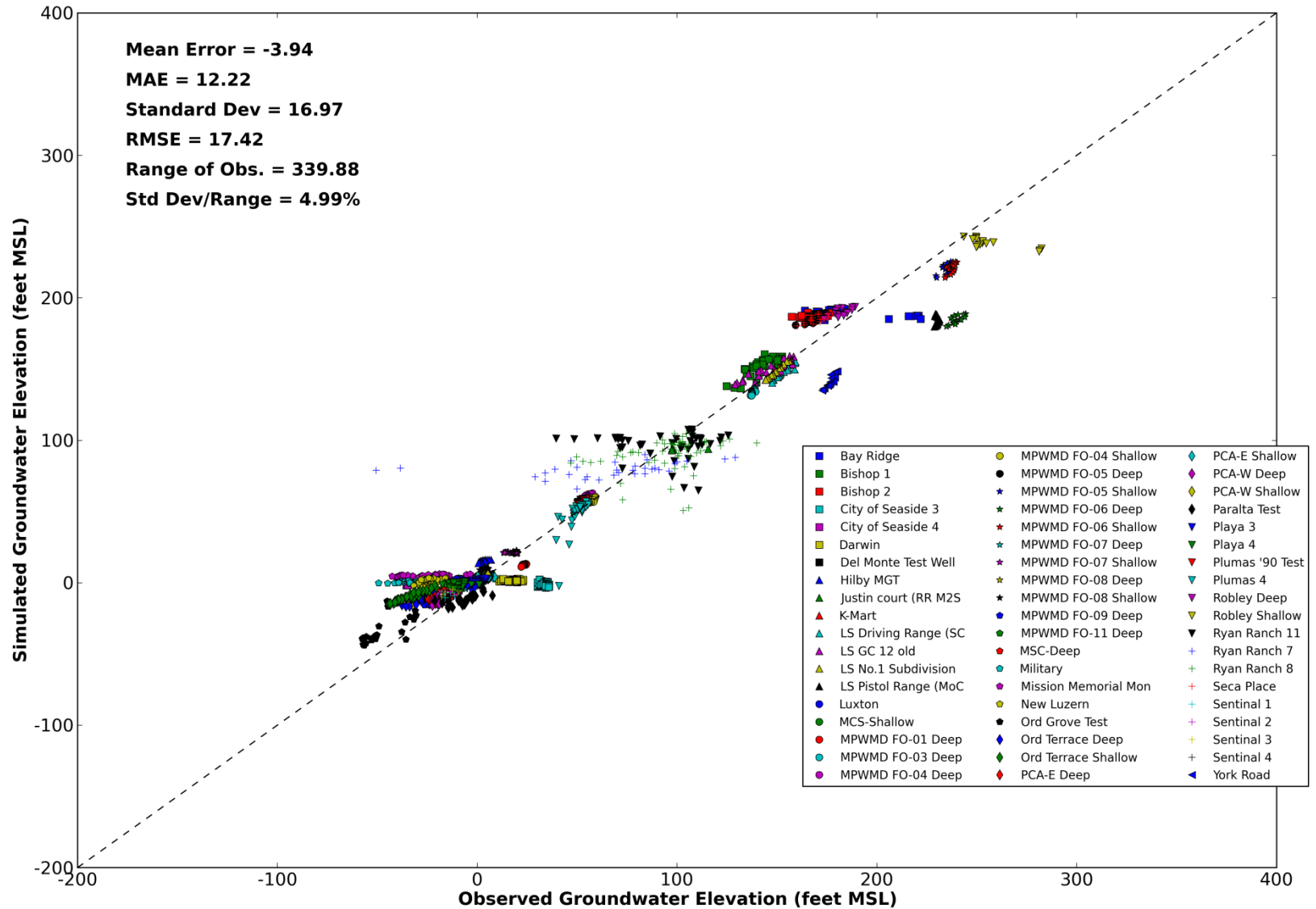


Figure 10: Simulated Versus Observed Groundwater Elevations - Updated Data (2009–2013)

The mean error is the average error between measured and simulated groundwater elevations for data on Figure 8 through Figure 10.

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

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.

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

The standard deviation of the errors is one measure of the spread of the errors around the 45° line on Figure 8 through Figure 10. The population standard deviation is used for these calculations.

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

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 Figure 10, and is calculated as the square root of the average squared errors.

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

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 13.25 feet. This is approximately 3.2% of the total range of observed groundwater elevations of 411.3 feet. For the original period the RMSE of 12.6 feet is 3.0% of the range of 411.3 feet. For the updated period the RMSE of 17.4 feet is 5.0% of the range of 339.9 feet.

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 -3.05 feet. This is approximately 0.7% of the range of observed groundwater elevations. For the original period the mean error of -2.86 feet is 0.7% of the range. For the updated period the mean error of -3.94 feet is 1.2% of the range.

On average, the model errors are within an acceptable range for all three periods analyzed. These results suggest that the model remains in good calibration after the updated period has been added, but that agreement between simulated and observed values begins to weaken for the updated period.

A second graph used to evaluate bias in model results is shown on Figure 11, Figure 12, and Figure 13. These figures graph the observed groundwater elevations versus model residual (observed elevation minus simulated elevation) for the entire model period, the original period, and the updated period. Results from a non-biased simulation will appear as a cloud of data points clustered around the zero model residual line. Results that do not cluster around the zero residual line show potential model bias. Results that display a trend instead of a random cloud of points may suggest additional model bias.

The results plotted on all three figures (Figure 11 through Figure 13) show that the calibrated model results have a minor bias towards overestimating high observed groundwater elevations. The greatest overestimations (points that fall below the horizontal zero line) appear for the updated period when observed groundwater elevations are low. In addition, all three periods appear to show trends for individual wells, indicating additional model bias.

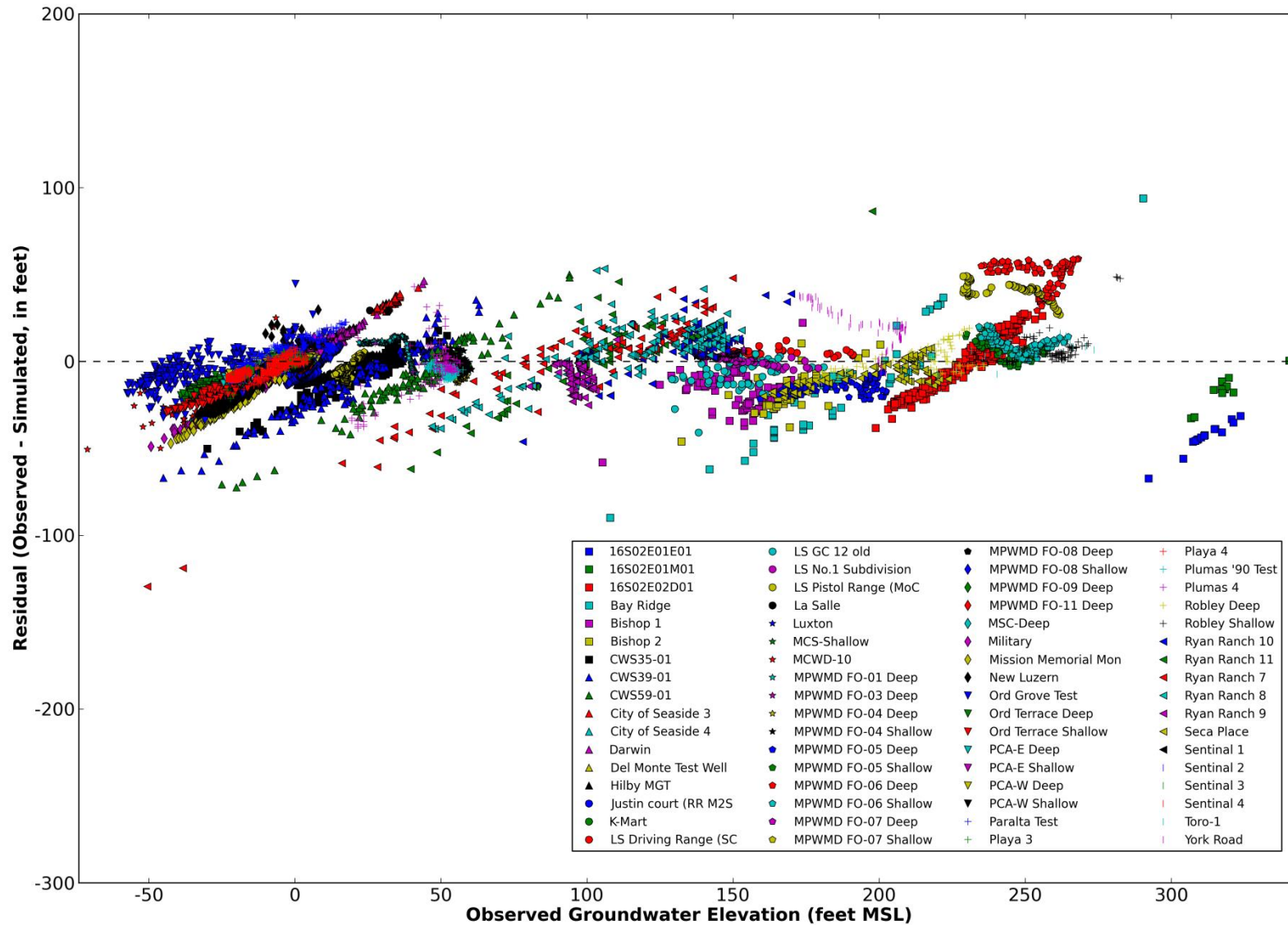


Figure 11: Observed Groundwater Elevations Versus Model Residual - All Data (1987–2013)

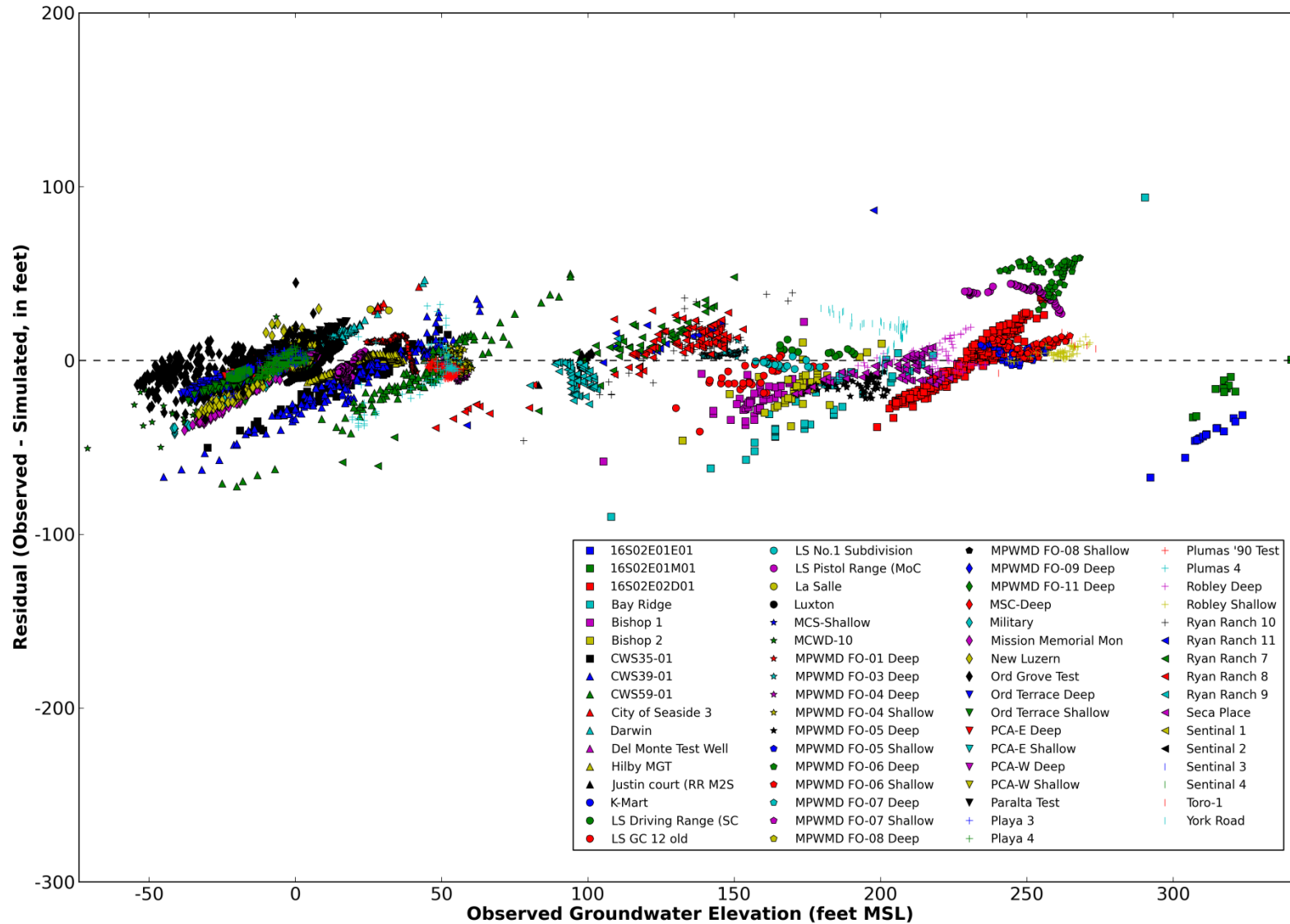


Figure 12 Observed Groundwater Elevations Versus Model Residual - Existing Data (1987-2008)

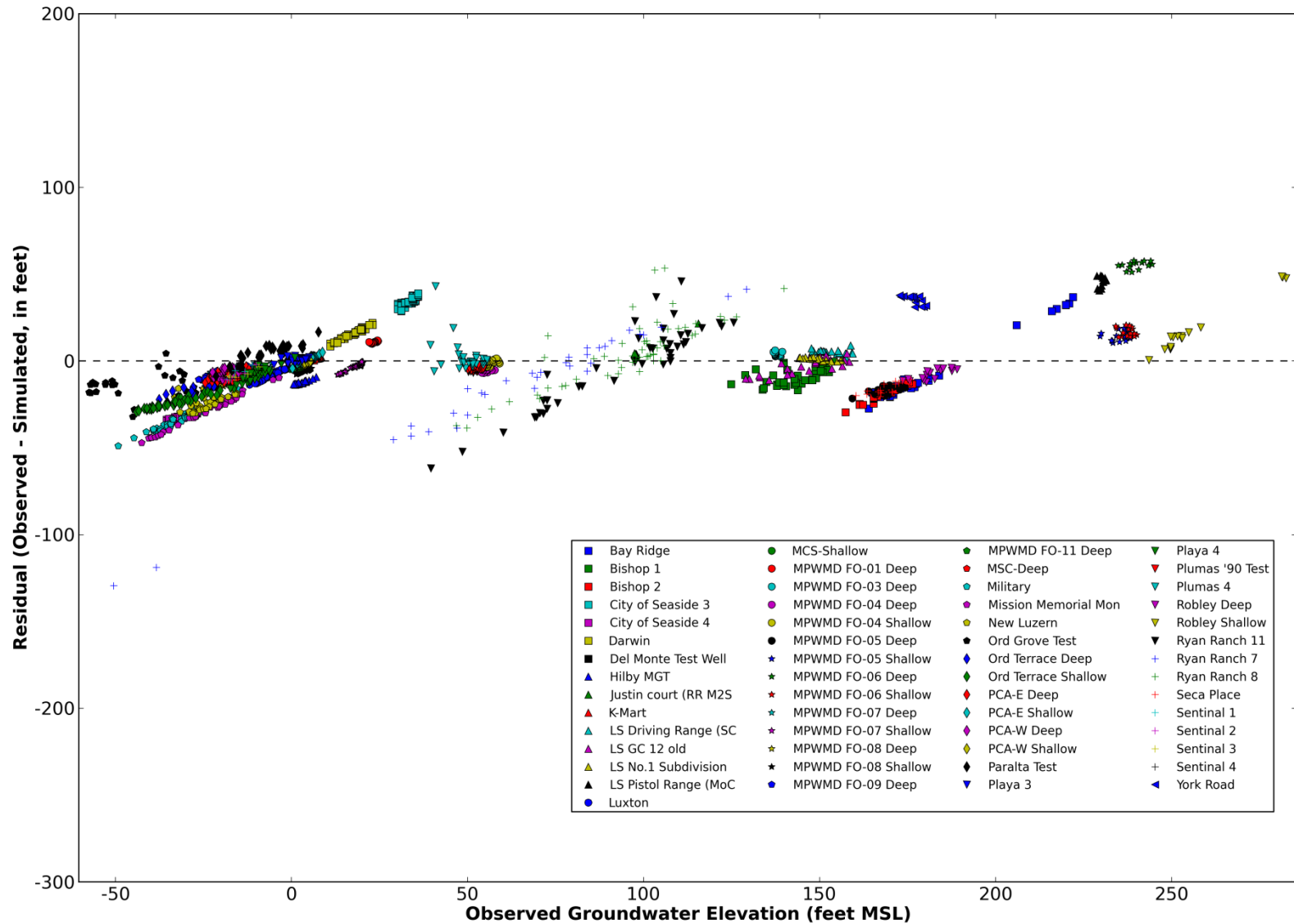


Figure 13: Observed Groundwater Elevations Versus Model Residual - Updated Data (2009–2013)

Conclusions

Four conclusions result from the model update:

1. The performance of the model for Laguna Seca subarea wells indicates that the model continues to provide reliable simulations for the Laguna Seca subarea (Appendix Figures A8 – A12). As a result, recent simulations of future groundwater conditions in the Laguna Seca subarea are plausible and can currently be trusted for making management decisions.
2. Although the performance of the model during the updated period is worsening, the calibration of the model remains within acceptable standards.
3. The northern boundary condition needs to be updated to reflect real groundwater elevation variations for the model period of 2005-2013. The behavior of the northern boundary will impact flows and the ability to calibrate the model for the area of the model that is adjacent to the northern boundary. An alternative method for defining this boundary condition will have to be developed that does not rely upon simulations from the Salinas Valley IGSM.
4. 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.

References

- Anderson, M.P., and W.W. Woessner. 1992. *Applied groundwater modeling, simulation of flow and advective transport*, Academic Press, Inc., San Diego, California, 381 p.
- HydroMetrics WRI. 2009. *Seaside Groundwater Basin Modeling and Protective Groundwater Elevations*, prepared for Seaside Groundwater Basin Watermaster. November.

APPENDIX A: HYDROGRAPHS

DRAFT

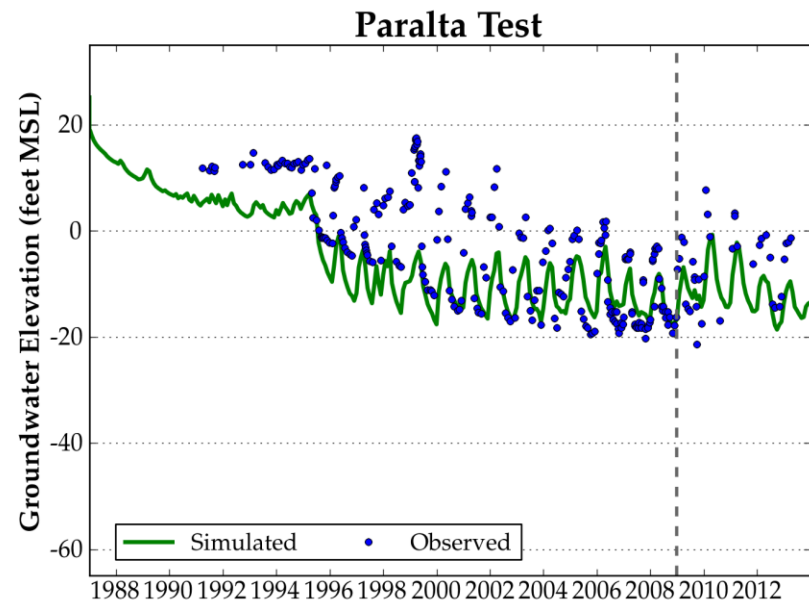
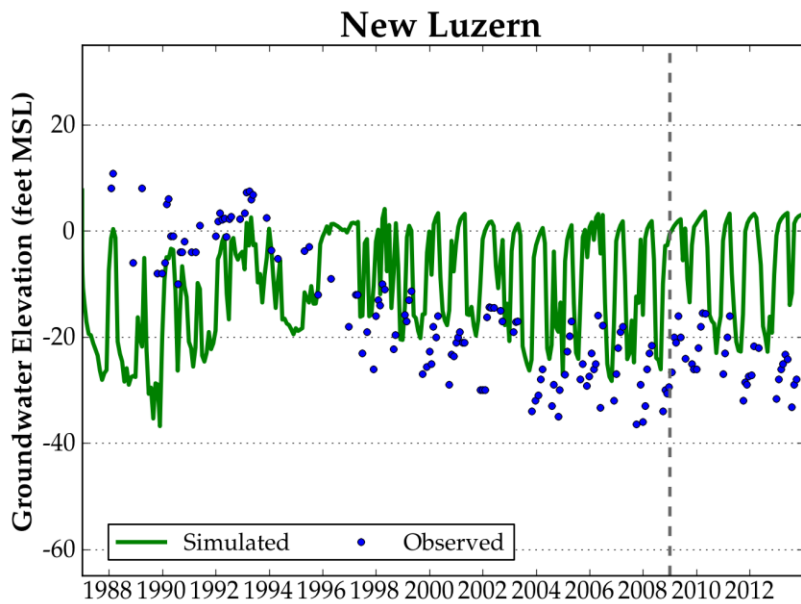
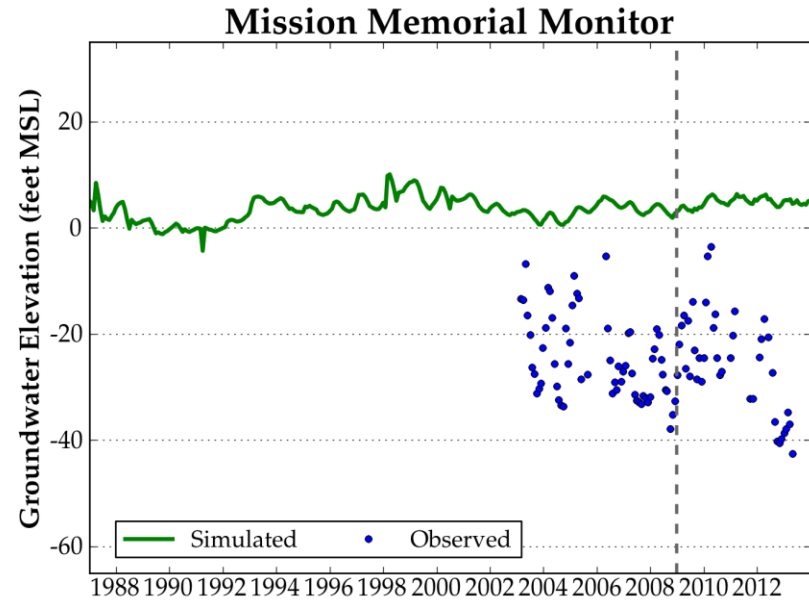
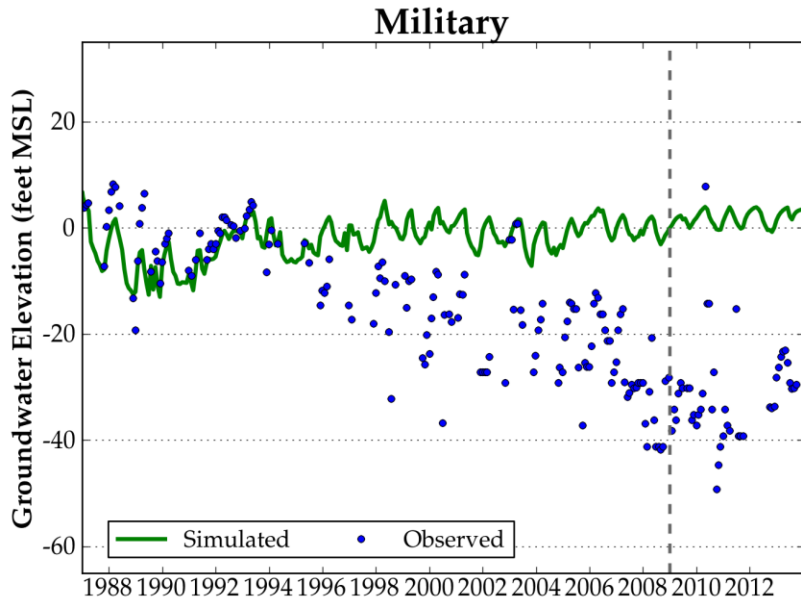


Figure A1: Northern Coastal Subarea Hydrographs

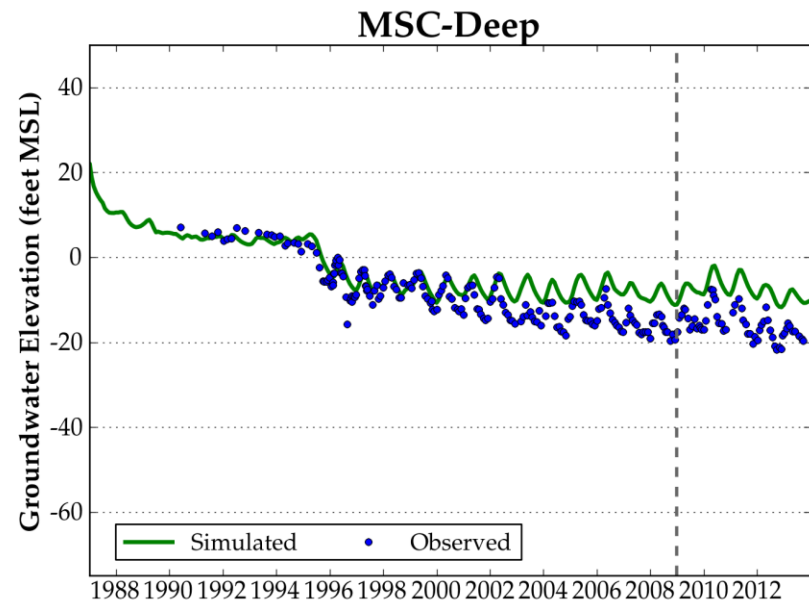
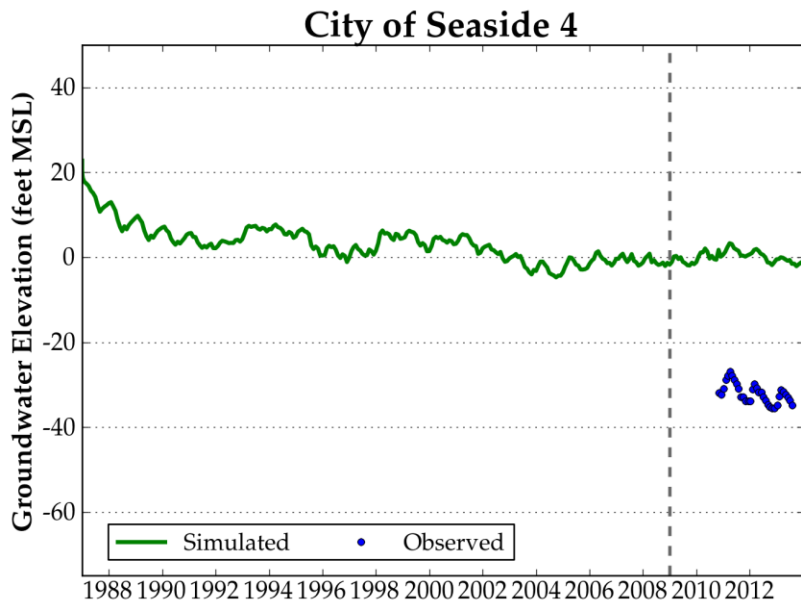
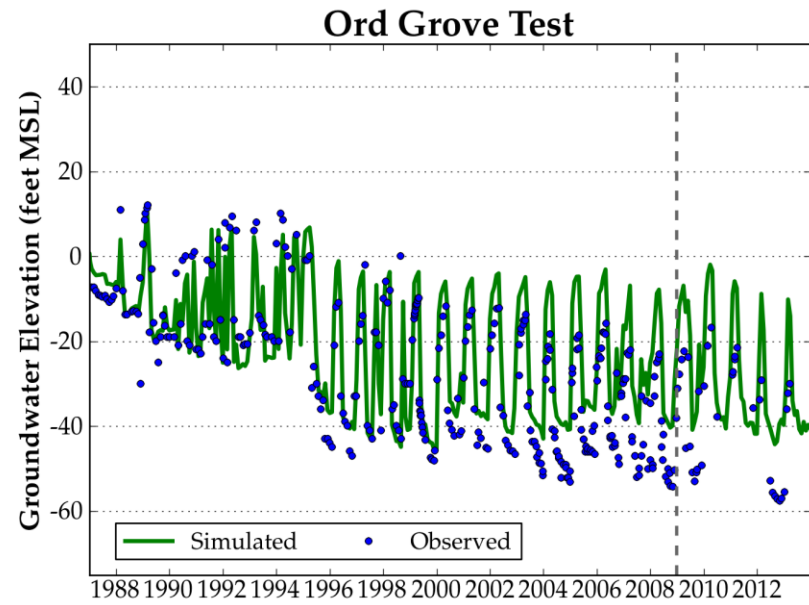
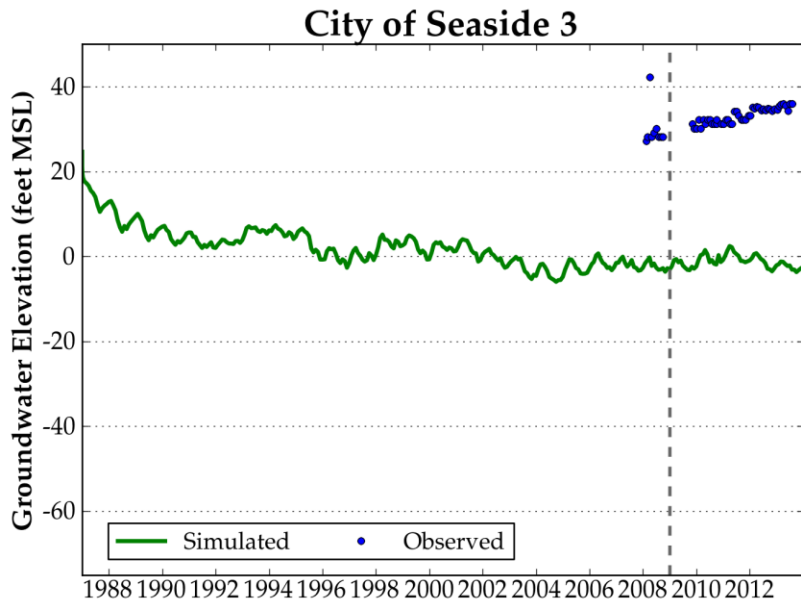


Figure A2: Northern Coastal Subarea Hydrographs

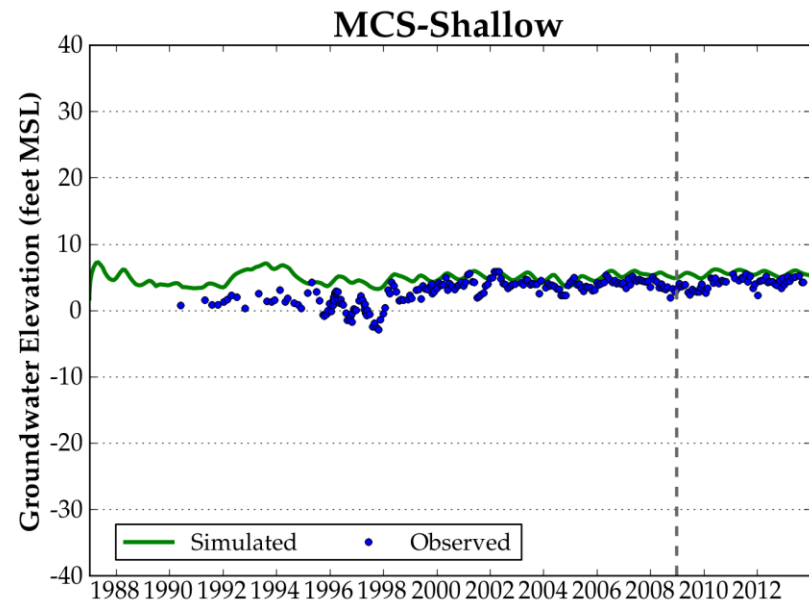
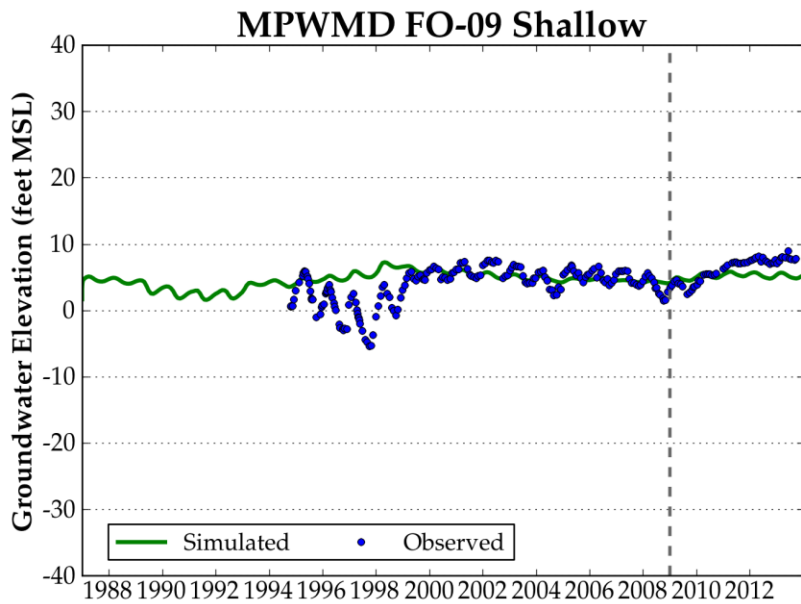
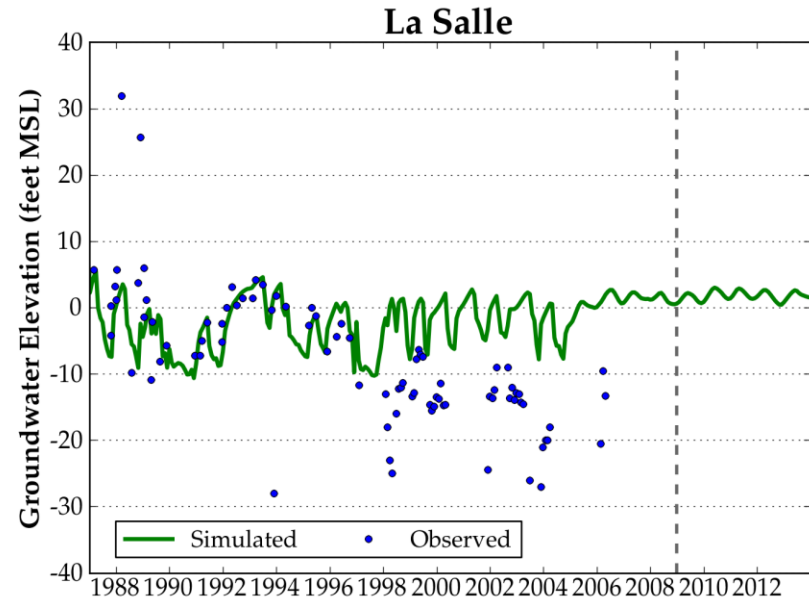
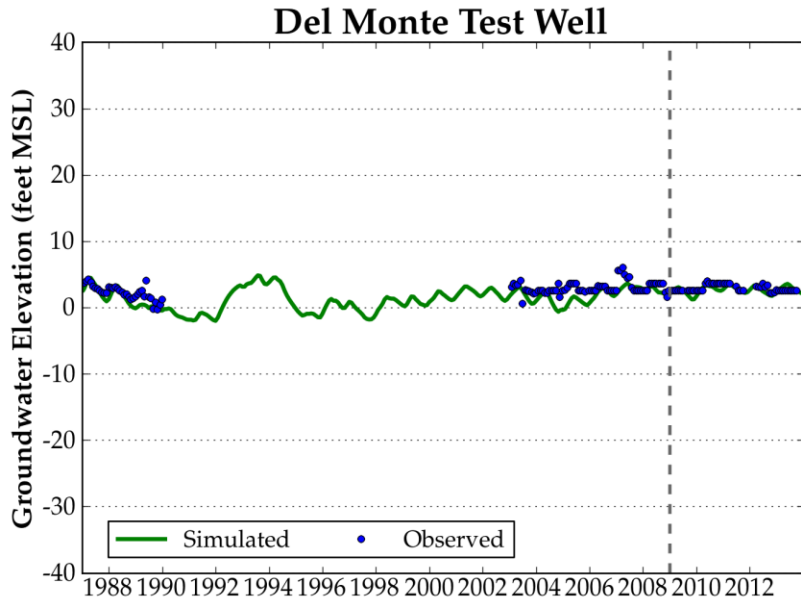


Figure A3: Northern Coastal Subarea Hydrographs

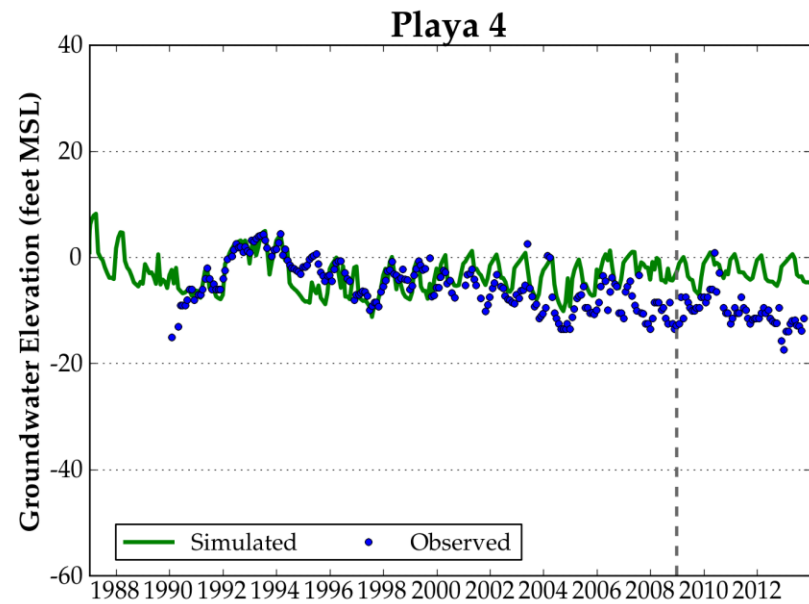
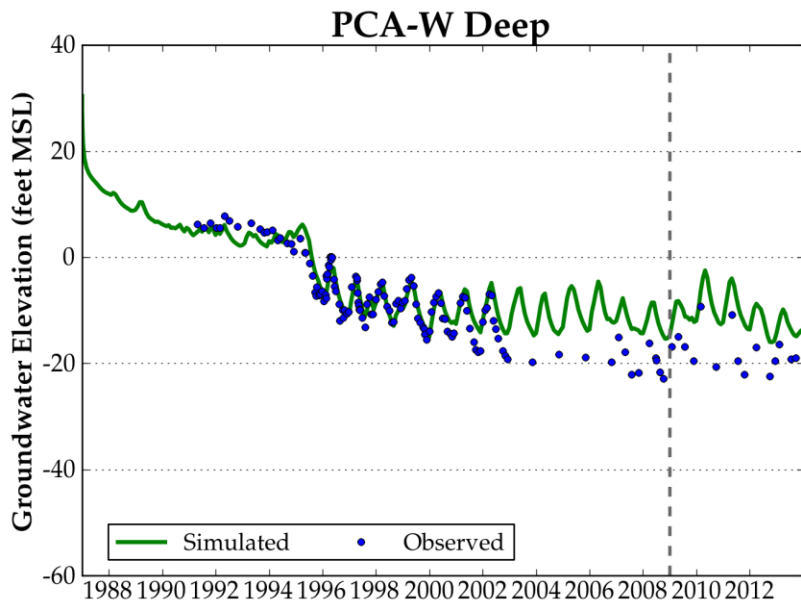
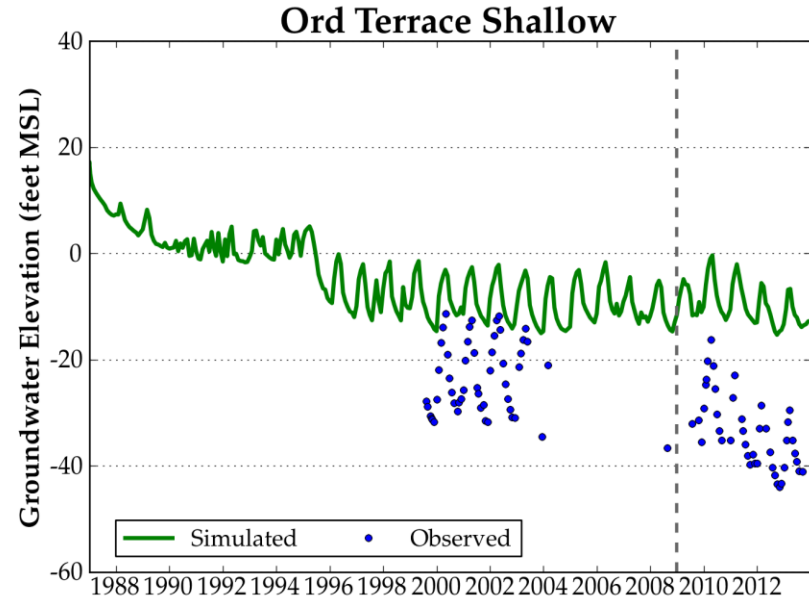
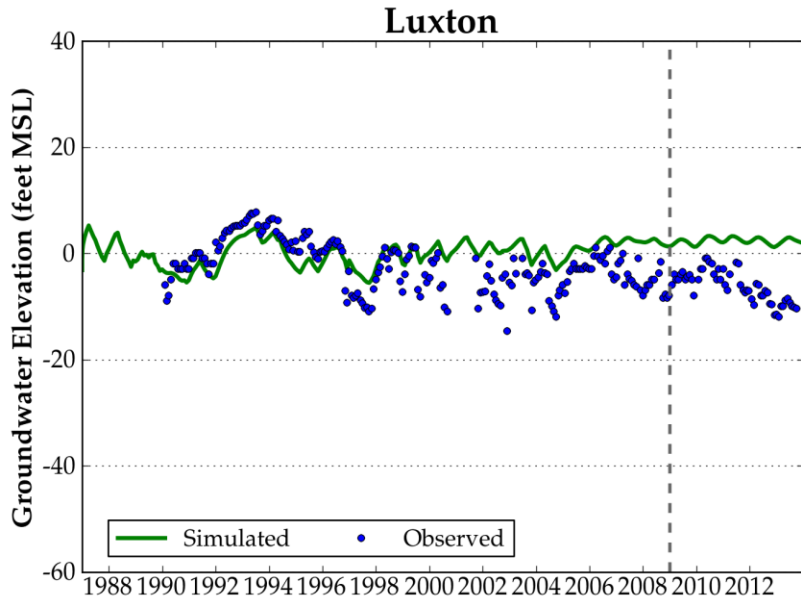


Figure A4: Northern Coastal Subarea Hydrographs

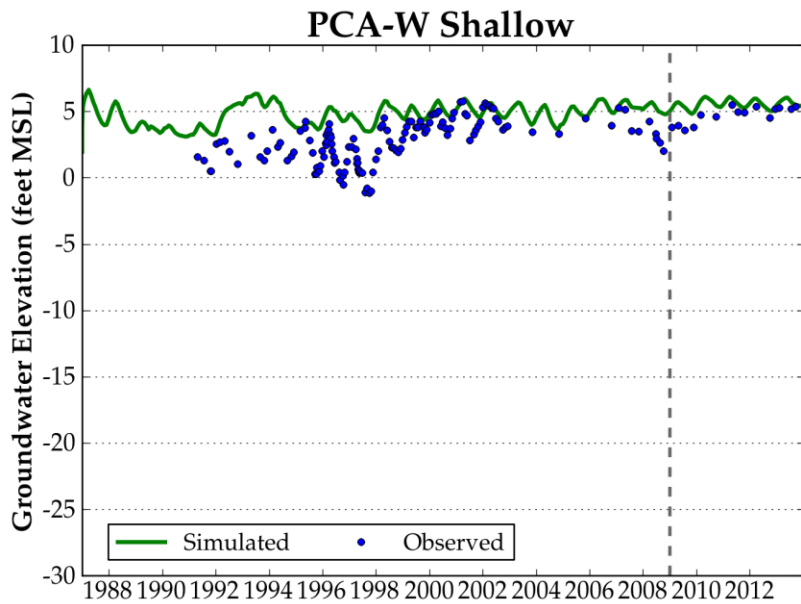
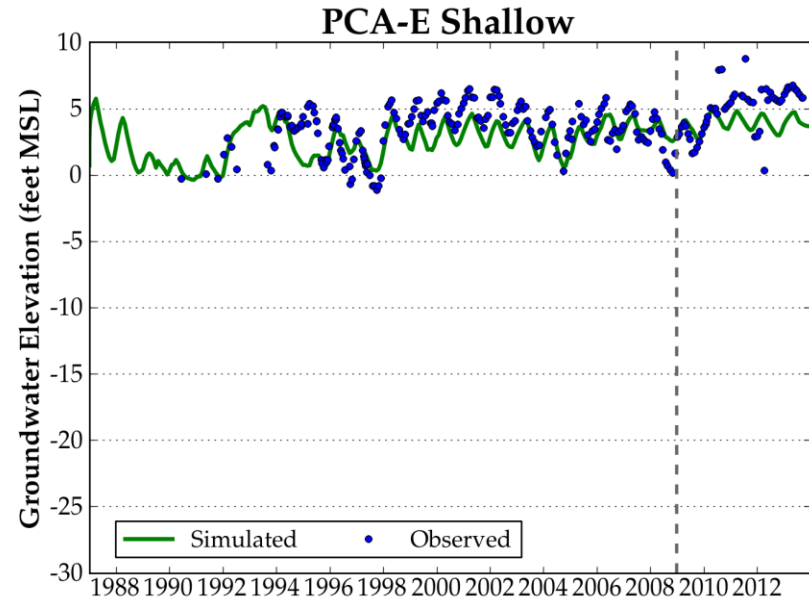
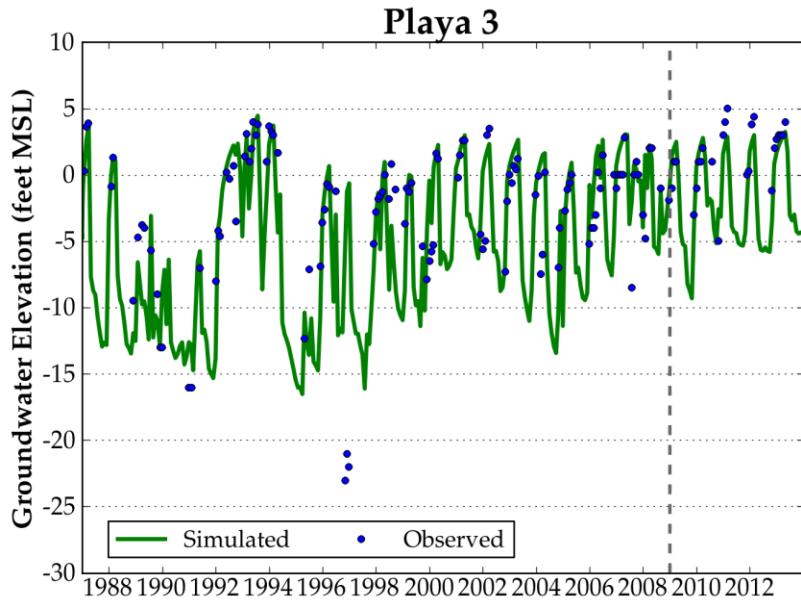


Figure A5: Northern Coastal Subarea Hydrographs

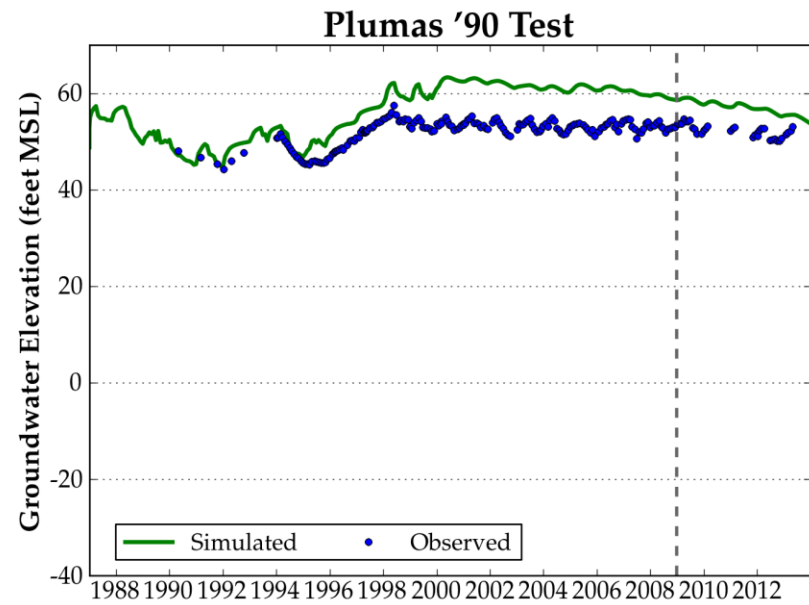
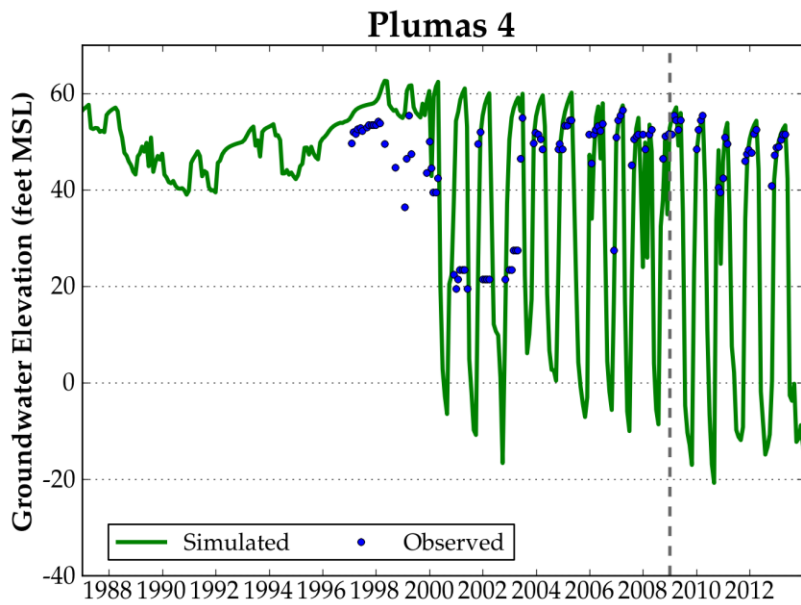
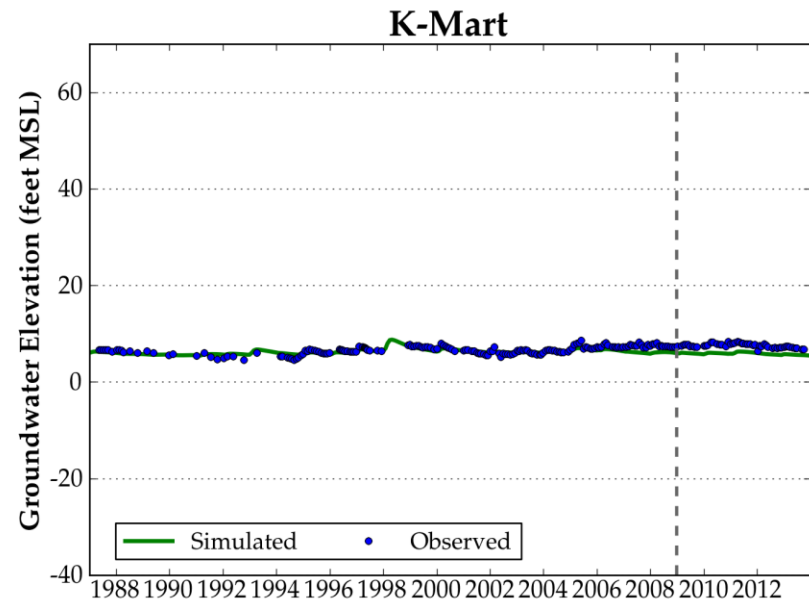
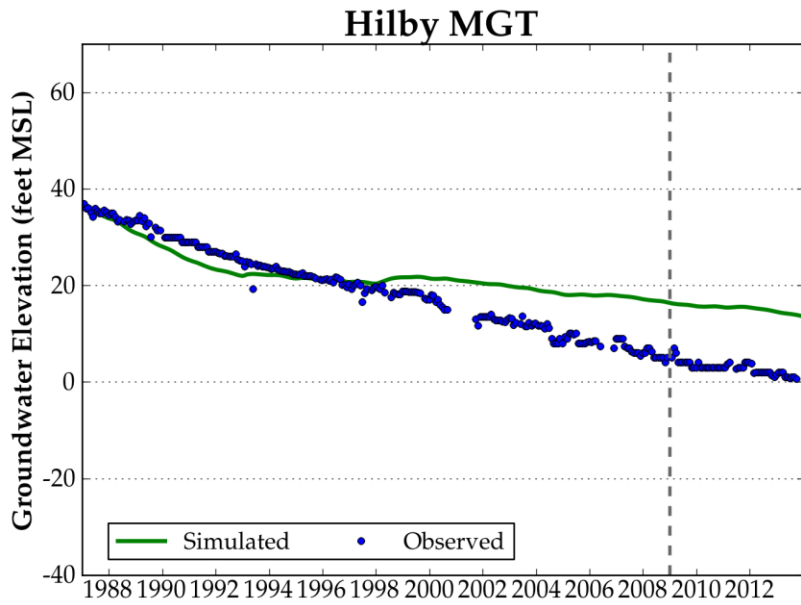


Figure A6: Southern Coastal Subarea Hydrographs

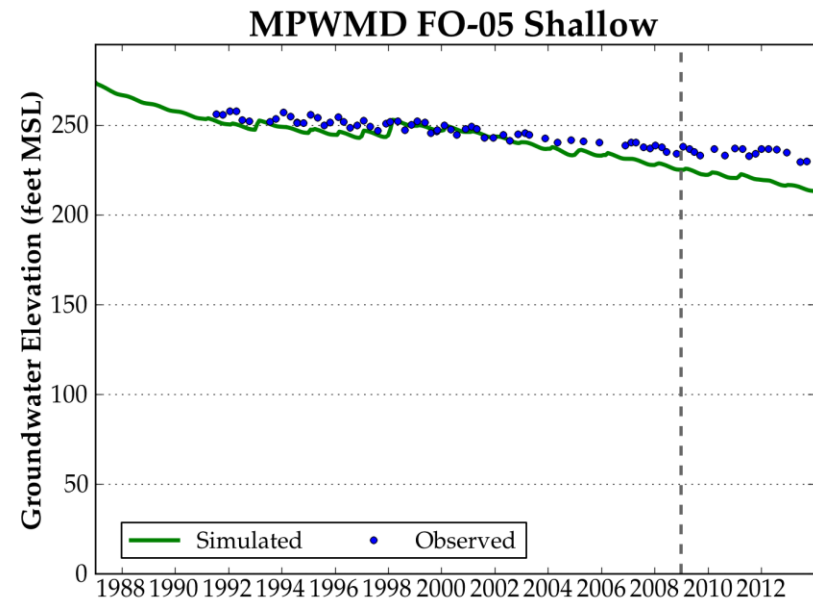
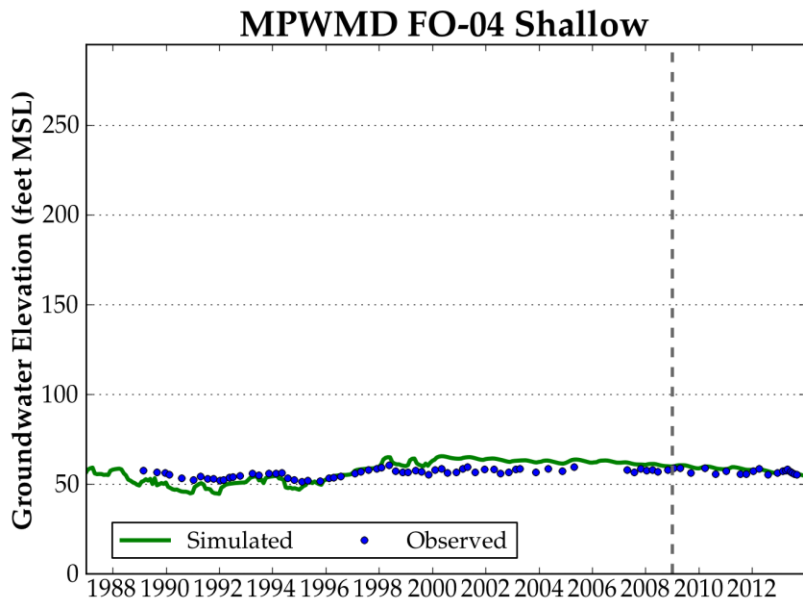
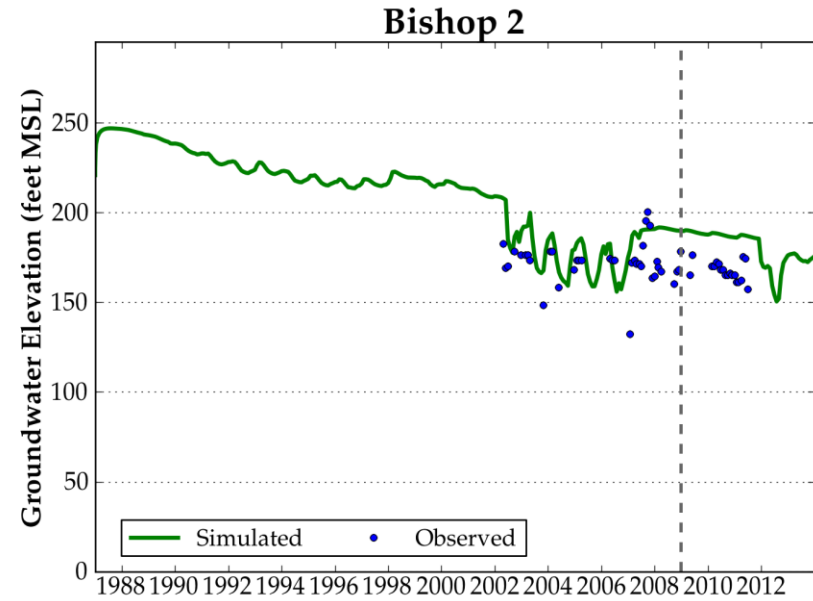
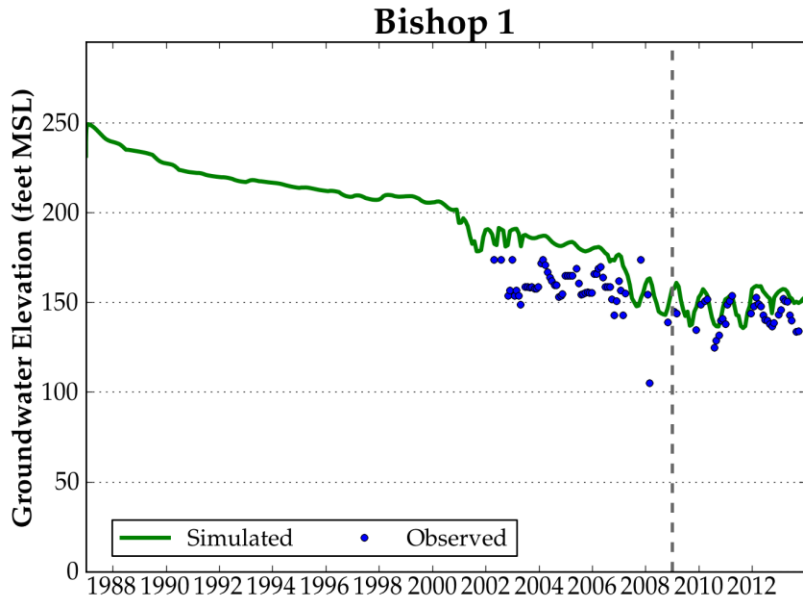


Figure A7: Southern Coastal Subarea Hydrographs

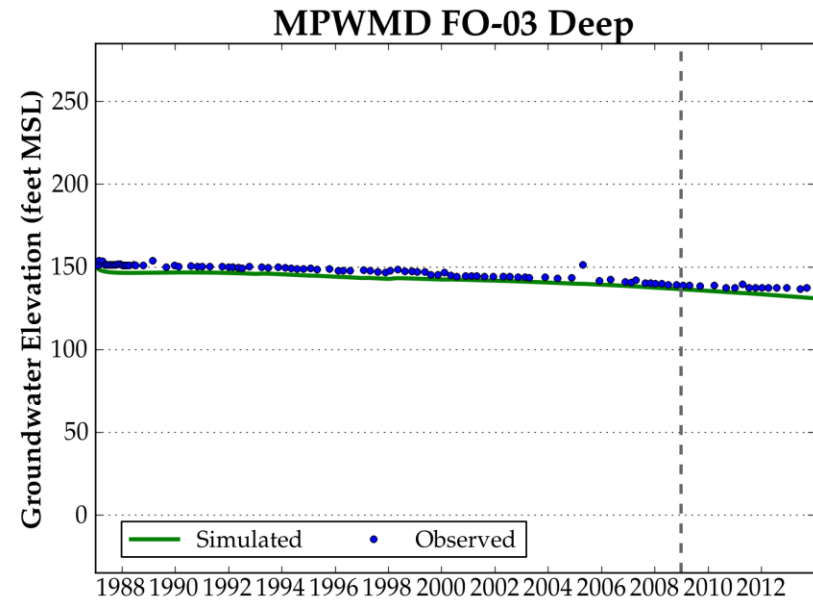
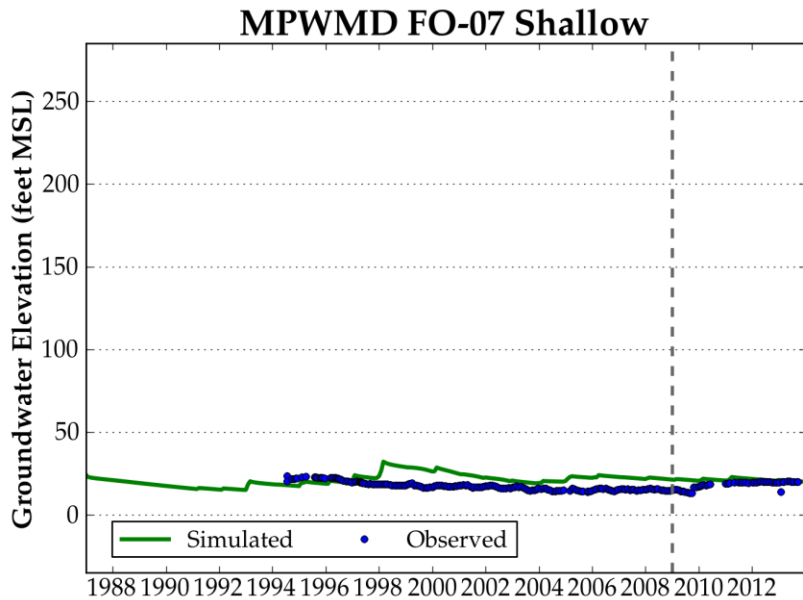
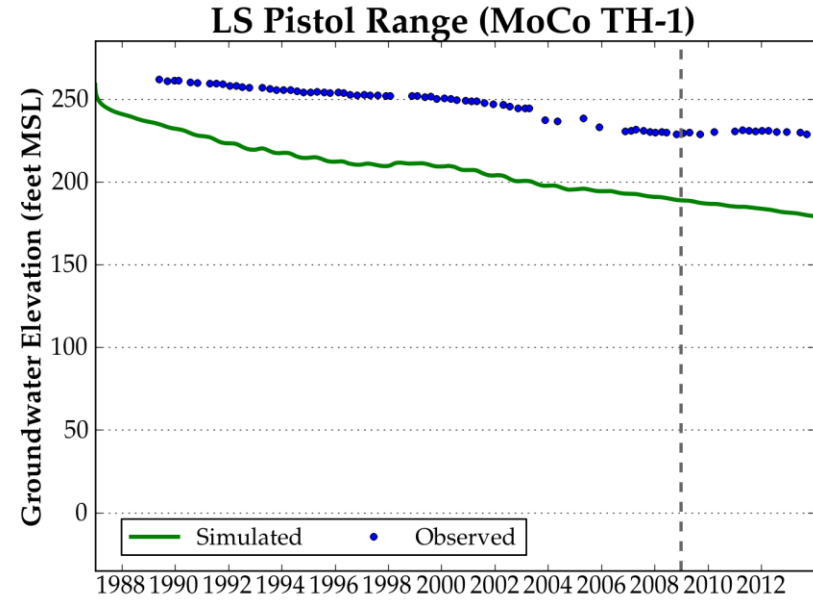
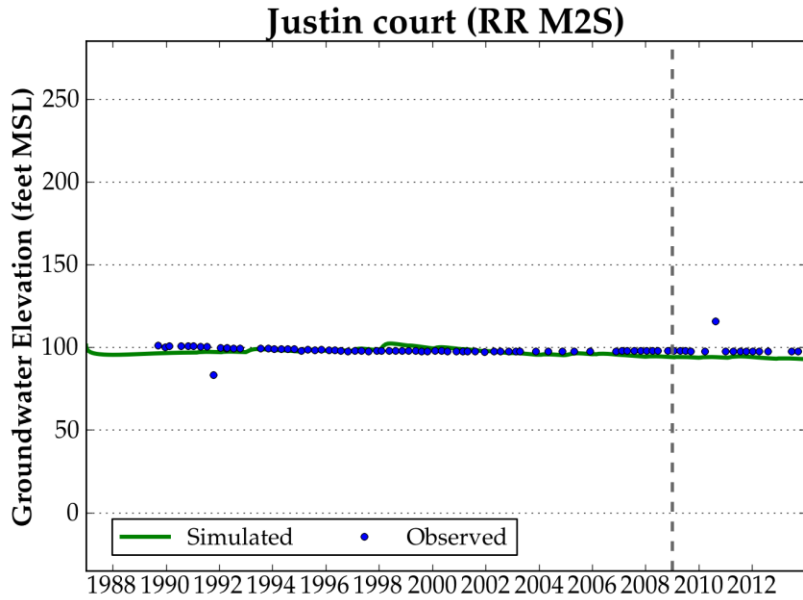


Figure A8: Laguna Seca Subarea Hydrographs

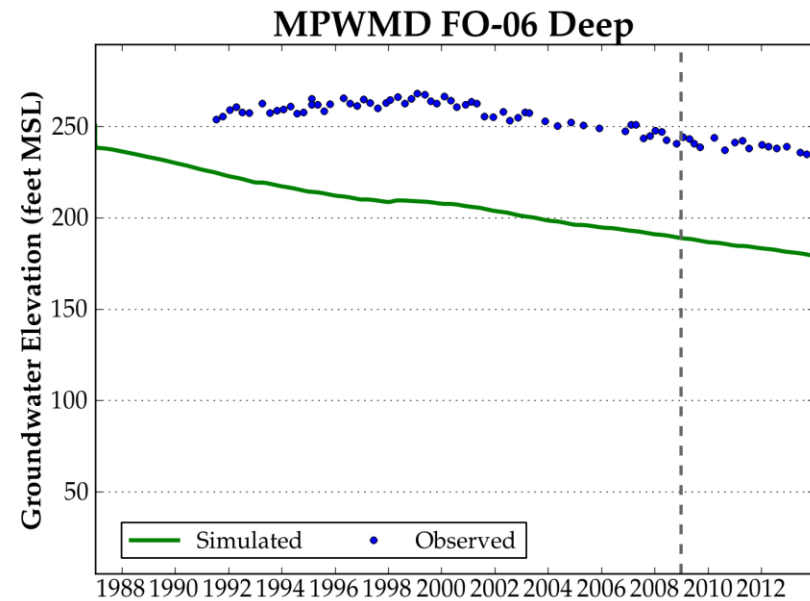
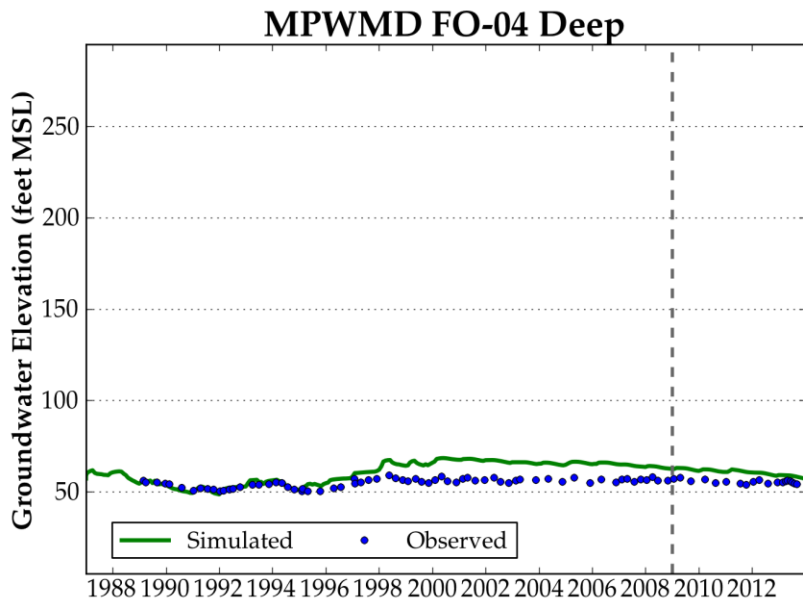
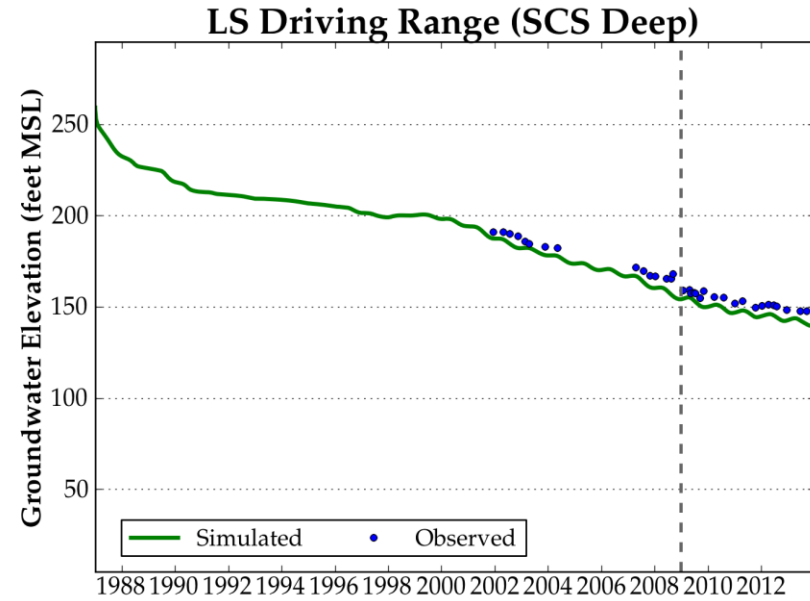
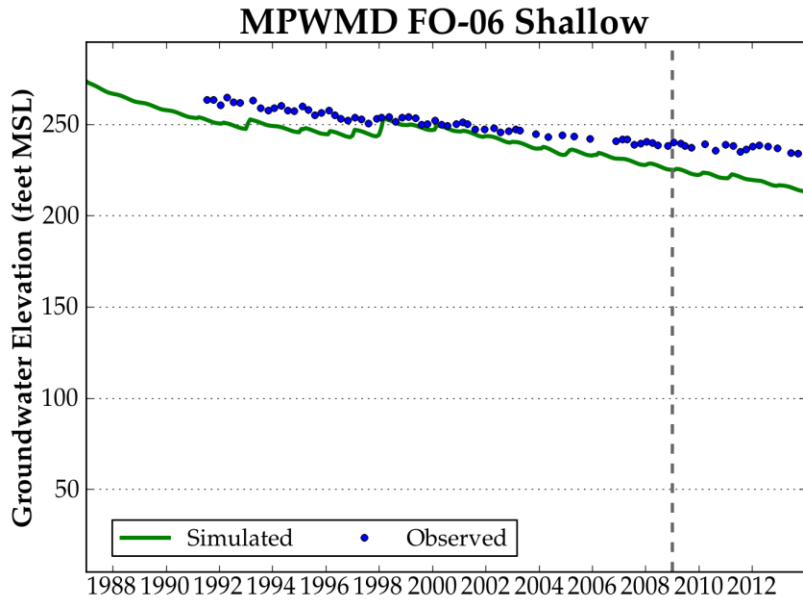


Figure A9: Laguna Seca Subarea Hydrographs

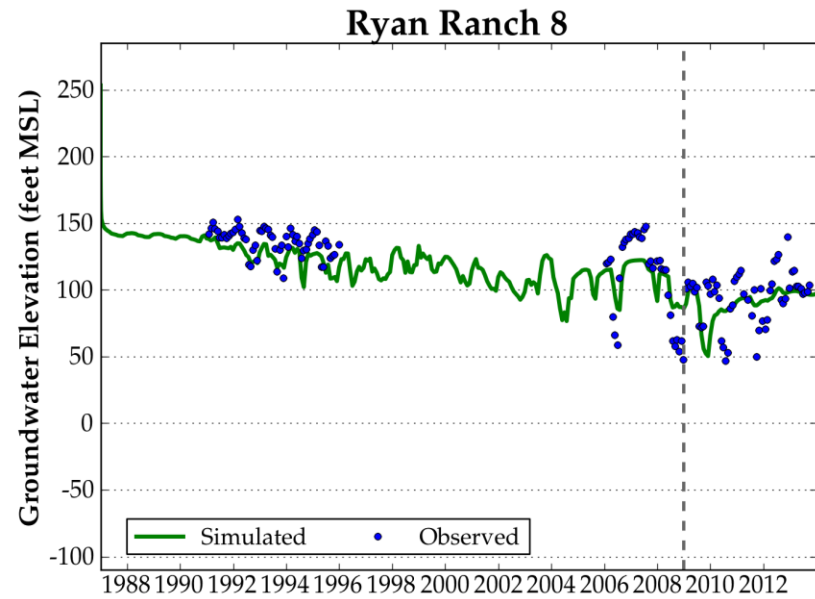
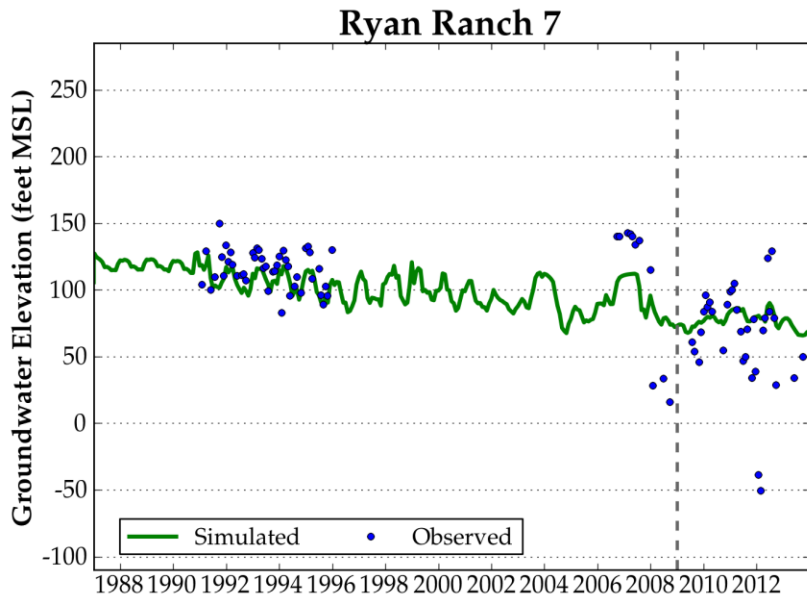
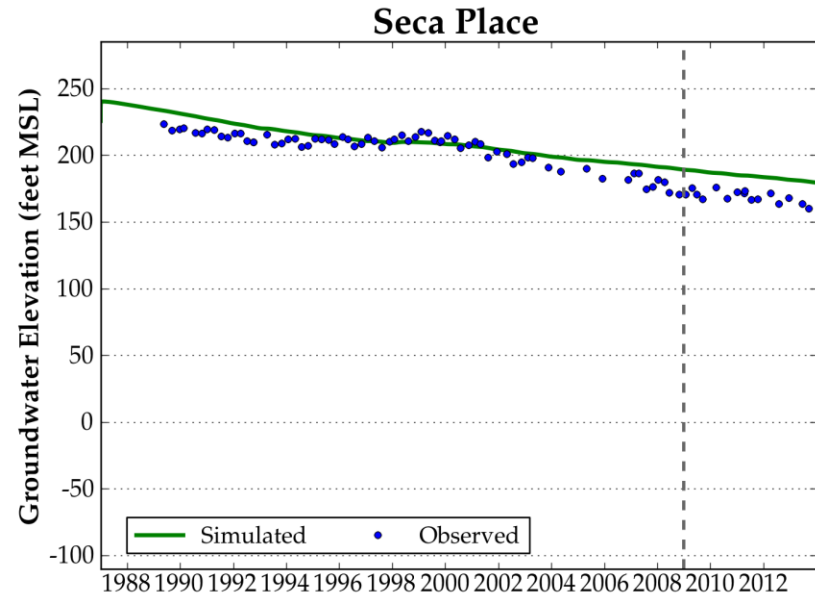
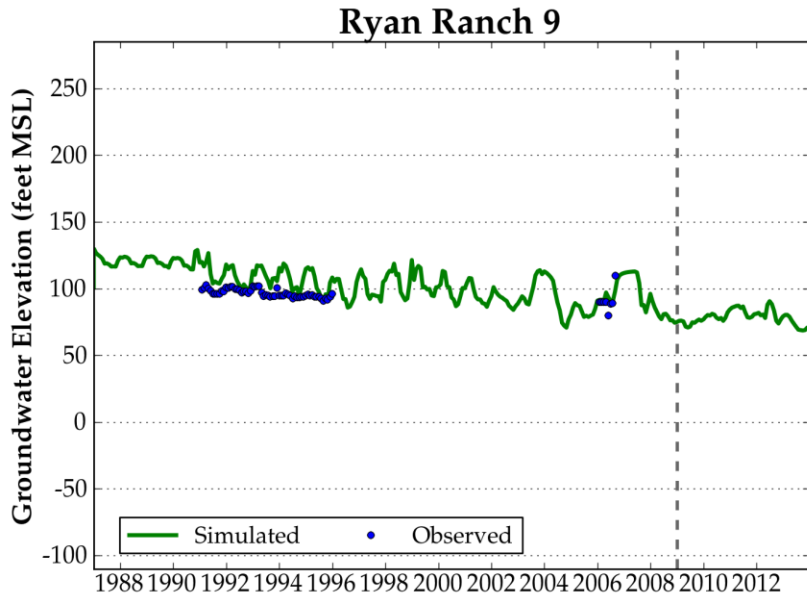


Figure A10: Laguna Seca Subarea Hydrographs

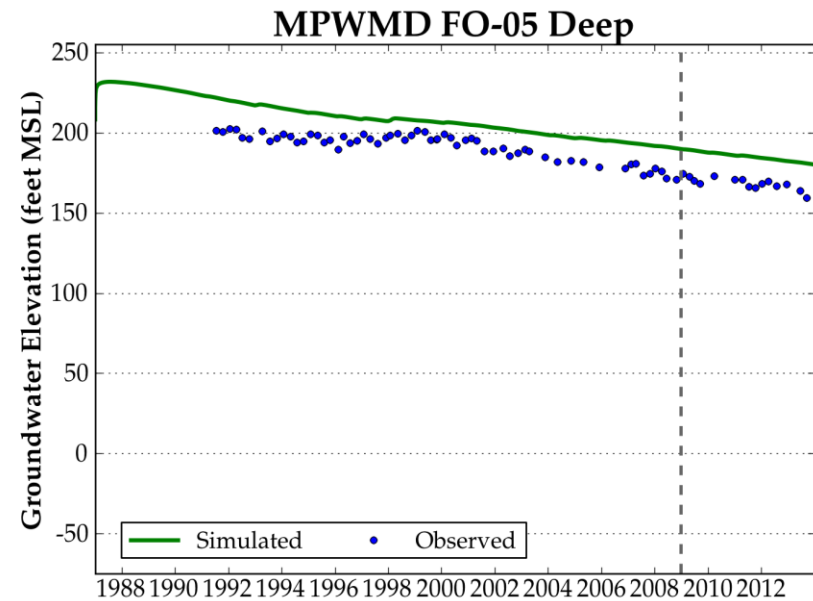
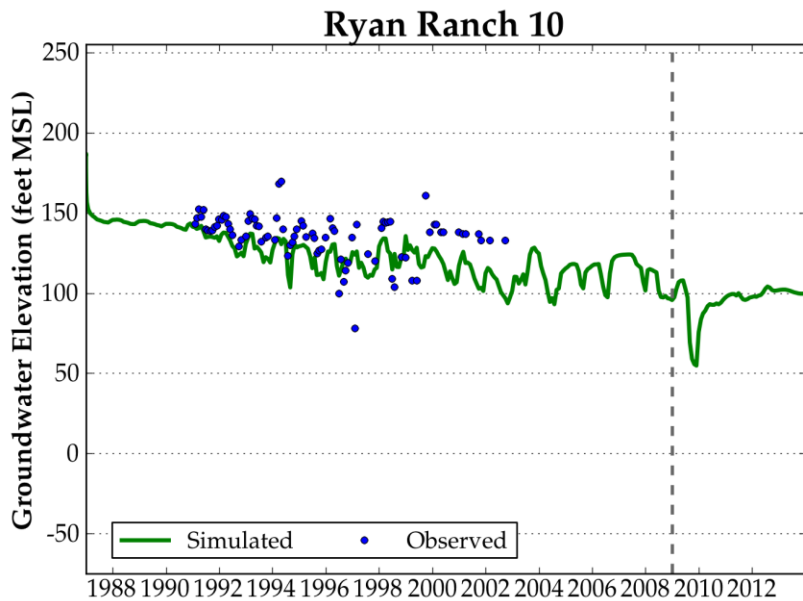
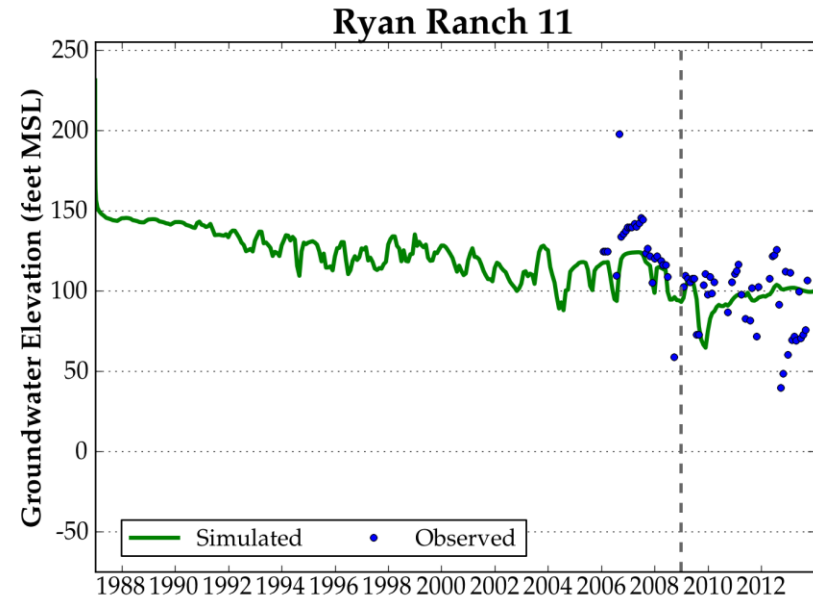
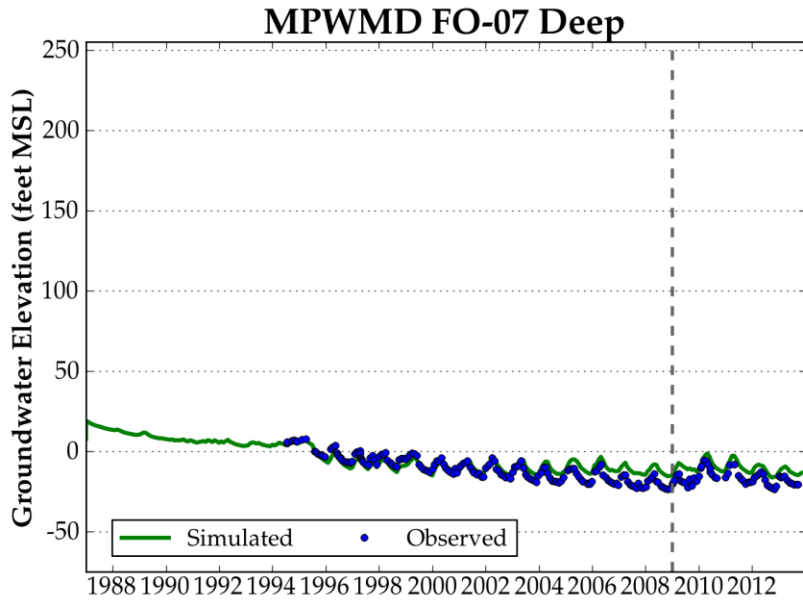


Figure A11: Laguna Seca Subarea Hydrographs

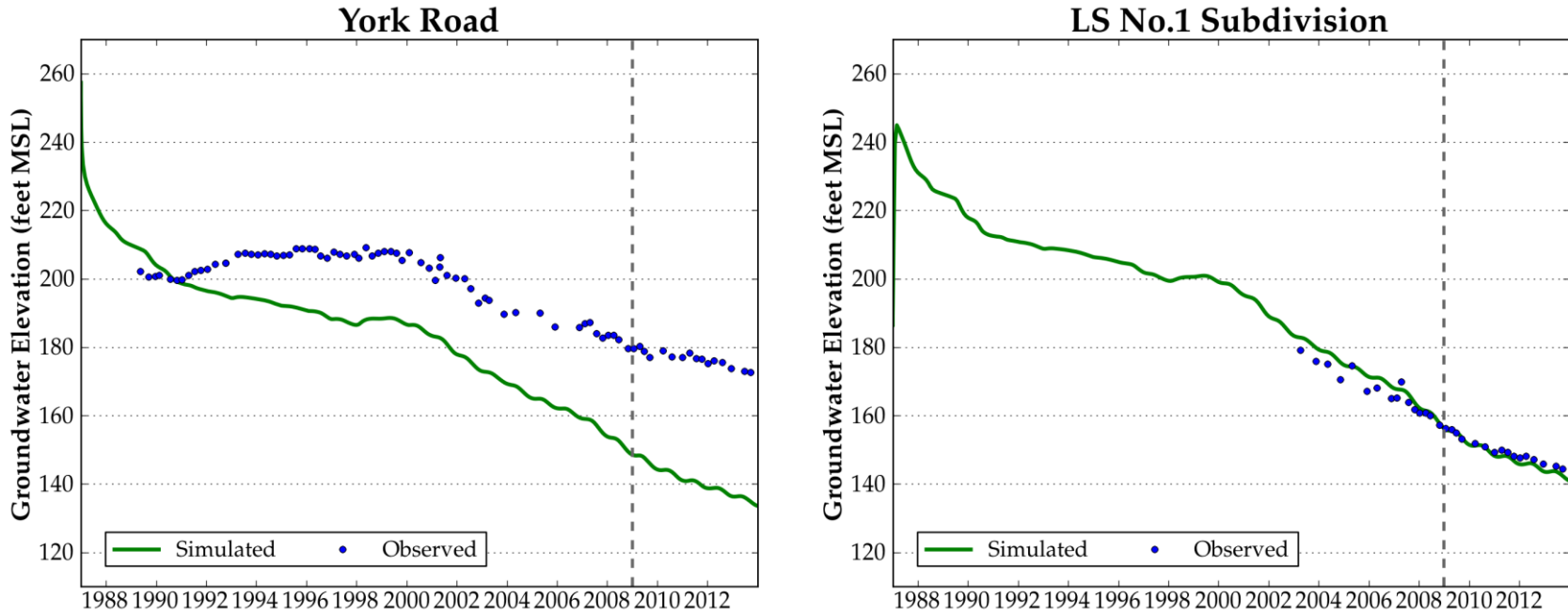


Figure A12: Laguna Seca Subarea Hydrographs

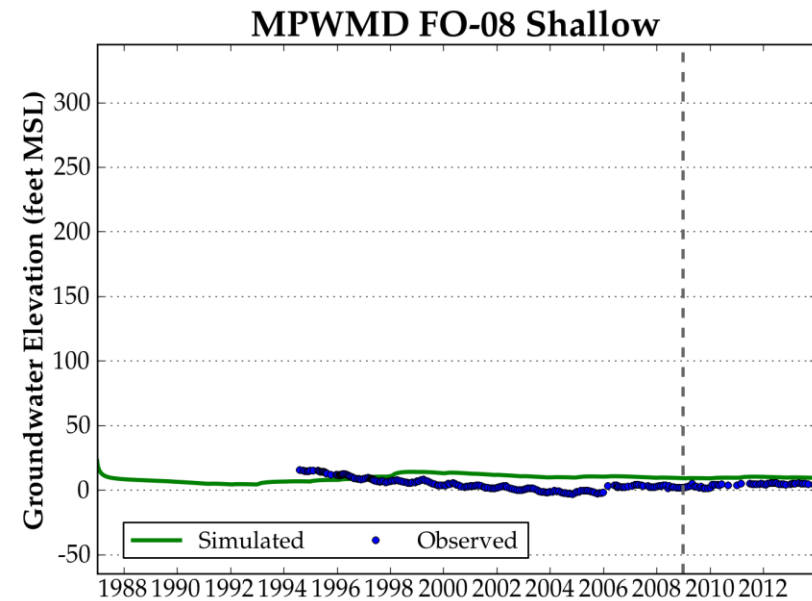
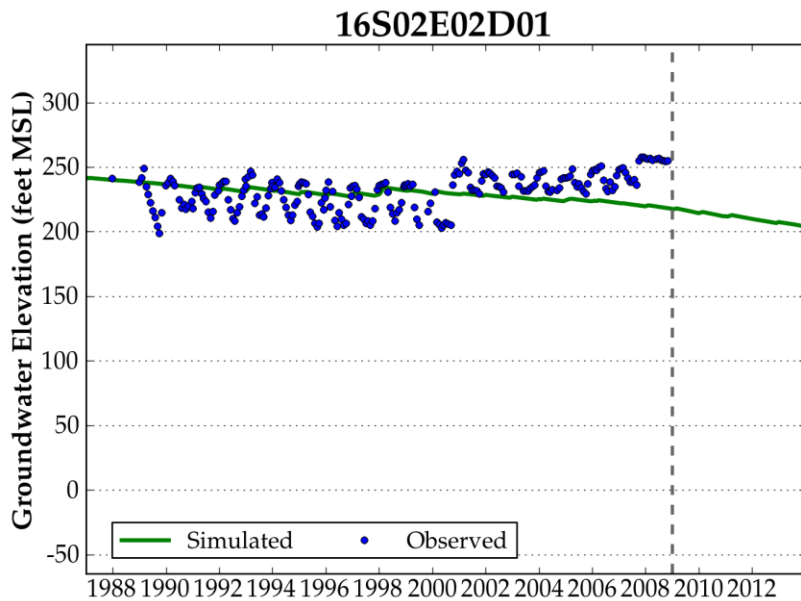
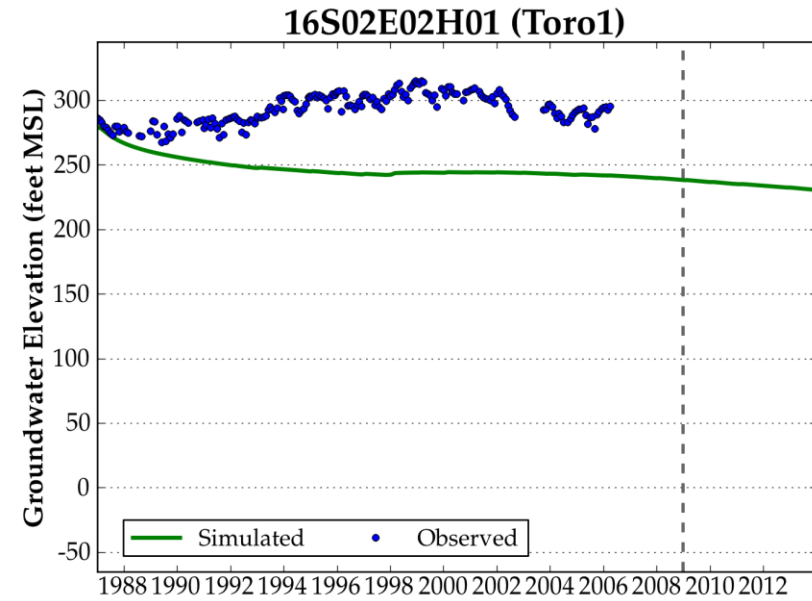
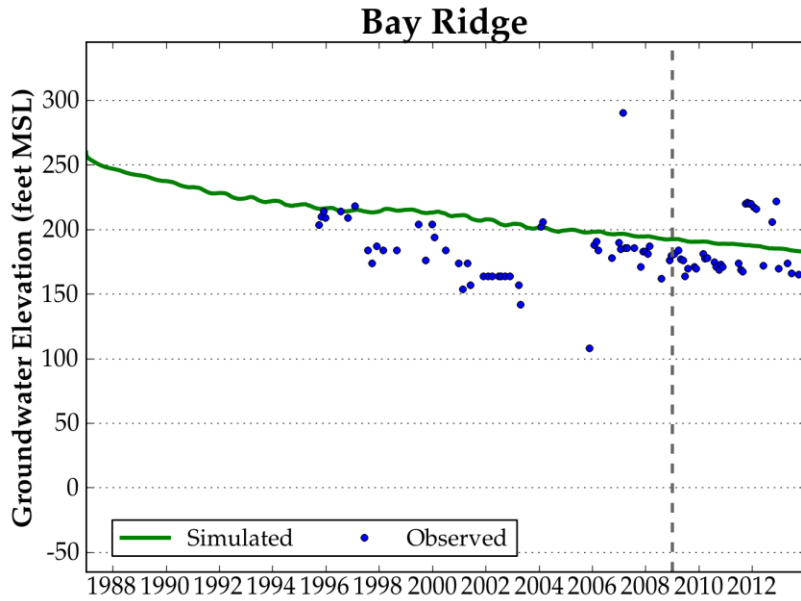


Figure A13: Hydrographs from Wells Outside of the Seaside Groundwater Basin

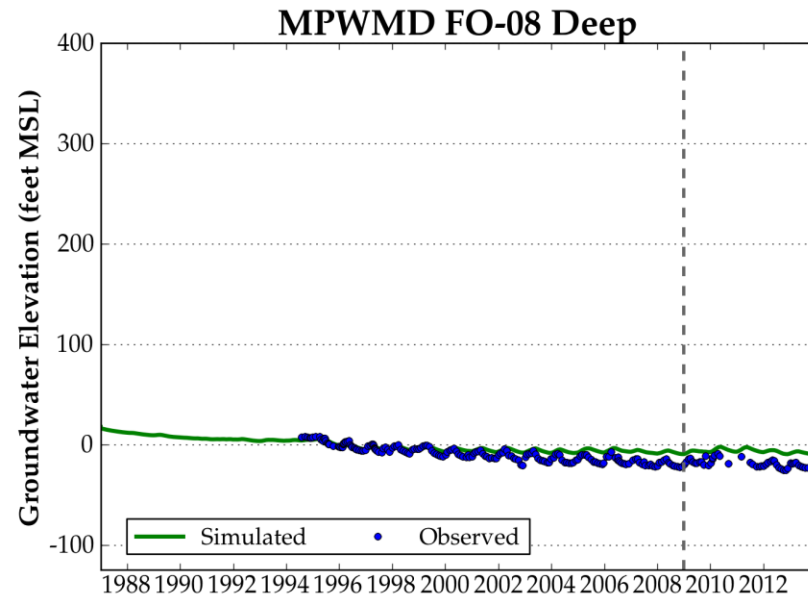
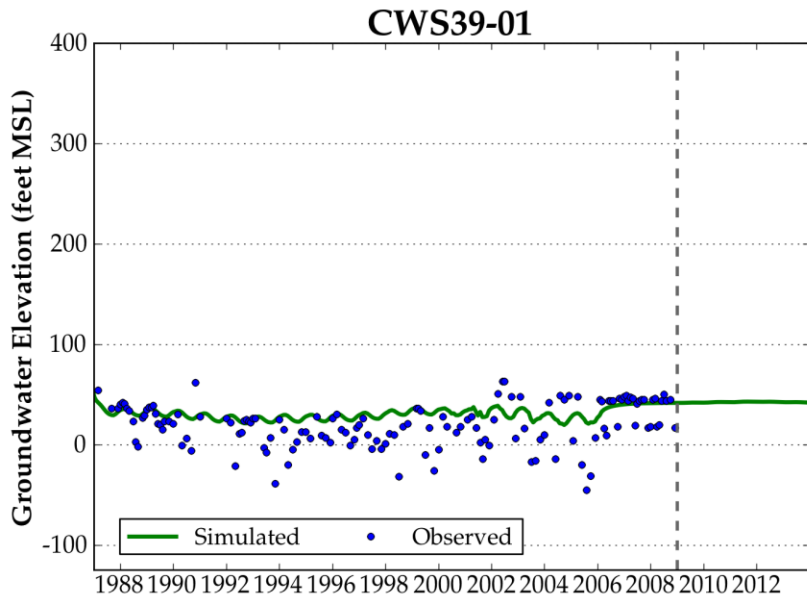
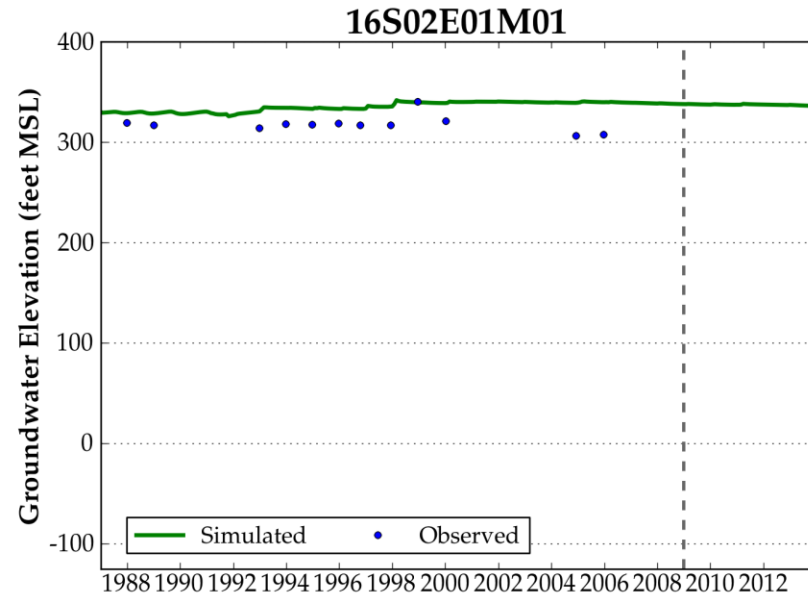
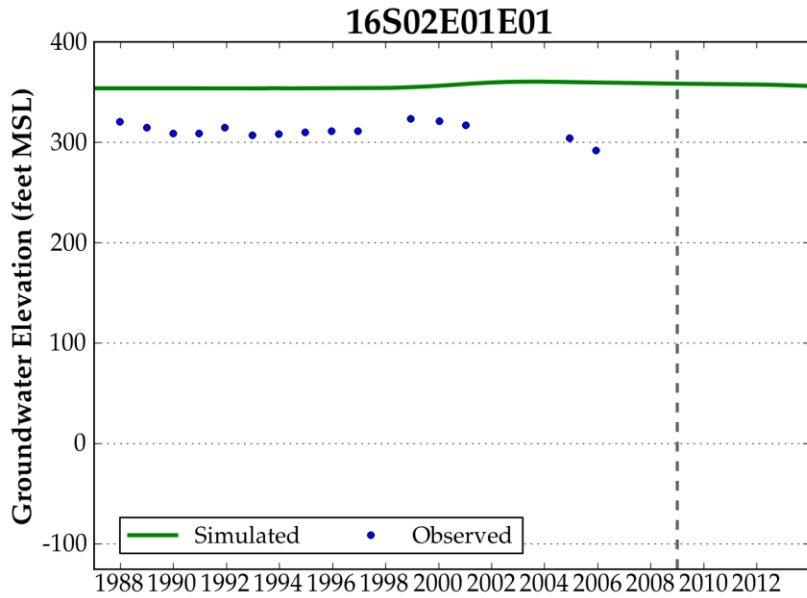


Figure A14: Hydrographs from Wells Outside of the Seaside Groundwater Basin

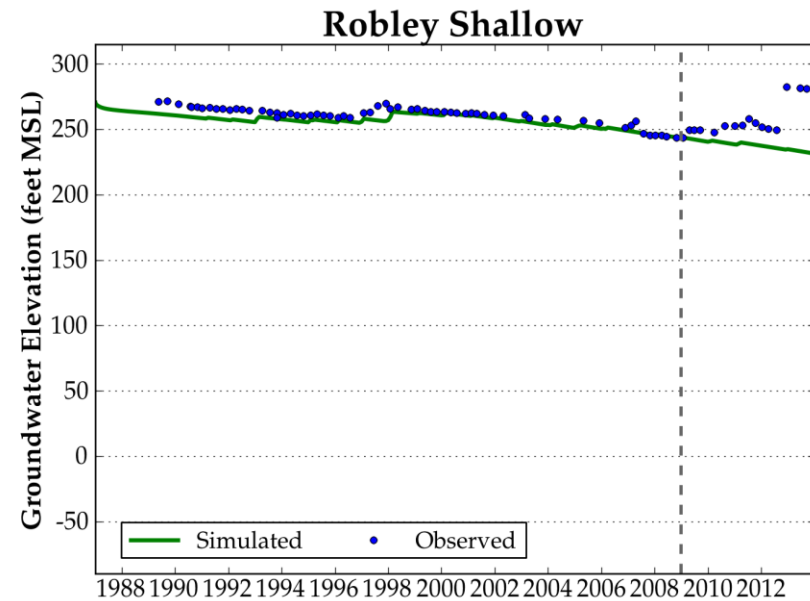
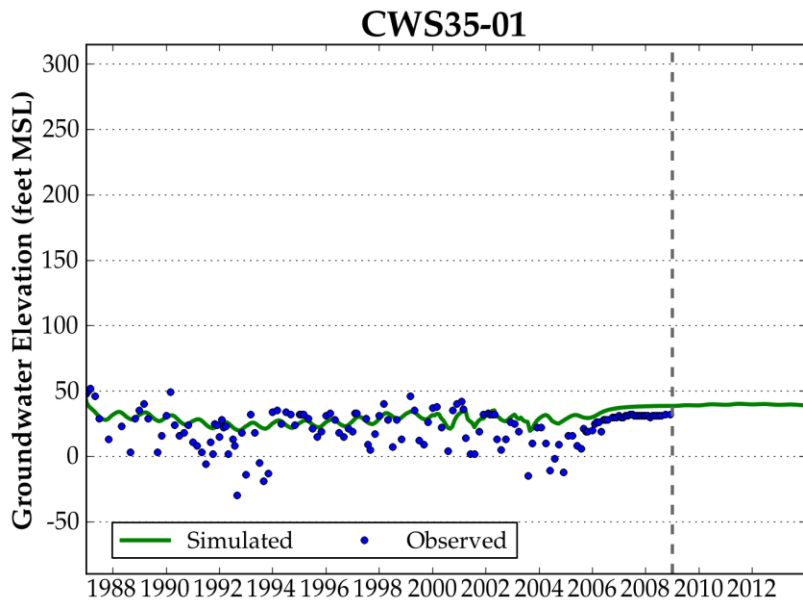
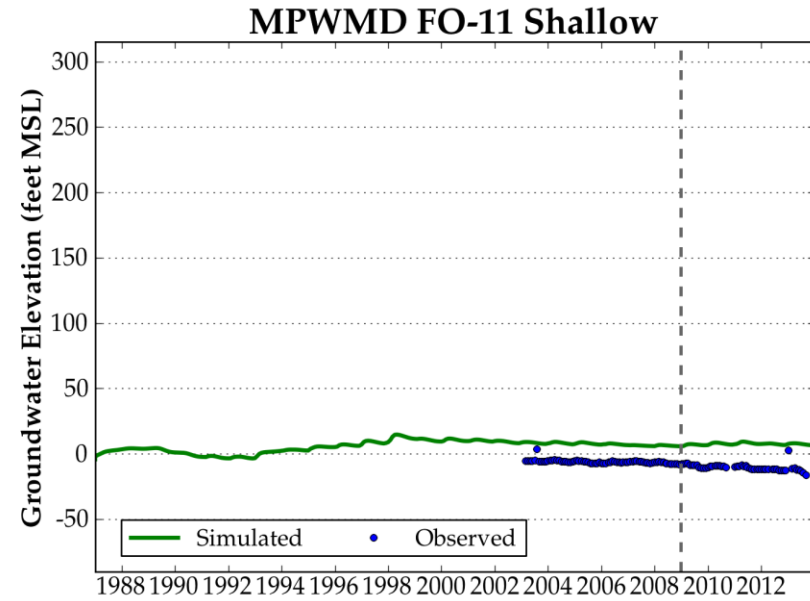
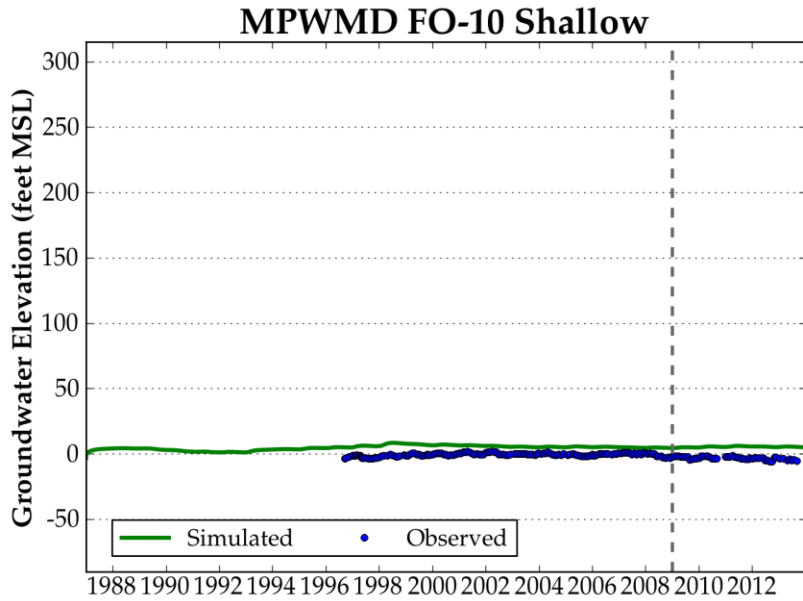


Figure A15: Hydrographs from Wells Outside of the Seaside Groundwater Basin

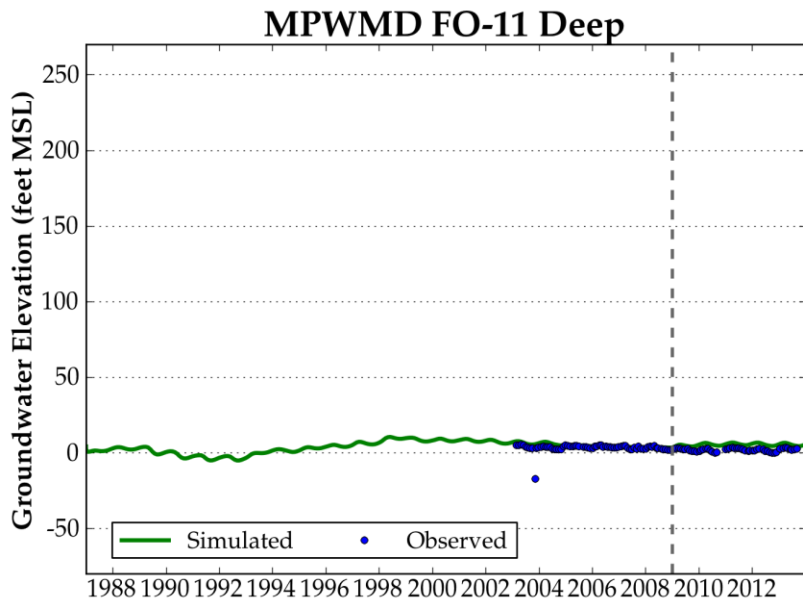
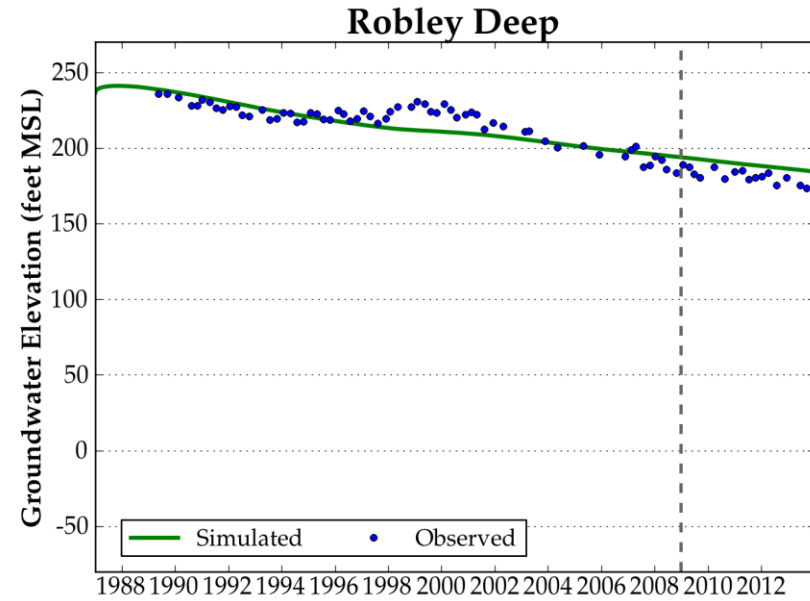
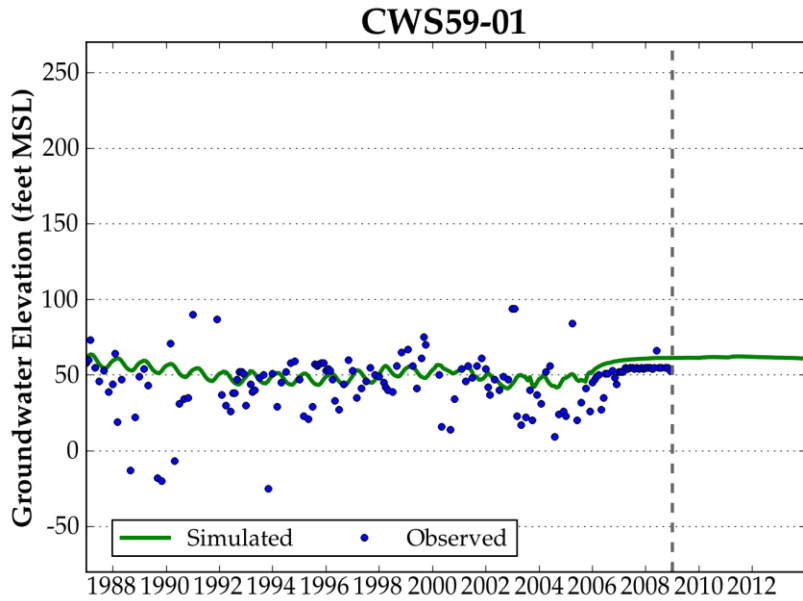


Figure A16: Hydrographs from Wells Outside of the Seaside Groundwater Basin