<u>**EXHIBIT 4-A**</u>

Proposal for Calibrating the Carmel River GSFLOW Model using PEST

PROBLEM

The Carmel River originates in the Santa Lucia Mountains in Central California and drains a 660 km^2 area before flowing into the Pacific Ocean at Carmel Bay. Competing water needs in the basin has led the Monterey Peninsula Water Management District (MPWMD) to develop an integrated ground water– surface water GSFLOW model of the basin (Markstrom and others, 2008). The model will be used to simulate instream flow needs for steelhead in the Carmel River and to model different water supply scenarios and their impacts on the Carmel River. An initial version of the model has been developed; however, the MPWMD is interested in contracting to the U.S. Geological Survey to provide formal calibration of the GSFLOW model using available hydrogeologic data.

SCOPE

This proposal describes a cooperative program that will calibrate the GSFLOW model of the Carmel River basin using the automated parameter estimation software, PEST. The MPWMD will work in cooperation with the U.S. Geological Survey (USGS).

OBJECTIVES

This study will calibrate the previously developed coupled watershed/groundwater-flow model (GSFLOW) for the Carmel River basin. The objective of this study is to formally calibrate the GSFLOW model using PEST to provide simulated results that match historical measured streamflow and groundwater heads data to the extent possible given existing hydrogeologic data.

RELEVANCE AND BENEFITS

The proposed study addresses the USGS science strategy direction "A Water Census of the United States: Quantifying, Forecasting, and Securing Freshwater for America's Future" (U.S. Geological Survey, 2007). Specifically, the study addresses freshwater availability, documents water-storage capabilities of the aquifer system, and refines and develops surface water/groundwater models to help better understand the aquifer system.

APPROACH

The USGS will calibrate the previously developed GSFLOW model of the Carmel River basin using the automated parameter estimation software PEST (Doherty, 2010). Calibration of the GSFLOW model will be done using the following previously measured hydrogeologic and hydro-meteorlogic data types:

(1) Water level observations from selected wells in the basin that are deemed to be of high quality in terms of accuracy;
(2) River flows at selected gaging stations located within or at the boundaries of the model;
(3) Estimates of actual ET.

Calibration for this project will focus on parameters related to the groundwater model component of GSFLOW. Accordingly, parameters that will be adjusted in the calibration process will include spatially distributed vertical and horizontal hydraulic conductivity, aquifer storage parameters, and river and tributary stream hydraulic properties. Additionally, phreatophyte (riparian vegetation) root depths also will be adjusted to match best estimates of groundwater ET. Final estimated parameter values will be checked for reasonableness.

The calibration period will consist of a 5-10 year span that will be selected to include, to the degree possible, the variability in climatic conditions as depicted in the historical record. The model will be calibrated to the wide range of conditions in order to provide model fidelity for predicting future hydrogeologic conditions in the basin. However, confidence in the calibrated model is provided only for those conditions that occur during the calibration period. Calibration of the model will include the following advanced calibration features provided by PEST:

- **Pilot Points**-Pilot points are arbitrary points in space that facilitate estimation of spatially-distributed hydraulic properties of an aquifer; for example, hydraulic conductivity. Because cell-by-cell estimation of aquifer properties is not possible, pilot points offer a compromise between strict piecewise-constant zonal (i.e., ‘zonation’) approaches and under-determined cell-by-cell estimation of spatially-distributed aquifer properties. The flexibility afforded by pilot points allows parameter heterogeneity to emerge during automated parameter estimation routines in areas where observations support it, while at the same time keeping the number of estimable parameters within a reasonable range. As the parameter values assigned at pilot point locations are perturbed, the associated spatially-continuous parameter field is re-Kriged and used by the process model, in this case, GSFLOW/MODFLOW-NWT.

- **Regularization**-Regularization helps to not only stabilize the numerical aspects of the inverse problem, it also allows the modeler to impart expert knowledge (commonly referred to as “soft” knowledge) in to the parameter estimation problem. In regions of the model where historical observations provide sufficient information to override user-specified preferred values (i.e., significantly improved model fits result from adjusting parameter values away from their regularized, or “preferred,” values), PEST will introduce parameter heterogeneity that is supported by the collected data. Without regularization, model “over-fitting” may occur as parameters take on widely varying values for small improvements in model fit.
- **Observations Weighting**-The objective function minimized by PEST is the sum of squares of the weighted residuals, where residuals are calculated as the simulated value minus the observed value. There is no limit on the number of observations or observation types that can be incorporated into PEST’s objective function. However, because the relative contribution of each observation-simulated value residual to the overall objective function value depends on the assigned weights, they must be chosen carefully. In addition, the selection of appropriate observation weights can limit the influence of highly uncertain observations and enables comparison of measurements with non-commensurate units in a single objective function because weighted residuals are dimensionless.
- **Time-series Processing**-A number of surface-water flow time series will be used during model calibration. With appropriate processing, the information content contained in surface-flow time series beyond the straight-forward targeting of daily flowrates can be extracted. For example, the difference between successive time steps may be an equally important observation to target as the absolute value of the observed flowrates themselves. In addition, differences in observed flow rates between two gages may be the most important calibration target for guiding PEST to an improved hydrologic

simulation. In other words, these additional observations support estimation of additional model parameters resulting in a more accurate simulation.

DELIVERABLES

The USGS will provide the MPWMD the calibrated GSFLOW model data files. An unpublished technical memo will be provided that documents calibration results, in the form of fit statistics, and other calibration metrics calculated by PEST as part of the standard parameters estimation analysis. No formal sensitivity analysis will be provided.

SCHEDULE

The calibration work and reporting will require approximately 4 months to complete. This work will begin following approval and singing of the contract between the USGS and MPWMD.

BUDGET

Possible funding by federal fiscal year is presented below. The availability of Federal funding for this project is uncertain at this point. Total funding by federal fiscal year is presented below.

	FFY16	FFY17	Total
PEST Calibration	$40,000		$40,000
Technical memo	$10,000		$10,000
Total	$50,000		$50,000

REFERENCES

Doherty, J., 2010. Methodologies and software for PEST-based model predictive uncertainty analysis: Watermark Numerical Consulting, Brisbane, Aus.

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW-Coupled Ground-water and Surface-water FLOW model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6-D1, 240 p.

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