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TECHNICAL MEMORANDUM

To: Kim Adamson, Soquel Creek Water District
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From: Cameron Tana and Derrik Williams

Date: January 23, 2015

Subject: Groundwater Model Uses and Capabilities (Task 1B)

Soquel-Aptos Groundwater Model

On October 28, 2014, HydroMetrics WRI held the first of two scoping meetings with representatives of the Basin Implementation Group (BIG) and its partners (collectively referred to as the scoping group with participants listed below) on the Soquel-Aptos groundwater model. The meeting focused on setting expectations for the uses of the model and defining the requirements for model capabilities. This technical memorandum details our understanding of the BIG's priority uses for the model and the necessary model capabilities to meet those uses.

Based on scoping group comments on this draft memorandum, we will develop a work plan for developing the model (Task 1C) that may include a revised scope, cost, and schedule for approval by the BIG.

Model Code Choice

The model code must have the capabilities for changing model inputs and model evaluation described below. During the meeting, we decided that the best approach is to develop a model based on the MODFLOW family of groundwater model codes (Harbaugh, 2005). MODFLOW is public domain software developed by the U.S. Geological Survey and is a widely accepted groundwater model code. The scoping group endorsed a desire to use relatively accessible tools where possible and to avoid using proprietary code.

MODFLOW also has a modular design with packages or versions that can be added or used to include different capabilities. Additional capabilities have been created for MODFLOW that will address evaluating effects on stream flow and movement of the seawater interface.

Model Use Priorities

Our discussion of model uses can be divided into two aspects of modeling. The first aspect consists of what model inputs the scoping group would like to change in future simulations. The model inputs could reflect future changes in groundwater use and management activities, or changing hydrologic conditions. The second aspect consists of the how the model outputs will be evaluated. Model outputs may include changes in groundwater levels, changes in stream flows, and effect on seawater intrusion.

The following sections identify the top and medium priorities for the model's use. Each discussion of priorities is followed by an explanation of how the priorities will be incorporated into the model

TOP PRIORITIES FOR FUTURE MODEL INPUTS

Based on the October 28 meeting, the following are the model inputs that the scoping group would like to vary or modify in future simulations:

- Overall pumping quantities
- Pumping rates and locations, including pumping coordination
- Availability of supplemental supplies, specifically supplies that are recharged or injected
- Non-agency pumping, including alternative water use factors
- Changes in hydrologic conditions, such as climate change

These inputs are standard for a groundwater model assuming that the inputs such as pumping, recharge/injection, and hydrology can be estimated external to the model.

TOP PRIORITIES FOR EVALUATING MODEL OUTPUTS

Based on the meeting, the following model output are how the scoping group would like to evaluate the future model scenarios.

- Comparing groundwater levels to established protective elevations for preventing seawater intrusion
- Time for basin recovery i.e. time for groundwater levels to rise to protective elevations
- Effects on stream flow
- Movement of seawater interface

For the first two bullets, evaluating simulated groundwater levels over time is a basic use of a transient groundwater model. Since the protective elevations for preventing seawater intrusion have been estimated, comparing groundwater levels to the protective elevations over time will be straightforward.

Evaluating effects on stream flow and movement of seawater interface requires choosing the appropriate add-on capabilities. The possible capabilities and proposed choices are discussed below.

MODEL CAPABILITIES FOR EVALUATING STREAM FLOW

The main package for evaluating effects on stream flow in MODFLOW is the stream flow routing (SFR) package (Prudic et al., 2006 and Niswonger and Prudic, 2010). The SFR package calculates flows between streams and groundwater based on stream and groundwater levels. Flow is routed downstream based on the calculated flows in and out of the streams. The SFR package includes several options for calculating stream water levels based on the stream flow. However, runoff from the watershed needs to be provided as input to the SFR package and the SFR package does not calculate the relationship between runoff and areal recharge.

GSFLOW (Markstrom et al., 2008) uses the SFR package, but can calculate runoff from the watershed and areal recharge based on rainfall and return flow. GSFLOW adds the USGS' Precipitation Runoff Modeling System (PRMS) to MODFLOW for a fully integrated watershed-groundwater model. Because modeling surface water-groundwater interaction is a top priority use of the model, we recommend implementing GSFLOW.

We have previously developed a PRMS model to estimate deep recharge for the basin. The existing PRMS model was spatially discretized based on sub watersheds. The USGS recommendation for developing a GSFLOW model is to discretize PRMS to match the rectangular grid used by MODFLOW. Therefore, we plan to create a new grid based PRMS model for GSFLOW, but we will be able to use the input data sets prepared for the previous PRMS model. When both surface water and groundwater are fully calibrated in the GSFLOW model, recharge estimates from the GSFLOW model will supersede estimates from the existing PRMS model.

There are also available codes that connect MODFLOW to codes that simulate full surface water routing that are used to evaluate floods such as the Army Corps of Engineers HEC models. It is not a priority for the groundwater model to evaluate the surface water flows at that level of detail requiring time discretization on the order of minutes. The daily time step of GSFLOW is sufficient for evaluating the relationship between stream flows and groundwater.

Another potentially relevant package that GSFLOW uses is the unsaturated zone flow (UZF) package (Niswonger et al., 2006). We still need to evaluate whether we need to implement this package for the Soquel-Aptos groundwater model for areas where there are stream systems such as Valencia Creek that are separated from groundwater by an unsaturated zone. Adding the UZF package will add computational challenges for the model so we will evaluate whether or not including it will likely change model results.

One challenge in modeling the surface flow-groundwater interaction for the Soquel-Aptos basin is that surface flow occurs in terrace deposits that cut across all hydrostratigraphic units of the Purisima Formation and the Aromas Red Sands. Developing a strategy for appropriately connecting terrace deposit layer at the surface to underlying hydrostratigraphic units will be important.

MODEL CAPABILITIES FOR EVALUATING MOVEMENT OF SEAWATER INTERFACE

MODFLOW's seawater interface (SWI2) package simulates a sharp interface between saline groundwater and fresh groundwater based on density differences (Bakker et al, 2013). The SWI2 package approach is to solve the groundwater flow equation with modifications for density effects. The other main approach used by SEAWAT (Langevin et al., 2007) and other codes to solve both the groundwater flow equation and the advective-dispersive transport equation for the transport of salts. The SWI2 package does not account for diffusion and dispersion and will not be able to estimate salt concentrations like SEAWAT but the SWI2 package is much less computationally intensive. To fulfill the top priority of simulating movement of the seawater interface, the SWI2 package should be sufficient. The SWI2 package is not currently incorporated into GSFLOW, but the U.S. Geological Survey has estimated that it would be a week's worth of effort to incorporate it (approximately $30,000).

One challenge in modeling the seawater interface in the Soquel-Aptos basin is that the interface has been observed in the Aromas area but not in the Purisima area. An assumption will have to be made about where the interface might be in the Purisima. One approach could be to assume the interface is located just offshore in order to estimate a lower bound of time before it is detected. The related challenge is how to relate the assumed location in the Purisima area with the observed location across multiple hydrostratigraphic units.

MEDIUM PRIORITIES FOR EVALUATING MODEL OUTPUT

At the meeting, two additional evaluations of model output were identified as being important, but not as high priority as the top priorities listed above. These medium priorities include:

- Estimating the travel time of supplemental supplies, such as recycled water, from recharge or injection point to point of discharge
- Estimating the in-well pumping water levels, to illustrate impacts of well interference

MODEL CAPABILITIES FOR EVALUATING TRAVEL TIME OF RECHARGE AND INJECTION

There may be a need to evaluate the time for recharge or injection of supplemental supplies to reach production wells. For example, regulations for injecting recycled water require a minimum amount of residence time before the recycled water is extracted. The USGS code MODPATH (Pollock, 2012) can be used for particle tracking based on MODFLOW (or GSFLOW) results to provide these estimates, but the additional effort for setting up MODPATH was not included in our submitted scope.

MODEL CAPABILITIES FOR EVALUATING PUMPING WATER LEVELS FOR WELL INTERFERENCE

A groundwater model could be used to evaluate well interference by simulating pumping water levels in production wells. Pumping water levels can be simulated in MODFLOW using the multi-node well (MNW2) package by applying the skin effect that represents the well's inefficiency (Konikow et al., 2009). We are planning on using the MNW package for the model because there are a number of production wells screened across multiple hydrostratigraphic units. However, we are not planning on simulating the skin effect due to additional numerical computation that would entail and the added calibration of skin effect to pumping water levels. These skin effects can be calibrated during subsequent modeling exercises.

PROPOSED APPROACH TO MEDIUM PRIORITIES

Because these evaluations are medium priorities, we propose constructing the groundwater model so that the capabilities to perform these evaluations can be added in the future, but not to add it to the current scope. Our current approach is to address the top priorities, and allow for these capabilities to be added later.

REJECTED PRIORITIES FOR MODEL USE

Two other model uses were discussed at the scoping meeting and were not identified as current priorities:

- Simulating contaminant transport for evaluating releases from hazardous waste sites

- Predicting water quality effects of seawater intrusion

These model uses require full transport simulation capabilities using codes such as MT3D (Zheng, 2010) or SEAWAT, which would be a significant additional effort to develop.

Advanced Analyses with Groundwater Model

Once the groundwater model is developed, several additional types of analyses can be performed based on the model. This usually involves running the model multiple times with changes to model input. The types of analyses include:

- Predictive uncertainty analysis
- Sensitivity analysis
- Optimization

Predictive uncertainty analysis can be used to estimate the uncertainty of model results based on calibration error. This quantifies the range of prediction results based on model runs that are within an acceptable level of calibration error. Our submitted scope includes using PEST software (Watermark, 2005) that we plan to use for model calibration to evaluate the uncertainty of the preferred groundwater management alternative identified in an alternative analysis.

Sensitivity analysis is sometimes used to evaluate the effect of changing calibration parameters, but this often results in uncalibrated results. We recommend using sensitivity analysis to evaluate the effect of changing input variables that do not change the calibration parameters. These variables could include future hydrologic estimates such as those related to climate change or alternatives for the location of the seawater interface in the Purisima Formation.

Optimization is based on changing an input that groundwater managers can control to best achieve some management objective. For example, the distribution of pumping can be optimized to minimize recovery time.

Further discussion of the need or desire to perform any of these advanced analyses should take place at the second scoping meeting.

Non-Technical Issues for Groundwater Model Use

Other uses of the groundwater model that are not related to model capabilities, but should be honored include:

- The model will be used as tool for public outreach and education;
- The model will be available for funding partners to use going forward

Summary of Model Capabilities

Based on the prioritization of model uses, the following model capabilities are planned for the Soquel-Aptos groundwater model beyond the standard MODFLOW capabilities and packages:

- Use GSFLOW. This combines a MODFLOW model for simulating groundwater, and a grid-based PRMS model for simulating watershed flows
- Incorporate the SFR2 package. This simulates flows between streams and groundwater with streamflow routing
- Possibly incorporate the UZF package. This simulates unsaturated zone flow for areas with separation between streams and groundwater. If a review suggests the UZF package would not change the model output, it will not be used.
- Incorporate the SWI2 for simulating a sharp seawater interface. This will require U.S. Geological Survey effort to incorporate the code into GSFLOW.
- Incorporate the MNW2 -multi-node well package for simulating production wells screened across multiple hydrostratigraphic units
- Use PEST parameter estimation software for model calibration and predictive uncertainty analysis

Scoping Meeting #1 Participants

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References

Bakker, M., F. Schaars, J.D. Hughes, C.D. Langevin, and A.M. Dausman, 2013, *Documentation of the seawater intrusion (SWI2) package for MODFLOW*, U.S. Geological Survey Techniques and Methods.

Harbaugh, A,W, 2005, *MODFLOW-2005, the U.S. Geological Survey modular ground-water model – the Ground-Water Flow Process*, U.S. Geological Survey Techniques and Methods 6-A16

HydroMetrics WRI,2011, *Estimation of Deep Groundwater Recharge Using a Precipitation-Runoff Watershed Model, Soquel-Aptos, California*, prepared for Soquel Creek Water District, Central Water District, and the City of Santa Cruz, August.

Konikow, L.F., G.Z. Hornberger, K.J. Halford, and R.T. Hanson, 2009, *Revised multi-node well (MNW2) package for MODFLOW ground-water flow model*, U.S. Geological Survey Techniques and Methods 6-A30.

Langevin, C.D., D.T. Thorne Jr., A.M. Dausman, M.C. Sukop, and W. Guo, , 2008, *SEAWAT Version 4: A Computer Program for Simulation of Multi-Species Solute* *and Heat Transport*, U.S. Geological Survey Techniques and Methods Book 6, Chapter A22.

Markstrom, S.L., R.G. Niswonger., R.S. Regan., D.E Prudic,, and P.M. Barlow, 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.

Niswonger, R.G. and D.E. Prudic, 2010, *Documentation of the Streamflow-Routing (SFR2) Package to include unsaturated flow beneath streams – A modification to SFR1*, U.S. Geological Survey Techniques and Methods 6-A13.

Niswonger, R.G., D.E. Prudic, and R.S. Regan, 2006, *Documentation of the Unsaturated-Zone Flow (UZF1) Package for modeling unsaturated flow between the land surface and the water table with MODFLOW-2005*, U.S. Geological Survey Techniques and Methods 6-A19

Pollock, D.W., 2012, *User Guide for MODPATH Version 6 – A Partical Tracking Model for MODFLOW*, U.S. Geological Survey Techniques and methods 6-A41.

Prudic, D.E., L.F. Konikow, and E.R. Banta, 2004, *A New Streamflow-Routing (SFR1) Package to Simulate Stream-Aquifer Interaction with MODFLOW-2000*, U.S. Geological Survey Open-File Report 2004-1042.

Watermark Numerical Computing, 2005, *PEST: Model-Independent Parameter Estimation User Manual,* 5th Edition

Zheng, C., 2010, *MT3DMS v. 5.3 Supplemental User's Guide*, prepared for U.S. Army Corps of Engineers.