Attachment 5. Work Plan

Introduction

The work for this LGA Grant Proposal involves the development and utilization of an integrated groundwater/surface water numerical flow model called GSFLOW to simulate surface water and groundwater movement in the Solano County area. The purpose of this model is to provide a tool for decision-makers and groundwater suppliers to optimize conjunctive use and groundwater management in the Solano County area within the context of a complex hydrogeologic system in which multiple water bearing units to depths greater than 2,000 feet below ground surface are utilized for public supply. This effort would utilize GSFLOW, an open source, tested, and established Groundwater and Surface Water Flow (GSFLOW) modeling platform produced by the U.S. Geological Survey (GSFLOW). GSFLOW is based on the integration of two widely used modules namely the Precipitation-Runoff Modeling System (PRMS) and the Modular Groundwater Flow Model (MODFLOW-2005). This coupled integrated hydrogeologic model was chosen as a powerful tool for analyzing complex water-resources problems that consider feedback processes that affect the timing and rates of evapotranspiration, surface runoff, soil-zone flow, subsidence, and groundwater/surface water interactions (**Figure 1**).

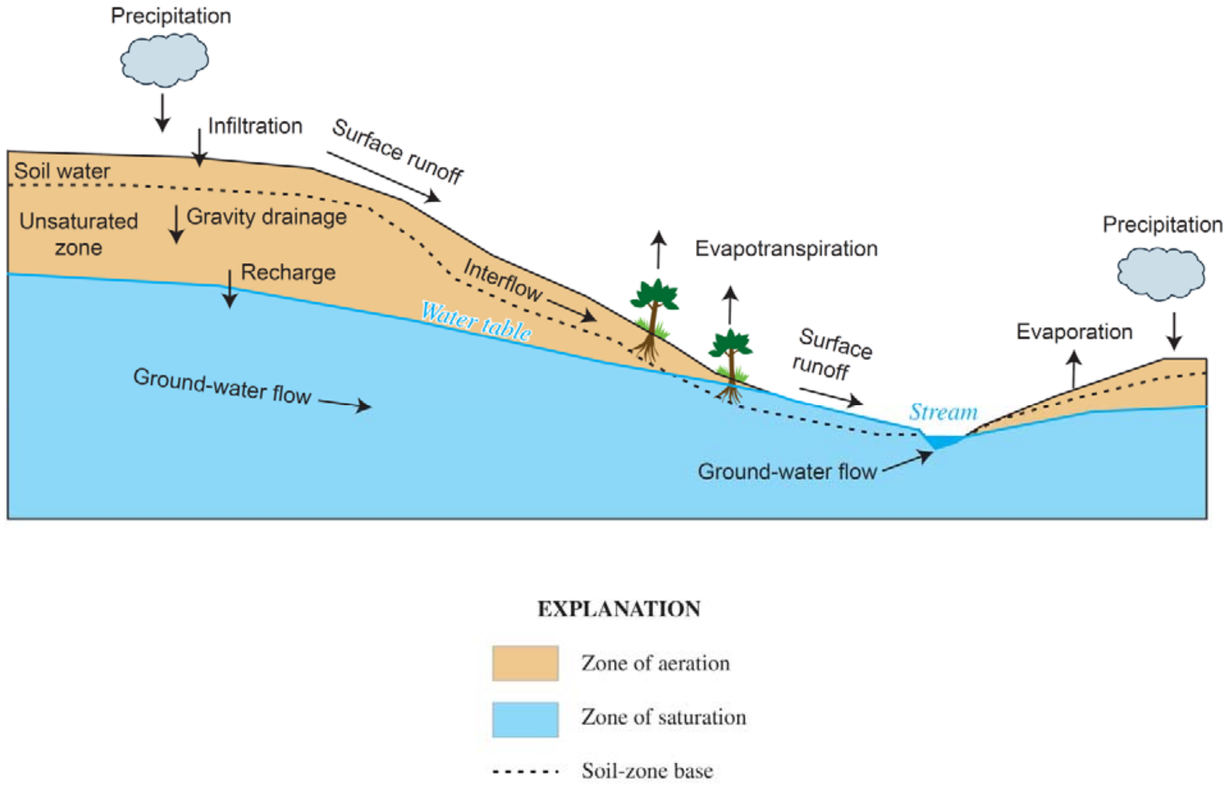

Figure 1 Distribution, flow, and interaction of water on the land and in the subsurface.

GSFLOW simulates coupled groundwater/surface water flow in one or more watersheds by simultaneously simulating flow across the land surface and within subsurface saturated and unsaturated materials and within streams and lakes. GSFLOW can be used to evaluate the effects of such factors as land use changes, climate variability, and groundwater withdrawals on surface and subsurface flow. Important inputs consist of climate data such as measured or estimated precipitation, air temperature, and solar radiation. Other key input data include groundwater stresses (such as withdrawals) and model boundary conditions.

The model area will preliminarily cover the area between the following boundaries (**Figure 2**):

- Northern Boundary: Approximately one mile north of Putah Creek
- Eastern to Southern Boundary: Approximately one mile east of the Sacramento River to south of Rio Vista to the boundary between the Solano Subbasin and the Suisun-Fairfield Valley Basin.
- Western Boundary: The western model boundary would follow the Solano County western boundary to just north of Fairfield then the model boundary would follow the boundary between the Suisun-Fairfield Valley Basin and the Solano Subbasin.

This section provides a description of the work plan broken down into seven major tasks. The tasks include:

1. **GSFLOW Model Development and Calibration,**
2. **Conjunctive Use Simulations,**
3. **Pumpage Distribution Simulations,**
4. **Recharge and Interconnectivity to Lower Freshwater Aquifer Zones Used for Supply,**
5. **Examining the Implications of Lowered Groundwater Levels and Potential Subsidence,**
6. **Determining the Groundwater Budget for the Complex Aquifer System in the Greater Solano Area, and**
7. **Documentation and Reporting.**

These tasks will satisfy the following goals related to groundwater resource management:

- Simulate the results of conjunctive use activities such as increased groundwater pumping (upper and lower portions of the aquifer system) during dry years and reduced pumping during wet years;
- Simulate the effects of redistributing pumpage either horizontally or vertically to reduce drawdowns in the basal aquifer zone of the Tehama Formation;
- Examine recharge and interconnectivity to the lower freshwater bearing zones;
- Examine the implications of lowered groundwater levels and potential subsidence;
- Determine the groundwater budget for the complex aquifer system such as exists in the greater Solano area;

- Address questions concerning long-term reliability of supply from the deeper freshwater-bearing units in the northern Solano County area; and
- Examine whether pumping from planned conjunctive use activities have an effect on surface water flows (i.e., streamflow depletion in the Sacramento River).

Descriptions of each task, including the specific purpose, goals, and objectives that these tasks relate to in terms of existing GWMPs, are below.

Task 1. GSFLOW Model Development and Calibration

This task includes the development of the GSFLOW numerical model and the calibration of the model. This is the most important task as it lays the foundation for analyzing all of the different management scenarios. It incorporates several aspects of GWMP objectives including the collection of groundwater level data that are used for calibration purposes.

The model development follows the conceptual model of the Solano County area, which has already been well-formulated through previous work for SCWA and the City of Vacaville. For example, the geologic framework has been studied and documented for most of the proposed model area. The hydrologic framework, including the physical extents of the aquifer system, features that impact or control the groundwater flow system, and analysis of groundwater flow directions and media type, has also been studied previously and will be applied to the model. Hydraulic properties including transmissivity, hydraulic conductivity, specific yield, and storativity have also been studied previously for various aquifer units in Solano County. Sources and sinks of water to the aquifer system, including groundwater wells, evapotranspiration, leakage across confining layers, and flow to or from surface water bodies are already conceptually understood and will provide another key component to the conceptual model.

Task 1.1 Model Development – GSFLOW/PRMS Input Files

Input files for the GSFLOW and PRMS control which equations and input parameters are employed for the watershed and climatic variables used for moving water that either falls and travels via runoff to a surface water body, or through the soil zone, subsurface, and eventually making it to the groundwater table. Time-series input data will be gathered from publicly available sources and organized into the correct format to be used in the model domain. Sources of data to be used may include, as available: pan evaporation, streamflow from local gaging stations, precipitation, solar radiation, daily minimum and maximum temperature, and the form of precipitation (rain, snow, unknown). In terms of quality assurance and quality control (QA/QC), some internal checks and formatting will be performed to assure that the input data are of high quality and can therefore by relied upon. This will include, but is not limited to:

- plotting time series data to investigate and/or extract inappropriate outliers that may be artifacts of erroneous entries in the record,
- ensuring that the input data is consistent with the conceptual framework of the model,

- checking that all measurement units are consistent with the model input files' needs,
- identifying any data deficiencies and potential sources of error due to uncertainty,
- formatting the input data to assure that the input files will work properly with the model platform, etc.

The model area (**Figure 2**) will first be divided into watersheds, and will then be discretized into a network of hydrologic response units (HRUs) based on hydrologic and physical characteristics such as drainage boundaries, land surface altitude, slope, plant type and cover, land use, distribution of precipitation/temperature/solar radiation, soil morphology and geology, and flow direction. The delineation and discretization of each watershed into HRUs will be done using Geographic Information System (GIS) analysis. The GIS coverages used here will include publicly available digital elevation maps (DEMs), land use coverages from the California Department of Water Resources (DWR) for Solano County, climate station locations from various public sources (including the National Oceanic and Atmospheric Administration's National Climatic Data Center (NCDC) and DWR's California Irrigation Management Information System (CIMIS)), soil coverage from the Natural Resources Conservation Service's (NRCS) soil survey geographic database (SSURGO), and geologic coverage from U.S. Geological Survey Scientific Investigations Map 2918. These public datasets have already been put through thorough quality assurance and quality control checks by the various government agencies responsible for sharing them with the public, limiting the need for additional QA/QC.

Task 1.2 Model Development – MODFLOW-2005 Input Files

Input files for the finite-difference, three-dimensional groundwater flow model, MODFLOW-2005, will be created in this subtask. This involves using previously created geologic interpretations of the subsurface to set up layers and grid information based on hydrogeologic properties (including aquifer zone thickness, hydraulic conductivity, storage, porosity, etc.). Model layers and grid sizes will be assembled using GIS mapping techniques with the appropriate level of detail to insure that the model will be capable of addressing the goals related to groundwater resources management as stated above. Groundwater pumping data will be requested and collected from SCWA member entities, as well as estimated for agricultural and private groundwater extraction rates and locations. The groundwater extraction will be simulated with enough detail to represent different aquifer units (aka different model layers) that are being pumped. Surface water data, including streamflow data will be collected and entered into the appropriate format in this subtask as well for all rivers and lakes in the model area.

Task 1.3 Model Calibration

In order to have a tool that can be used for multiple groundwater and surface water purposes, this GSFLOW model will need to be calibrated to match simulated (modeled) and observed (real) data. The most common and practical method of model calibration involves matching simulated and observed groundwater levels. This process of comparison and calibration of the GSFLOW model to actual data is part of the QA/QC of this project, and will ultimately enhance the accuracy of modeling results. Calibration is the process of adjusting hydraulic parameters, boundary conditions, and initial conditions within reasonable ranges to obtain a match between observed and simulated values of water levels or flow rates. Another part of the calibration process is performing a sensitivity analysis, which involves determining the effect of parameter variation on model results. This will identify aquifer parameters, stresses, and boundary conditions that have the most influence on model calibration and therefore predictions in different scenarios.

For computing residuals (or the difference between measured and simulated values), there are plenty of aquifer-specific groundwater level data in the City of Vacaville area, for example, that will provide the raw data for calibration in that area. Other groundwater level data throughout the model area available from SCWA member entities and DWR will also be used for calibration. Measured water level data will preferably be used for wells that are completed in a unique aquifer unit (although water levels from composite or unknown well completions may also be used for calibration in areas lacking aquifer-specific data). Model input parameters will be adjusted based on results of the calibration process to better simulate reality and create a robust and stable model.

Task 2. Conjunctive Use Simulations

The Integrated Regional Water Management Plan (IRWMP) developed for SCWA and its member agencies describes regional policies and projects for long-term water resources planning and management. Entities within the county that rely on groundwater for all or a portion of their supply include the cities of Vacaville, Rio Vista, and Dixon and water districts such as Rural North Vacaville Water District (RNVWD) and Solano Irrigation District (SID). Additional groundwater development is planned in other areas as a means of increasing water supply availability and reliability. The IRWMP recognizes that groundwater in Solano County is underutilized; however, more information is needed to determine where and to what extent greater utilization is possible. The studies conducted as part of SCWA's "Northern Solano County Groundwater Monitoring Program" (begun in 2006) and also the "AB 303 Solano Groundwater Investigations Project" by SCWA in coordination with others has accomplished a lot of the physical conceptual foundation work necessary for the development of the GSFLOW model proposed in this grant application. Correspondingly, additional information and analyses are required to evaluate the availability of groundwater in conjunction with surface water to meet future water requirements.

The overall goal of this task is to consider the potential effects of conjunctive water use scenarios on stakeholders in the greater Solano area, including the Sacramento River and other significant surface water courses in the model area. Agencies such as DWR and the USBR would be especially interested in the quantification of the potential for streamflow depletion of such surface water courses in response to conjunctive use of groundwater in the model area.

Task 2.1 Meeting/Coordination with SCWA Member Entities to Develop Scenarios

This task would involve a meeting and/or other coordination with SCWA member entities to develop simulation scenarios for future conjunctive use operational goals. The scenarios would also include consideration of changed demands during normal, single-dry, and multiple-dry year periods.

Task 2.2 Run Conjunctive Use Simulations

This task will use the calibrated GSFLOW model for the Solano area to simulate the first groundwater management scenario topic involving conjunctive use activities. Conjunctive use activities will include increased groundwater pumping (in both the upper and lower portions of the aquifer system) during dry years and reduced pumping during wet years. Different conjunctive use schemes will be simulated and results will be presented in the documentation. This task directly relates to improving the understanding of the conjunctive use element of groundwater management to implement the goals and objectives of GWMPs in Solano County.

Task 3. Pumpage Distribution Simulations

This task will seek to simulate the effects of developing new and/or redistributing deep pumpage either horizontally over a spatial area or vertically over different aquifer units with the goal of reducing drawdowns in the basal zone. This task directly relates to improving the understanding of the relationship between pumping effects and maintaining desired groundwater levels (i.e., levels that do not show continued decline and/or would not contribute to significant inelastic subsidence) by focusing on the basal zone as an important aquifer unit for public water supply (existing and for potential future development). Maintaining stable groundwater levels with the above-noted attributes is a key objective of the GWMPs in Solano County.

Task 3.1 Pumpage Simulations Deep Basal Zone of Tehama Formation

This task involves simulations of present and redistributed pumpage from the basal zone of the Tehama Formation as well as simulations that consider future development of groundwater from this zone.

Task 4. Recharge and Interconnectivity to Lower Freshwater Aquifer Zones Used for Supply

As part of the “AB 303 Solano Groundwater Investigations Project” conducted by SCWA in coordination with others, Component 1 of the project was on hydrogeologic interpretation of the deep aquifer system in northern Solano County. The primary goal of Component 1 was to develop a fundamental understanding of the basal Tehama and other deep aquifer formations and their relationship with overlying units. Findings of the project included:

- The basal Tehama Formation is highly confined and groundwater levels appear to be affected at significant distances (e.g., beyond 5 miles) from where groundwater is pumped from this unit;
- Although the Tehama Formation outcrop area north of Vacaville is relatively extensive, the upper part of the Tehama Formation is dominated by lower permeability materials that likely reduce recharge to the basal unit;
- The depth of the basal unit of the Tehama Formation and the lower permeability of overlying materials hinders vertical recharge;
- Some leakage through overlying confining units may occur, however, this should be further evaluated;
- Groundwater released from storage in confining units may be a more significant source of short-term recharge to the basal unit than leakage through these units; and
- Groundwater level data and trends examined for the period from 2002 to about 2008 suggested that full spring groundwater level recovery was generally not occurring. Although this is a short observation period, this response, combined with the extended cone of depression in the northern Solano area, indicates that the flow occurring in the direction of the cone had not yet stabilized to equal groundwater discharge from that area.
- Observations also suggested that groundwater recharge sources are limited and may be further constrained. When groundwater released from storage in confining beds is no longer recoverable, it no longer serves as a source of recharge.

One of the objectives for the new SCWA monitoring sites was to expand groundwater level data for the basal zone and overlying zones of the Tehama Formation to assess the extent of effects of basal zone pumping. Levels measured at the new SCWA monitoring sites indicate that basal zone pumping has a wider effect than previously recognized. Continued groundwater monitoring will confirm this response to basal zone pumping, although the effect is not unexpected due to the highly confined nature of this deeper part of the aquifer system.

Increased groundwater extraction in the basal Tehama Formation will continue to lower groundwater levels. Levels are also likely to decrease below historic levels, especially in areas where there has been little to no prior development of groundwater supplies from the basal Tehama Formation. Groundwater levels may reach a new equilibrium between extraction and recharge or, at some stage of total groundwater level development from this deep unit, would continue to decline reflecting a net deficit in the overall groundwater budget.

It is planned that groundwater can be utilized to a greater extent in the Solano Subbasin. However, more information is needed to determine where and to what extent greater utilization is possible. The added zone-specific water level monitoring with the new SCWA facilities contribute to the data needed to improve the understanding of current groundwater conditions in the aquifer system and establish a baseline against which to assess the response of the aquifer system to future groundwater development. Most importantly, use of the GSFLOW model will aid evaluation of recharge in relation to pumpage as described below for this task.

Task 4.1 Evaluation of Simulation Results Related to Recharge Mechanisms

This task will use the GSFLOW model to examine the behavior of recharge and the interconnectivity of the lower freshwater bearing aquifer zones. This task will build off of Task 3, in observing the differences in flow to the lower freshwater aquifer zones using historic and current pumping patterns, as well as using different pumpage distributions performed in Task 3. Gaining further understanding on recharge mechanisms and defining recharge areas is a fundamental component of groundwater management.

Task 4.2 Prepare Map of Recharge Areas to Different Units of Aquifer System

One product of this task will be a map showing recharge areas for recharge to different units of the aquifer system in the Solano model area, which will satisfy the latest addition to the Water Code (WC 10753.7(a)(1)) and requirement of GWMPs.

Task 5. Examine the Implications of Lowered Groundwater Levels and Potential Subsidence

The above observations from the “AB 303 Solano Groundwater Investigations Project” (as noted in Task 4) further suggested that groundwater recharge sources are limited and may be further constrained. Given these conditions, the potential subsidence is a very important consideration.

As part of SCWA’s “Northern Solano County Groundwater Monitoring Program”, two continuously operating references (CORS) stations were installed in May 2012 in the project study area to monitor changes in land surface elevation at each respective site. Each CORS station will record vertical and horizontal land surface movement utilizing global positioning technology. The elevation data collected at each station, data from existing CORS stations, and data from traditional surveys will be used along with water level data collected from wells in the monitoring program and pumpage data from area wells to determine if a correlation exists between groundwater levels and ground surface elevation changes. These data will be used along with the GSFLOW model for the ultimate goal of developing groundwater resource utilization strategies that minimize land subsidence.

Task 5.1 Evaluate Simulation Results Related to Potential for Subsidence

This task will use the GSFLOW model to examine the implications of lowered groundwater levels and potential subsidence. As maintaining stable groundwater levels and avoiding subsidence is a main objective in GWMPs in Solano County, this task will help to investigate how groundwater levels and subsidence can impact groundwater as a resource.

Task 6. Determine the Groundwater Budget for the Complex Aquifer System in the Greater Solano Area

This task will use the output from the calibrated GSFLOW model to determine the groundwater budget for the complex aquifer system in the greater Solano area. This task will explore the different flow components of the GSFLOW model including precipitation, evapotranspiration, streamflow, boundary flow, and pumpage. An improved understanding of flow components on the model area as a whole, as well as between different user-defined zones (including aquifer units, watersheds, political boundaries, etc.), will aid groundwater managers when making decisions on how to best use their groundwater resources.

This task will summarize flow components for key scenarios stemming from Tasks 2 and 3 including changes in flows during normal, dry and multiple-dry water years. The model simulation results would be used to evaluate the potential effects of variations in the rate, timing, or location of area pumpage and under different water year types.

Task 7. Documentation and Reporting

Project deliverables for assessing progress and accomplishments will be in the form of a draft and final project documentation report. The entire project is expected to be completed in approximately one year from the start of LGA funding (assumed start date of April, 2013). The draft and final reports will document the data gathering procedures and methodologies used for completing each task described above.

SCWA will be responsible for providing the draft and final grant reports for the grant. Accordingly, this task covers the main deliverable, namely the comprehensive model documentation report (draft and final) that will describe in detail all of the model inputs, assumptions, interpretations, calibration, water budgets, recharge mechanisms, and water management scenarios (conjunctive use, different pumpage distribution regimes, and the implications of lowered groundwater levels and subsidence). This document will serve as a guide for groundwater managers to refer to when making decisions about groundwater pumpage, conjunctive use operations, and recharge protection. It will also provide the documentation needed to understand how the GSFLOW model works, which will enable future users to customize model scenarios based on specific groundwater management needs. Input from SCWA member entities will be encouraged between the draft and final document reports are completed to assure that a high quality product results from this effort.

Task 7.1 Draft Report

This subtask involves preparing the Draft Report for review. The will include model documentation as described above, results, and findings. It will be provided to SCWA, DWR and SCWA member agencies for review and comment.

Task 7.2 Final Report

Prepare final Report. The Final Report will be finalized after addressing any comments received on the draft.

Task 8 Quarterly Progress Reports

SCWA will be responsible for providing quarterly progress reports to DWR. SCWA will collect information from the consultant performing much of the Tasks under the grant. The quarterly progress reports include six reports that will document the data gathering procedures and methodologies used for completing each task described above. Completion statuses of each task will be recorded in each progress report in order to present a sound strategy for evaluating progress and performance at each step of the project.