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APPLICATION OF ARC HYDRO GROUNDWATER TO THE SACRAMENTO REGIONAL MODEL

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ABSTRACT: The Sacramento Regional Model (SRM) encompasses an area of approximately 1,360 square miles (871,000 acres), overlying the North American and South American subbasins of the Sacramento Valley Groundwater Basin, and the Cosumnes subbasin of the San Joaquin Groundwater Basin. The SRM was developed on behalf of the City of Roseville to provide an analytical tool to support Aquifer Storage and Recovery Operations and modeling efforts that are being conducted to maintain the quality and ensure the long-term availability of groundwater to meet backup, emergency, and peak demands. The SRM utilizes GMS and Arc Hydro Groundwater (AHGW) as pre- and post-processing tools. GMS was used for the initial creation and calibration of the model, and the Arc Hydro Data Model (AHDM) and AHGW tools were used to process, store, and manage model inputs and outputs for the SRM model. The AHDM provided a component to generate native MODFLOW input files from automated custom workflows, developed using the ArcGIS Model Builder Application, which were directly linked to the AHDM. The AHGW tools, in combination with GMS, provide the long-awaited bridge for integrating geospatial processing tools with groundwater modeling needs with an ArcGIS framework.

KEY TERMS: Arc Hydro; automated workflows; geodatabase; groundwater; MODFLOW

INTRODUCTION

The Sacramento Regional Model (SRM) was developed on behalf of the City of Roseville to provide an analytical tool to support Aquifer Storage and Recovery Operations and modeling efforts that are being conducted to maintain the quality and ensure the long-term availability of groundwater to meet backup, emergency, and peak demands. The SRM encompasses an area of approximately 1,360 square miles (871,000 acres), overlying the North American and South American subbasins of the Sacramento Valley Groundwater Basin, and the Cosumnes subbasin of the San Joaquin Groundwater Basin. The SRM is bounded on the northern end by the Bear River, on the west by the Feather and Sacramento Rivers, to the south by the Mokelumne River, and by the Sierra Nevada Mountains to the east (**Figure 1**).

The SRM is a 10-layer model, representing the five major stratigraphic units of the region. The Ione Formation is the oldest formation, overlain by the Valley Springs Formation, the Mehrten Formation, the Turlock Lake Laguna Formation, and the Riverbank Formation. The formations outcrop along the eastern side of the

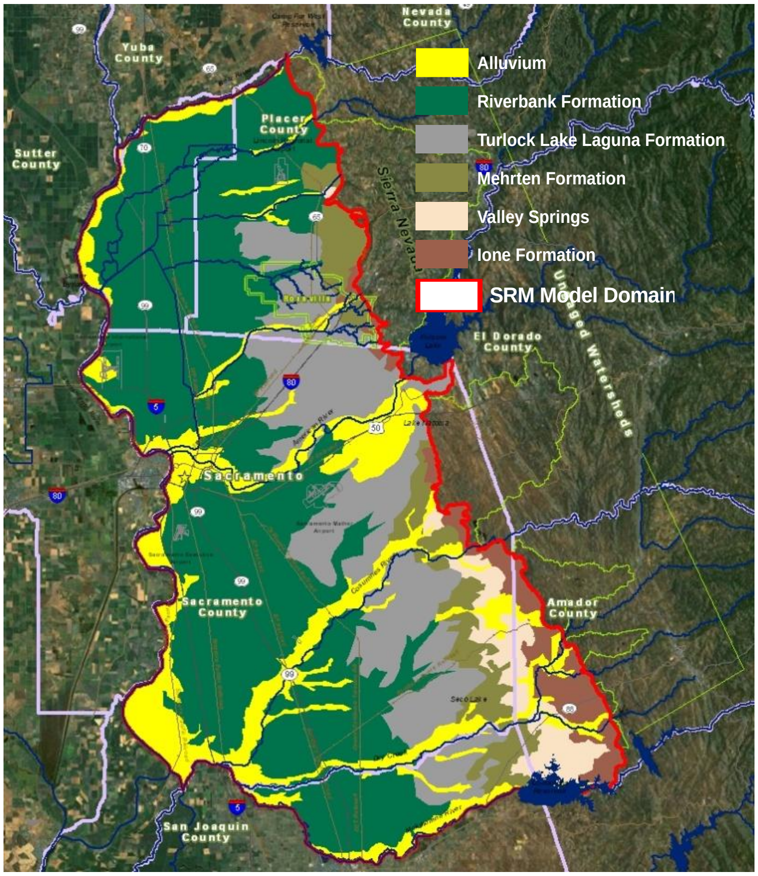

Figure 1 SRM Site Vicinity Map

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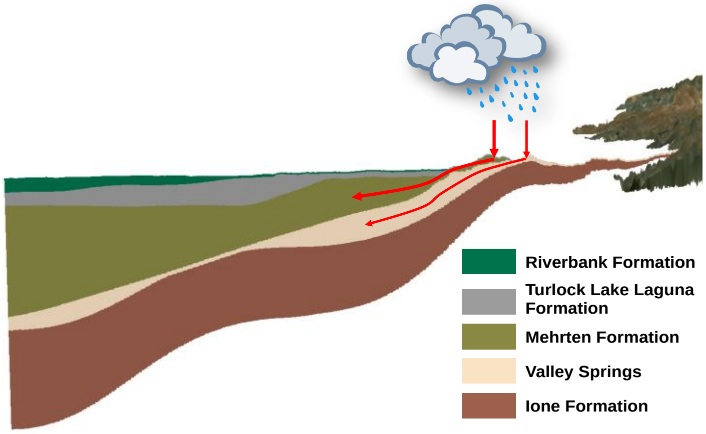

Figure 2 Outcrop Model

SRM domain. The incorporation of the geologic outcrops was essential to accurately represent recharge and stream/aquifer interactions to the appropriate model layer (**Figure 2**).

The surficial deposits within the SRM are generally consolidated sediments of low permeability which inhibit the vertical percolation of water to the underlying aquifer, except in areas overlain by younger alluvial deposits or tailings which are more predominant in the vicinity of major streams and rivers. Due to the low infiltration of the surficial soils, recharge predominantly occurs near the major rivers and in areas where alluvial deposits exist. Recharge is also believed to enter the model from secondary fracturing along the eastern side of the SRM domain in the areas of outcrops. These recharge areas are represented using a total of seven ungaged watersheds. Recharge from ungaged watersheds and areal recharge to the SRM are sophisticated processes that incorporate components of land use operations, soils types, precipitation, and irrigation practices, and are calculated using automated workflows developed in ArcGIS with the AHGW tools and stored within the Arc Hydro Geodatabase.

In addition to how water enters the system, the SRM inherits another layer of complexity associated with the water supply and demand processes that dictate how water moves out of the SRM. The use and application of water requires significant attention because both water use and water supply in the region vary by area. Supply and demand can be accounted for using surface water, groundwater, treated water or some combination thereof. Both the supply and demand of water also vary temporally for each region; certain water restrictions may apply which impact the source of available water and have to be incorporated into the water accounting framework for the region.

The hydrogeology of the SRM is non-trivial as well, adding a layer of complexity to understanding how water moves within the SRM. The major formations are predominantly composed of silts, sands, and clays, generally low in permeability. In contrast to these low permeable sediments and surficial deposits, an extensive network of ancestral streams exists in the region that create an intricate network of high permeable fingers that weave throughout the low permeable deposits, providing localized paths of least resistance which are believed to play an integral role in the movement of both groundwater and contaminants in the subsurface (**Figure 3**).

The availability of water is a significant concern in the area, and therefore, the mechanisms that dictate how water enters the system, leaves the system, and moves within the system must be simulated within the SRM. However important it is to understanding water use, application, and demand, this information is often difficult to ascertain. The SRM is a tool that was originally developed to support ASR operations for the City of Roseville; however, the SRM has blossomed into a tool that provides a mechanism to understand, visualize and support complicated water management decisions for the entire region. The incorporation of AHGW tools with the SRM provided the ability to successfully model the complexity of the region in a timely, cost effective, well-structured and visually intuitive fashion.

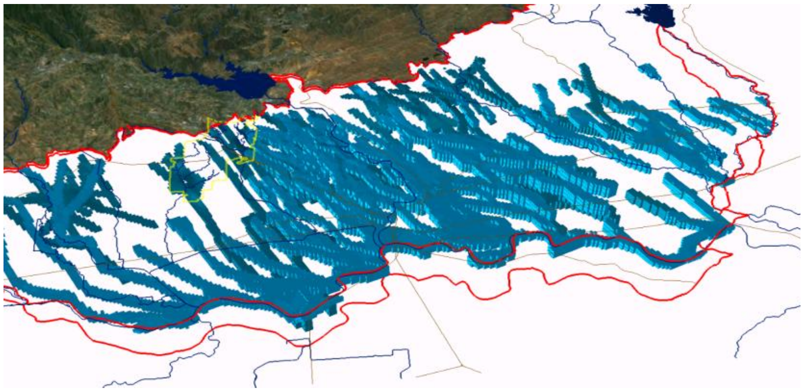

Figure 3: Ancestral Streams.

ARC HYDRO GEODATABASE AND ARC HYDRO TOOLKIT

The SRM utilizes GMS and AHGW as pre- and post-processing tools. GMS was used for the initial creation and calibration of the model, and the AHDM and AHGW tools were used to process, store, and manage model inputs and outputs for the SRM.

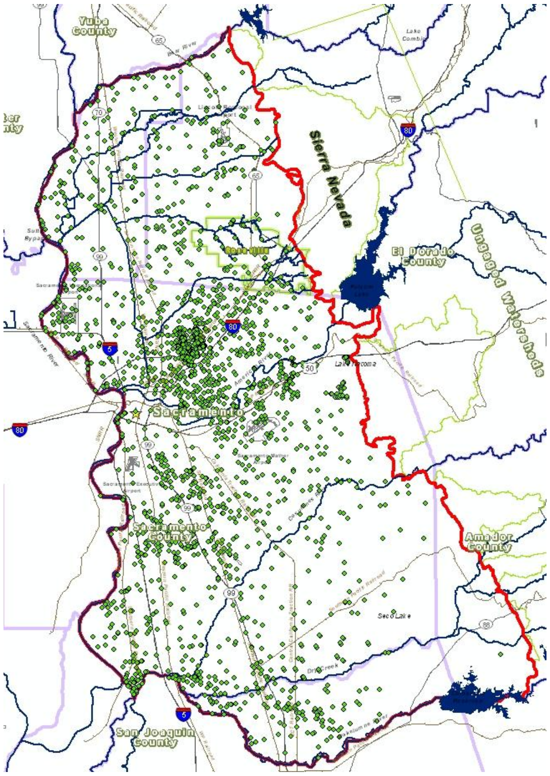

Figure 5 Well Locations.

The development of the Arc Hydro geodatabase was an iterative process; updates and modifications were done periodically throughout the calibration process. The first phase of the Arc Hydro geodatabase included compiling all of the wells in the region, including monitoring wells, supply wells, ASR wells, and exploratory wells (**Figure 4**). These wells were compiled from a variety of sources, including local municipalities like the City of Roseville, state agencies, including the California Department of Water Resources, and regional databases that were previously development for regional water boards. Each well was assigned a unique Hydro ID. The Hydro ID is used to query and visualize the data within the Arc Hydro environment. The use of well information in the SRM was an important aspect of every phase of model development. During the development of model stratigraphy, well information was used to establish the vertical demarcation of stratigraphic units based on well driller's logs, to establish areas of high and low permeability zones and for correlation to existing ancestral streams. During steady-state model calibration, the Make Time Series Statistics tools within the AHGW tools were used to generate monthly averages of groundwater levels for calibration input files.

During the post-processing phase of the SRM, the AHGW tools were used to generate cross sections and fence diagrams (Figure 5) for "on-the-fly" presentation to clients at specific well locations or areas within the domain for demonstration to water purveyors during discussions and meetings. The foundation for developing very detailed water budgets for each water purveyor throughout the simulation time period was based upon the AHDM and the geoprocessing tools in the AHGW Tools, and some of the native ArcGIS geoprocessing tools, including summary statistics and zonal statistics.

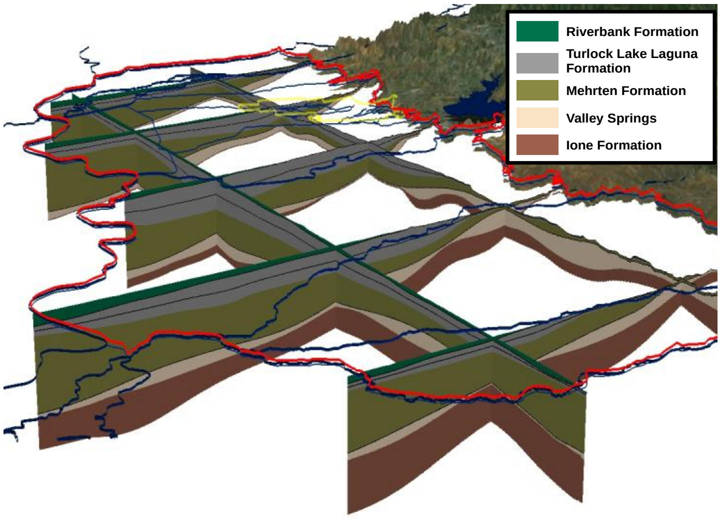

Figure 4 Fence Diagram.

CONCEPTUAL MODEL DEVELOPMENT

A conceptual model is a general description of the site, including the principal groundwater formations and geologic units, including major and minor faults that may influence the flow of groundwater, major water sources including areas of recharge, subsurface inflow, and surface water interactions, and discharge areas, including springs and subsurface outflows. The conceptual model was developed in a GIS environment and then converted to the numerical model interface. The entire conceptual model is stored with the Arc Hydro Geodatabase and can be manipulated and updated rather easily. The conceptual model consisted of several critical elements: the stratigraphy of the model (**Figure 6**), which defines the foundation for the numerical model layering and the model outcrops; the geologic materials zones (**Figure 7**), which are used to spatially assign the hydrologic inputs, including horizontal conductivity, vertical anisotropy and storage based upon the specific geologic properties of the corresponding material for each model layer; the ancestral streams, which delineate the lateral and vertical extent of the ancestral streams, the sources and sinks, which are used to store the pumping information from supply wells, remediation wells and demand wells, as well as the inputs for surface water features such as river, streams, and reservoirs. The last element of the conceptual model includes the observations which are used to calibrate the numerical model, comparing the simulated responses of the model to observation data from monitoring wells within the SRM. All of these features are stored and managed within the Arc Hydro Geodatabase and can be visualized in both ArcView and ArcScene applications.

AUTOMATED WATER DEMAND/RECHARGE WORKFLOW (AWDRW)

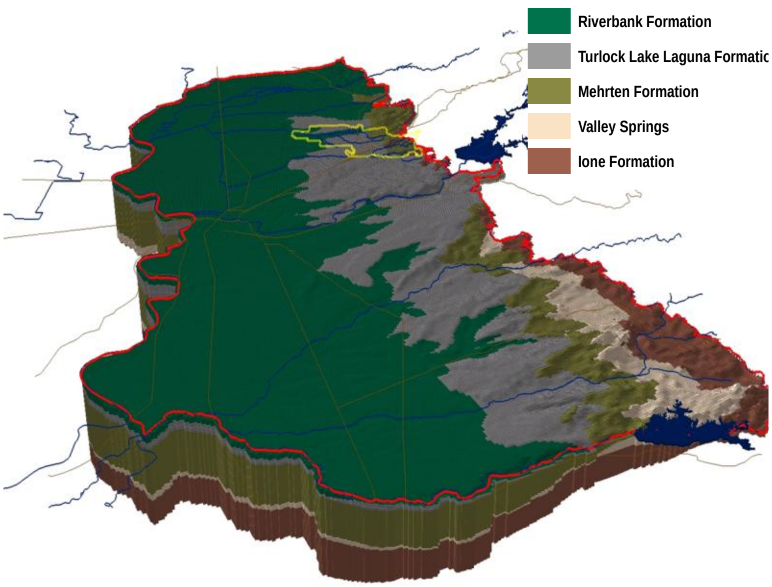

Figure 6 SRM Stratigraphy.

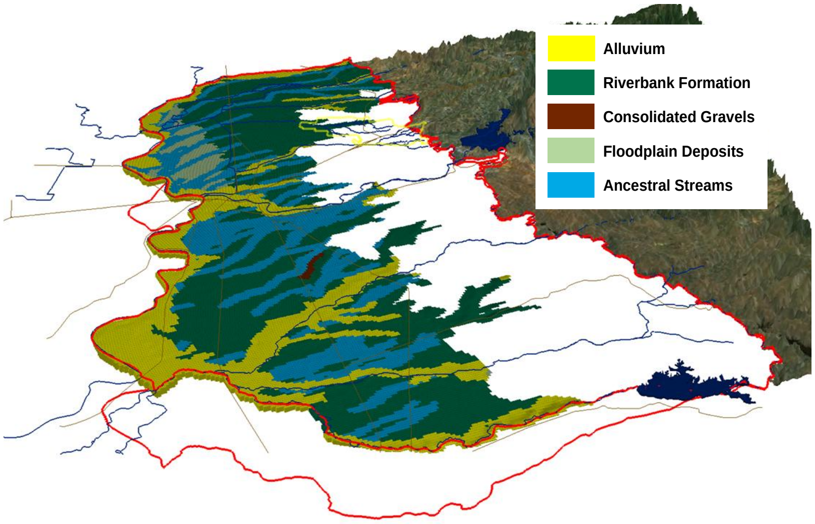

Figure 7 Hydrogeologic Zones for Model Layer 1.

Working from a base of low level tools, automated workflows and custom modifications to the tools provided the mechanism that allowed complex processes, such as recharge and water demand to be calculated in a timely and efficient manner (Figure 8). This information incorporates a significant amount of spatial and temporal data that are all stored within the Arc Hydro Geodatabase. The first phase of the AWDRW consists of a series of surface water/groundwater model simulations using the United States Geological Survey (USGS) Gridded Surface Subsurface Hydrologic Analysis (GSSHA) Model. The GSSHA simulations were performed to be able to develop recharge coefficients for input into the groundwater model. The GSSHA simulations incorporated land use data, Farm Survey data, PRISM precipitation data, stream flow data and meteorological data. A series of 19 soil-type/land-use (STLU) combinations were developed and assigned a specific STLU ID. Each cell within the GSSHA simulation was assigned a specific STLU ID; these IDs were specific to each GSSHA simulation that was performed. The results of the GSSHA simulations are specific to each water year classification in the automated recharge process once the water demand portion of the automated section was complete.

The second aspect of the AWDRW was water demand calculations. This section of the automated workflow consisted of establishing a baseline land use classification throughout the entire SRM, associated with each land use was a unique water demand unit factor, a factor that accounts for the amount of water required to satisfy the particular demand of each land use. The agricultural water unit demand factors were taken from published values developed by the California Department of Water Resources. The urban demand factors were a combination of published values specific to a municipality, or were estimated based on published reports. The setup of the demand model provided a level of “calibration” for the urban demand factors based on real data, for those areas where data existed. This loop in the AWDRW provides valuable output for water regulators and managers throughout the region for forecasting and water banking scenarios.

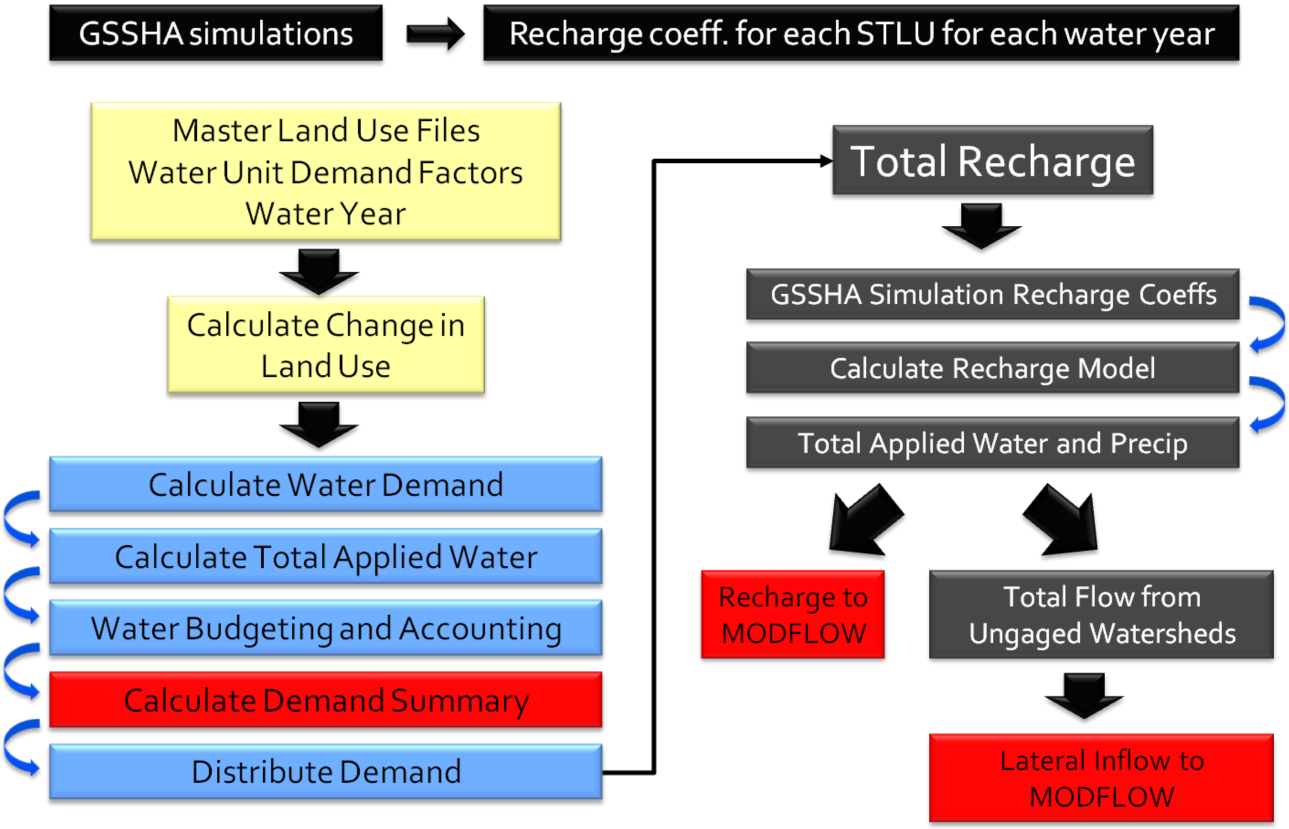

Figure 8: Automated Water Demand/Recharge Workflow (AWDRW)

Once a baseline land use classification was assigned, there was a need to be able to simulate changing land use patterns. Using information from the baseline land use data and electronic Farm Data Surveys, which provided a lower resolution of land use surveys, a change in land use from one year to the next was calculated. Input into the AWDRW includes land use data that varies every two years, water unit demand data that varies monthly, precipitation data that varies monthly, and GSSHA recharge factors that are specific to each water year classification. Using the Arc Hydro geodatabase and the AHGW tools, these features were stored in a database and processed using the Model Builder Application in the ESRI software. Once total water demand is calculated for every stress period (monthly), a budgeting exercise had to be completed to be able to tabulate the total amount of water supplied to the region, versus the total water that is demanded for each region. If the total water demand is greater than the total water supplied to the region, than the remaining portion is distributed evenly to selected wells designated for each water purveyor or zone within the model domain. The AHDM stores all the information that goes into the inputs for the automated calculations as well as the outputs from each process. This provides a transparent and well-organized mechanism that allows for easy manipulation when additional new information is acquired. Custom summary tables can be tabulated for each water purveyor and statistics can be run for each area because everything is done within the ArcGIS environment.

A subsequent branch of the AWDRW includes calculating the recharge. The recharge model incorporates the GSSHA recharge coefficients, the PRISM precipitation data, the applied water from irrigation that is an output from the water demand model, and the specific land use information that is stored as shapefiles with the Arc Hydro Geodatabase. The AHDM was used to store the native input files. The AHGW tools were used to convert GIS data into native MODFLOW format for direct input to GMS for large, complex, transient datasets.

Once the final recharge has been calculated the last branch of the AWDRW calculates the total inflow from ungaged watersheds. Using tools in the AHGW interface, the output from the demand model is converted to shapefiles which can be read directly into GMS. Using the tools to automate processes, we were able to process model input at an exceptional rate. We were able to process water demand calculations for the entire simulation period in a day. Without these tools, this effort would have taken a couple of weeks. This saves time and money not just during model development, but also for model updates and revisions.

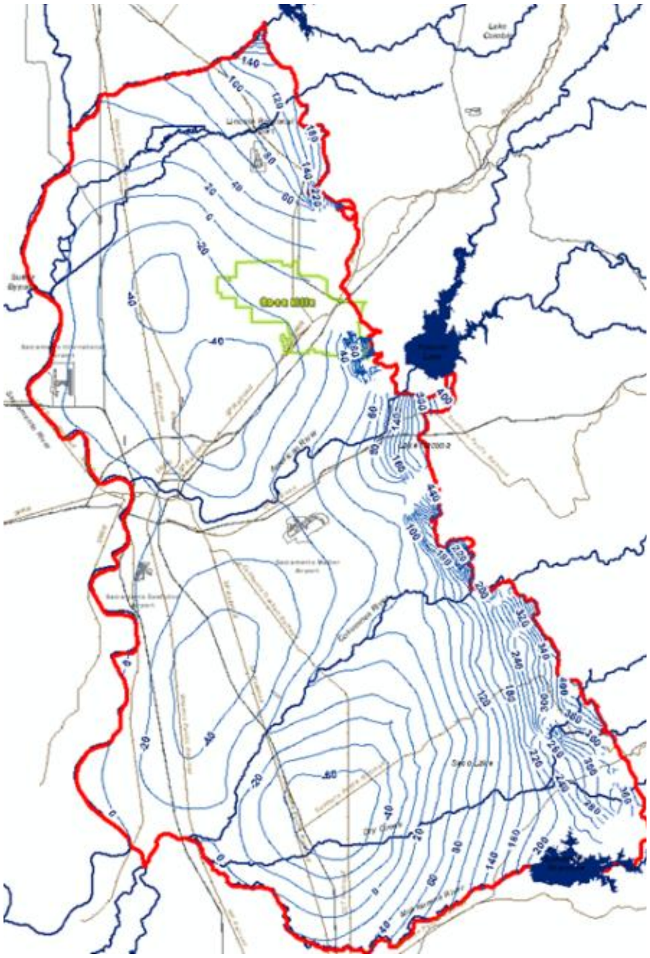

Figure 9 Simulated Water Levels.

MODEL RESULTS

Once the automated workflows and the conceptual model were converted to the numerical model, a series of iterative simulations were performed for both the steady-state and transient models in order to calibrate the model to field-observed heads and flows. The calibrated model in GMS can be brought into ArcGIS using the AHGW tools. Once the calibrated model is in the ArcGIS environment, AHGW tools were used to represent model input features and calibrated water levels (**Figure 9**) which can be displayed for specific model layers or for specific time periods. Using the controls available in the AHGW toolbar, one can toggle between stress periods and see the groundwater contours change, based upon the specified input period selected.

CONCLUSIONS

The AHGW tools, in combination with GMS, provide the long-awaited bridge for integrating geospatial processing tools with groundwater modeling needs with an ArcGIS framework. The ability to automate input features and complicated workflows provided a huge cost savings for the project. Furthermore, the ability to automate features reduces redundant operations and input errors. The clean and transparent architecture of the AHDM provides the fundamental building blocks for a strong regional model that can be updated and shared across boundaries. AHGW tools have revolutionized the way complex numerical models can be viewed, shared, and managed and have provided the key to building a strong foundation to support complex decisions to manage and protect the valuable resources for the greater Sacramento area.

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