MokeWISE Program Methodology:
Project 4b: Amador and Calaveras Counties Hydrologic Assessment

April 2015

Problem Statement and MokeWISE Stakeholder Interests

The current and future rural populations within Calaveras, Amador, and other Sierra Nevada foothill counties is putting increasing pressure on local water resources. Part of that growth is dependent on groundwater supplied from individual or community wells. However, a significant number of wells fail either as a result of droughts or simply due to the structural inability of the local groundwater system to yield the required demand. Furthermore, such failures likely will be exacerbated by climate change due to impacts on groundwater recharge. Because recharge is the small fraction of precipitation remaining after runoff and the soil-water use of the vegetation cover, a small climatic change will have an exaggerated impact on groundwater.

Very little quantitative information is available on the carrying capacities of the local groundwater systems within Sierra Nevada foothill areas. Those groundwater systems occur mostly in poorly permeable fractured rock, within which groundwater storage is limited to the small volume represented by the fracture openings. Natural recharge occurs seasonally from the deep percolation of precipitation during the winter. However, the recharge is the small percentage of precipitation remaining after the loss of precipitation to runoff or the consumptive use of vegetation. This characteristic makes the foothill groundwater systems very sensitive to seasonal, year-to-year, and long-term changes in precipitation.

While the foothill groundwater systems can be described qualitatively, little quantitative information is available. However, making land use and water-resource decisions would be greatly facilitated by developing a quantitative assessment of the local carrying capacity for the foothill groundwater systems. Information is needed regarding the recharge to these systems with respect to precipitation, soils, vegetation cover, topography, geology, and other factors. Information is also needed regarding the sensitivity of yields to drought and potential climate change. Finally, tools are needed so that decision makers can apply such quantitative information to specific situations.

This study seeks to answer questions regarding groundwater recharge in Amador and Calaveras Counties so that sustainable groundwater evaluations can be determined to guide land use decisions and provide direction to water agencies to meet planned water needs.

The estimated preliminary cost for this study is $600,000.

Some entities have many interests affected by groundwater, including the following:

- Approving projects only if there is adequate water to serve them;
- Protecting key agricultural lands;
- Ensuring that land uses do not put conversion pressure on agricultural lands.

In Calaveras County, both local utilities, the Environmental Health Department, and at times the Board of Supervisors have emphasized the unreliability of groundwater for domestic supplies. In addition, it has long been recognized that agricultural operations have limited access to inexpensive alternatives to groundwater. As a result, there has been support to leave groundwater resources to support agricultural activities in Calaveras County, while locating new commercial, industrial, and residential development in proximity to existing community centers, where they can be served by water utilities using surface water supplies. Additional groundwater studies may strengthen the support for such a position.

Considerations for this project include:

- If and how to replace groundwater lost to climate change. This study could provide information on economically, socially, and environmentally sound options.
- If and how to fairly limit the correlative use of groundwater so that the resource is sustained. This study could provide information on promising options.

Project Information

Project Description

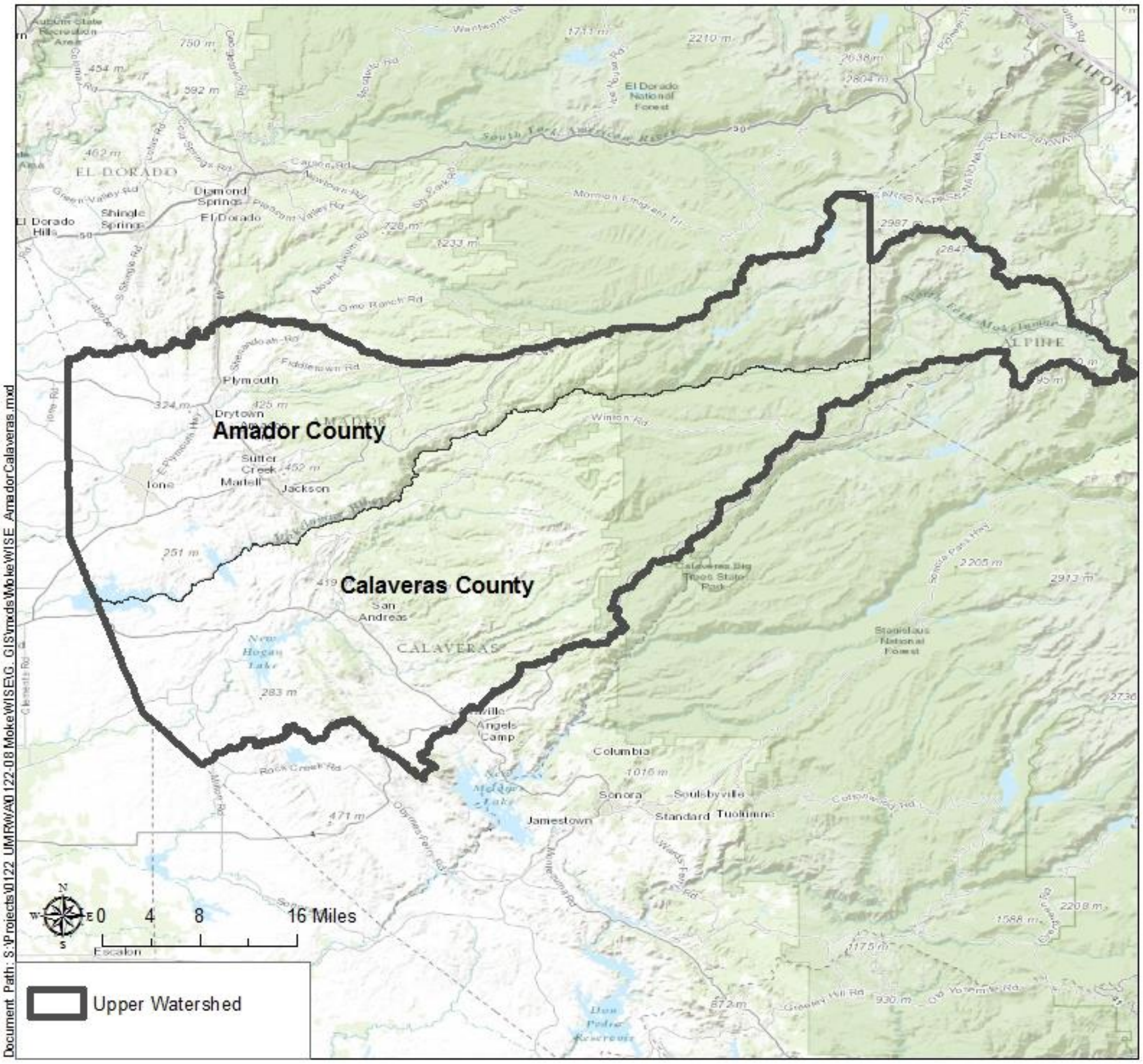
The overall study approach is to characterize the groundwater setting by using watershed water budgets to estimate recharge. Watersheds with streamgaging data would be used. The watershed-scale recharge estimates would be partitioned to smaller geographic scales based on the geographic distribution of precipitation, vegetation cover, soils, geology, and other watershed characteristics. The information derived from gaged watersheds then would be extrapolated to the entire study area. The ultimate work product would be a characterization of the groundwater carrying capacity for the entire study area.

The study will involve characterizing the hydrogeology, existing groundwater use, groundwater recharge and discharge, and groundwater carrying capacity within the foothill areas of Amador and Calaveras Counties.

Project Location

The study will encompass areas within Amador and Calaveras counties, as shown below in Figure 1.

Figure 1: Amador and Calaveras Counties



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Project Sponsor

The lead sponsors for this project are Amador Water Agency and Calaveras County Water District. Jackson Valley Irrigation District has been identified as the co-sponsor.

Scope of Work

Task 1. Hydrogeologic Setting

The study area is underlain by a variety of rock and deposits, and the characteristics of those materials have a fundamental influence on the occurrence and availability of groundwater. To characterize the hydrogeologic setting, geologic, lineament, and hydraulic maps will be produced for the study area.

Subtask 1.1 Geology

The geologic setting represents a primary influence on the occurrence and availability of groundwater within the study area. Groundwater occurs in regional distribution of fractured igneous and metamorphic rocks, and it occurs in local distributions of overlying alluvial deposits.

A geologic map will be prepared for the study area from existing mapping. Existing mapping will be compiled from the U. S. Geological Survey, California Geological Survey, geologic journals, university dissertations, and other sources. This mapping will be compiled into an overall geologic map of the study area. To the extent allowed by the existing information, the compiled map will delineate the occurrences of subunits within the igneous and metamorphic rocks.

Subtask 1.2 Geologic Lineaments

Geologic lineaments represent the effects of fracturing and faulting of rocks. Correspondingly, the transmissivity of the underlying rocks often is correlated with the density and other characteristics of mapped lineaments. Lineaments are defined as linear geologic features that can be mapped from aerial and satellite images. However, the density and other characteristics of mapped lineaments depend on both the characteristics of the images and the method used to delineate lineaments on the images. Different image characteristics or delineation methods will produce a different lineament map. Nevertheless, a useful lineament map can be produced with a set of sufficiently detailed images and an objective delineation method.

Based on these considerations, a lineament map will be prepared for the study area. The purpose of the map is to quantify the density and other characteristics of lineaments over the study area. That quantification will be used within other elements of the study to facilitate characterizing the geographic distribution hydraulic conductivity and other hydraulic characteristics of the rocks underlying the study area. The map will be based on existing aerial or satellite digital images. Quantitative procedures will be used to delineate lineaments on the digital images.

Subtask 1.3 Hydraulic Characterization

The transmissivity of the rocks within the study area depends on the fracture characteristics. The water-transmitting and water-storage capacities depend on the abundance, orientations, lengths, apertures, and other fracture characteristics. Correspondingly, well yields reflect these fracture characteristics. Higher aquifer transmissivity and well yields tend to occur in areas with more abundant fractures, multiple fracture orientations, longer fracture traces, and larger apertures. While aquifer transmissivity can be derived from the small-scale mapping and testing of fractures, that approach is impractical for characterizing the overall geographic distribution of transmissivity within study area. The alternative approach will be to identify the statistical patterns represented in the well data for the study area.

The California Department of Water Resources has well-completion reports on most of the existing wells within the study area, and those reports will be used in the characterization of aquifer transmissivity within the study area. The reports contain information on the well location, depth, construction, geologic setting, and other information. A significant number of the reports contain the results of a well-yield test, where the results tend to include information on the pre-test groundwater level, pumping rate, test duration, and water-level drawdown. That information will be translated into the local transmissivity of the groundwater system near the well. The approach will involve three steps as follows:

<u>Compile Data</u>. Well-completion reports will be obtained from the California Department of Water Resources for all the reported wells within the study area. The information within the reports will be entered into a geospatial database. Protocols will be developed and applied to the database to screen for unreliable data and to correct or delete such data.

<u>Estimate Transmissivity</u>. For wells with data on a pumping rate and drawdown, those data will be translated into the aquifer transmissivity at the well. The ratio of the pumping rate over the drawdown is the specific yield for the well. The transmissivity will be estimated by scaling the specific yield based on a factor derived from the Theis or similar equation. This is a well-established general procedure, but specific scaling factors will be developed for the study area.

<u>Characterize Aquifer Physical Properties</u>. Water-transmitting fractures tend to decrease in abundance and aperture with depth below the land surface, with a corresponding decrease in aquifer hydraulic conductivity with depth. The decay in hydraulic conductivity typically crates an effective local base to the groundwater system at several hundred feet below the land surface. The decrease in depth is often described with an exponential, power, or similar decay function. Such a function will be fitted statistically to the transmissivity data to derive both parameter values for the decay function and the effective thickness of the groundwater system. However, the decay function most likely will have a spatial variability corresponding to geographic factors such as geologic unit, topography, lineament characteristics, and other

variables. To incorporate these variables, a geostatistical analysis will be applied to develop a relation describing the geographically variability of hydraulic conductivity throughout the study area. The results of that analysis will be used to develop maps showing aquifer physical properties throughout the study area.

Task 2. Existing Groundwater Use

Water budgets will be used to quantify the hydrologic characteristics of the groundwater systems within the study area. The existing groundwater use will be an element of the water budgets. Correspondingly, groundwater pumping within the study area will be estimated. Additionally, the returns from irrigation and wastewater disposal will be estimated, for returns generated by either groundwater or surface-water use. The approach will involve three steps as follows:

Compile Data. Data will be compiled from existing sources. Land-use and population data will be compiled from sources such as Amador and Calaveras counties, water districts, cities, California Spatial Information Library, U. S. Census, U. S. Geological Survey, National Resources Conservation Service, and other sources. Water-use information will be compiled from Amador and Calaveras counties, water districts, and other sources. Maps showing water-distribution areas will be obtained from cities, water districts, and other water purveyors. Satellite and aerial imagery will be obtained from the U. S. Geological Survey and other sources. Data will be entered into a geospatial database

Estimate Groundwater Pumping. Groundwater pumping by individual users and community water-supply systems will be estimated. For individual residences outside a public or community service area, groundwater pumping will be estimated based on the occurrence of a residence, the unit interior water use per residence, and the irrigated area per residence. For individual agricultural users, groundwater pumping will be estimated from the irrigated acreage and vegetation type. For public or community water-supply systems, groundwater pumping will be estimated from available water-delivery records or the estimate number and type of connections within the service area. Satellite imagery will be an important tool for identifying irrigated acreages. Existing satellite based delineations of irrigated acreages will be obtained from the California Spatial Information Library, U. S. Geological Survey, and National Resources Conservation Service. Those delineations will be supplemented with an analysis of multi-spectral satellite imagery obtained from the U. S. Geological Survey and other sources. That analysis will include delineating the distribution of the Normalized Difference Vegetation Index (NDVI), which is a measure of vegetation vigor. The work product will be a map showing the geographic distribution of gross groundwater pumping throughout the study area.

Estimate Irrigation and Wastewater Returns. Irrigation and wastewater returns, which represent groundwater recharge from irrigation and wastewater disposal, will be estimated, including returns from surface-water use. For irrigation returns, they will be estimated based on the delineation of irrigated areas, applied water, precipitation, potential evapotranspiration, and the effective crop coefficient for the vegetation. While the potential evapotranspiration and precipitation will be derived from existing climatic data, the effective crop coefficient will be derived from the NDVI derived from satellite imagery. However, the calculation of returns is linked to the calculation of groundwater pumping by common data elements, and a certain amount of adjusting of both quantities will be required in order to obtain pumping and return that are consistent with irrigated acreages, crop types, potential evapotranspiration, cultivation and irrigation practices, precipitation, and other factors. For wastewater returns from residences with individual septic systems, returns will be estimated based on the interior water use. For public or community wastewater treatment systems, returns will be estimated based on either available records or on the number and type of connections and the receiving water. The work product will be a map showing the geographic distribution of groundwater returns throughout the study area.

Task 3. Groundwater Recharge

Groundwater recharge will be identified for selected watersheds within the study area and then extrapolated to the overall study area. The extrapolation will be accomplished by developing, from the selected watersheds, a relation that expresses recharge as a function precipitation, soils, vegetation cover, geology, topography, and other factors. The selected watersheds will be analyzed by constructing surface-water and groundwater budgets for each. The approach will involve seven steps as follows:

<u>Compile Data</u>. Existing streamflow, climatic, soils, vegetation, groundwater, and other data will be compiled for the study area. Streamflow data will be compiled from the U. S. Geological Survey, California Department of Water Resources, water districts, and other sources. Climatic data will be compiled from the National Weather Service, California Department of Water Resources, and other sources. Soils data will be compiled from the National Resources Conservation Service. Vegetation data will be compiled from the U. S. Geological Survey, National Resources Conservation Service, and other sources. Multispectral satellite or aerial imagery will be obtained from the U. S. Geological Survey. Groundwater-level and chemistry data will be compiled from the U. S. Geological Survey, California Department of Water Resources, and other sources. The streamflow, climatic, soils, vegetation, groundwater, and other data will be entered into a geospatial database.

<u>Identify Watersheds</u>. Watersheds will be selected for the development of water budgets. The watersheds most likely will have areas ranging from 1 to perhaps10 square miles, but other watershed areas will be considered. Watersheds will be selected to represents a variety climatic, vegetation, and geologic settings. Watersheds will be selected where the boundaries of the local groundwater system coincide with the boundaries of the watershed.

While this is the primary selection criterion, the availability of existing hydrologic data also will be an important consideration.

Collect Supplemental Data. The existing data for the selected watersheds probably will not meet the study needs, and supplemental data will be collected. Most likely, supplemental streamflow and groundwater monitoring will be required. With respect to streamflow, continuous streamflow data will be collected at some sites, while periodic streamflow measurements will be made at other sites. With respect to groundwater conditions, data will be collected in existing wells. Continuous water-level data will be collected in some wells, and periodic water-level measurements will be made in other wells. In addition, water samples from some wells will be analyzed for chloride and other constituents, where the chloride data will be used in the estimation of groundwater recharge. All of the collected data will be entered into a geospatial database.

Estimate Recharge Using Water Budgets. The groundwater recharge within the study watersheds will be identified based on the construction of surface-water and groundwater budgets for each watershed. Recharge will be calculated as the residual of the groundwater budget. Additional, recharge will be calculated independently based firstly on a chloride mass balance approach and secondly on the consumptive use of the vegetation cover. Water budgets will be constructed for average annual conditions. If the existing and supplemental data allow, water budgets with be constructed additionally for a set of representative wet and dry years.

Water-budget components will be quantified based on the compiled and supplementary geologic, climatic, streamflow, and groundwater data data. The surface-water budgets will be used to partition precipitation into runoff and infiltration and to identify stream-aquifer interactions. The principal outflow component of the surface-water budget is runoff, which will be identified by partitioning measured streamflow into runoff and baseflow. The baseflow in turn represents the net groundwater discharge to the stream. The groundwater-budget terms other than recharge will be quantified, and precipitation recharge will be calculated as the difference between the quantified inflow and outflows. The water-budget inflows include the precipitation recharge, streamflow recharge to the groundwater system, and recharge from water-use returns. The outflows include groundwater discharge to the stream, groundwater consumption by phreatophytes, groundwater underflows, and pumping.

Estimate Recharge Using Chloride Method. The chloride method will be used to derive an independent estimate of precipitation recharge. The method involves constructing a chloride budget for the soil profile. The inflow for the budget is the dissolved chloride flux represented by precipitation. The outflow is the chloride flux represented by the deep percolation of precipitation below the rooting zone of the vegetation cover. The percentage of precipitation that becomes recharge is the ratio of the dissolved precipitation chloride over the dissolved percolation chloride. The precipitation flux includes both wet and dry fall, which will be characterized based on existing precipitation data or the collection of supplemental data. The percolation flux will be characterized based on groundwater samples collected form existing wells.

Estimate Recharge Using Satellite Images. Satellite imagery will be used to derive an additional independent estimate of precipitation recharge. An image analysis will quantify the consumptive use of the vegetation cover, and the recharge will be calculated as the difference between the precipitation infiltration and vegetation consumptive use. The image analysis will be based on the Normalized Difference Vegetation Index (NDVI), which is calculated from the red and near infrared reflectances. The NDVI value for a pixel corresponds to the crop coefficient for that pixel. Correspondingly, an appropriately scaled NDVI value multiplied by the potential evapotranspiration yields the actual evapotranspiration. The image analysis will be conducted for a sample set of wet and dry years. For each selected year, monthly images will be analyzed to derive the seasonal variations in consumptive use, and subsequently to calculate the annual consumptive use.

Extrapolate Results. The recharge estimated for the study watersheds will be extrapolated to the overall study area by relating recharge to topographic, geologic, climatic, and vegetation characteristics. To incorporate these variables, a geostatistical analysis will be applied to develop a relation describing the geographically variability of precipitation recharge throughout the study area. The results of that analysis will be used to develop maps showing recharge throughout the study area.

Task 4. Groundwater Carrying Capacity

Assessing the carrying capacity of the groundwater systems within the study area is more complicated than considering just the recharge. The response of groundwater systems to development is characterized by lower groundwater levels and the capture of natural discharge. This is demonstrated by comparing the natural and developed states of a typical groundwater system.

Under natural conditions, groundwater flow is in general accordance with topographic slopes within the watershed. Correspondingly, the boundaries of the groundwater system tend to coincide with the boundaries of the watershed. Groundwater flows in the subsurface down the hillslopes toward the watershed axis, and it then flows down the axis. Often the groundwater table on the hillslopes will intersect the land surface in draws and other topographic features. At those intersections, seasonal seeps and springs that support groundwater dependent vegetation, where the consumptive use of that vegetation represents discharge from the groundwater system. Likewise, the groundwater table along the watershed axis will intersect the stream channel, and that intersection produces seasonal discharge from the groundwater system into the channel. The shallow groundwater table along the watershed axis additionally will support the growth of phreatophytes, where the consumptive use of that vegetation represents another discharge from the groundwater system. Under this natural condition, the discharges from the groundwater water system equal the recharge to the system such that the long-term discharge equals the long-term recharge.

Groundwater development disrupts the natural equilibrium of the groundwater system. The effect of development is the capture the natural discharge from the groundwater system. Pumping causes groundwater levels to decline, including within the shallow-groundwater areas where groundwater is consumed by vegetation or discharges to a stream channel. Corresponding to the reduction in groundwater levels, the consumptive use of groundwater by vegetation is reduced and the groundwater discharge to streams is reduced. The impact is to reduce the acreage or density of groundwater dependent vegetation and to reduce the baseflows in streams. Given sufficient time, these natural discharges will be reduced by the quantity of the net pumping within the watershed, and a post-development equilibrium will be established. That net pumping is the pumping less the wastewater or irrigation returns to the groundwater system, which is identical to the consumptive use of the pumped groundwater.

The groundwater-level declines associated with development depend on the proximity of the pumping to areas of natural groundwater discharge. Furthermore, the declines do not depend on the recharge to the groundwater system, except that the natural discharges are an expression of the recharge. If a water-supply well is located near a natural discharge, the natural discharge will be captured, and a new equilibrium established, with a small long-term groundwater-level decline near the well. If a water-supply well is located distant from a natural discharge, the capture of the discharge will correspond to a large long-term groundwater level decline near the well. With sufficient distance from an area of natural discharge, the decline required to produce a post-development equilibrium will exceed the usable aquifer thickness, and the well will go dry. This will be the case regardless of the natural recharge within the vicinity of the well.

The sustainability of groundwater development within the study area depends on the ability to capture natural discharge. However, the capture of natural discharge will impact groundwater-dependent vegetation and baseflows in streams. To address these issues, response functions will be developed that describe the expected long-term impacts of pumping at particular locations on groundwater levels and natural discharge. This most likely will involve developing groundwater models of the study watersheds and then using the model results to develop relations that can be applied throughout the study area.

Task 5. Outreach and Coordination

Targeted and public outreach are critical components of regional water project development. In order to successfully develop a groundwater supply study project in the region, many different stakeholders and interested parties will need to be engaged, coordinated with and consulted along the way.

Subtask 5.1 Perform Outreach and Public Discussion for Project Development

In this task the project team will reach out to former MokeWISE Mokelumne Collaborative Group (MCG) members, City officials, other agency officials, the agricultural community, other interested stakeholders and the general public to provide information on the program analysis and recommended alternatives. This support includes, but is not limited to, development of summary or outreach documents, coordination of meetings with representatives of State and Federal agencies, meeting with water agencies that may participate in the project and presentations to public officials and the general public. Coordination with former interested members of the MCG and other interested stakeholders will be implemented throughout the project.

Subtask 5.2 Coordinate with Groundwater Sustainability Agency(ies) (GSAS)

The recently signed Sustainable Groundwater Management Act (SGMA) has the potential to greatly affect groundwater management in the region. Assembly Bill (AB) 1739 requires the formation of a groundwater sustainability agency (GSA) to submit a groundwater sustainability plan (GSP). If multiple GSAs and/or multiple GSPs are created within a single basin, they must be coordinated to achieve overall basin sustainability or be subject to state intervention. AB 1739 also outlines new authorities designated to GSAs, including the ability to impose fees. Senate Bill (SB) 1168 would require that each groundwater basin be characterized with a priority and include consideration of adverse impacts on local habitat and local streamflows. SB 1319 would authorize the State Board to designate certain high- and medium-priority basins as probationary basins. Each of these bills has the potential to alter the groundwater landscape within the MokeWISE region, particularly in the lower watershed.

This task includes coordinating with entities participating in the GSAs for the Eastern San Joaquin and Cosumnes Groundwater Subbasins. The GSA(s) will be responsible for developing and implementing the Groundwater Sustainability Plans (GSPs) for the subbasins. Coordination with the GSA entities should be ongoing throughout this hydrologic assessment process in order to position projects for potential inclusion in the GSP(s) and associated funding opportunities.

Study Products

The overall study will result in a number of work products. While some will address scientific audiences, other work products will address the needs of decision makers and the public. The anticipated work products are as follows:

Prepare Technical Report. A technical report will be prepared that describes the study methods and results. The purpose of the report is to describe the study in sufficient detail that it can be critically reviewed with respect to its scientific foundations and results. The primary audience for the report with be technically oriented stakeholders.

Produce Groundwater Atlas. An atlas will be prepared on the study results. The purpose here is to prepare a reference that will be useful to public decision-makers, the public, and other interested parties. The atlas will be a large-format publication that contains maps, graphs, and text that will be understandable by the non-scientific community.

Develop Geospatial Database. All of the basic data compiled or collected for the study will be entered into a geospatial database. The database will store spatial and temporal data, most likely using the ArcGIS format.

Publish Scientific Papers. Scientific papers will be prepared on critical elements of the study and submitted for publication in a peer-reviewed hydrologic journal. The purpose here is twofold. Firstly, the study methods and results will be subjected to independent critical by journal reviewers. Secondly, the study results will be made available to the wider scientific community. A papers will be prepared on the geologic characterization of the study area, and another paper will be prepared on the quantification of recharge.

Budget

The estimated budget for this study is assumed to be $600,000, as it is expected to include some preliminary field investigations and covers a large geographical area.

References

Dunn Environmental, Inc. 2012. *Groundwater Supply Study and Integrated Regional Groundwater Management Plan for the Lake Camanche Water Improvement District No.7*.

RMC Water and Environment (RMC). 2015. MokeWISE Program Final Memorandum: Water Availability Analysis. January 9.