SUMMARY

Title: Hydrologic Characterization and a Coupled Watershed and Groundwater-Flow Model of the Russian River Watershed, California
Cooperating agency: Sonoma County Water Agency (SCWA) and California State Water Resources Control Board (State Board)
Period of project: 2016-2019
Geographic Scope: Potter Valley, Ukiah Valley, Sanel Valley, Alexander and Cloverdale areas of Alexander Valley, Healdsburg area of Santa Rosa Valley, Santa Rosa Valley, and Lower Russian River Valley as defined by California Department of Water Resources in Bulletin 118.
Problem Most basins in the Russian River watershed (RRW) currently rely on a combination of Russian River water and groundwater to meet demand. The primary uses of water in the RRW include agricultural irrigation, municipal supplies, rural domestic uses that are outside of municipal system (i.e., private wells and municipal water companies) and commercial uses (e.g., wineries). Current and future challenges to managing RRW water resources include: available flows for fisheries, extreme events due to climate change, flood impacts, increasing water-supply demands, decreasing water availability, and streamflow and groundwater storage depletion.
Objectives: The primary objectives of this project are to: 1) refine the understanding of the RRW hydrologic system based on an analysis of new and available field data; and 2) develop a coupled watershed/groundwater-flow model for the RRW that will facilitate improved management of the region's water resources.
Relevance and Benefits: This study will assist SCWA, the State Board, and other stakeholders to better understand the potential impacts of increasing groundwater demand on water levels and in developing strategies for efficient surface-water/groundwater management. The USGS will address significant issues of stream-aquifer interaction and develop new, transferable tools for analyzing multi-basin water management. The study addresses the priority water-resource issue "A Water Census of the United States: Quantifying, Forecasting, and Securing Freshwater for America's Future" identified in "Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017."
Approach: Specific tasks will be: 1) interpret available data, collect new data, and characterize the geohydrology of RRW — including refining hydrologic budgets and conceptual models of the hydrologic system; 2) development and application of a coupled watershed and groundwater-flow model; and 3) describe the results of the study in a USGS report.
Anticipated products: A USGS Scientific Investigations Report will describe the updated geohydrologic characterization of the RRW and the development, calibration, and application of the coupled surface-water/groundwater-flow model.

Hydrologic Characterization and a Coupled Watershed and Groundwater-Flow Model of the Russian River Watershed, California

PROBLEM

The Russian River Watershed (RRW; fig. 1) is a diverse region of 1,500 square miles of urban, agricultural and forested lands in northern Sonoma County and southern Mendocino County, California. The Russian River is prone to droughts and floods (highest recurrent flood damages in California). This flashiness is due in large part to the prevalence of atmospheric rivers for the region, which comprise, on average, nearly 50 percent of precipitation. This highly variable hydrology presents significant challenges for flood, water supply and environmental water managers.

The recently enacted California Sustainable Groundwater Management Act (SGMA) identifies two of the basins (Santa Rosa Plain and Ukiah Valley) within the RRW as medium-priority basins; therefore, groundwater-sustainability agencies will need to be formed in each basin by June 30, 2017 and groundwater sustainability plans will need to be developed by January 2022. In addition, other basins within the RRW could be reprioritized into high/medium priority once the California State Department of Water Resources conducts basin reprioritization in winter 2017. This work will help support those management efforts.

Most basins in the RRW currently rely on a combination of Russian River water and groundwater to meet demand. The primary uses of water in the RRW include agricultural irrigation, municipal supplies, rural domestic uses that are outside of municipal systems (i.e., private wells and mutual water companies) and commercial uses (e.g., wineries and recreation). Current and future challenges to managing RRW water resources include: available flows for fisheries, extreme events due to climate change, flood impacts, increasing water-supply demands, decreasing water availability, and streamflow and groundwater-storage depletion.

SCOPE

This proposal describes a cooperative project that will study and report on the water resources in the RRW (fig. 1). The Sonoma County Water Agency (SCWA) and California State Water-Resources Control Board (Water Board), in cooperation with the U.S. Geological Survey (USGS), will be responsible for different portions of this study.

OBJECTIVES

The primary objectives of this project are to: 1) refine the understanding of the RRW hydrologic system based on an analysis of new and available field data; and 2) develop a coupled watershed/groundwater-flow model for the RRW that will facilitate improved management of the region’s water resources.

Specific elements in objective 1 are to: quantify present-day hydrologic conditions, including a hydrologic budget and distributed recharge estimates; quantify changes in groundwater levels and streamflow that have occurred during the past few decades and relate these changes to water-resources development, changes in land use, and environmentally-based management [e.g., the Biological Opinion (National Marine Fisheries Service, 2008) and the Federal Energy Regulatory Commission license for the Potter Valley Project (Federal Energy Regulatory Commission, 2004)]; quantify groundwater and surface-water interchange; characterize the geochemistry of the RRW;

improve the definition of the hydrostratigraphy and the groundwater-flow system; and evaluate the potential changes to streamflow in the Russian River and its tributaries associated with future projections of groundwater pumping and climate change.

Specific elements in objective 2 are to develop a numerical model that: 1) simulates past and present surface-water and groundwater conditions, including reservoir releases and stream diversions (addressed by including consideration of: A) water rights into the reservoir and river operations model, MODSIM, and B) riparian evapotranspiration into GSFLOW); 2) quantifies spatially and temporally distributed groundwater and surface-water exchanges; 3) can be efficiently coupled to output from global circulation models (GCMs) to assess the impacts of potential climate change on future hydrologic conditions (Huntington and Niswonger, 2012); and 4) can be readily applied to evaluate potential impacts from land- and water-use changes on future hydrology.

Development of the coupled watershed/groundwater-flow model for RRW will be documented in a USGS report and the model will be available to SCWA, the Water Board, other interested parties and the public to test and analyze various potential future water-management scenarios.

RELEVANCE AND BENEFITS

Groundwater is a critical resource, which is closely connected with surface-water resources in the RRW and is expected to be an important component of water supply in the future. Municipal, commercial, rural-residential and agricultural users consumptively use both surface water and groundwater in the RRW. Studies in this cooperative project will provide much of the hydrologic information needed by SCWA, the Water Board, and other RRW stakeholders to better understand the potential impacts of climate variability and change, and associated changes in groundwater use on groundwater levels, stream discharge, stream-aquifer interaction, and water quality. The project also will provide the information and models needed by SCWA, the Water Board, and others for improved decision making regarding the RRW's surface- and groundwater resources. Development of an integrated hydrologic and reservoir/river operations model for the RRW will allow for better management of all water resources in the watershed.

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

GENERAL HYDROLOGIC DESCRIPTION OF THE RUSSIAN RIVER WATERSHED

The drainage area of the Russian River is in the northern part of the California Coast Ranges section of the Pacific Border province (Fenneman, 1931). The northern Coast Ranges trend northwestward, parallel to the major structural features of the region. The mountain range that lies west of the Russian River valley and extends to the coast is commonly called the Mendocino Range, or the Mendocino Highlands. The highland area east of the lower and middle Russian River valley areas is known as the Mayacmas

Mountains (fig. 1). The altitude of the highlands ranges from about 2,000 to 6,000 ft. The highest point in the Coast Ranges, at an altitude of 6,381 ft, is on Mount Sanhedrin, about 15 mi northeast of Willits. The altitude of the divide on the west side of the Russian River ranges from 1,400 to 3,000 ft; and on the east side, from 3,000 to 4,000 ft. The altitude of the mountains bordering the Russian River increases slightly from south to north.

The proposed study area is drained by the Russian River (fig. 1), a principal river in the northern coastal area of California between San Francisco and Eureka. The Russian River begins about 16 mi north of Ukiah and flows southward for about 90 mi through alluvium-filled valleys and mountain gorges to Rio Dell. There the river turns abruptly westward, crosses the Coast Ranges, and flows to the Pacific Ocean at Jenner, California. The entire river is about 110 mi long, but the drainage basin through which it flows is about 85 mi long. The valley of the Russian River ranges in width from 12 to 32 mi and the watershed has an area of about 1,485 square mi. There are 12 USGS-operated stream gages on the Russian River. Lake Sonoma and Lake Mendocino (which receive water from the Potter Valley Project) are reservoirs that supply water to the Russian River. The supplied reservoir water is important for Chinook salmon and steelhead trout fisheries and for water supply. Lake Sonoma supplies water during the fall and winter to sustain Chinook salmon and steelhead trout habitat. Lake Mendocino is an important source of water for cities and agriculture within the upper Russian River basin above the confluence of Dry Creek. Both reservoirs are important for municipal, industrial, rural, and recreational uses.

A comprehensive hydrologic characterization or modeling study of the RRW has not been reported. Cardwell (1965) described the geohydrology of selected subbasins within the RRW (Potter Valley, Ukiah Valley, Sanel Valley, Alexander and Cloverdale areas of Alexander Valley, Healdsburg area of Santa Rosa Valley, and Lower Russian River Valley). In addition to the aforementioned subbasins, Cardwell (1958) and Nishikawa (2013) described a seventh subbasin, the Santa Rosa Valley. Metzger and others (2006) updated the description of the geohydrology and geochemistry of the Alexander Valley. The California Department of Water Resources (2003) has also described the seven RRW groundwater subbasins.

As described by Cardwell (1965), the rocks in the Russian River valley may be divided into three general groups on the basis of age and water-bearing properties. These groups are, from oldest to youngest, 1) consolidated rocks of Jurassic and Cretaceous age, 2) deformed poorly consolidated or unconsolidated continental, volcanic, and marine rocks of Cenozoic (Pliocene and Pleistocene) age, and 3) under-formed and unconsolidated alluvial deposits of Quaternary age, comprising the terrace deposits of Pleistocene age, dissected alluvium of Pleistocene and Recent age, and alluvium of Recent age.

The oldest rocks in the area are those of the Franciscan and Knoxville Formations of Jurassic and Cretaceous age. These formations constitute the bedrock in most of the northern Coast Ranges. The Franciscan and Knoxville Formations in the vicinity of Healdsburg and Alexander Valley are overlain by a thick unnamed conglomerate of Late Cretaceous (?) age. Wells tapping the conglomerate in the upland area between the northwestern parts of Dry Creek and Alexander Valleys supply adequate water for domestic use.

In the middle Russian River valley area (Healdsburg area and Alexander Valley), the Sonoma Volcanics of Pliocene age, the marine Wilson Grove (formally called the Merced) Formation of Pliocene and Pleistocene (?) age, and the continental Glen Ellen Formation of Pliocene (?) and Pleistocene age crop out discontinuously. Although these formations are of limited areal extent, they are important sources of groundwater locally.

In the upper Russian River valley (Potter Valley, Ukiah Valley, and Sanel Valley), continental deposits considered to be equivalent to the Glen Ellen Formation crop out along the margins of the present alluvial valleys. These deposits are an important source of water for domestic and stock supplies.

Alluvium includes most of the unconsolidated deposits of Recent age that underlie and form the present alluvial plains in the Russian River valley. The alluvium is the principal source of groundwater in all the valley areas. The stream-channel deposits are differentiated from the alluvium in areas where these deposits are spatially extensive.

APPROACH

In order to better understand surface-water and groundwater issues in RRW, the USGS is proposing to characterize the integrated hydrologic system of the RRW. This study will include the effects of variability in climate, geology, biota, and human activities (including regulatory effects) on water availability and surface-water flow in the RRW.

The characterization of the RRW will require the development of a Geographic Information System (GIS) database, data compilation, data collection, and the development of a coupled hydrologic and reservoir/river operations model. Specifically, the USGS-developed integrated Groundwater Surface-water Flow model (GSFLOW; Markstrom and others, 2008) and the reservoir and river operations model MODSIM (Labadie and others, 2000) will be used.

GSFLOW allows for an improved numerical representation of dynamic surface-water/groundwater interactions (Markstrom and others, 2008). This model has been successfully applied in the Santa Rosa Plain groundwater study (Woolfenden and Nishikawa, 2014) and several other watersheds across the world (e.g., see list provided at: http://water.usgs.gov/ogw/gsflow/). In addition, a recent study reviewed available surface-water/groundwater models for application to modeling the Alexander Valley and found that GSFLOW was one of two preferred models (Kennedy/Jenks Consultants, 2015). During these recent studies, tools have been developed that allow much faster and more streamlined development of GSFLOW models and the analyses of their results. This proposed study will take advantage of these tools.

Development of a useful tool to understand and analyze the integrated hydrologic system (GSFLOW model) is aided by broad information about climate, hydrogeology, vegetation, land use, water management, and other system variables that affect the flow and storage of water within the RRW. For this project, there are both data collection and modeling tasks needed to characterize and analyze the system. The data collection/analysis and modeling activities will be conducted in parallel such that each can inform the other.

Task 1: Stakeholder Outreach

An important component of this project is outreach to the various stakeholders in the RRW, including local agencies, communities, water managers, and agricultural entities. In order to help solicit information and data that will benefit the project, it is important that this stakeholder input be received early in the process. This outreach will be conducted to receive broad stakeholder input regarding the identification of important water-resources issues in the RRW. It will also be used to help gather data and insights into the hydrologic system and how it is utilized and managed. Although groundwater is managed locally on an informal basis, there are two agencies that manage the Russian River: the SCWA (water supply) and the Army Corps of Engineers (flood protection). Local stakeholders will provide important insight to improve understanding the Russian River system in addition to the challenges in using and managing water resources in the watershed. Stakeholder meetings and information dissemination will occur throughout the life of the project so that all parties are kept up to date on study findings.

Of primary importance for this task is gathering stakeholder input as early in the project as possible. This will facilitate the process of data compilation that will eventually benefit the development of the model. In addition, a positive start to stakeholder outreach may result in broader "buy-in" from RRW water users regarding making data available to the study or allowing the USGS to collect data from their properties.

The Russian River Independent Science Review Panel (RRISRP) was established by a group of local water suppliers, and agricultural and watershed organizations in an effort to "establish a sound scientific basis for future water supply and watershed management decision making in the Russian River." The possibility of the RRISRP acting as the project's independent technical review committee will be explored. In addition, the RRISRP is scheduled to publish a conceptual model report by May 2016. The geographic scope of this report is the upper river above Dry Creek and will focus on tributaries, specifically surface-water/groundwater interactions and possible impacts to riparian ecosystems. This study will consider the RRISRP conceptual model when developing the GSFLOW model. The committee may also provide guidance regarding model development (e.g., assumptions, model construction, etc.) and defining future water-use, water-availability and management scenarios for simulation by the model.

Task 2: Data Collection and Analysis

In order to better understand the integrated hydrologic system and improve the model's ability to simulate key hydrologic processes, a number of data collection activities, syntheses, and analyses will be undertaken. Specifically this task will involve three parts:

a. Data compilation and development of an integrated GIS database
b. Data collection
c. Data interpretation and geohydrologic characterization

These steps are important for accurate evaluation of surface-water/groundwater interaction, reliability of the surface-water/groundwater system given present-day and future water-use forecasts, and future climate-change impacts.

Task 2a: Data compilation and development of an integrated GIS database

The first part of task 2 will involve data compilation and development of information necessary for model input files—a GIS will be the primary means of organizing data for archiving, searching, interrelating, and displaying hydrologic and related information. Data compilation will include compiling maps of climate, surficial geology, vegetation, land use, well locations, stream networks and reservoir information, and digitizing of drillers' logs. Drillers' logs and geophysical data will be used to define and map alluvial thickness, regionally extensive aquifers (coarse-grained material) and aquitards (fine-grained material), depth to bedrock, and other general hydrogeologic features. Although data may be sparse, groundwater-level data, aquifer-test data, and streamflow records will be compiled to help develop an understanding of the hydrogeology and the flow system, and for use as observations/prior-information for model calibration.

Data used to estimate annual groundwater discharge will also be compiled. These data include: pumping, land-use, vegetation type, and vegetation density. For example, data from previous studies analyzing vineyards and riparian evapotranspiration will be compiled and used. Pumping data will be evaluated to determine the areal distribution and quantity of pumpage for each of the developed aquifers. The only known pumping data is from municipal sources. Agricultural pumpage will be estimated based on stakeholder input, land-use data, irrigation-system efficiency, reference evapotranspiration, and crop-coefficients to determine the consumptive use of water. The vegetation data will be used to estimate evapotranspiration associated with riparian vegetation along the Russian River and its tributaries.

The USGS will work collaboratively with SCWA, the Water Board, and other local stakeholders to develop the GIS database of the RRW. The USGS will work with SCWA to convert an existing HEC-ResSim operations model (Klipsch and Hurst, 2007) developed by SCWA into MODSIM for simulating reservoir and river operations, which will be coupled to GSFLOW. SCWA staff will review the MODSIM model and provide quality control to confirm that the MODSIM results agree with the existing databases that have been developed for the RRW by SCWA, other local stakeholders, and the USGS. Additional sources of data include the California Department of Water Resources (DWR), California Department of Public Health, Mendocino County, the California Nevada River Forecast Center, and the Sonoma County Department of Health Services. The GIS will form the basis for all tasks, including the identification of data gaps and the determination of needs for new data collection. All GIS metadata will be documented according to USGS guidelines (http://gio.usgs.gov/egis/metadata/).

Task 2b: Data collection

This task involves collection and analysis of new data, with a focus on water-quality sampling of the RRW. These efforts will be designed on the basis of the preliminary model results and error evaluations. Data-collection campaigns for the RRW characterization will be designed according to the need to further refine understanding of the hydrologic conceptualization of the system. Where possible and practical, preliminary model simulations will help guide the collection and characterization. Specific tasks will include refining hydrologic budgets and updating conceptual models of the groundwater-flow system based on the new data and the results of ongoing USGS geologic studies in the basin.

Water-quality samples will be collected from selected wells, springs, and streams. These activities will require significant landowner and stakeholder participation. Initially, existing wells will be used and selected based on compiled data in the GIS and in consultation with SCWA and stakeholder technical staff. Sampling will focus on delineating the source and age of groundwater in the main water-bearing zones (aquifers) and characterizing the current water quality. The sampling will build on recent water-quality data collected as part of the USGS Groundwater Ambient Monitoring and Assessment (GAMA) program (Kulongoski and others, 2006; 2010; Mathany and others, 2011). For this study, water-quality analysis will include basic inorganic constituents and nutrients. The stable isotopes of oxygen and hydrogen will be used to provide information on sources of recharge, and tritium/helium and/or carbon-14 analyses will be used to provide information on groundwater age and travel time. Specific analyses of constituents of particular concern, such as arsenic, iron, manganese, and nitrate also will be conducted.

Specifically, 5-10 wells per groundwater subbasin will be sampled per year for the first two years of the project. All wells will be analyzed at the USGS National Water Quality

Laboratory (NWQL) for major and minor ions; basic nutrients; and trace metals. The stable isotopes of oxygen and hydrogen will be analyzed at the Reston Stable Isotope Laboratory. Selected wells will be analyzed for tritium/helium and/or carbon-14 age-dating analyses. Sampling locations will be chosen based on a review of existing water-quality data.

All water-level and water-quality data will be entered into the USGS NWIS (National Water Information System) database. Approximately 10 percent of the number of environmental samples collected will be added as quality-control samples. These samples will include field blanks and sequential replicates, and will be targeted for selected groups of constituents as needed. All data collection and documentation of metadata will be done according to USGS guidelines with the aid of the California Water Science Center Data Program.

Task 2c: Data Interpretation and Geohydrologic Characterization

The geohydrologic characterizations of the RRW, based on previous USGS and DWR studies, will be analyzed and updated based on new interpretations and data collected for this study. This will involve reassessing the hydrostratigraphy and geometry of the water-bearing units, quantifying the distribution and quantity of recharge and discharge (including pumpage), and evaluation of geochemical characteristics of the basin. The main goals are to develop an updated representation of the hydrostratigraphy and geologic structures of the basin; obtain improved estimates of the hydraulic properties of the water-bearing deposits; quantify the groundwater budget; evaluate the dynamics of surface-water/groundwater interaction; characterize the general geochemical characteristics and the sources and ages of groundwater; and identify geochemical and hydrogeologic data gaps.

As part of this study, USGS geologists in Denver, CO, working closely with project personnel from this study, will develop a geologic framework model of the major water-bearing units in the RRW. The overall goal of the framework modeling is to define the three-dimensional geology; this will be accomplished through areal geologic mapping, geophysical surveys, and various topical studies (including geochronology, sediment transport patterns, and fault histories). Researchers will use these data along with newly collected geochemical data to reassess the hydrostratigraphy, structures, and geometry of the major water-bearing units of the groundwater basin. Digital geometries of major water-bearing units (aquifers) will be created as part of this task. This framework model will provide the starting point for our reassessment of the geohydrology of the area and will be the foundation used to develop the GSFLOW model.

Parameterization of the GSFLOW model will incorporate all available information regarding land use and vegetation, topography, geologic and soils maps, groundwater-level records, stable isotopes, and synoptic and continuous flow measurements made at various locations along the river. GSFLOW will be used to simulate evapotranspiration within riparian areas on the basis of soil moisture, water-table altitude, vegetation types and densities, and satellite data such as Normalized Difference Vegetation Index (NDVI). MODSIM will be used to estimate surface-water diversion amounts on the basis of priority, supply, and demand. For parcels that receive surface water and use groundwater, it will be assumed that surface water will be used first, and any residual water demand will be met by groundwater. Wells that have been geographically located and wells with locations inferred on the basis of known water use will be activated within the model automatically to supplement surface-water shortfalls. Surface-water and groundwater demands will be estimated on a seasonal basis using land-use maps, industrial and municipal requirements, and crop water requirements for agricultural areas.

In addition, SCWA is currently working with the USGS to enhance and develop climate scenarios based on the BCM (Flint and Flint, 2007a; Flint and Flint, 2007b; Flint and Flint, 2011; Flint and others, 2011; Flint and Flint, 2012; Flint and others, 2012; Flint and others, in prep). As much as possible, this study will build on, utilize, and/or do comparisons with this work. In particular, an examination of the differences in, and uncertainty of, the BCM-derived estimates and those developed as part of this study will be undertaken.

There will be a particular focus on collecting information on the changing dynamics of stream/aquifer interaction along the Russian River as groundwater pumpage has increased since groundwater was first extracted in the RRW. Gaging-station records will be analyzed to determine: 1) seasonal periods with flow consisting primarily of groundwater discharge, and 2) seasonal depletion of streamflow caused by groundwater pumping and evapotranspiration of riparian vegetation along the Russian River. Stream gage records, synoptic seepage runs, and previous analyses by SCWA, will provide historic and current information to define gaining and losing reaches of the stream. Specific plans for seepage runs will be made after historic data are reviewed and field reconnaissance completed. However, in general, two seepage runs are planned: one in the fall and the second in the spring.

In addition to data gaps indicated by the preliminary GSFLOW model, gaps in the geochemical and hydrogeologic data also will be identified using the available data compiled in Task 2b and the new data collected in this task. These gaps may include identifying wells where depth-dependent water-quality data are needed or locations where multiple-piezometer monitoring sites are needed. If available, these additional data will help refine the three-dimensional characterization of the RRW.

Task 3: Development of a GSFLOW model

The goal of this task is to develop a GSFLOW model of the RRW (fig. 1). This will be accomplished in two steps: step 1 will be to develop an preliminary, transient GSFLOW model that is capable of doing scoping runs and to identify data gaps, and step 2 will be to develop a final, refined and fully calibrated transient model capable of investigating the complex surface-water/groundwater interactions in the RRW. Woolfenden and Nishikawa (2014) describe the results of a GSFLOW model of the Santa Rosa Plain watershed (called the Santa Rosa Plain Hydrologic Model or SRPHM). Due to its regional nature, it is anticipated that the horizontal and vertical discretization of the RRW model will be much coarser than the SRPHM (1,000 ft by 1,000 ft). The Santa Rosa Plain watershed will not be simulated explicitly; where the SRPHM borders the Healdsburg area of Santa Rosa Valley will be treated as a boundary condition in the preliminary and final RRW models. GSFLOW model boundaries will follow the RRW topographic divides throughout the basin and will be treated as no-flow boundaries, with the exception of the Santa Rosa Plain watershed, where the boundary will follow a buffered area adjacent to the river.

The preliminary, transient model will be coarse in its representation of geology, land use, and water use and will rely on easily accessible data. The simulation horizon will be the period of record of the most complete pumpage dataset. The model will be calibrated and evaluated according to sub-watershed budgets, average groundwater levels from available data, and correspondence between climate variability and streamflow variability. Model errors will be evaluated to identify sensitive parameters affecting the solution and regions in the model that require further refinement in parameterization and(or) data to constrain the solution. In this manner, the model will be used to focus data mining and data collection and in-depth characterization of the hydrologic system in areas where the model unsatisfactorily simulates historical hydrologic conditions.

Utilizing the integrated GIS database from Task 2a, all the required input files for the GSFLOW model will be developed. The automated calibration software PEST (Doherty, 2010) will then be used to refine initial hydraulic parameters and to explore heterogeneities in hydraulic properties within hydrogeologic units required to improve simulations results relative to observation data. Calibration with PEST will include using pilot points and regularization. Pilot points are arbitrary points in space that facilitate estimation of spatially-distributed hydraulic properties of an aquifer; for example, hydraulic conductivity. Because cell-by-cell estimation of aquifer properties is not possible, pilot points offer a compromise between strict piecewise-constant zonal (i.e., 'zonation') approaches and under-determined cell-by-cell estimation of spatially-distributed aquifer properties. Regularization helps not only to stabilize the numerical aspects of the inverse problem, also it allows the modeler to impart expert knowledge (commonly referred to as "soft" knowledge) in to the parameter estimation problem. Calibration will combine the geohydrologic characterization from task 2C and within-geologic unit characterization through the pilot point and regularization methods provided by PEST.

The GSFLOW model will be developed in three phases. The first phase will consist of the development, calibration, and application of the Precipitation Runoff Modeling System (PRMS) component of the model. The PRMS model will be calibrated to measured stream-discharge data. This work will be closely integrated with existing BCM modeling work in the watershed and the GIS database developed for task 2A.

The second phase will consist of the development, calibration, and application of the groundwater-flow model (MODFLOW) component of the GSFLOW model. Specifically, steady-state and transient versions of the MODFLOW model will be developed. The models will be calibrated to measured groundwater-level, stream-discharge, and geochemistry data (e.g., age-dating or stable-isotope data). It should be noted that groundwater flow through fracture apertures (fracture-flow) in the Franciscan Formation, which dominates much of the watershed area, will not be simulated explicitly, but rather approximated as flow through an equivalent porous media. The use of the equivalent-porous-media approach is suitable at the scale of this model; however, it may not be appropriate at local scales where fracture flow is predominant. The focus of the model will be to accurately simulate the interactions of surface water and groundwater that predominantly occur in the alluvial portion of the system.

The third phase consists of combining the MODFLOW and PRMS models into the coupled GSFLOW model. This phase will include additional calibration of the integrated model using combined transient surface-water and groundwater targets. Typically, when MODFLOW and PRMS models are calibrated separately, and are then combined for GSFLOW simulations, modest additional calibration is required to account for changes in surface and groundwater exchanges in the integrated model.

Task 4: Coupling GSFLOW with MODSIM

A reservoir management and river operations model will be developed using the MODSIM software on the basis of the existing HEC ResSim model developed by SCWA. To the extent possible, historical measurements of reservoir releases and river diversions will be specified in the GSFLOW model. However, historical measurements of water use are not completely available. For this case, MODSIM will be used to simulate historical river diversions that are unknown and can be estimated on the basis of water-right priorities, simulated water supply, and water demand. For example, MODSIM is effective for estimating reservoir releases and river diversions during water-supply shortfalls, when the distribution of available water is complicated by priority and shortfalls are supplemented by groundwater wells. MODSIM can calculate water allocation constrained by management objectives, such as minimum instream flows for fish passage. Additionally, MODSIM will be used for simulating water distribution for future hydrologic conditions and for basin management scenarios. The combined GSFLOW-MODSIM model provides comprehensive simulation of hydrologic processes to estimate water supply that is coupled with operations/planning impacts for representing water use and distribution by humans. The tool provides detailed transient analysis of water-use forecasts, climate-change impacts, and other water-management issues of interest to the broader stakeholder community.

Following completion of final transient integrated GSFLOW-MODSIM model, future hydrologic and water-use conditions will be simulated for the next century relying on CMIP5 projections of future climate change conditions (Stocker and others, 2013). SCWA, in cooperation with the USGS, has developed multiple downscaled climate futures (240 m spatial resolution, 1 day time steps) for the next century using the CMIP5 projections. These climate data sets will be used to simulate hydrologic and water-supply forecasts in the RRW using six different climate projections for the next century. In addition to incorporating climate forecasts that represent climate change scenarios, changes in land use and water demand will be incorporated into the future hydrologic simulations using the integrated GSFLOW-MODSIM model.

Deliverables

The USGS will provide quarterly updates to the Water Board, SCWA, and local stakeholders via telephone or WebEx. In addition, USGS personnel will meet in person with the Water Board, SCWA, and local stakeholders on at least an annual basis.

A USGS Scientific Investigations Report characterizing the hydrology of the RRW and summarizing results of the GSFLOW model of the RRW will be completed for colleague review by the first quarter of FFY19, and it should be approved for publication by the end of the fourth quarter of FFY19. The characterization of the RRW will be based on the hydrogeologic and geochemical analyses. The GSFLOW model will be documented by describing the conceptual model, model development, model calibration (including any relevant tables and figures), model results (including any relevant groundwater and surface-water hydrographs and hydrologic budget information), and water-use scenarios. The report will include an integrated assessment of the response of surface- and groundwater resources to changes in water demands and climatic influences. The model will be developed to help water managers and interested stakeholder better manage their watershed system demands by providing water-use scenarios and estimating the effects of water-use decisions both numerically and graphically. Uncertainty analyses generally will be incorporated into these model runs, particularly with regard to the impact of pumping, given the sparseness of available data. An agreed-upon set of scenarios will be developed based on input solicited from participating water managers and interested stakeholders. One of these scenarios will evaluate the impact of climate change on water supply reliability. All pre- and post processors will be made available to SCWA, state, and stakeholders.

All models developed for this study will be archived according to the new Policy and Guidelines for Archival of Surface-Water, Groundwater, and Water–Quality Model Applications (http://water.usgs.gov/admin/memo/GW/gw2015.02.pdfhttp://water.usgs.gov/admin/memo/GW/gw2015.02.pdf):

OFFICE OF GROUNDWATER TECHNICAL MEMORANDUM 2015.02
OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM 2015.01
OFFICE OF WATER QUALITY TECHNICAL MEMORANDUM 2015.01.

In addition to the formal reports, progress reports, and frequent meetings, a website will be developed to facilitate communication and coordination with SCWA and other relevant stakeholders. The USGS will provide technical assistance to the State Board and SCWA with the model during the life of the project; however, formal training in the use of the model is beyond the scope of this study. It is expected that this assistance will increase during the final six months of the project when the model is completed and the report is going through the review process.

SCHEDULE

A project timeline is shown in Table 1. More details on some of the tasks are below:

1) By the end of the second quarter of Federal Fiscal Year 2017 (FFY17), the preliminary, transient GSFLOW model of the RRW will be completed. This initial,

transient model will provide water-resource managers with an overview of the integrated hydrologic system. As this model is developed, it will help guide the data-collection efforts. In addition, stakeholder and RRICRP input will guide the data-collection and model-building efforts.

2) By the end of the second quarter of FFY18, the final, transient GSFLOW model of the RRW will be completed. The transient model will incorporate climate variability and other dynamic changes in the system. In addition, it will be compared with newly collected geologic, geophysical, and geochemical data and updated accordingly.

3) By the end of FFY18, The MODSIM model will be completed and coupled to GSFLOW to incorporate transient reservoir outflow to the Russian River. This model will allow the cooperators to review the components and parts of the model and determine what additional stresses or forecasting runs will be necessary.

4) All data compilation and collection tasks will be completed by the end of FFY17.

5) All geochemical and geohydrologic analyses will be completed by the end of FFY18.

6) During the life of the project, the USGS will provide technical assistance to the State Board and SCWA on the use of the model.

7) At the end of the project (end of 4 years), the site characterization and model report will be published along with the archive and release of the model. The report, model, and all documentation will all be publicly available and online.

	FFY16				FFY17				FFY18				FFY19			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1. Stakeholder Outreach	x	x	x	x	x	x	x	x	x	x	x	X	x	x	x	x
Task 2a: Data compilation/GIS	x	x	x	x	x	x										
Task 2b: Data collection	x	x	x	x	x	x	x	x								
Task 2c: Geohydrologic Characterization		x	x	x	x	x	x	x	x							
Modeling Tasks. Task 3: GSFLOW model																
Initial, transient GSFLOW Model	x	x	x	x	x	x										
Final, transient GSFLOW Model	x	x					x	x	x	x						
Task 4: Coupling GSFLOW with MODSIM																
Couple GSFLOW w/ MODSIM							x	x	x	x	x	X				
Model Scenarios and Forecasting									x	x	x	x				
Transient Model complete for review												x				

Deliverables																
Quarterly Updates	x	x	x	x	x	x	x	x	x	x	x	X				
Website	x	x	x	x	x	x	x	x	x	x	x	X	x	x	x	
Technical Assistance	x	x	x	x	x	x	x	x	x	x	x	X	x	x	x	
Report																
Manuscript										x	x	X	x			
Review													x			
Editorial review														x		
Final Review															x	
Publish Report																x

Table 1. Work plan by federal fiscal year, quarter, and task.

BUDGET

SCWA, the Water Board, and USGS will share the costs of the project. The availability of federal matching funds (FMFs) for this project is uncertain at this point. Depending on availability, the FMFs from earlier FFYs may need to be adjusted and/or postponed into later FFYs. Possible USGS and SCWA/Water Board funding by FFY is presented below.

	FFY16	FFY17	FFY18	FFY19	Total
USGS	$57,500	$76,300	$72,800	$48,100	$254,700
Cooperators	$420,500	$479,600	$296,200	$182,700	$1,379,000
TOTAL	$478,000	$555,900	$369,000	$230,800	$1,633,700

Table 2. Possible cooperator and USGS federal matching funds by federal fiscal year.

Personnel

The project will employ a GS-13 hydrologist, a GS-12 hydrologist, a GS-11 geochemist/geologist, a GS-9 physical scientist, a GS-9 information specialist, 3 GS-9 hydrologic technicians, and a GS-7 GIS specialist. The years and percentages of full time for each employee are presented in table 3.

Federal fiscal year (October 1 – September 30)	FFY16	FFY17	FFY18	FFY19
GS-13 hydrologist	10%	10%	10%	10%
GS-12 hydrologist	25%	25%	63%	29%
GS-11 geochemist/geologist	23%	38%	25%	17%
GS-9 physical scientist	16%	16%		
GS-9 information spec.	8%	8%	8%	8%
GS-9 hydro techs (total)		11%		
GS-7 GIS specialist	21%	21%	14%	14%

Table 3. Personnel used by federal fiscal year with percentages of full time for each employee.

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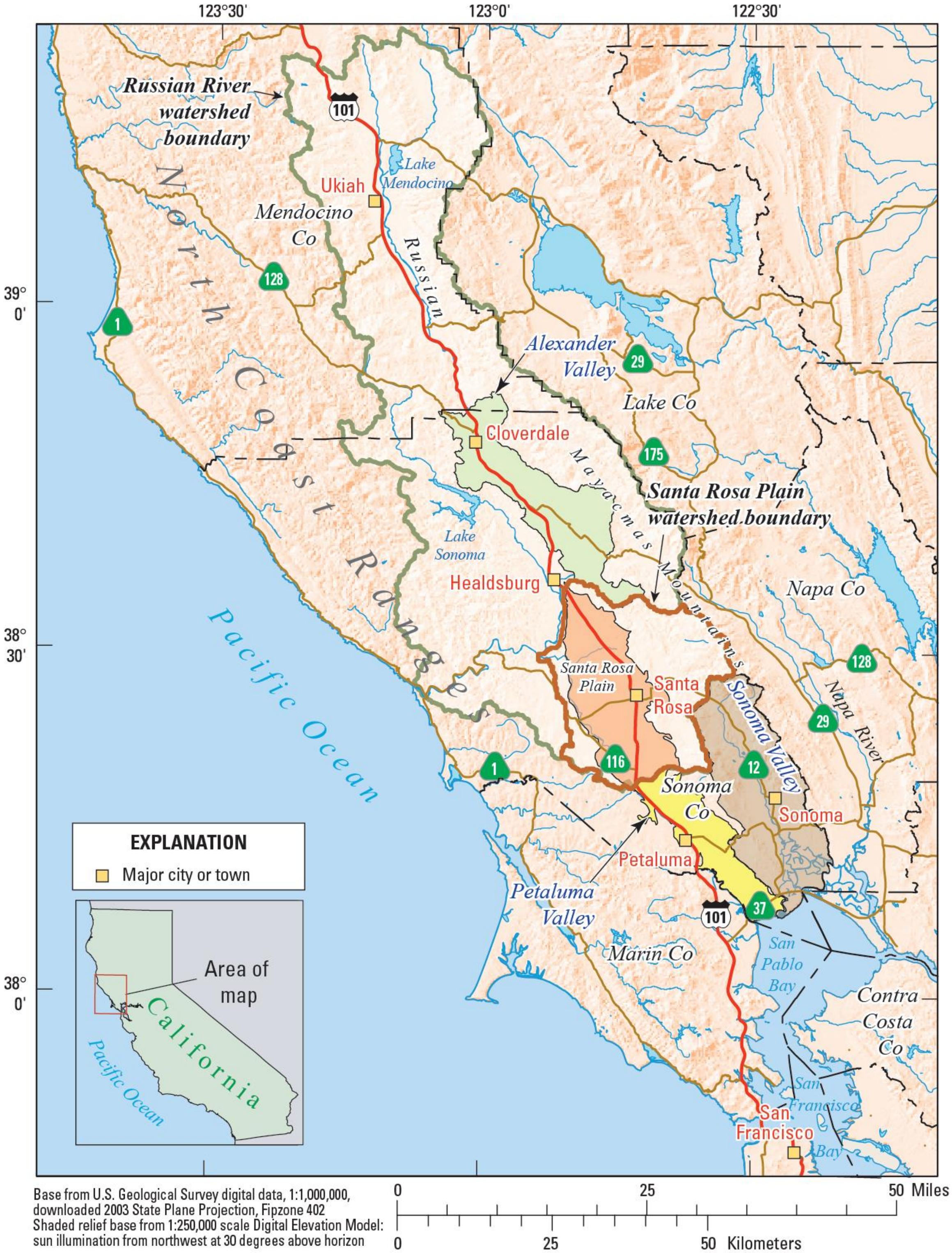

Figure 1. Boundaries of the Russian River watershed, Santa Rosa Plain watershed, Alexander Valley, Sonoma Valley, and Petaluma Valley, Sonoma County, CA.

Job Hazard *Analysis For New Projects*

- Check the numbered box(s) for all significant safety concerns this project should address. Significant safety concerns are commonly those that require training, purchase of safety equipment, or specialized preparation to address potentially hazardous conditions.
- Identify any unlisted safety concerns at bottom of the page.
- Provide details on the back of this page.

Proposal Number: 2016-02
Project Title (Short) Russian River Evaluation
Project Chief or Proposal Author Tracy Nishikawa

√	**Safety Concerns**
1. √	Wading, bridge, boat, or cableway measurements or sampling
2.	Working on ice covered rivers or lakes
3.	Measuring or sampling during floods
4.	Well drilling; borehole logging
5. √	Electrical hazards in the work area
6.	Construction
7. √	Working in remote areas, communication, office call in procedures
8. √	Ergonomics, carpal tunnel syndrome
9. √	Field Vehicles appropriate for task?- Safety screens, equipment restraints.
10.	All terrain vehicles, snowmobiles
11.	Helicopter or fixed wing aircraft usage
12.	Site access
13. √	Hypothermia or heat stroke
14. √	Hantavirus, Lyme Disease, Histoplasmosis, Pfiesteria, Others?
15. √	Contaminated water with sanitary, biological, or chemical concerns
16. √	Immunizations
17. √	Laboratory or mobile laboratory. Chemical hygiene plan.
18.	Hazardous waste disposal
19.	Hazardous waste site operations
20. √	Confined space
21.	Radioactivity
22. √	Respiratory protection
23.	Scuba Diving
24.	Electrofishing
25.	

26.	

Box no.	For each numbered box checked on the previous page, briefly: A. Describe the safety concern as it relates to this project. B. Describe how this safety concern will be addressed. Include training, safety equipment and other actions that will be required. C. Estimate costs.
1	1. Wading, bridge, boat, or cableway measurements or sampling: PFDs: Personal Floatation Devices (PFDs) will be provided to field personnel and must be worn when working in, over, or near a water body. Any exceptions, which are extremely rare, must be approved by the employee's supervisor, the CAWSC Safety Coordinator, and the CAWSC Director. Inflatable PFDs will be orally inflated at least twice per year to ensure these devices remain inflated for at least 24 hours. PFDs that fail this check will be immediately removed from service, quarantined, and destroyed. Hydrostatic inflatable PFDs will be auto-inflated and re-armed every four years or as indicated by the inflation device's expiration date. Wafer inflatable PFDs will be auto-inflated and re-armed annually or as indicated by the inflation device's expiration date. Results of all checks will be sent to the CAWSC Safety Coordinator.
5	5. Electrical hazards in the work area: All personnel will be informed of the DOI Learn course titled, "Safety: Electrical Safety Design" and encouraged to complete this course if they are not familiar with electrical hazards. No additional costs are expected.
7	7. Working in remote areas, communication, office call in procedures: Some parts of the study area may be remote. Center call-in procedures apply. Site-specific call in procedures for CAWSC facilities are located HERE
8	8. Ergonomics, carpal tunnel syndrome: Ergonomic assessments of employee workstations are available upon request to the safety coordinator. The CAWSC has developed an SOP for procuring approved ergonomic equipment. Employees should contact Stephen Schmitt, safety coordinator, for additional information.
9	9. Field vehicles appropriate for task? – safety screens, equipment restraints: The California Water Science Center uses vehicles for data collection activities, supply runs, and travel to and from meetings and conferences. **Vehicle Safety Maintenance and Inspection:** Vehicle maintenance resides with the person primarily responsible for upkeep of that vehicle. This person is to complete the USGS Vehicle Safety Inspection Checklist annually and file locally (i.e. in the location where the vehicle is stored). The checklist form can be accessed from the Center's Safety webpage. **Cargo Barriers:** Vehicles shall contain appropriate safety barriers to protect occupants from potential cargo projectiles. This pertains to vehicles in which the passenger and

	cargo compartments are not separate. Note: any modification to GSA vehicles (G-vehicles) must first be approved by GSA Fleet Service. Contact the CAWSC Vehicle Coordinator for information. **Training:** All employees who use any vehicles, including personal vehicles, while working for the USGS will complete an approved driver safety training course every three years. This requirement can be satisfied by successfully completing the 4-hour DOI Learn training compliance module titled "NSC Defensive Driving II". Alternatively employees can take the following free online course, http://www.dgs.ca.gov/orim/Programs/DDTOnlineTraining.aspx. The Certificate of Completion should be filed at the employee's duty station and a copy should be sent to the CAWSC Safety Coordinator. Supplemental driver safety training is available to employees who may be driving utility trucks.
13	13. Hypothermia or heat stroke: Heat stress, from exertion or hot environments, places workers at risk for illnesses such as heat stroke, heat exhaustion, or heat cramps. Symptoms include rapid pulse, heavy sweating, fatigue, dizziness, nausea, irritability, and muscle cramps. First Aid includes stopping work activities, moving to cool, shaded area, removing excess clothes, applying cool water to body, increasing fluid intake (water or Sports drink), seeking medical attention (if symptoms are severe or do not improve). Prevention includes monitoring the physical condition of yourself and coworkers, wearing light-colored, loose-fitting, breathable clothing (like cotton, not synthetics), scheduling heavy work for coolest parts of day, frequent breaks in shaded areas, and frequent water intake. Field personnel will be provided with First Aid training, adequate water, Sports drinks, shade, sunscreen (for body and lips), and shade (umbrella or canopy cover).
14	14. Hantavirus, Lyme Disease, Histoplasmosis, Pfiesteria, Others?: Hantavirus infection is a rare but serious illness. Typical symptoms are flu-like and include fever, headache, nausea, vomiting, muscle aches, diarrhea, abdominal pain and shortness of breath. These symptoms can occur any time between three days to six weeks (usually occurring around 14 days) after exposure. The usual host of this virus is the deer mouse, although other rodent species have been shown to be infected. The virus spreads by inhalation of air contaminated with rodent saliva, urine, and feces or if this matter is introduced to the body via eye rubbing or through broken skin. NEVER REMOVE DROPPINGS BY SWEEPING OR VACUUMING. Instead, wear respirator mask rated N-100 (see Safety Coordinator for CAWSC Respirator SOPs) and wear plastic or rubber gloves, ventilate area for at least 30 minutes, dampen carcass and droppings with bleach disinfectant (100 mL bleach to 900 mL water), damp mop contaminated area, thoroughly wash hands, face, and clothes after cleaning.
15	15. Contaminated water with sanitary, biological, or chemical concerns: Surface water in some areas may have low to moderate levels of contamination from sewage or agricultural runoff. Although concentrations are likely to be not

	so high as to pose an immediate danger to workers on-site, USGS activities will conform to site access and hygiene requirements at those sites. Field personnel will be advised of the contamination risk and will be provided onsite with protective equipment and supplies (e.g. impermeable gloves, splash resistant safety glasses, clean water supply, and antibacterial soap). Field personnel will be informed that they are entitled to no-cost Hepatitis-A, Hepatitis-B, and Tetanus vaccinations. Appropriate dust masks will be supplied if needed.
16	16. Immunizations: Field personnel will be informed that they are entitled to no-cost Hepatitis-A, Hepatitis-B, and Tetanus vaccinations.
17	17. Laboratory or mobile laboratory - Chemical hygiene plan: Employees will complete Laboratory Safety and Hazardous Communications training including a lab walk-thru with Megan McWayne (Placer Hall Lab Safety Officer) or Mike Land (San Diego San Diego Safety Officer). Alternatively, employees may take these courses using DOI Learn. Employees will take Lab Safety and Hazardous Communications Refresher Training every three years. This training will be provided by either of the two Lab Safety Officers (Megan McWayne or Mike Land). Employees will read and sign the CAWSC Chemical Hygiene Plan (contact Megan McWayne or Mike Land). Employees will be provided with appropriate safety equipment including splash-resistant safety glasses, gloves, and lab coat. Insulated gloves, mitts, or towels will be used to handle dry ice safely.
20	20. Confined space: CAWSC SOPs for work involving "non-permit" confined space are located at, SAFETY PLANS & PROCEDURES
22	22. Respiratory protection: USGS employees who need to use a respirator to perform their work safely need to undergo a no-cost (to the employee) medical examination, training, and a fit test. Respiration SOPs are currently in the review process for the CAWSC. Please contact Stephen Schmitt, safety coordinator, for details.

Discussed job hazard analysis (JHA) with District

Collateral Duty Safety Officer Yes_√__ No____

and/or copy of JHA given to
Collateral Duty Safety Officer Yes____ No____

District Chief ____ Date ___________
Regional Program Officer ______________________________ Date ___________