Work Plan: Sonoma Creek Ground Water Model Development Addendum

SUBMITTED TO:

State Water Resources Control Board
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1 INTRODUCTION

To support State Water Resources Control Board (Water Board) actions to address emergency drought conditions across California, hydrologic modeling and analysis tools are being developed to contribute to a comprehensive decision support system that assesses water supply and demand and the flow needs for watersheds throughout the State. The models will be used to evaluate scenarios including current hydrologic conditions, water allocation, changes in demand, and the impact of extreme events such as droughts or atmospheric rivers. As part of this effort, the Sonoma Creek watershed model is being developed by Paradigm using the Loading Simulation Program in C++ (LSPC). Since groundwater plays an important role in Sonoma Creek watershed, integration of a robust groundwater model with LSPC was considered.

This workplan addendum outlines the details on how groundwater flow processes will be incorporated within the watershed modeling framework developed by Paradigm using LSPC. The groundwater domain will be modeled using an existing MODFLOW model and will be coupled with LSPC to simulate the integrated surface water-groundwater hydrologic system. The MODFLOW model supports the development of the Groundwater Sustainability Plan (GSP) for the Sonoma Valley Groundwater Sustainability Agency (GSA) which operates within Sonoma Valley subbasin. This workplan was developed with the assumption that the model and any supporting data and information such as observed groundwater and streamflow data, well and boring log data, land surface elevation data, conceptual model, available aquifer test data (if any), and any other relevant information/data will be provided by the GSA.

The objective of incorporating groundwater flow processes using MODFLOW within the watershed modeling system is to benefit from MODFLOW's strengths in conserving water budgets, simulating groundwater storage change, and simulating groundwater processes to enhance the modeling system capabilities by accounting for the effects of groundwater stress on surface water flows. The anticipated use of the integrated LSPC-MODFLOW model is to assess short and long-term changes in groundwater conditions and evaluate the effects of these changes on surface water flows. The LSPC-MODFLOW model will be used for supply and demand planning purposes. This will include running various scenarios for supply (e.g., dry, average, and wet year conditions) and demand (e.g., water rights and environmental flows) to inform the Water Board's decision-making.

2 GEOLOGIC SETTING

This section summarizes the geology and hydrogeology of the Sonoma Creek watershed to support the conceptual groundwater model. The discussion is based primarily on Farrar et al. (2006), with supplemental information from published regional geologic and fault mapping.

The generalized geologic map of the Sonoma Creek watershed shown on Figure 2-1 was developed from the Sonoma County geology source layer used for this project and clipped to the watershed boundary. The original units were consolidated and renamed for display based on published geologic mapping and unit descriptions from Graymer et al. (2007), Wagner and Bortugno (1982), and Jennings et al. (2010).

2.1 Geology

The Sonoma Creek watershed is located in a northwest-trending valley between the Sonoma Mountains to the west and the Mayacamas Mountains to the east. The valley is underlain by Holocene and Pleistocene alluvial and basin-fill deposits, Miocene to Pliocene volcanic and sedimentary rocks, and older Jurassic to Cretaceous bedrock.

The youngest mapped units are Quaternary deposits and include alluvial, playa, and estuarine deposits (Q), landslide and hillslope deposits (Qls), and older alluvial, fan, and terrace deposits (Qoa). Younger Holocene alluvial deposits occur mainly along Sonoma Creek, its tributaries, and the valley floor and consist of clay, silt, sand, and gravel. Near Schellville and San Pablo Bay, these deposits include fine-grained estuarine material. Older Pleistocene alluvial deposits occur mainly on terraces and older fans along the valley margins, while landslide and hillslope deposits occur on the surrounding upland slopes.

The late Pliocene to Pleistocene Huichica and Glen Ellen Formations are grouped on Figure 2-1 as an undivided unit (QThg). Together with other Pliocene to Pleistocene sedimentary deposits (QPc), these basin-fill units contain interbedded clay, silt, sand, gravel, conglomerate.

The late Miocene to Pliocene Sonoma Volcanics (Tsv) occupy much of the upland portions of the Sonoma Creek watershed and underlie the basin-fill units in the valley. The Sonoma Volcanics are mapped as an undivided unit on Figure 2-1 but consist of a variety of volcanic rocks and volcaniclastic deposits, including lava flows, tuffs, breccias, scoria, debris-flow, and lahar deposits.

Miocene sandstone (M) occurs locally within the watershed. Older Mesozoic bedrock includes Jurassic to Cretaceous Great Valley Sequence sedimentary rocks (KJgvl), Franciscan Complex graywacke and mélange (KJfs), greenstone (KJfgs), mélange (KJfm), and ultramafic and serpentine rocks (um). These rocks form much of the bedrock beneath and surrounding the valley and are exposed primarily in the northeastern Mayacamas Mountains and locally in the southern Sonoma Mountains.

The valley is a broad northwest-trending structural depression shaped by folding and faulting. Volcanic and sedimentary layers generally dip toward the valley center, while local faults offset and disrupt these units. The Rodgers Creek Fault and related splays occur along the western and southwestern side of the watershed near the Sonoma Mountains. The southern Bennett Valley Fault Zone extends through the northwestern and western Sonoma Mountains and converges southward with the Rodgers Creek Fault. The concealed Eastside Fault is inferred beneath the eastern side of the valley near Sonoma, Boyes Hot Springs, and Agua Caliente (Farrar et al., 2006).

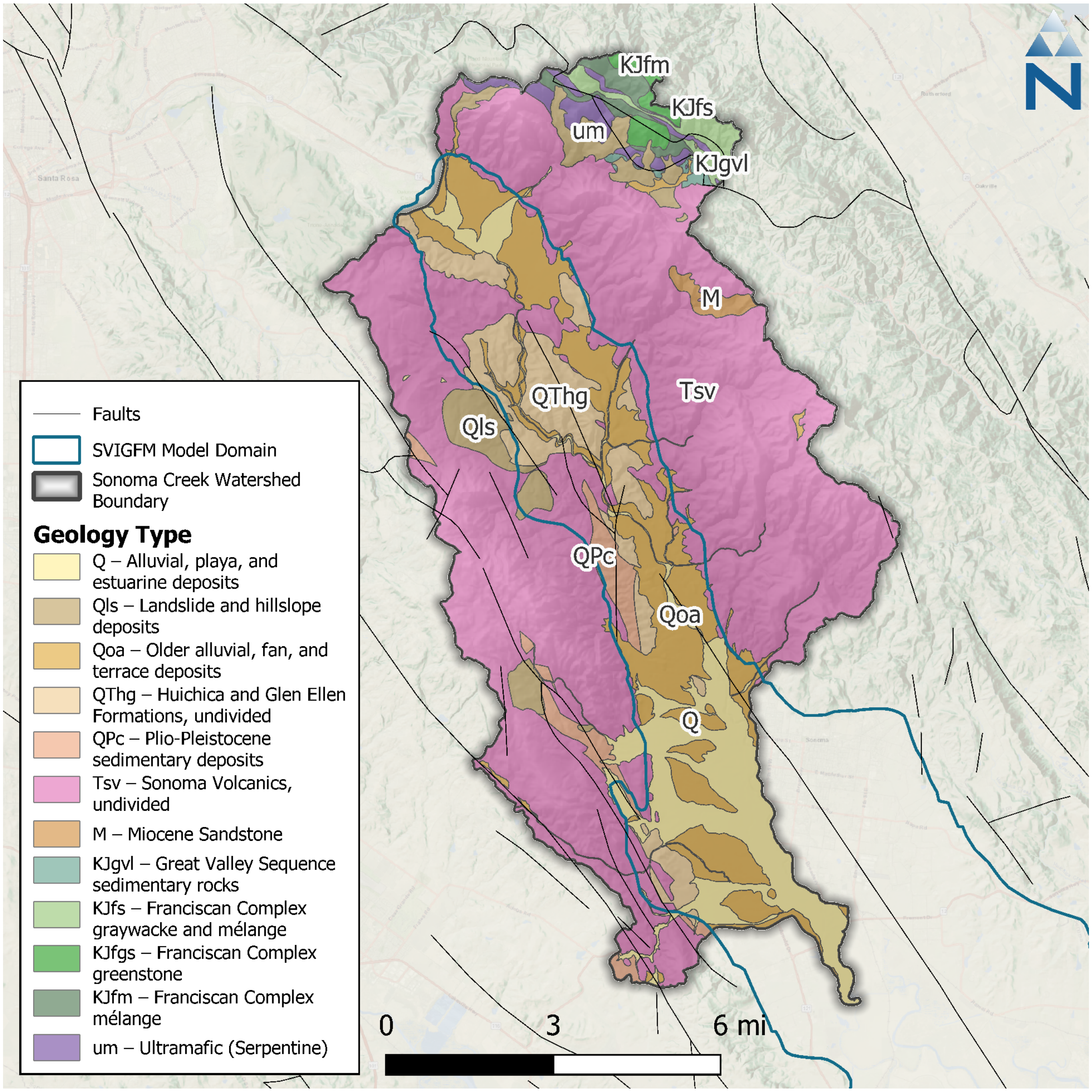

Figure 2-1. Generalized geology for the Sonoma Creek watershed study area.

2.2 Hydrogeology

The principal water-bearing units in the Sonoma Creek watershed are the younger and older alluvial deposits (Q and Qoa), the Huichica and Glen Ellen Formations and related basin-fill deposits (QThg and QPc), and the Sonoma Volcanics (Tsv). Water-bearing properties within these units vary with the distribution of coarse-grained sediments, fractures, and less-permeable layers.

The younger and older alluvial deposits form the principal shallow aquifer along Sonoma Creek, its tributaries, and the valley floor. The deposits thin along the valley margins and reach approximately 300 feet near the valley center. Sand and gravel zones have the highest well yields and are locally connected to Sonoma Creek. Fine-grained estuarine deposits near Schellville and San Pablo Bay have lower permeability and may contain brackish or saline groundwater.

The Huichica and Glen Ellen Formations and related basin-fill deposits contain discontinuous sand and gravel layers separated by clay and silt. The Glen Ellen Formation is estimated to be about 600 feet thick near Glen Ellen and about 900 feet thick west of Kenwood. The Huichica Formation may exceed 1,000 feet beneath parts of the valley floor and contains more coarse material near its base. These values represent total formation thickness, not continuous aquifer thickness. Groundwater occurs mainly within coarse-grained layers, while clay and silt restrict vertical flow and may confine deeper groundwater.

The Sonoma Volcanics vary in composition and water-bearing properties. The most productive zones occur in fractured lava, scoria, interflow material, and unwelded tuff, while massive lava, debris-flow deposits, and lahar deposits generally have lower permeability. Because these productive zones are discontinuous, well yields can vary considerably over short distances.

The Franciscan Complex and ultramafic rocks generally have low primary porosity and permeability. Groundwater occurs mainly in fractures, weathered zones, and fault zones. These bedrock units generally produce low well yields, although locally fractured areas may provide enough groundwater for individual domestic wells.

Geologic structures also influence groundwater movement. The Sonoma Volcanics and Glen Ellen Formation have been folded so that many permeable beds and water-bearing zones dip toward the valley center. Because groundwater moves mainly through these relatively thin zones, folding may redirect groundwater and limit connections where less-permeable material interrupts them. Faults may locally enhance, restrict, or redirect groundwater flow. The concealed Eastside Fault has been interpreted as a possible barrier to groundwater flow, but its hydraulic effect remains uncertain.

3 GROUNDWATER HYDROLOGY

The Sonoma Creek watershed contains two groundwater basins as delineated by Bulletin 118 (CDWR 2020a). The watershed overlaps with the Kenwood Valley basin (# 2-019), and the Sonoma Valley subbasin (# 2-002.02), with a sliver containing negligible overlap at the border of the Petaluma Valley basin (# 2-001). The watershed does not fully contain any basins. Approximately 32% of the watershed area falls within the groundwater basins delineated by Bulletin 118 and the remaining 68% consists of upland areas outside the designated basins and is underlain by Sonoma Volcanics and older consolidated bedrock units, including Franciscan Complex, Great Valley Sequence, and ultramafic rocks.

As per the Sustainable Groundwater Management Act's (SGMA) Basin Prioritization Dashboard details (CDWR 2020b), the Sonoma Creek watershed has a variety of prioritizations as designated by SGMA. The Kenwood Valley basin is Very Low priority due to total groundwater use of less than 2,000 acre-feet/year. Approximately half of the Kenwood Valley basin falls within the Sonoma Creek watershed. The Sonoma Valley sub-basin is High priority due to declining water levels, saline intrusion, and a large number of water supply and total wells. Approximately the upper third of the Sonoma Valley subbasin falls within the Sonoma Creek watershed. The Sonoma Valley GSA operates within the Sonoma Valley sub-basin (Sonoma Valley GSA 2021). Figure 3-1 is a map overlaying the Sonoma Creek Watershed, the Bulletin 118 Sonoma Valley and Kenwood Valley subbasins, and the Sonoma Valley GSA model domain.

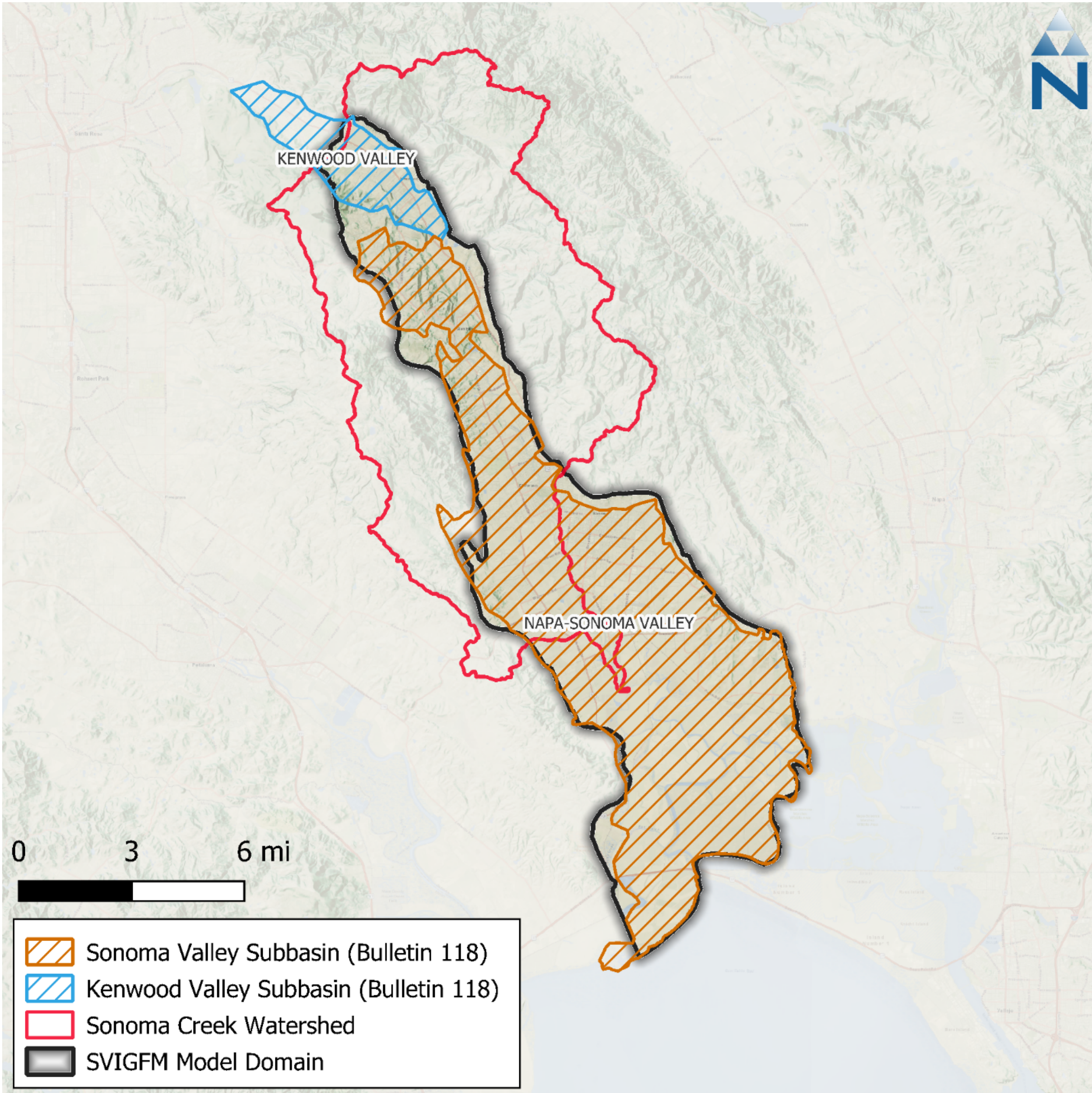

Figure 3-1. Outlines of Sonoma Creek Study Area, Napa-Sonoma Valley Sub-Basin Boundary (Bulletin 118), Kenwood Valley Sub-Basin (Bulletin 118), and Sonoma Valley Integrated Groundwater Flow Model (SVIGFM) Domain Boundary[1].

3.1 Water Budget Components

The USGS Sonoma Valley model simulated a water budget for the year 2000, estimating inflows including 36,600 acre-feet/year from natural recharge, 1,570 acre-feet/year from seawater in San Pablo Bay, and 1,270 acre-feet/year infiltrating from Sonoma Creek. Estimated outflows included 769

[1] The Sonoma Valley Integrated Groundwater Flow Model (SVIGFM) was not available at the time of preparing this Work Plan. The boundary shown on the map was digitized by georeferencing the maps included in the Sonoma Valley Groundwater Sustainability Plan (GSP).

acre-feet/year to the Bay Mud deposits, 755 acre-feet/year to San Pablo Bay, 30,400 acre-feet/year flowing to Sonoma Creek, and 8,340 acre-feet/year of groundwater pumping. Approximately 10% of the groundwater pumping is supplied through storage depletion (Farrar et al. 2006). Bulletin 118 reports did not contain groundwater budget information for the Kenwood Valley basin but referenced a 1958 study by the USGS that estimated a groundwater storage capacity of 40,000 acre-feet. Within the USGS public domain models for Northern California, the Sonoma Valley model partially overlaps the Sonoma Creek basin (USGS 2024). Figure 3-2 shows the annual water budget components reported in the USGS groundwater analysis for Sonoma Valley (Farrar et al. 2006). A more recent Sonoma Valley groundwater budget for Water Years 2012-2018 is provided by the Sonoma Valley GSA (2021) estimating a net decrease in groundwater storage in the order of 900 AFY.

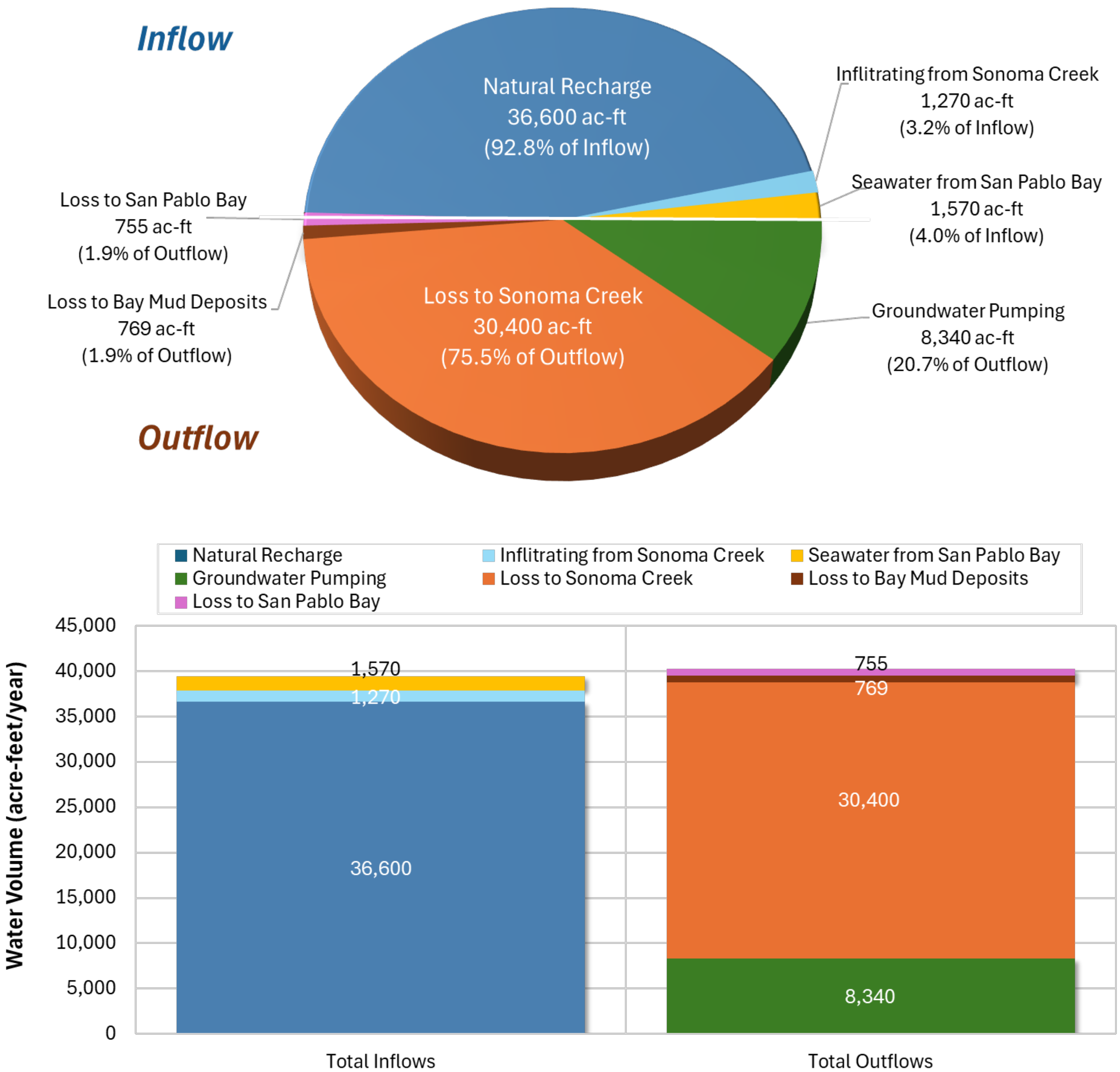

Figure 3-2. Annual Groundwater Budget Components for Year 2000 as per the USGS Sonoma Valley Model (Farrar et al. 2006: Table 7).

4 DATA NEEDS

Several geological, spatial, and temporal data sets are needed for LSPC-MODFLOW model configuration and calibration. Table 4-1 is a summary of data needs:

Table 4-1. Anticipated data needs for LSPC-MODFLOW configuration and calibration

Type	Data Source	Application/Usage
Model Files	All MODFLOW model input and output files	LSPC-MODFLOW model development
Geology	Hydrogeologic Conceptual Model (HCM) data and information	These data will provide the underpinnings for numerical groundwater model development
Other Supporting Data	Digital Elevation Model (DEM) data or Lidar data	For land surface and streambed elevations
	Aquifer pumping test data, if available, or any other aquifer properties datasets	For parameterizing associated subsurface properties
	Digitized well logs with texture information	Used for developing aquifer parameters
	Airborne electromagnetic (AEM) data	Used for developing aquifer parameters
	Shapefiles that are relevant for model development and calibration	Used for data processing
Observation Data	Groundwater elevation data	Groundwater model calibration
	Streamflow data	Surface water model calibration
	Spring flow data, if any.	Spring flow parameterization

A few data gaps and limitations are noted here. Wells reporting water levels are concentrated within the groundwater basin, and hence water levels and groundwater storage change information are generally not available within the non-basin areas. All available water level information outside the subbasin will be used to support model calibration.

5 MODEL DEVELOPMENT

The groundwater model will be developed and integrated with the existing LSPC Model. Figure 5-1 shows a schematic of the integrated modeling approach.

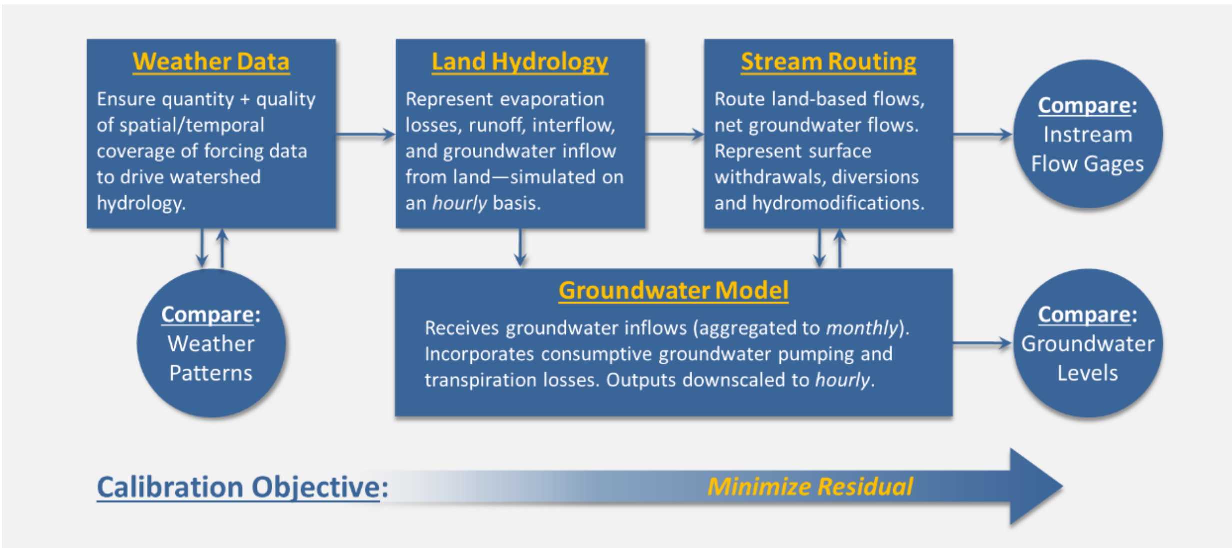

Figure 5-1. Integrated modeling approach for the Sonoma Creek Watershed Model.

5.1 Background

Several groundwater models have been developed for the Sonoma Valley. One of the early models developed by the USGS (Farrar et al., 2006) simulated a period of 1974-2000 using the MODFLOW-2000 code (Harbaugh et al, 2000). The model was further developed by Bauer (2008) and the modeling period was extended to 2006. Building on these initial modeling studies, the first version of Sonoma Valley Integrated Groundwater Flow Model (SVIGFM V1, Sonoma Water, 2020b) simulated the period 1969-2014 using MODFLOW One Water Hydrologic Model (MF-OWHM, Hanson et al, 2014) by incorporating surface water components as part of an integrated model. The most recent groundwater flow model, SVIGFM V2, was developed by Sonoma Water (2020a) with a simulation period from Water Year (WY) 1970 through 2018. SVIGFM V2 is anticipated to be extended through WY 2025 (Sonoma Valley GSA, 2021, Appendix 7-A). SVIGFM V2 will be utilized for developing the integrated LSPC-MODFLOW model.

5.2 Code Selection

MODFLOW (Langevin et al., 2017) is an open source, publicly available, three-dimensional code that can represent spatial and temporal variability of groundwater heads, aquifer properties, and all relevant boundary conditions needed to appropriately simulate flow conditions in the relevant basins and to meet the modeling objectives. MODFLOW is recommended for simulating groundwater flow conditions and integrating flow between groundwater and surface water. Specifically, MODFLOW-NWT (Niswonger et al, 2011) will be used for the integrated LSPC-MODFLOW model. Given that the underlying groundwater simulation code for MF-OWHM is MODFLOW-NWT, it can be seamlessly integrated with LSPC as an explicitly coupled process iterating between the two simulators, ensuring that integrated water budgets for the surface water-groundwater system are conserved.

5.3 Model Extent and Discretization

The spatial extent of the groundwater model for the LSPC-MODFLOW integrated model discussed in this workplan will align with the LSPC model domain, i.e., the Sonoma Creek watershed boundary, as shown in Figure 3-1. This spatial extent includes the alluvial Sonoma Valley subbasin as designated by CDWR's Bulletin 118 (also shown in Figure 3-1) and the non-basin areas. The LSPC-MODFLOW model will rely on SVIGFM V2 to provide data and model structure for the groundwater domain. Although the active domain of the SVIGFM V2 model only covers the areas in and around the Sonoma Valley subbasin, the inactive domain of SVIGFM V2 encompasses the entire Sonoma Creek Watershed. If the watershed extents are marginally larger than the SVIGFM V2 extents, water inflow provided by LSPC from the areas outside of the SVIGFM V2 margins will be mapped to the closest SVIGFM V2 model cells to conserve water budgets without the need for extending the SVIGFM V2 domain. Therefore, no change in SVIGFM V2 model extent (including the inactive domain) is anticipated for the LSPC-MODFLOW integrated model development. The active area of the SVIGFM V2 will be expanded to include the non-basin areas. The grid spacing used by SVIGFM V2 will be retained for the LSPC-MODFLOW model. The overlapping portions of the LSPC-MODFLOW and the SVIGFM V2 models can be used for seamless integration of the two models and for data exchange, water budget comparisons, and future model collaboration purposes with the help of zone budgets for both individual models.

The southern end of the SVIGFM V2 model will be curtailed in the LSPC-MODFLOW model. An appropriate boundary condition will be imposed at the southern end of the model to represent the potential lateral inflow or outflow occurring from the LSPC-MODFLOW model.

For the overlapping areas, the vertical extent of the SVIGFM V2 model will be used for the LSPC-MODFLOW model. For the non-basin areas outside of the SVIGFM V2 active domain extents, a uniform depth of 100 feet will be assigned to accommodate groundwater recharge and flow occurring within the fractured bedrock. The total depth in those areas may be adjusted upon further review of data or if any additional information becomes available.

The simulation period of the LSPC-MODFLOW model will be Water Year (WY) 2003 through 2023. Monthly stress periods will be used for the LSPC-MODFLOW groundwater model. Additional data will be generated to assign boundary conditions for simulation periods for which data are not available in SVIGFM V2.

Any faults used within the SVIGFM V2 model will be retained within the LSPC-MODFLOW model. More faults may be added as needed within the bedrock portions of the model.

5.4 Aquifer Properties

Lithologic texture model was developed by Sonoma Water using lithologic data and well-completion reports for approximately 2,000 water wells in Sonoma Valley (Sonoma Valley GSA, 2021). Available aquifer data in the form of lithologic logs, well logs, and boring logs will be reviewed to assess the viability of using a tool called Texture2Par (Scantlebury et al, 2022) to develop and refine aquifer properties. Texture2Par is a basin characterization tool developed for California Department of Water Resources (CDWR). It has been successfully implemented in several regional scale CDWR's Central Valley models such as the Sacramento Valley Simulation Model (SVSim) and the Fine-Grid version of the Central Valley Simulation Model (C2VSim-FG). Zonal representation of alluvial basins for fractured systems is available in Texture2Par and will be utilized to represent basin and non-basin areas. Any additional information such as aquifer tests will be utilized to develop aquifer properties.

5.5 Boundary Conditions

Groundwater recharge will be provided by LSPC. Evapotranspiration will be represented by LSPC and therefore, will not be considered for the MODFLOW model. Streams will be represented using the streamflow routing (SFR) package of MODFLOW and will provide stream-aquifer flow rates. Lateral flow boundaries will be represented either as no-flow boundaries along the periphery of the watershed on the upgradient end and will be represented as a general-head boundary (GHB) package where flow is expected to occur across the model domain at the southern end of the model. Well head information available from monitoring wells close to the boundary will be used to inform the time varying GHB boundary values. Groundwater pumping locations, depths, and rates will be obtained from SVIGFM V2. Pumping data derived from SVIGFM V2 will be compared against LSPC water demand assessment as a quality assurance check. Additionally, the delivery location of the water, on-farm storage of stormwater and recycled water as well as the relevant canal system through the valley floor will be accounted for consistency with the SVIGFM V2 model. Any major differences observed will be discussed with the State Board.

5.6 Initial Conditions

Initial heads will be generated that appropriately represent the head distribution for the selected simulation starting time. Any head and flow observations available for the starting time will be used for generating initial heads for the groundwater model. A 'warm-up' period may be simulated to achieve equilibrium within groundwater heads to create reasonable starting conditions.

6 MODEL CALIBRATION

Groundwater calibration will aim to improve the model performance in simulating groundwater head values, vertical head differences (if any paired well observations are available), stream-aquifer flow, streamflow, and any other pertinent information such as, but not limited to, water budget estimates. Parameter ESTimation (PEST) software (Doherty, 2009) will be used for model calibration. A PEST-facilitated calibration approach will be used, in which simulated and observed values will be matched to achieve goodness-of-fit, while ensuring that the generated parameters are within a plausible physical range. The objective function will be reduced up to the point that the calibrated parameters are meaningful, thus avoiding 'overfitting' of parameters. Overfitted models may improve history-matching at the cost of distorting simulation results during scenario application or predictive analyses. The objective of the calibration process will be to ensure that a robust model is developed that targets history matching while representing the parameter information that is independently available. Water budgets will be developed at both the watershed scale and other spatial scales as needed (e.g. HUC 12).

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