Task 3.2

Conceptual Model Review of Napa Valley Groundwater Model

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1.0 Introduction

The purpose of this technical memorandum is to provide a general review of the Napa Valley Groundwater model (groundwater model) produced by DHI Water & Environment (DHI) as part of the 2005 *Napa County Baseline Data Report (2005 BDR)* (Jones & Stokes et al., 2005). This memorandum is not intended to be a full peer-review in which model code, input/output files, and output results would be analyzed. Opinions stated herein are based solely on a review of the 2006 *Final BDR Technical Appendix* (DHI, 2006a), which presents the model code, model construction, calibration, and application of modeling efforts introduced in Chapters 15, 16, and 17 of the BDR. Further information on the groundwater model was reviewed from the *2005 BDR* and a 2007 technical memorandum *Modeling Analysis in Support of Vineyard Development Scenarios Evaluation* (DHI, 2007) in which the groundwater model was updated/expanded and applied in evaluating various vineyard development scenarios. The scope of Luhdorff & Scalmanini, Consulting Engineers' (LSCE) work, described herein, included a review of the conceptual model developed by DHI from which the inputs to the groundwater model were based. In addition, information provided on the model code, construction, and development of the groundwater model and model calibration were also reviewed. The focus of LSCE's work was to assess whether the information provided in the reviewed documents was complete and whether the model can be used for the stated purpose for which it was developed.

This technical memorandum includes a summary description of the information provided in the documents regarding the purpose of the groundwater model, the conceptualization of the groundwater system being modeled (the conceptual model), groundwater model construction and development, and groundwater model calibration, with each section followed by the results of LSCE's review. Tables and figures from DHI's *Final BDR Technical Appendix* (2006) and *Sensitivity Analysis of the Napa County Water Quantity and Water Quality Models* (2006) referred to in the text of this memorandum have been included in **Attachments A and B**, respectively.

1.1 Groundwater Model Purpose

The groundwater model was developed by DHI in conjunction with the Napa Valley and Lake Berryessa Surface Water models to simulate existing groundwater and surface water conditions on a regional basis. The groundwater model could be further developed in the future to assess localized and site specific environmental effects related to specific projects.

The groundwater model focused on those regions within Napa County where "groundwater is a significant source of potable water" (DHI, 2006a), primarily in the North Napa Valley and the Milliken-Sarco-Tulucay (MST) and Carneros Subareas.

The purpose of the groundwater model as currently constructed is for assessing regional rather than local groundwater conditions. From what was reviewed, it appears that further work on the groundwater model would be necessary for it to be considered for local or site specific applications. The groundwater model also focuses on selected subareas of the Napa Valley where groundwater is a significant source of potable water. This seems to indicate that areas

where there are currently significant amounts of private pumping (not municipal or agricultural) are where the groundwater modeling effort was focused. Areas where future growth is anticipated in the County, where private groundwater pumping is anticipated to increase, do not appear to have been a focus of the model effort.

2.0 Model Code Selection

As described in the reviewed reports and documentation, the groundwater model was created in conjunction with the Napa River and Lake Berryessa Surface Water models and water quality models for Napa County using the proprietary MIKE SHE model code. Specifically, the groundwater model covered the same area as the Napa River Surface Water model, while the Lake Berryessa Surface Water Model simulated a different portion of Napa County. MIKE SHE is a "physically based distributed hydrologic model that simulates the major flow components of the land-based portion of the hydrologic cycle" (DHI, 2006a). The model code allows for the coupling of groundwater and surface water models. As a groundwater model, MIKE SHE is similar to MODFLOW, as they both incorporate a modular structure in which the user can add components of the hydrologic cycle which are represented in the modeled area. The surface water model code incorporates several model components, each containing several solution options for the processes being simulated. The surface water model provides the ability to simulate groundwater recharge from the simulation of surface water features (overland flow, channel flow, and precipitation). Also, MIKE SHE provides flexibility by allowing the modeler to emphasize more important processes while simplifying less important ones.

The description of the model code, which was presented in the model reports and documentation, and the menu of model components and solution methods that could be or were selected for modeling the groundwater system in the Napa Valley indicate that MIKE SHE is a complex model code in which a clear understanding of the purpose for developing the model and a well developed conceptual model are required. Otherwise the selection of model components and solution algorithms will introduce limitations to the use of the model. It appeared from the documentation that the groundwater model coupled to the surface water model is not simulating important stream aquifer interactions, selected recharge processes, and geologic features which may impact groundwater flow. This may be the result of the lack of a complete description of these issues in the documentation or a shortcoming in the model code. A follow-up conversation with Jeremy Kobor indicated that the surface and groundwater models are fully coupled and fully simulate stream-aquifer interaction (Kobor, 2010). Further investigation of the groundwater and surface water model files will be necessary to confirm the simulation of groundwater and surface water interactions.

All groundwater modeling platforms have limitations which must be considered in selecting which model platform to use. MIKE SHE, as applied in creating the Napa Valley Groundwater model, is limited in the following way. In creating the Napa Valley Surface Water model, which was used as a dynamic boundary condition for the groundwater model, the two-layer UZ/ET (unsaturated zone/evapotranspiration) method was selected to represent conditions in the unsaturated zone and the Linear Reservoir algorithm was selected to represent the saturated zone or groundwater system. The use of these two algorithms together does not allow the groundwater table to fluctuate throughout the model domain. This simplification, as outlined in section 2.5.1.1

of *Final BDR Technical Appendix* (DHI, 2006a), can lead to an underestimation of ET and creates a semi-integrated groundwater/surface water model which "lacks the gradient-driven properties of flow of a fully physically based solution." Essentially, discharge of groundwater to surface water features was not simulated or is partially simulated. As stated in section 2.5.1.1 of *Final BDR Technical Appendix*:

> "The linear reservoir algorithm for the [saturated zone] is a groundwater balance tool that provides baseflow into the MIKE 11 river network. Use of the linear reservoir algorithm is effective for establishing water budgets, but should not be used for applications where the specific groundwater questions need to be addressed." (DHI, 2006a)

For this reason, the current modeling approach could not be used to investigate pumping induced changes to groundwater/surface water interactions (e.g., changing seepage losses due to declining groundwater levels). This limitation could be resolved where necessary by using the 3-dimensional finite difference algorithm (instead of the linear reservoir algorithm) for the Napa Valley Surface Water model, assuming no computational limitations would prevent this.

Overall, the selection of the MIKE SHE platform may be adequate for modeling the groundwater conditions that exist in the Napa Valley. However, the current selection of model code options may not allow the groundwater model to adequately represent groundwater conditions, and especially groundwater/surface water interactions, in the Napa Valley as is discussed in greater detail below. In addition, the complexity of the model code would likely require Napa County to contract out work utilizing the groundwater model rather than having in-house capability to run predictive scenarios to assess impacts from future developments or groundwater management programs.

3.0 DHI Conceptual Model

The first step in creating any groundwater/surface water model is to develop a conceptual understanding of the geologic and hydrologic conditions of the area being modeled. This conceptualization (commonly referred to as the conceptual model) is created based on available knowledge of the area and is the foundation from which a model is developed. The conceptual model also provides constraints on the adjustment of model inputs during model calibration. Partial descriptions of some conceptual model components that were incorporated in the groundwater model are described in the *Final BDR Technical Appendix* (DHI, 2006a) and *Modeling Analysis in Support of Vineyard Development Scenarios Evaluation* (DHI, 2007). This section provides a brief overview and preliminary evaluation of the conceptual model components that were used for the Napa River Watershed Groundwater model.

The documentation that was reviewed did not present a clear understanding that a conceptual model was developed to form the basis for the development of the groundwater model. The documentation lacked complete descriptions of all the recharge and discharge components that exist in the Napa Valley in addition to geologic features which may impact groundwater flow in the model area. The documentation focused on a description of the primary water producing geologic units that are present in the North Napa Valley area and the MST and Carneros Subareas. The groundwater model covers the Napa River watershed with the north, east, and

west boundaries following drainage divides and the southern boundary open to the San Francisco Bay (**Figure 2-6, Attachment A**). The complex geology of the Napa Valley area and the MST Subarea was briefly described with references to previous USGS (Faye, 1973; Johnson, 1977; Farrar and Metzger, 2003) reports. A description of the Huichica Formation in the Carneros Subarea was not presented. The Napa River watershed was generally conceptualized as a large basin of impermeable rock overlain in three distinct areas by more permeable units. The three areas that were the focus of the groundwater model were the North Napa Valley area and the MST and Carneros Subareas. Each of these three areas was represented as a separate water-producing geologic unit. The geologic unit that is the primary source for groundwater in the North Napa Valley area was the Napa Valley Alluvium, which consists of highly permeable, unconsolidated alluvium eroded from the surrounding hills/mountains and concentrated in the center of Napa Valley. This alluvium is unconfined near the surface and semi-confined at depth. Wells screened within this unit tend to be highly productive (yields on the order of 3,000 gpm). The extent of the alluvium and thickness was extrapolated south of the North Napa Valley area through a review of previous reports and well logs. The thickness of the alluvium increases in a westerly and southerly direction within the Napa Valley Floor toward the San Francisco Bay. Values and distribution of hydraulic conductivity (K) for the North Napa Valley area reflected a similar distribution as was presented in Faye (1973), and extrapolated to the rest of the Napa Valley Floor to the south. The initial values of K ranged from 0.5 to 80 feet/day. In the MST Subarea, the primary aquifer consists of fractured and interbedded tuffaceous Sonoma Volcanics located east of the Soda Creek Fault. There is a small area of the MST located west of the Soda Creek Fault in which alluvium is the primary groundwater-bearing unit. Within the Sonoma Volcanics, yields are on the order of 150 gpm in the more productive wells. The tuffaceous member of the Sonoma Volcanics, which is the primary aquifer for the MST Subarea east of the fault, is underlain by relatively impermeable andesite. The Carneros Subarea is dominated by the Huichica Formation. Well yields are generally less than 5 gpm in this area. There is very little geologic or groundwater level data available for the Carneros Subarea which limits the conceptualization and representation of this area.

The description of boundary conditions, including recharge and discharge components of the model domain, were limited to brief descriptions of the primary uses of groundwater for irrigation, private domestic use, and open space along with selected recharge components related to precipitation and streamflow. Groundwater pumping in Napa County is limited to agricultural irrigation (>95% vineyards), irrigation of open spaces, rural residential use, and winery use. None of the municipalities in the county rely on groundwater. Pumping data for each of these uses were estimated since residential and agricultural pumping are not metered, and no electric consumption records were available for irrigation wells. As a result, a number of assumptions were implemented in the estimation of groundwater pumping. These assumptions included estimating total groundwater pumping rates to be equal to existing and projected water demands for rural residential, open space irrigation, and winery use, as reported in a 2005 report by West Yost and Associates (WYA, 2005). These demands were distributed evenly over areas designated as “developed” in land-use data that did not fall within city boundaries of any of the municipalities (**Figure 2-31 Attachment A**). Groundwater pumping for irrigated agriculture was based on California Department of Water Resources (DWR) estimates of applied water for vineyards in the Napa Valley. The DWR data were based on 2001 data which reported vineyard irrigation at 38,600 ac-ft/yr applied to 34,300 acres of vineyards (equivalent to 13.5 in/yr).

Precipitation was described as the primary recharge source along with recharge from streamflow. Precipitation data were derived from precipitation stations around Napa County and from statewide estimates.

3.1 Preliminary Evaluation of Conceptual Model

The documentation of the conceptual model for the area was not well described or explained. The conceptual model should account for or include a description of the following items:

- Regional and local geologic conditions, including structural features which influence groundwater flow and occurrence;
- Regional and local groundwater conditions and trends;
- Groundwater recharge components and occurrence, including precipitation, recharge from irrigation, imported water, recharge from streams and other surface water features, manmade recharge facilities, and subsurface inflows. The spatial and temporal variability of these components should be presented;
- Discharge components, including groundwater pumping, evaporation, and evapotranspiration of irrigated crops and native vegetation should be presented. In addition, the quantity and purpose of groundwater pumping, groundwater discharge to streams, and subsurface outflow should be discussed; and
- Aquifer properties of the various geologic units being simulated;

The conceptualization of the Napa River watershed presented a general description of the major geologic units that ultimately were simulated in the Napa Valley Floor, including the MST Subarea. However, a description of the Huichica Formation in the Carneros Subarea was not presented. Information regarding features which influence groundwater flow (impermeable units, faults, etc.) were not fully addressed, especially the role of the Soda Creek Fault in the MST Subarea. The description of recharge components failed to address groundwater recharge from irrigation, the fate of imported water which is used by municipalities for water supply, the fate of water pumped for private use, and stream/aquifer interaction within the model area. Some of the discharge components which exist in the model area such as contribution of groundwater to streamflow and subsurface outflows in the model area were either not well documented or absent. The information provided on the distribution of aquifer properties in the geologic units was incomplete as the distribution of storage values (specific yield and storativity) and level of confinement for the aquifer units present in the model area were not fully described. The understanding of the distribution of K in the North Napa Valley area was primarily referenced from previous documents; however, the understanding of K distribution in the remaining portion of Napa Valley was not verified by an examination of existing data (well logs).

In summary, there was not a complete description of the conceptual model or an identification of the components of the conceptual model that exist in the Napa Valley. As a result, it is difficult to assess how representative the groundwater model is to the Napa River watershed system being simulated. A follow-up letter from Jeremy Kobor (Kobor, 2008) identified the lack of data in the Carneros Subarea in particular and the Napa Valley in general, however, there remains a lack of

completeness in the identification of hydrogeologic processes that exist which could lead to model input parameters (discussed further below) that were adjusted during calibration from not being representative of groundwater conditions within the watershed area.

4.0 Model Development and Construction

The groundwater model encompasses the Napa River watershed and consists of two layers. The upper layer was designated as being unconfined and the lower layer was designated as confined. Three primary areas within the Napa River watershed were the focus of the groundwater model: the Napa Valley Floor and the MST and Carneros Subareas. The Napa Valley Groundwater model is a regional representation of the three primary aquifers in the Napa River watershed: 1) Napa Valley Alluvium (Valley Floor), 2) Permeable Sonoma Volcanics (MST Subarea), 3) Huichica Formation (Carneros Subarea). Aquifer parameters were based on geologic studies of the areas being modeled, where available, and were estimated otherwise. The Napa Valley Alluvium was simulated as the primary water-bearing unit in the Napa Valley Floor, while the tuffaceous unit of the Sonoma Volcanics and the Huichica Formation were the primary water-bearing units simulated in the MST and Carneros Subareas. The initial assignments of aquifer properties for these three water-bearing units were based on information presented in historical documents (Faye, 1973) for the Napa Valley Alluvium and Johnson (1977) for the Sonoma Volcanics in the MST. No information was available for the Huichica Formation so values an order of magnitude less than the Sonoma Volcanics were used initially (for hydraulic conductivity). Aquifer values for the impermeable rock units that were simulated in areas outside the Napa Valley Floor, including outside the MST and Carneros Subareas, were assigned aquifer properties based on literature values. The aquifer values were subsequently revised during model calibration. **Table 1** lists the initial values of aquifer properties that were input into the groundwater model. Literature values representative of impermeable rocks (Fetter, 2001) were used to represent the impermeable units of the remaining Napa River watershed.

The selection and description of boundary conditions were not discussed in any of the documentation provided other than the tidal fluctuations in the San Francisco Bay that were used in the southern portion of the model domain. The model domain is subdivided into cells that are 250 meters on each side. The calibration period is four years in length and spans from January 2000 to December 2003. Time steps vary from 15 minutes to 8 hours. The use and length of stress periods were not reported. The methodology used in selecting initial conditions was also not reported.

Table 1
Aquifer Properties as Reported in Final BDR Technical Appendix (DHI, 2006a)

	Alluvium	Huichica Formation	Impermeable Sonoma Volcanics	Permeable Sonoma Volcanics (MST)
Kxy (ft/day)	40 to 110	0.2	1.00E-04	2
Source	Table 2-11	Table 2-11	Table 2-11	Table 2-11
Kz (ft/day)	4 to 11	0.2	1.00E-04	2
Source	Table 2-11	Table 2-11	Table 2-11	Table 2-11
Sy	0.08	0.035	0.02	0.046
Source	Table 2-11	Table 2-11	Table 2-11	Table 2-11
n	0.25	0.15	0.02	0.2
Source	Table 2-11	Table 2-11	Table 2-11	Table 2-11
Ss	8.84E-06	1.41E-06	1.38E-06	1.43E-06
Source	Table 2-11	Table 2-11	Table 2-11	Table 2-11

Kz = vertical hydraulic conductivity; Kxy = horizontal hydraulic conductivity;
Sy = specific yield; n = porosity; Ss = specific storage
Adapted from Table 2-11, Figures 2-29 and 2-30 (Attachment A)

4.1 Pumping/Irrigation

Groundwater pumping was distributed evenly, using wells, over lands designated as the major land use categories (rural residential, improved open spaces, wineries, and agricultural irrigation) (**Figure 2-32 Attachment A**). The water demand, realized in the model as distributed pumping and irrigation, was spread throughout the year as described in **Table 2-12** (**Attachment A**). **Table 2** provides a breakdown of groundwater pumping as applied in the Napa Valley Groundwater model.

Pumping was implemented in the model as a series of pumping wells with the pumping being evenly distributed over those areas which used groundwater and were outside of city boundaries. The amount of groundwater pumped for irrigation was assumed to be similar to the volume applied for irrigation. The amount of groundwater pumped for irrigation did not change on an annual basis and accounted for frost protection, heat protection, and irrigation needs.

Table 2
Groundwater Pumping by Area*
(reported as ac-ft/yr)

Groundwater Use Category	North Napa Valley	Milliken-Sarco-Tulucay Subarea	Carneros Subarea	Total
Rural Residential	2300	800	350	3450
Improved Open Spaces	1111	1564	96	2771
Wineries	974	87	259	1320
Irrigated Agriculture*	-	-	-	38600

* Adapted from Napa County Final BDR Technical Appendix (DHI, 2006a)
** Values for distribution of irrigated agricultural pumping by area not reported.

4.2 Representation of Streams

Streamflow was modeled using MIKE 11, a one-dimensional hydrodynamic module used to analyze the movement of water in a river network, including flow through man-made structures and other surface water features. The main stream and 2 to 3 tributaries from each of the 188 watersheds in the Napa River Watershed Model area were extracted from the 1-meter resolution digital elevation model (DEM) provided by the County. Upstream boundaries for each of the streams were defined by a no-flow boundary condition at the upper topographic limit of the watersheds. The downstream boundary was defined as the point where the Napa River crosses the southern county boundary. Tidal water levels from the Mare Island Navy Shipyard National Oceanic and Atmospheric Administration station were used for the southernmost boundary condition. Stream channel dimensions were derived using an empirical relationship that relates the upstream drainage area to the average channel width and depth for streams in the San Francisco Bay region (See *Final BDR Technical Appendix* pg. 2-11). The MIKE SHE groundwater model acts as a dynamic boundary condition for the MIKE 11 model.

4.3 Groundwater Recharge

Groundwater recharge for the Napa Valley Groundwater model is calculated in the Napa Valley Surface Water model and relayed as a “dynamic boundary condition” to the groundwater model. The amount of recharge relayed from the surface water model to the groundwater model is dependent on different soil types, their location and properties, stream channel properties (e.g., Manning’s coefficient), as well as a number of module-specific parameters. For instance, infiltration to the unsaturated zone is controlled by a time-invariant maximum infiltration rate that is spatially distributed according to soil type. Soil parameters used for the surface water and groundwater models are outlined in **Table 2-8** from *Final BDR Technical Appendix* (**Attachment A**).

All water balance information (including recharge) reported for the Napa Valley Groundwater model is given as a rate (in/yr) without the necessary model area required to calculate volumes. For this reason, a complete analysis of recharge to the groundwater model cannot be completed, nor can a volumetric water balance be calculated which is often a telling measure of the reliability of modeled results. Recharge values reported in *2005 BDR* are provided in **Table 3**.

Table 3
Estimated Groundwater Recharge*
(acre-feet)

Recharge Source	North Napa Valley	Milliken-Sarco-Tulucay Subarea	Carneros Subarea
Direct Precipitation	**	250	**
Streambed Infiltration	-	3,050**	-
Subsurface Inflow	-	2,100	-
Total	26,800	5,400	-
Years Considered	1962-1989	1975	-

***** As reported in the 2005 BDR.
** Greatest source of recharge to area

5.0 Review of Model Development

A review of the primary input parameters described in the reviewed documents is presented below. The primary input parameters include aquifer properties, groundwater pumping, groundwater/surface water interaction, and groundwater recharge.

5.1 Aquifer Properties

The input of aquifer properties was summarized fairly well in the *2005 BDR*, however, the text and figures in the reviewed documents did not segregate the aquifer parameters by model layer. The reviewed documents did not differentiate between the initial and calibrated values of aquifer parameters, primarily hydraulic conductivity. The selections of calibrated hydraulic conductivity values in the model were not always justified nor did they appear to represent the conceptual model description of the distribution and/or range of values in some areas.

Another issue is the reported specific yield (Sy) values. The text of the report (see *Final BDR Technical Appendix* pg. 2-16) states that Sy values for the Sonoma Volcanics and Huichica Formation were estimated under the assumption that Sy is roughly equal to porosity (n). Yet in **Table 1** (Table 2-11 in *Napa County BDR Technical Appendix*), reported n values are 3 to 4.5 times the reported Sy values. In both cases, the K and Sy values reported in **Table 1** were much more reasonable for the modeled system and although the text of the technical appendix repeatedly states that the values in **Table 1** are initial values, it appears that some of the initial

values have been replaced with other values. The values that were actually used in the model should be presented.

The MST Subarea was subdivided into three aquifer parameter zones that represented different hydraulic conductivity values. The values assigned to these zones were not adequately explained nor did they appear to be supported by the conceptualization of the MST Subarea or the USGS documents referenced in *Final BDR Technical Appendix* (DHI, 2006a) used as a basis for the assignment of aquifer properties. For instance, a sharp division was created near the center of the MST Subarea with a K of 250 ft/day to the north and Ks of 1 to 2 ft/day in the two zones located to the south (**Figure 2-30, Attachment A**).

While any groundwater model represents a simplification of the original conceptual model, a few limitations exist in the groundwater model which could lead to limitations in model application. In the MST Subarea, the Soda Creek Fault appears to have been left out of the model. This fault is a significant, well-defined structure which may have a notable influence on flow in the region.

As noted above, the geology of the region is conceptualized as a large drainage basin of impermeable rock overlain in three distinct areas (North Napa Valley area and the MST and Carneros Subareas) by more permeable units. Within each of these three areas, only the primary aquifer is considered while deeper units which are less permeable than the primary aquifer are not represented. For example, underlying the Napa Valley alluvium throughout most of the valley is the tuffaceous member of the Sonoma Volcanics. The tuffaceous member of the Sonoma Volcanics is the primary aquifer unit in the MST. While the contribution of these less permeable underlying units are likely minimal on the regional scale, this simplification may not be valid when modeling more local conditions. The contribution of these underlying layers may need to be incorporated as the model is applied in more local studies.

An additional limitation to the model is the limited to non-existent representation of other subareas within the model. Any part of the model not in the Napa Valley Floor, including the MST and Carneros Subareas, has been lumped into the category of “impermeable rocks”, which disregards any local geologic conditions. For this reason, the groundwater model should not be used to analyze these other subareas.

5.2 Groundwater Pumping

The simulation of groundwater pumping in the groundwater model is not fully explained as to whether pumping is distributed in multiple model layers or confined to a single model layer. Also, if pumping is simulated in multiple layers, then the distribution of pumping by layer needs to be clarified and the methodology that was used to segregate pumping by layer also needs to be explained. If the model is developed to simulate local site conditions in the future, the pumping distribution will need to be revised, especially if pumping is confined to a single model layer.

5.3 Groundwater/Surface Water Interactions

The precise method used to calculate groundwater/surface water interactions for the Napa Valley sub-domain is unclear. The primary source of confusion lies in the coupling of the two models. As a stand-alone model, the Napa Valley Surface Water model does not account for baseflow contributions from groundwater to streams, while the groundwater model does. According to **Table 2-20** (**Attachment A**), within the North Napa Valley area, tributary recharge accounts for 18% of all precipitation and the text states that the surface water model acts as a "dynamic boundary condition" for the groundwater model. It is unclear how tributary recharge is handled between the two models. It is also unclear whether the tributary recharge calculated in the groundwater model is accounted for in the surface water model. **Table 2-17** (**Attachment A**) suggests that the surface water model does not account for this contribution to streamflow and would, therefore, underestimate streamflow and groundwater recharge from the streams. Without further inspection of the model code and input files used, it remains unclear precisely how groundwater/surface water interactions are accounted for and how much error is introduced to both the groundwater and surface water models by the assumptions incorporated in their development.

5.4 Groundwater Recharge

The model currently accounts for recharge from precipitation and streams; however, recharge from applied irrigation is not accounted for. In addition, the fate of water used in municipalities, rural residential, and wineries is not discussed. It is not known if a portion of the water used in these areas is accounted for as groundwater recharge.

6.0 Model Calibration

The *Final BDR Technical Appendix* states that "…the goal of the calibration for the Napa Valley Groundwater Model was to provide a reasonable estimate of water-levels at the regional and subbasin level throughout a long-term simulation period" (pg. 2-18). Six wells were selected for calibration of the model, 3 wells are located in the North Napa Valley alluvium (50 to 434 data points per well) and 3 wells are located in the MST Subarea (7 to 9 data points per well) (**Figure 2-35, Attachment A**). No wells were selected from the Carneros Subarea due to a lack of groundwater data spanning the modeled time period. The text states that K, Sy, and S were used as variables in the calibration, although the methods used to adjust aquifer parameters are not outlined. Hydrographs comparing the calibrated model results to water level measurements are provided in the *Final BDR Technical Appendix* (**Figures 2-61 through 2-66, Attachment A**). In general, the northernmost wells (completed in the Napa Valley alluvium) most closely match observed water levels and trends. Measured and observed values in the north generally fall within 10 feet of each other. Modeled and observed water levels for the MST Subarea generally fall within 20 feet of each other, although some points differ by as much as 40 feet. This increased error in the MST Subarea is expected and likely attributed to the assumptions/simplifications incorporated to represent the complex geologic conditions of the area. Of greater concern is the fact that all of the calibration wells consistently over predict water levels by varying degrees.

While no sensitivity analysis is mentioned in the *Final BDR Technical Appendix*, a separate report, *Sensitivity Analysis of the Napa County Water Quantity and Water Quality Models* (DHI, 2006b) analyzes the sensitivity of the model to certain parameters. Unfortunately, the parameters selected for the sensitivity analysis are all related to surface water flow (**Table 1, Attachment B**). While these results are encouraging as far as the representation of different land uses throughout the surface water model, the sensitivity of the groundwater model to the estimated aquifer parameters remains unknown. As was mentioned in the *Final BDR Technical Appendix* (DHI, 2006a), a limiting factor in the development of the models was a lack of data. For the Napa Valley Groundwater model a number of simplifications were required to estimate the range and distribution of aquifer properties, especially in the MST and Carneros Subareas. Also, the Sy and Ss of each of the aquifer units were largely unknown.

6.1 Review of Model Calibration

The selection of a very short calibration period appears to be primarily related to the surface water model calibration period and not reflective of the availability of longer term groundwater level data that are available. The calibration of the groundwater model was extremely short (four years); and did not present any calibration statistics, residuals, or bias in model output. The limited length of the model calibration period resulted in the omission of extended dry and wet periods. Therefore, a high degree of uncertainty exists about the capability of the model to adequately represent how the groundwater basin responds to extremes in climatic conditions. In managing groundwater resources, it often is important to adequately forecast the response of groundwater levels when groundwater pumping is maximized during drought periods.

The limited selection of calibration wells is inadequate and is surprising given the extensive network of wells that exist in the Napa Valley Floor and the MST Subarea. The lack of any calibration in the Carneros Subarea or presentation of simulated groundwater levels in that area results in a lack of confidence in the reliability of the groundwater model to adequately represent the hydrogeologic conditions in that area.

The lack of a sensitivity analysis of the aquifer parameters that were selected prevents an evaluation of the model's level of uncertainty. A sensitivity analysis should be conducted in which variations of the aquifer parameters by an order of magnitude or more are applied to each individual parameter. This would be beneficial in assessing the level of uncertainty in the calibrated values.

To effectively analyze the development and reliability of any groundwater model, the inclusion of a volumetric water budget or mass balance is conducted. A typical water budget outlines inflows and outflows to the model domain from each of the various model components (e.g., pumping, discharge to streams, infiltration, and inflow/outflow at model boundaries). Checking these values against known or estimated values for the model area can help the developer/user to detect specific areas of concern; while the difference between total inflows and outflows provides a broader quantification of general model error (inflows and outflows should be roughly equal although a percent error of 5% or less is typically considered acceptable). The documentation available for the groundwater model does not provide a volumetric water budget. Instead rates in in/yr and percent of total rainfall were reported (**Tables 2-16, 2-17, 2-19 and**

2-20, Attachment A) without the model domain size which would allow for conversion to volumes. Nevertheless, examination of the data provided offers some insight into areas where the model could be improved.

Two tables outlining the groundwater model water balance are provided in *Final BDR Technical Appendix* (**Tables 2-19 and 2-20, Appendix A**), one table (2-19) summarizes the water balance for the whole groundwater model and a second table (2-20) compares modeled values for the portion of the Napa Valley north of Oak Knoll Avenue (north Napa Valley) to values from a 1991 report (Napa County Flood Control and Water Conservation District, 1991) which generally covered the same portion of the Napa Valley. Similar tables are also provided for the Napa Valley Surface Water model as well (**Tables 2-16 and 2-17, Appendix A**). As discussed in the BDR report, the most significant source of difference for both models is groundwater/ surface water interactions. In considering the total model domain, baseflow to streams accounts for 7.9 in/yr (**Table 2-19**), or 23% of total precipitation while baseflow from streams accounts for 0.3 in/yr, or roughly 1% of total precipitation. In the north Napa Valley area (Table 2-20), modeled baseflow to streams accounts for 42% of total precipitation, and baseflow from streams (tributary recharge) accounts for 18% of total precipitation. This is compared to 12% and 7% of total precipitation as reported in the 1991 report. Comparison of baseflow to streams and total groundwater/surface water interaction between the groundwater model and the 1991 report (Table 2-20) results in a difference of 30% (42% compared to 12%) and 41% (derived from the sum of baseflow to streams and tributary recharge values in the 1991 report and compared to the sum of the same values in the groundwater model as a percent of rainfall), respectively, in the distribution of water within the north Napa Valley area. These values become 22% and 23%, respectively, when considering the whole model area. If the model area is assumed to be 250,000 acres, a 25% difference represents 178,000 acre-feet/year of water. This discrepancy is most likely a result of how the coupled groundwater/surface water models treat this interaction.

7.0 Conclusions and Recommendations

The MIKE SHE Napa County groundwater model was developed by DHI as a regional planning tool to primarily evaluate watershed-scale conditions and how potential land-use changes in the watershed would affect groundwater and surface water conditions. Overall, the groundwater model provides a short-term snapshot of regional groundwater conditions for the Napa River watershed. The model needs additional work before it can be used for local purposes, especially in the MST and Carneros Subareas. The MIKE SHE model code provides flexibility in adapting the regional model for local scale applications and individual projects of variable extent and impact while accounting for both groundwater and surface water conditions. However, the code is complex with many variable and solution options which would entail extensive training should the County wish to use the model in-house without outside technical assistance.

The model developers conclude in the *Final BDR Technical Appendix* that "…specific scenarios for using the Napa Valley Groundwater model include evaluating diversion/groundwater pumping effects on stream flows, evaluating groundwater pumping effects on local water-levels, and studies of groundwater resources" (pg. 2-26). Application of the Napa Valley Groundwater model to basin-wide applications where the effects on groundwater resources from wet and dry

periods, along with local site-specific planning applications, is not recommended at this time for the following reasons:

- The short calibration period of four years was reportedly based upon limitations in selected surface water data availability and not on groundwater data availability. As a result, the ability of the model to adequately simulate longer term historical conditions that include wet and dry periods is unknown. Therefore, the use of the model in simulations where the objective is to assess long-term trends (greater than 10 years) and climate variations is not recommended;
- The groundwater model represents a regional watershed perspective which does not incorporate locally specific geologic and hydrologic attributes;
- Currently, the primary planning areas of the Napa Valley Floor and the MST and Carneros Subareas, are represented and the latter two subareas are either poorly calibrated or not calibrated at all;
- Other subareas which have existing or planned short term development of groundwater resources, including Pope Valley, are not represented;
- Solution algorithms for groundwater/surface water interactions are complex and introduce significant error;
- Groundwater/surface water interactions are modeled, but not in a fully active and dynamic method. Recharge is not accurately represented;
- Documentation of the model's boundary conditions was not available; therefore, it is not known how the boundary conditions might influence basin conditions or future regional groundwater and local scale analyses;
- The groundwater model contains hydraulic conductivity distributions that are not consistent with the conceptual model.

The short calibration period, the lack of simulation of extended wet and dry periods, and the poor calibration results along with the other items listed above result in a high degree of uncertainty. A significant level of effort would be needed to address these concerns. The complexity of the MIKE SHE model code limits the ability of Napa County staff in using the model for in-house analysis of regional and/or localized applications where groundwater is a primary focus. If Napa County does not want to rely fully on outside consultants for modeling services, it is recommended that a public domain model code, such as the USGS MODFLOW model code be used and a new regional model with a longer calibration period be developed. Once a regional model is developed with a longer calibration period, separate models which focus on localized areas of the County could also be developed, as needed, using boundary conditions from the regional model as a foundation.

As the MST will likely continue to be a recurring area of concern, it may be in the County's interest to refine the physical representation of this area to more closely represent known geologic structures and groundwater conditions. Currently, the structure of the MIKE SHE groundwater model and how it represents groundwater conditions in the MST Subarea does not appear to be supported by the conceptualization of the MST. Therefore, the use of the model to

simulate future groundwater development in the MST Subarea may not produce reliable information. Similarly, the existing model is not recommended for evaluating future groundwater conditions in the Carneros Subarea as a result of the lack of model calibration and limited understanding of aquifer parameters and groundwater conditions in this subarea.

8.0 References

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Attachment A

Table 2-11: Aquifer properties used in the Napa Valley Groundwater model.

Geologic Unit	n	Sy	Ss (ft-1)	Khoriz (ft/day)	Kvert (ft/day)
Alluvium	0.25	0.080	8.84E-06	40 - 110	4.0 - 11.0
Huichica Formation	0.15	0.035	1.41E-06	0.2	0.2
Impermeable Sonoma Volcanics	0.02	0.020	1.38E-06	1.0E-04	1.0E-04
Permeable Sonoma Volcanics	0.20	0.046	1.43E-06	2.0	2.0

Table 2-12: Monthly irrigation rates used in the Napa County Surface Water and Groundwater models.

Month	Irrigation (in/month)
January	1.49
February	1.49
March	-
April	-
May	1.35
June	1.35
July	2.12
August	2.12
September	2.12
October	-
November	-
December	1.49
Total	13.5

Table 2-15: Runoff volume error for the Napa Valley Surface Water model calibration.

Name	Simulated Runoff Volume (TAF)	Observed Runoff Volume (TAF)	Volume Error (%)
Napa River @ St. Helena	241	256	6
Napa River @ Napa	607	505	20
Lake Hennessey Inflow	100	83	20
Lake Hennessey Outflow	106	23	> 100
Lake Berryessa Inflow	1141	1289	11

Notes:

Calculations are for the entire simulation period (2000-2003)
TAF = Thousand Acre-Feet

Table 2-16: Simulated annual water balance for the Napa Valley Surface Water model.

	Depth (in/yr)	Volume (TAF/yr)
Rainfall	33.8	692
Evapotranspiration	20.3	416
Overland Flow to Streams	1.8	36
Groundwater Pumping	2.0	41
Infiltration	16.3	334
Baseflow to Streams	10.1	207
Irrigation	2.4	49
Stream Runoff	26.1	534

Table 2-17: Comparison between simulated water balance in the Napa County Surface Water model and Table 5-1 (Napa County Flood Control and Water Conservation District, 1991).

	1991 Report *		Model **	
	Depth (in/yr)	% of Rainfall	Depth (in/yr)	% of Rainfall
Rainfall	35	-	36	-
Irrigation	4.3	12	5.7	16
Tributary Recharge	2.4	7	-	-
Evapotranspiration	20	57	20	56
Groundwater Pumping	4.5	13	5.5	15
Stream Runoff	12	34	15	42
Baseflow to Streams	4.3	12	12	33

Notes:

* Annual Water Balance was calculated from a period of record from 1962 to 1989.
** Annual Water Balance was calculated for the simulation period 2000 to 2004.
- Linear Reservoir option for the groundwater model does not allow for stream recharge.

Table 2-18: Simulated annual water balance for the Lake Berryessa Surface Water model and comparison with the Napa Valley Surface Water model.

	Lake Berryessa Depth (in/yr)	Napa Valley Depth (in/yr)
Rainfall	37.0	33.8
Evapotranspiration	23.6	20.3
Overland Flow to Streams	1.5	1.8
Groundwater Pumping	0.3	2.0
Infiltration	13.9	16.3
Baseflow to Streams	8.6	10.1
Irrigation	0.3	2.4
Stream Runoff	19.8	26.1

Table 2-19: Simulated annual water balance for the Napa Valley Groundwater model.

	Groundwater Model Depth (in/yr)
Rainfall	34.4
Evapotranspiration	19.0
Overland Flow to Streams	3.7
Groundwater Pumping	2.5
Infiltration	11.6
Baseflow from Streams	0.3
Baseflow to Streams	7.9
Irrigation	2.1
Stream Runoff	22.8

Table 2-20: Comparison between simulated water balance in the Napa Valley Groundwater model and Table 5-1 (Napa County Flood Control and Water Conservation District 1991).

	1991 Report *		Model **	
	Depth (in/yr)	% of Rainfall	Depth (in/yr)	% of Rainfall
Rainfall	35	-	36	-
Irrigation	4.3	12	5.4	15
Tributary Recharge	2.4	7	6.4	18
Evapotranspiration	20	57	18	50
Groundwater Pumping	4.5	13	5.7	16
Stream Runoff	12	34	13	36
Baseflow to Streams	4.3	12	15	42

Notes:

* Annual Water Balance was calculated from a period of record from 1962 to 1989.

** Annual Water Balance was calculated for the simulation period 2000 to 2004.

Table 2-21: Water balance comparison between scenarios for the Napa Valley Surface Water model.

	Total Depth (inches/yr)		
Hydrologic Component	Existing Conditions	Scenario 1a	Scenario 1b
Rainfall	46	46	46
ET	25	19	16
Infiltration	19	24	16
Overland to River	4	5	14
Baseflow to River	12	15	10
River Runoff	19	22	27

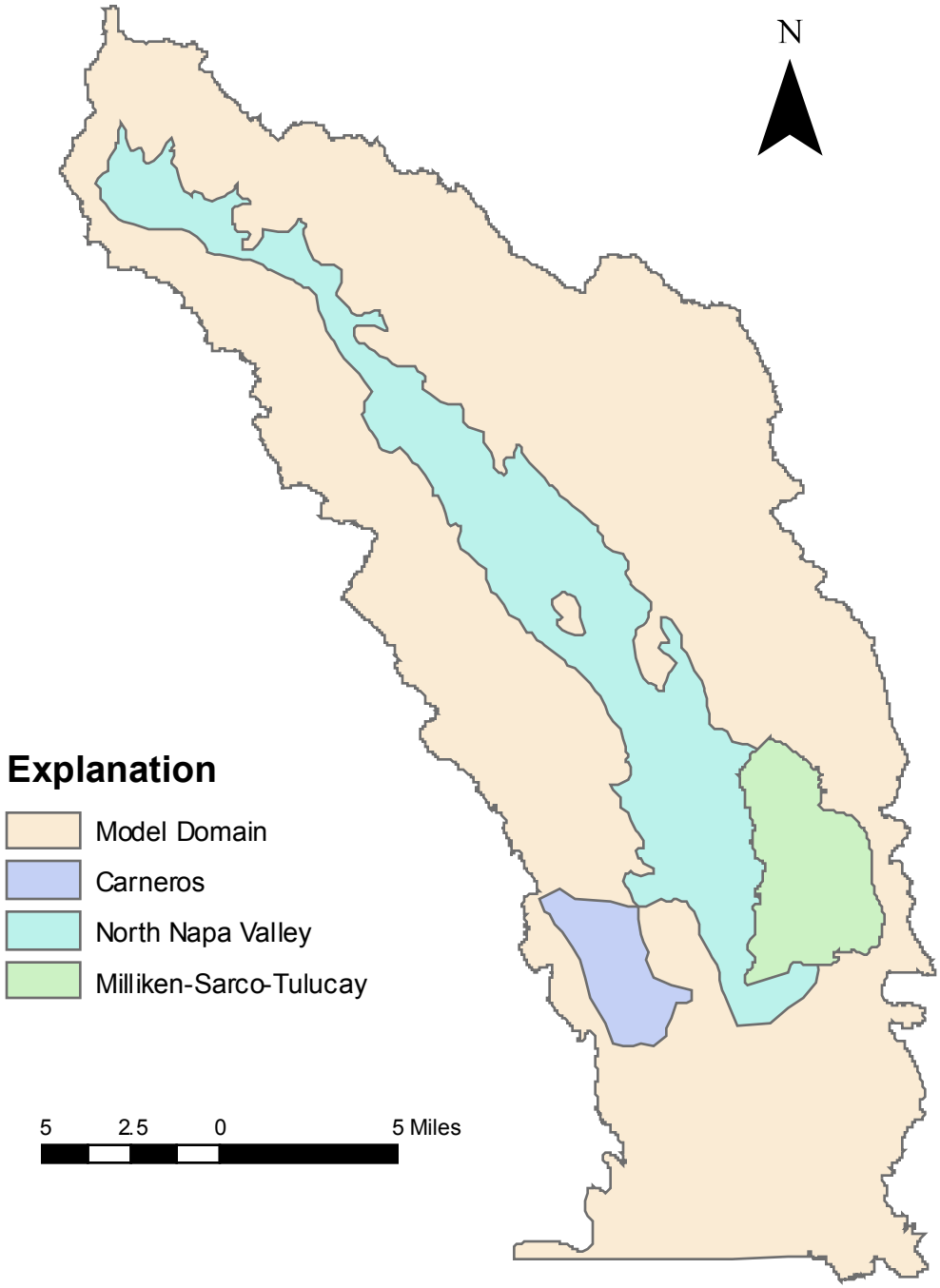

Figure 2-6: Map showing the approximate locations of the three largest groundwater basins in Napa County, North Napa Valley Groundwater Basin after CDWR (2004), Milliken-Sarco-Tulucay Groundwater Basin after Farrar and Metzger (2003), and Carneros Groundwater Basin after NFCWC (1991).

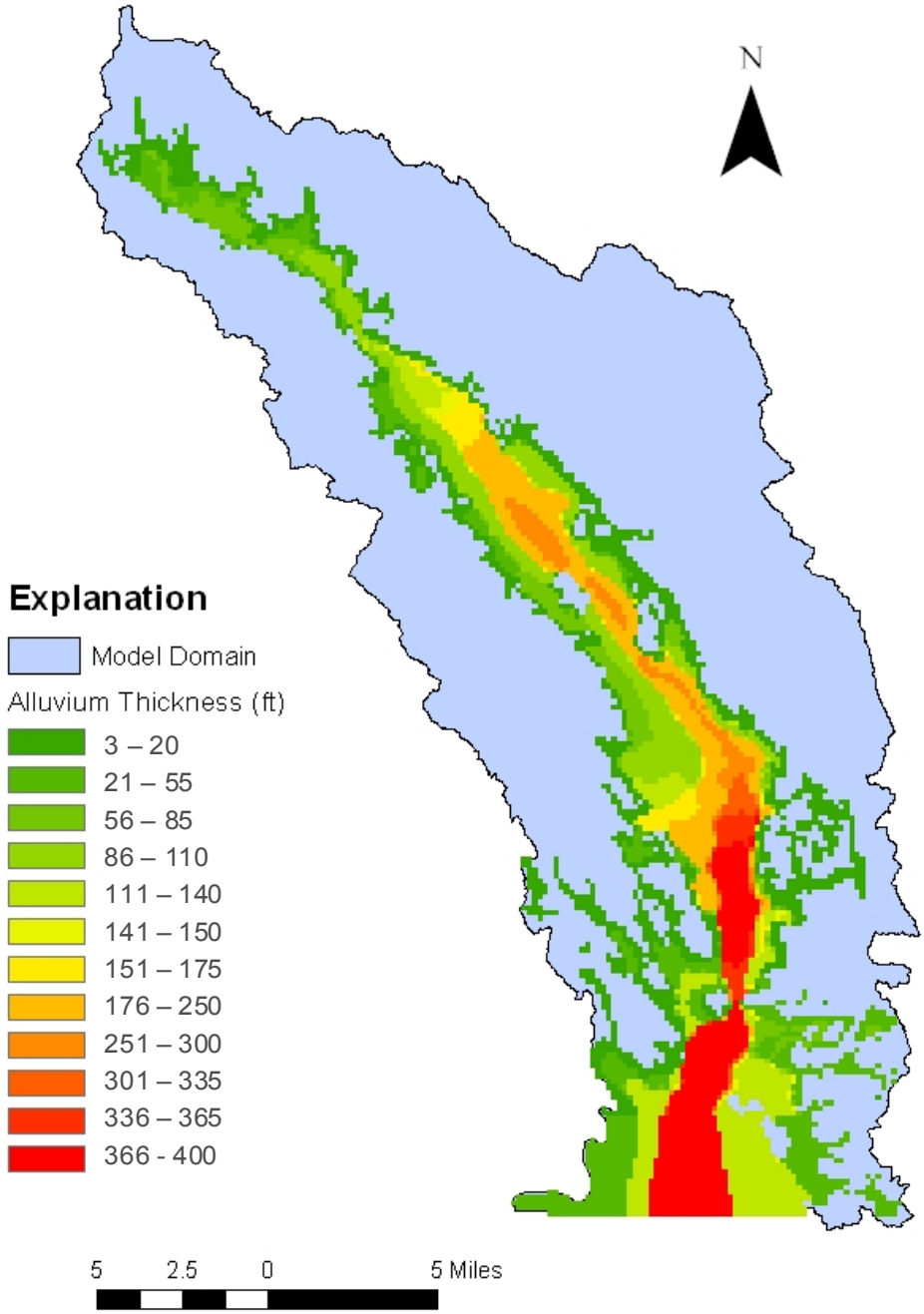

Figure 2-27: Extent and thickness of the alluvium lens in the Napa Valley Groundwater model.

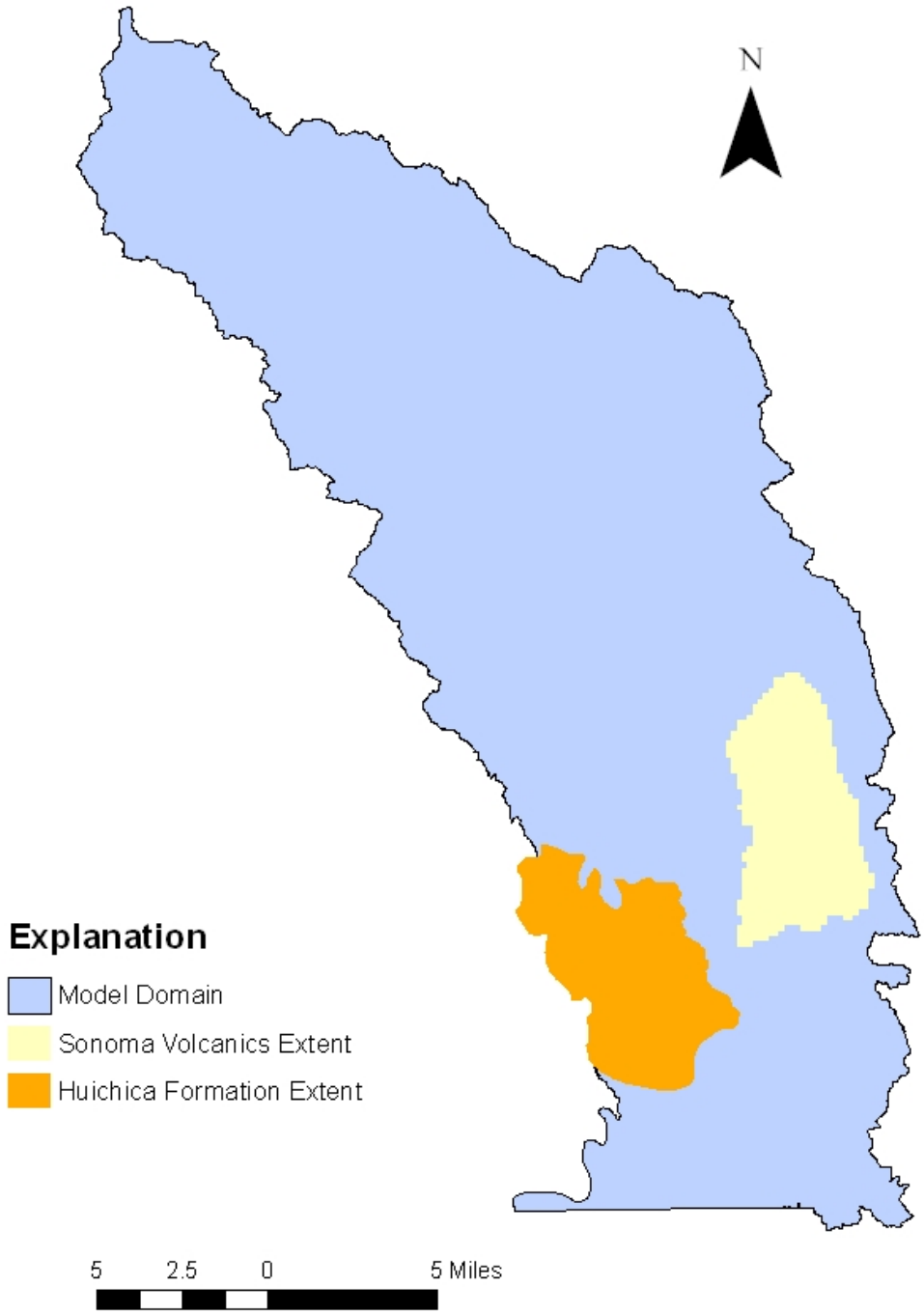

Figure 2-28: Extent of the Huichica Formation lens and the permeable Sonoma Volcanics (SV) in the Napa Valley Groundwater model.

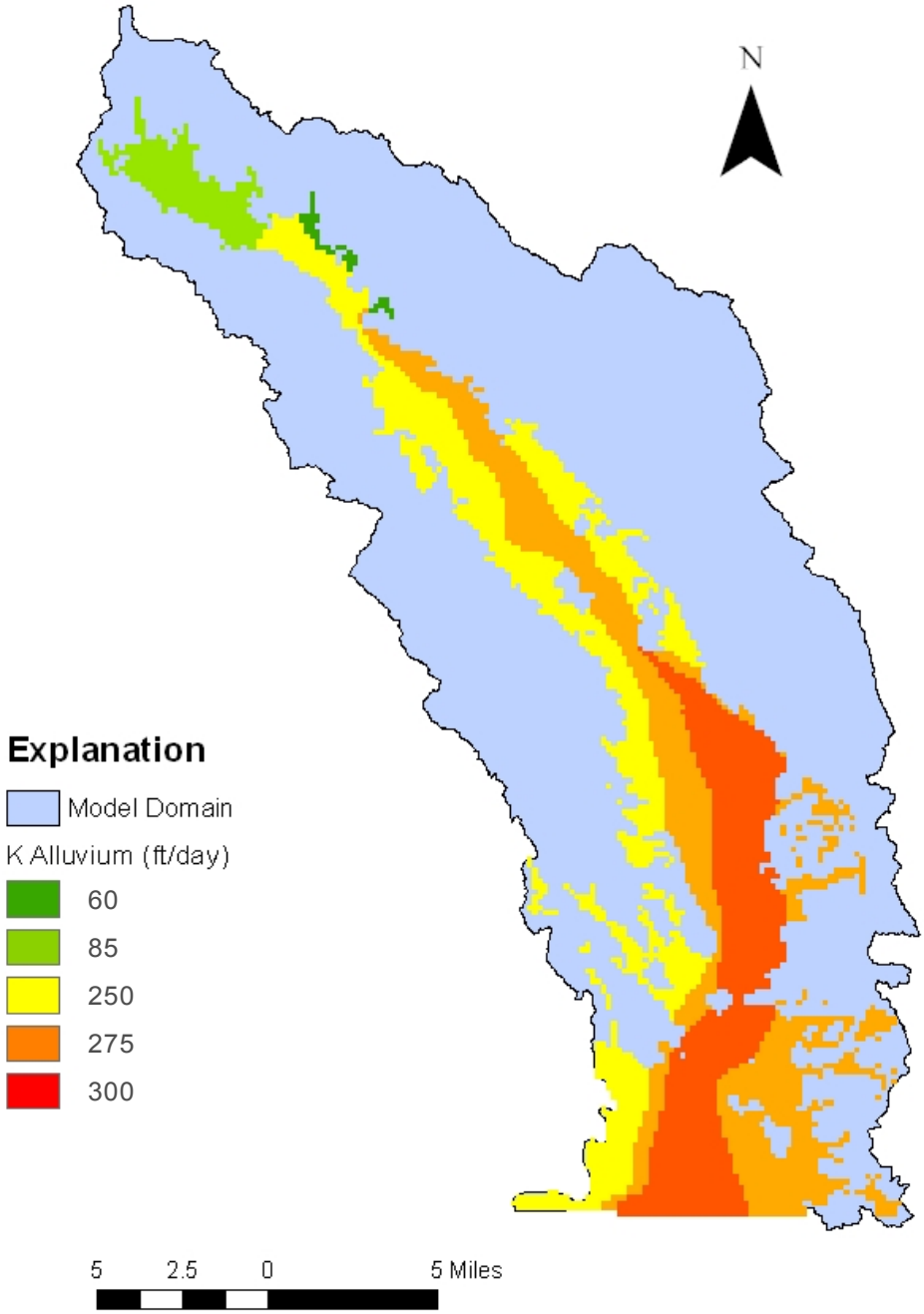

Figure 2-29: Distribution of hydraulic conductivity (K) values used for the alluvium in the Napa Valley Groundwater model.

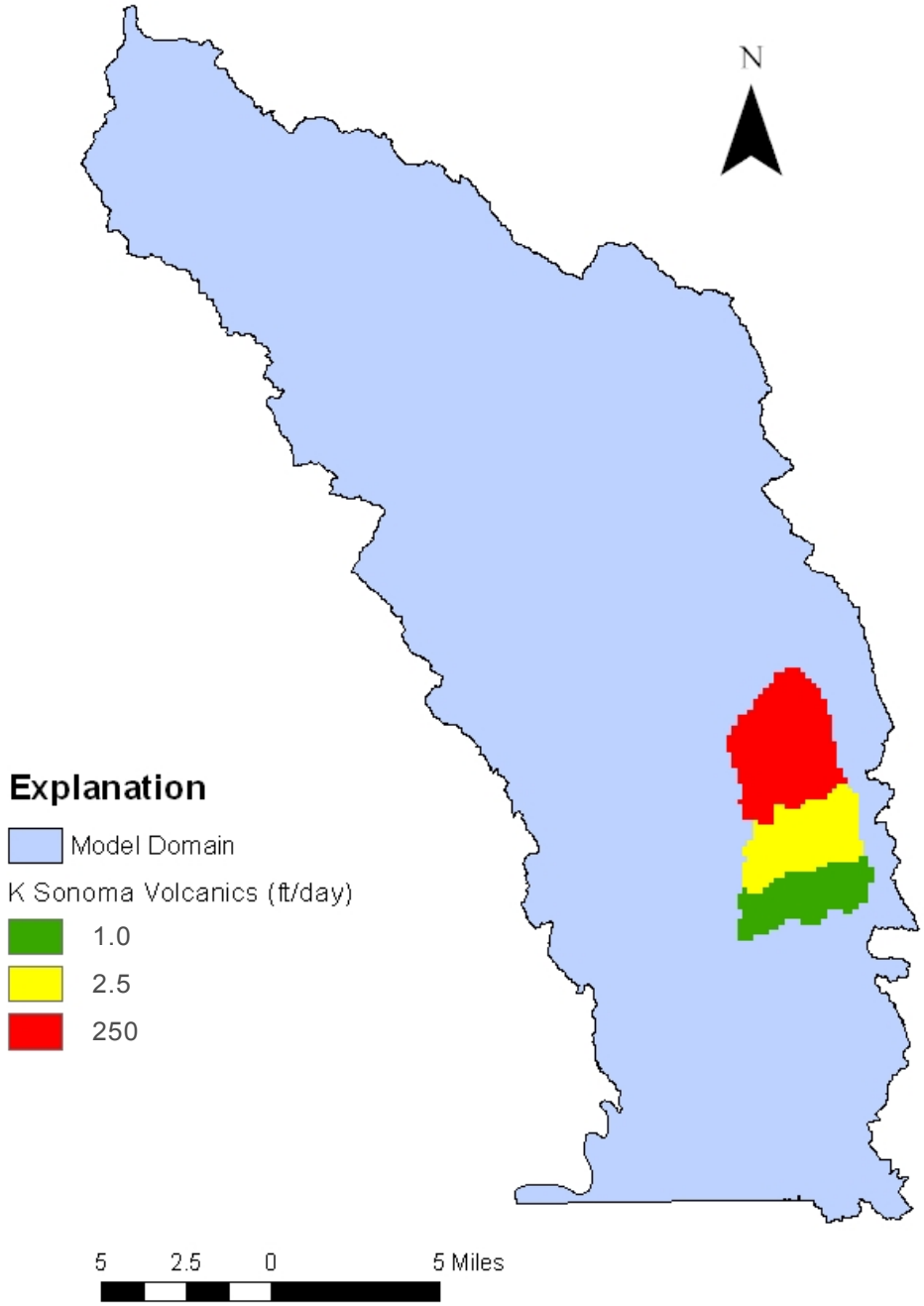

Figure 2-30: Distribution of hydraulic conductivity (K) values used for the Sonoma Volcanics in the Napa Valley Groundwater model.

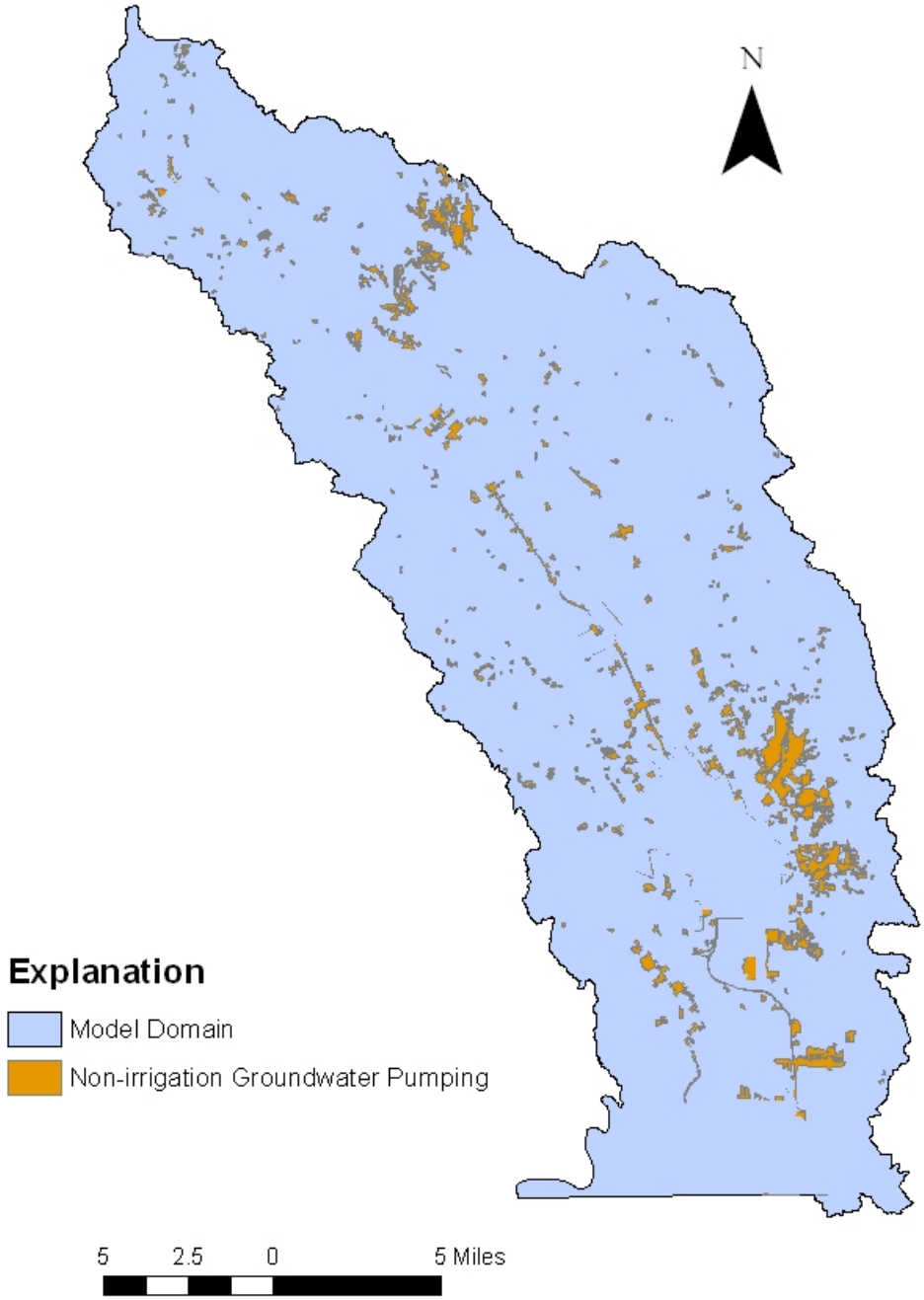

Figure 2-31: Distribution of non-irrigation groundwater pumping used in the Napa Valley Groundwater model.

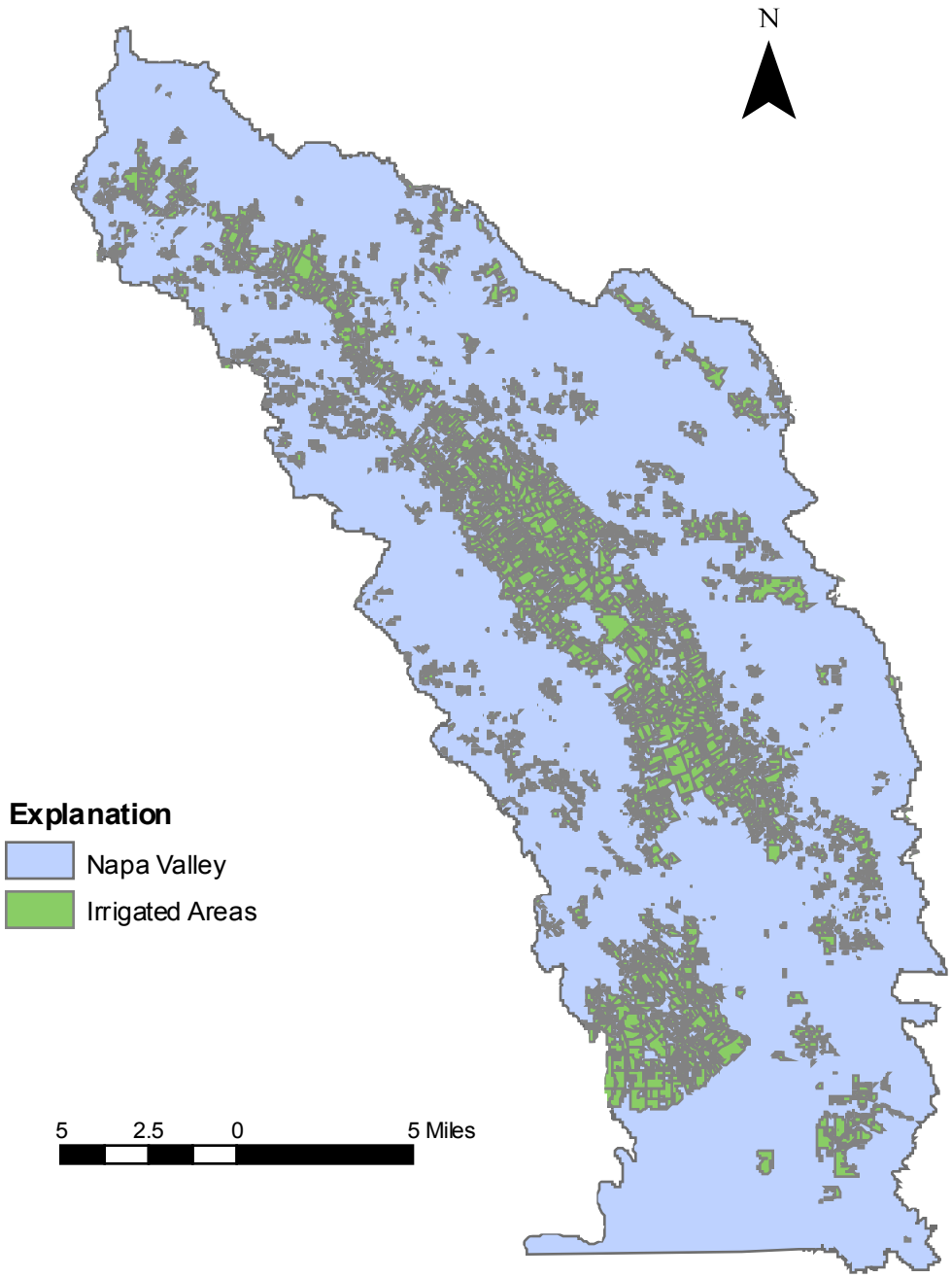

Figure 2-32: Irrigated areas in the Napa Valley Surface Water model and the Napa Valley Groundwater model.

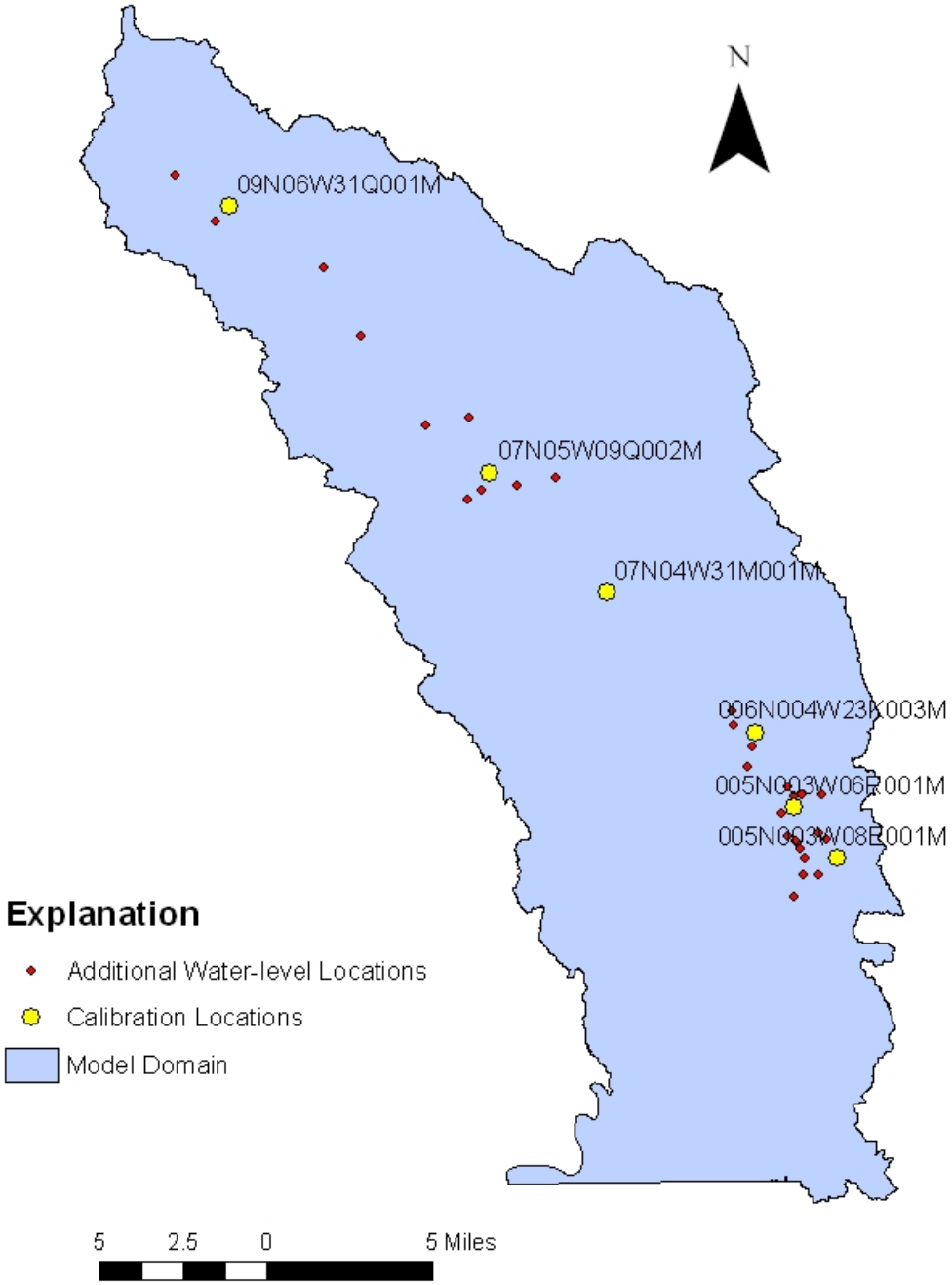

Figure 2-35: Water-level calibration locations in the Napa Valley Groundwater model and additional locations where water-level data is available.

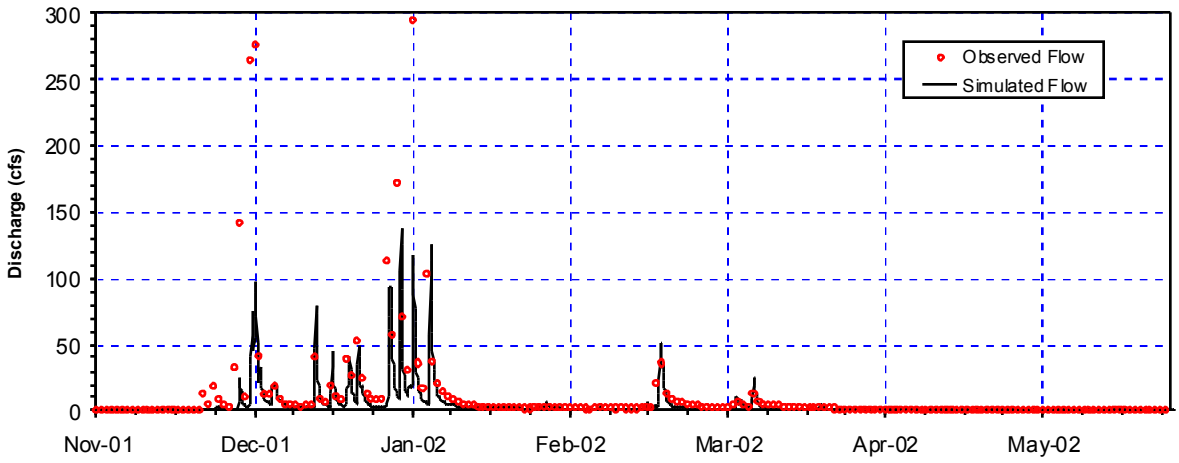

Figure 2-60: Simulated and observed discharges in the Napa Valley Groundwater model (Huichica Creek, Nov. 2001 – May 2002).

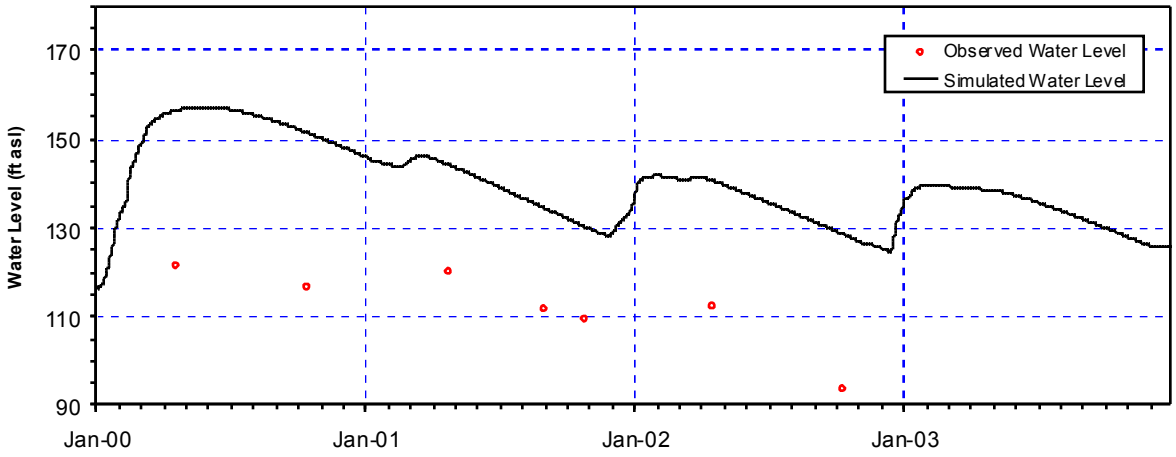

Figure 2-61: Simulated and observed groundwater levels in the Napa Valley Groundwater model (005N003W06R001M, Jan. 2000 – Dec 2003).

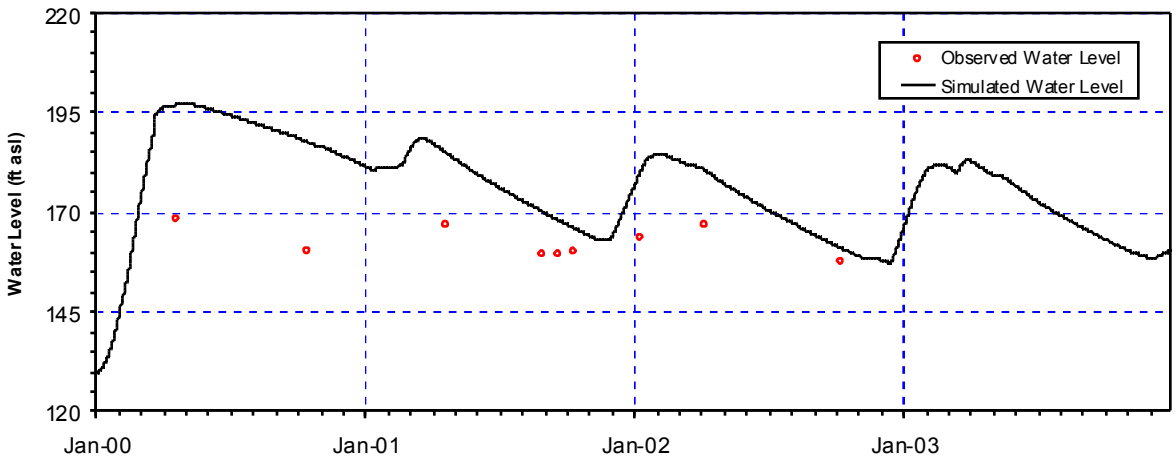

Figure 2-62: Simulated and observed groundwater levels in the Napa Valley Groundwater model (005N003W08E001M, Jan. 2000 – Dec 2003).

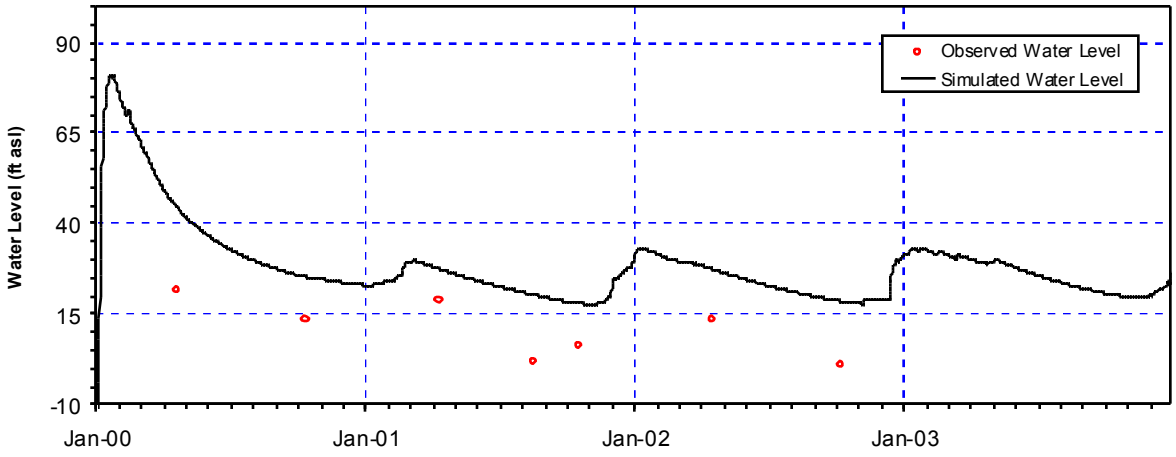

Figure 2-63: Simulated and observed groundwater levels in the Napa Valley Groundwater model (006N004W23K003M, Jan. 2000 – Dec 2003).

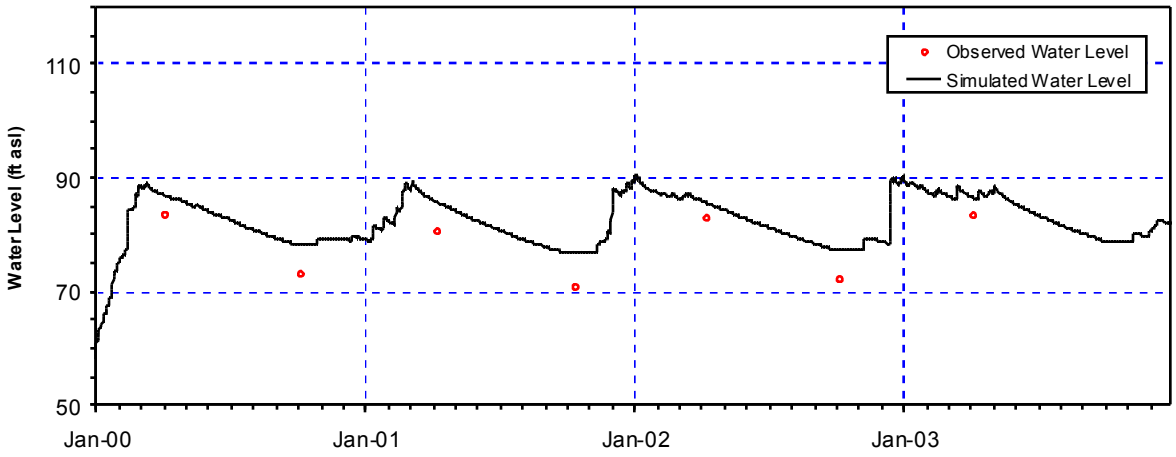

Figure 2-64: Simulated and observed groundwater levels in the Napa Valley Groundwater model (007N004W31M001M, Jan. 2000 – Dec 2003).

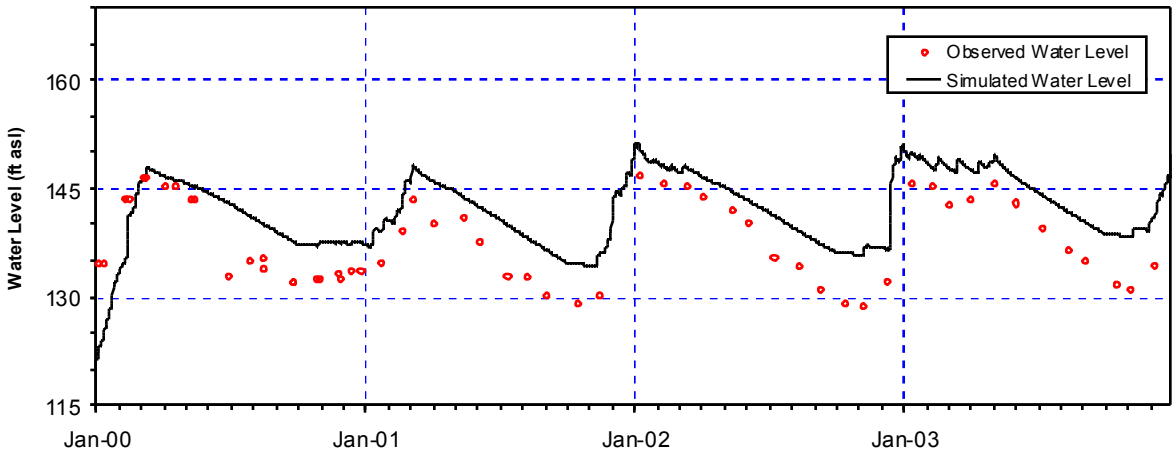

Figure 2-65: Simulated and observed groundwater levels in the Napa Valley Groundwater model (007N005W09Q002M, Jan. 2000 – Dec 2003).

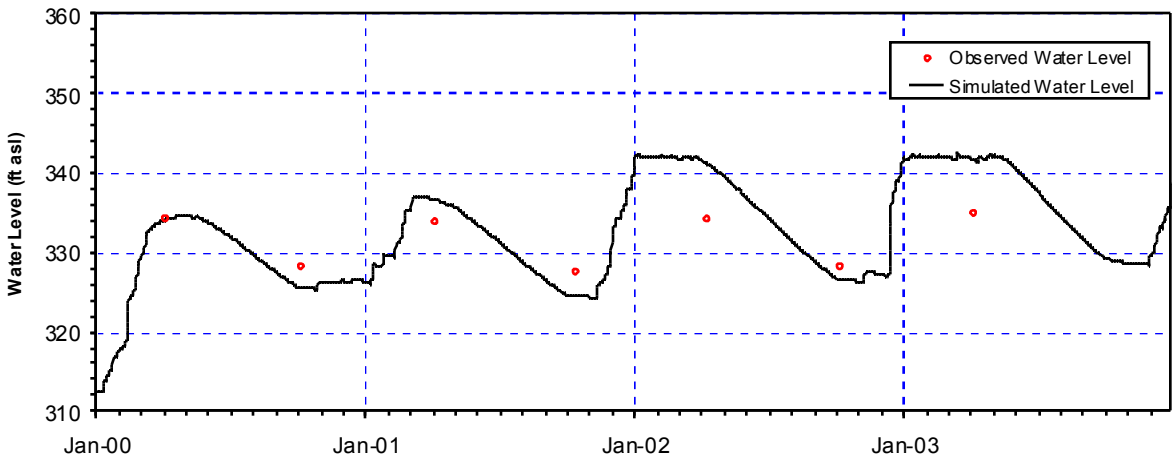

Figure 2-66: Simulated and observed groundwater levels in the Napa Valley Groundwater model (009N006W31Q001M, Jan. 2000 – Dec 2003).

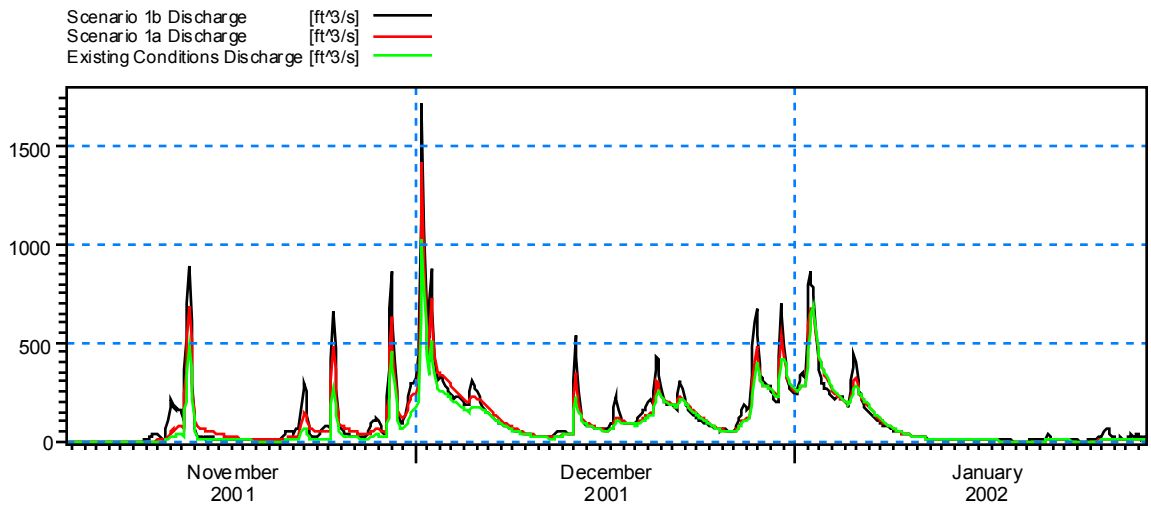

Figure 2-67: Simulated and observed discharges for scenarios 1a and 1b in the Napa Valley Surface Water model.

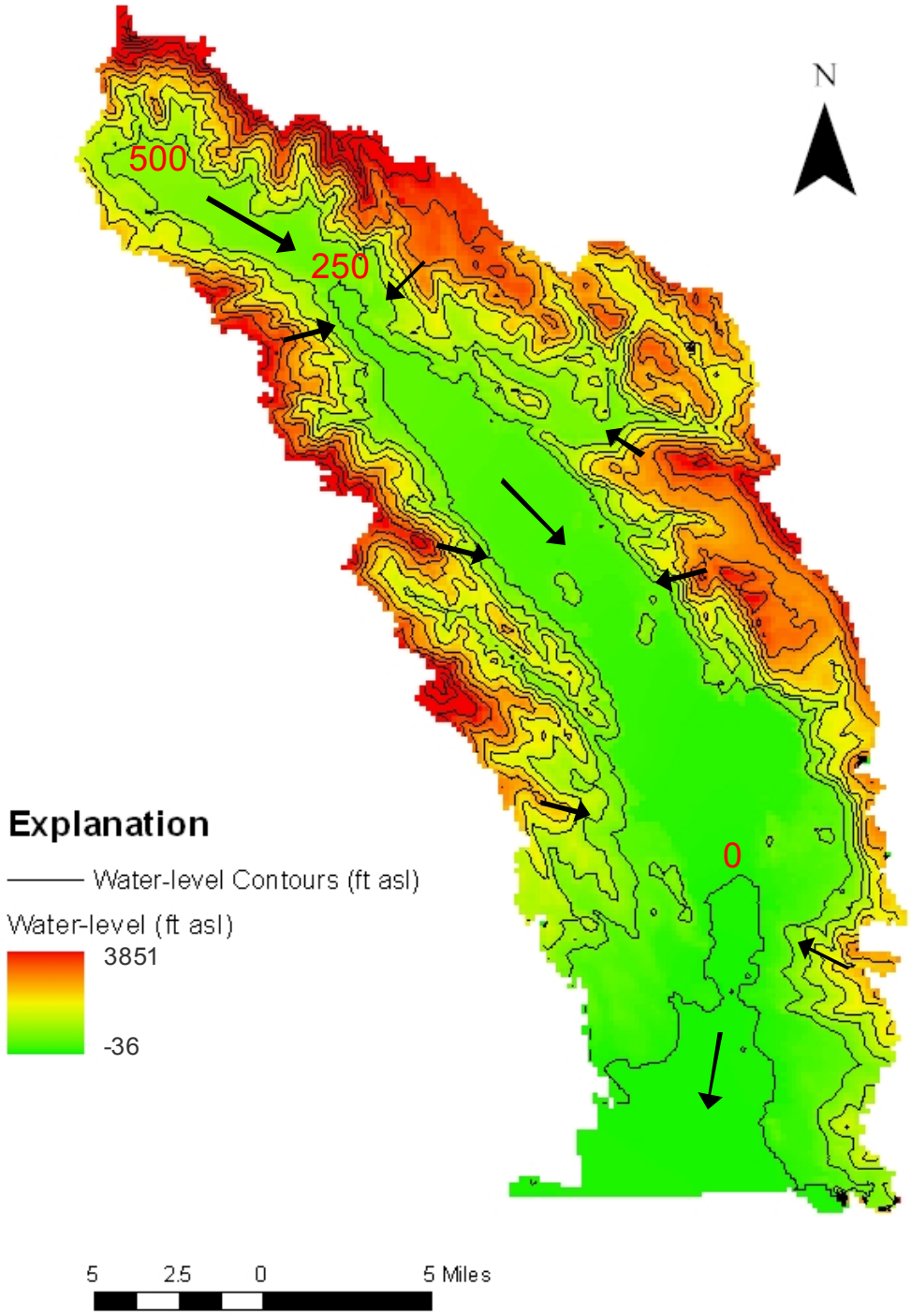

Figure 2-68: Simulated water-table surface in the Napa Valley Groundwater Model with arrows indicating the predominant directions of groundwater flow (August 2003).

Attachment B

Table 1: Parameters evaluated during the sensitivity analysis and the degree of variation.

Parameter	Change from Baseline	Range of Baseline Values
OL Manning's Rougness Coefficient (n)	+/- 35%	0.038 - 1.333
Rooting Depth (RD)	+/- 1 ft.	600 - 2000 mm
Crop Coefficent (Kc)	+/- 20%	1.0 - 1.3
Leaf Area Index (LAI)	+/- 20%	0.5 - 5.0

Table 2: Scenarios evaluated during the sensitivity analysis and the associated parameters that were adjusted for each.

Scenario	Adjusted Parameters
20% Increase in Development*	land-use, RD, Kc, LAI,OL Manning's n, soil infiltration capacity
20% Increase in Vineyards*	land-use, RD, Kc, LAI, OL Manning's n, irrigated areas
20% Increase in Water-use	surface water diversion rates, groundwater pumping rates

* exact change varied between basins, see text for explanation