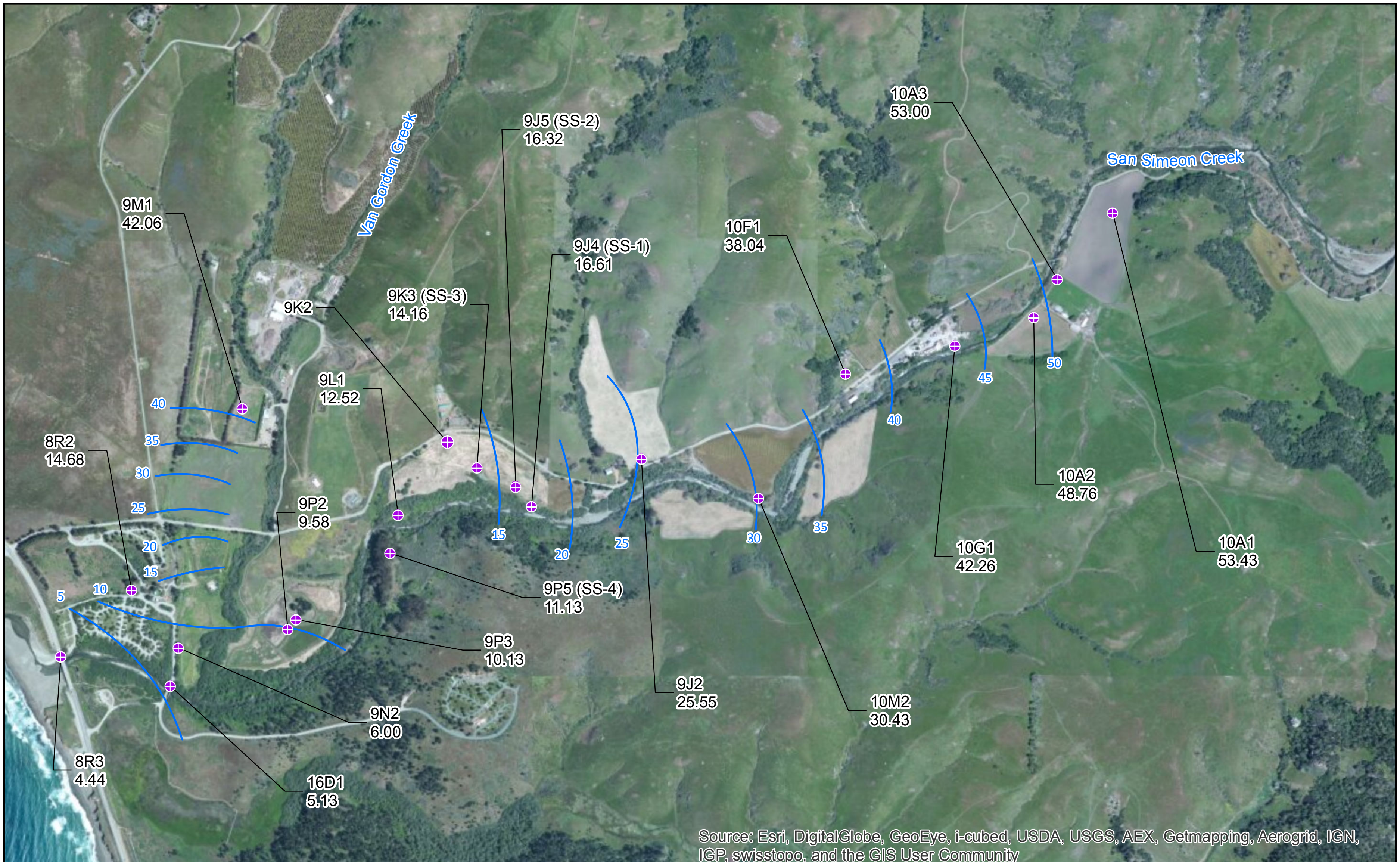

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Elevations are in NAVD88 datum.

Figure 2-5

Generalized Water Table – Winter 1989

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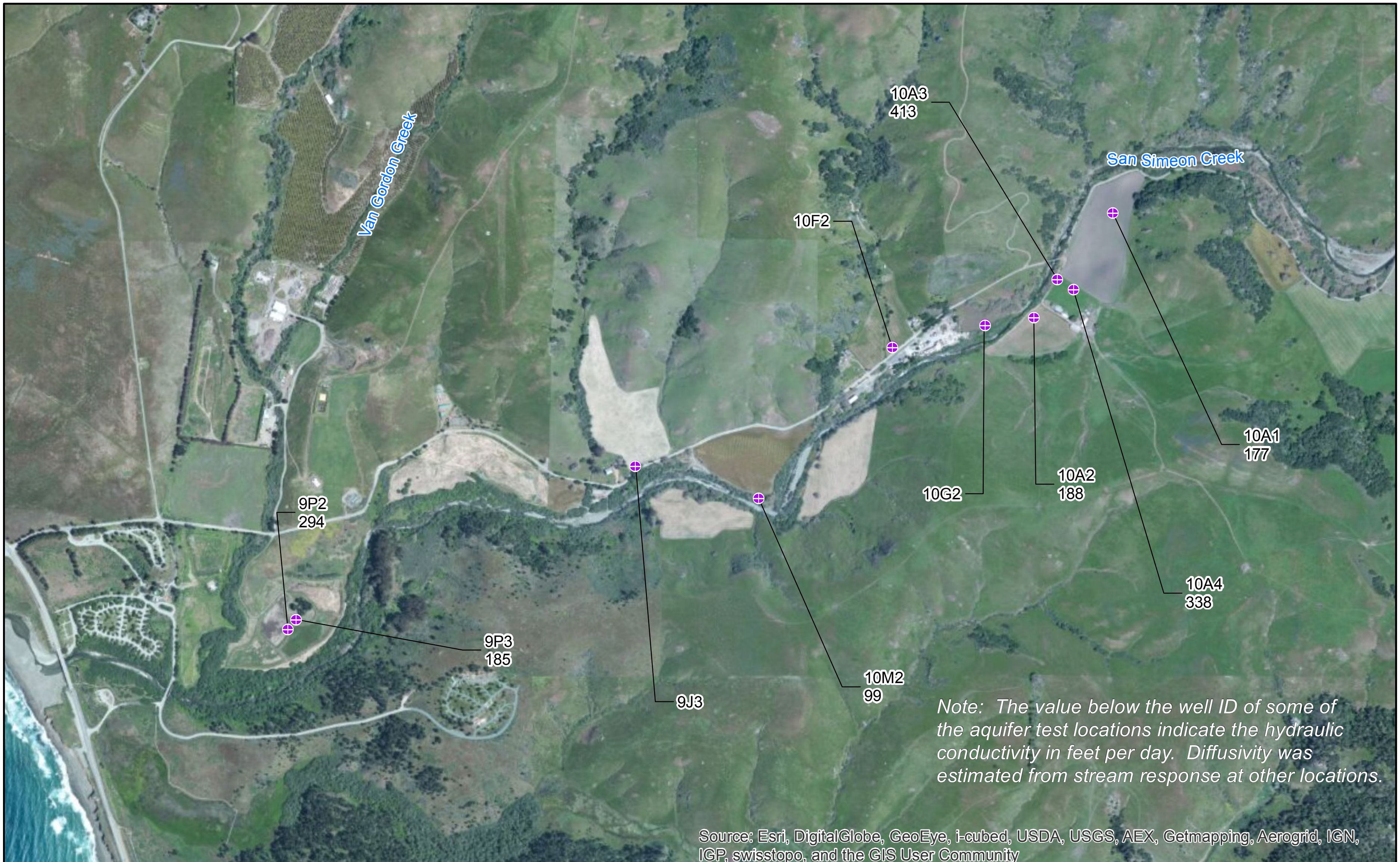

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Figure 2-6
Location of Aquifer Tests

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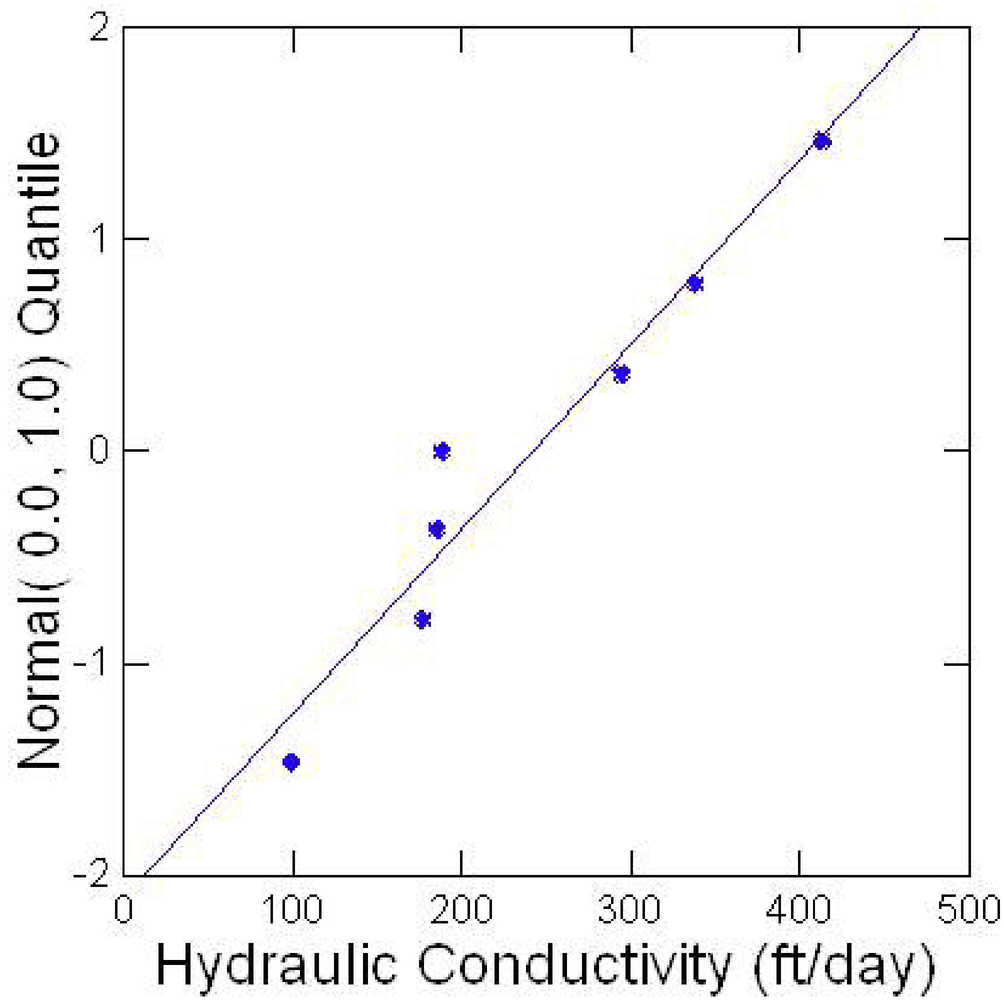

Note: Blue dots represent conductivity value from the 1998 USGS Report.

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Figure 2-7
Hydraulic Conductivity Statistical Distribution

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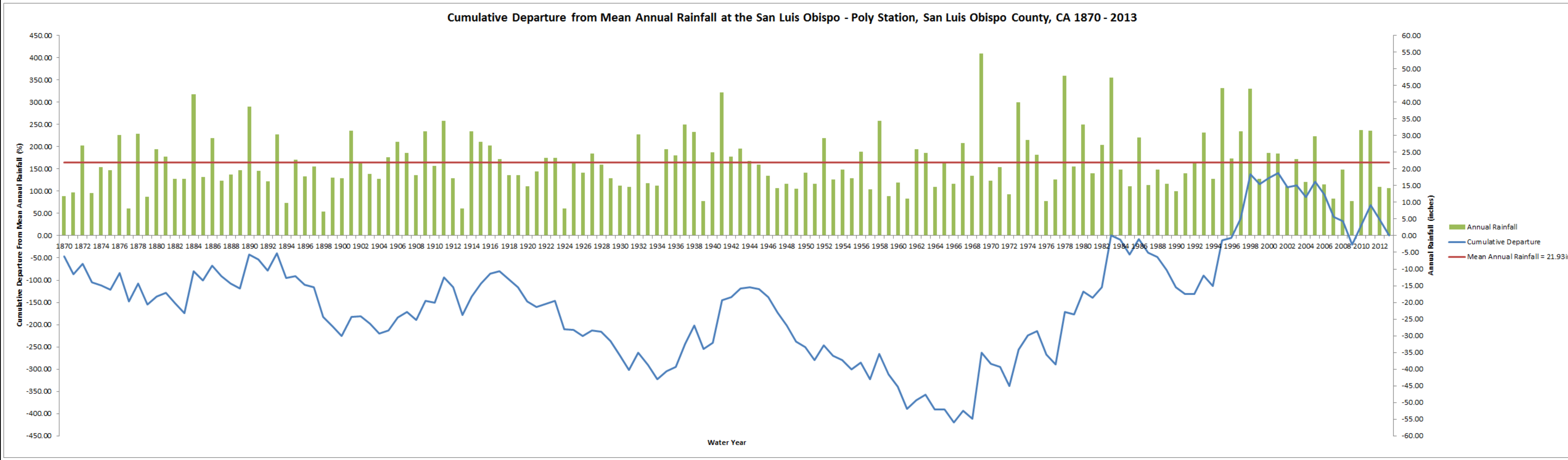

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Figure 2-8
Precipitation and Cumulative Departure
from the Long Term Average at San Luis Obispo - Poly Station

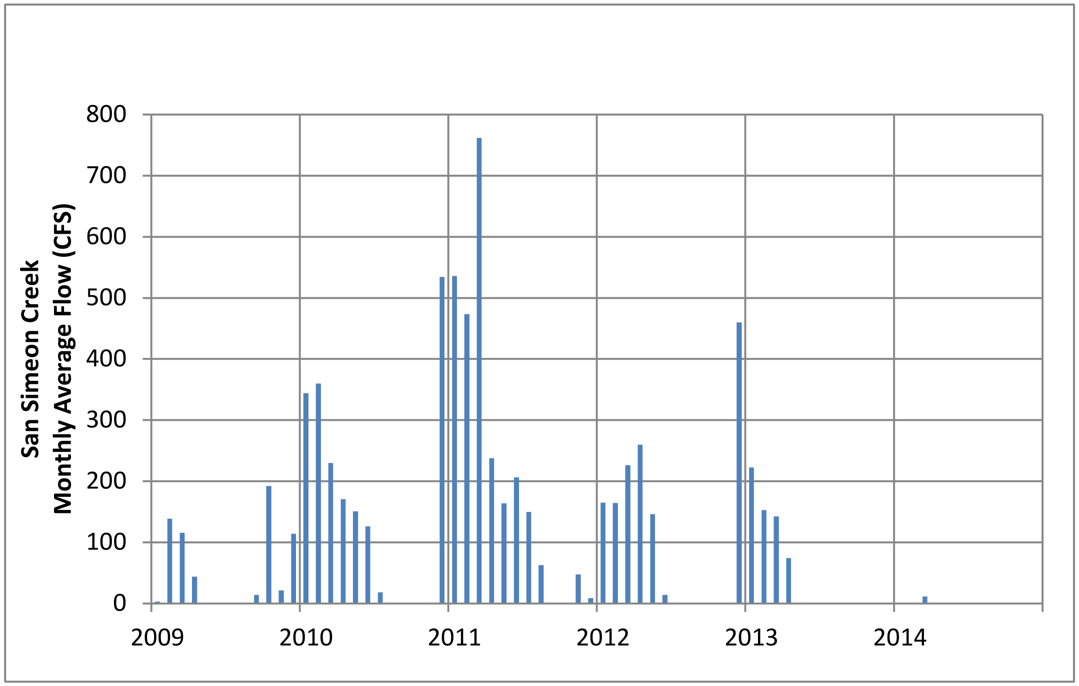

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Figure 2-9

Streamflow in San Simeon Creek and Groundwater Level Hydrographs in the 2009 - 2013 Period

CDM Smith

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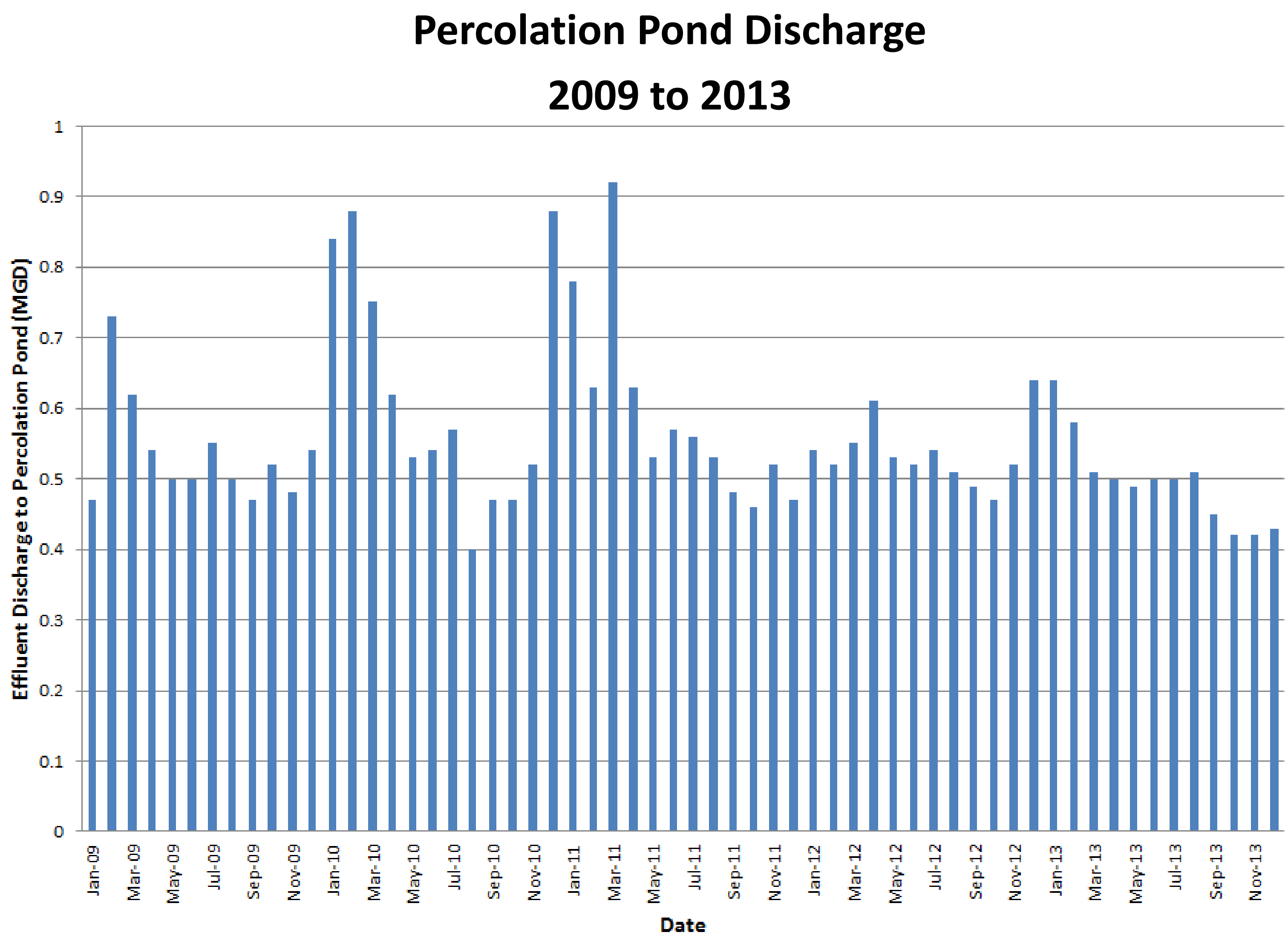

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Figure 2-10
Pecolation Pond Secondary Effluent Discharge 2009 to 2013

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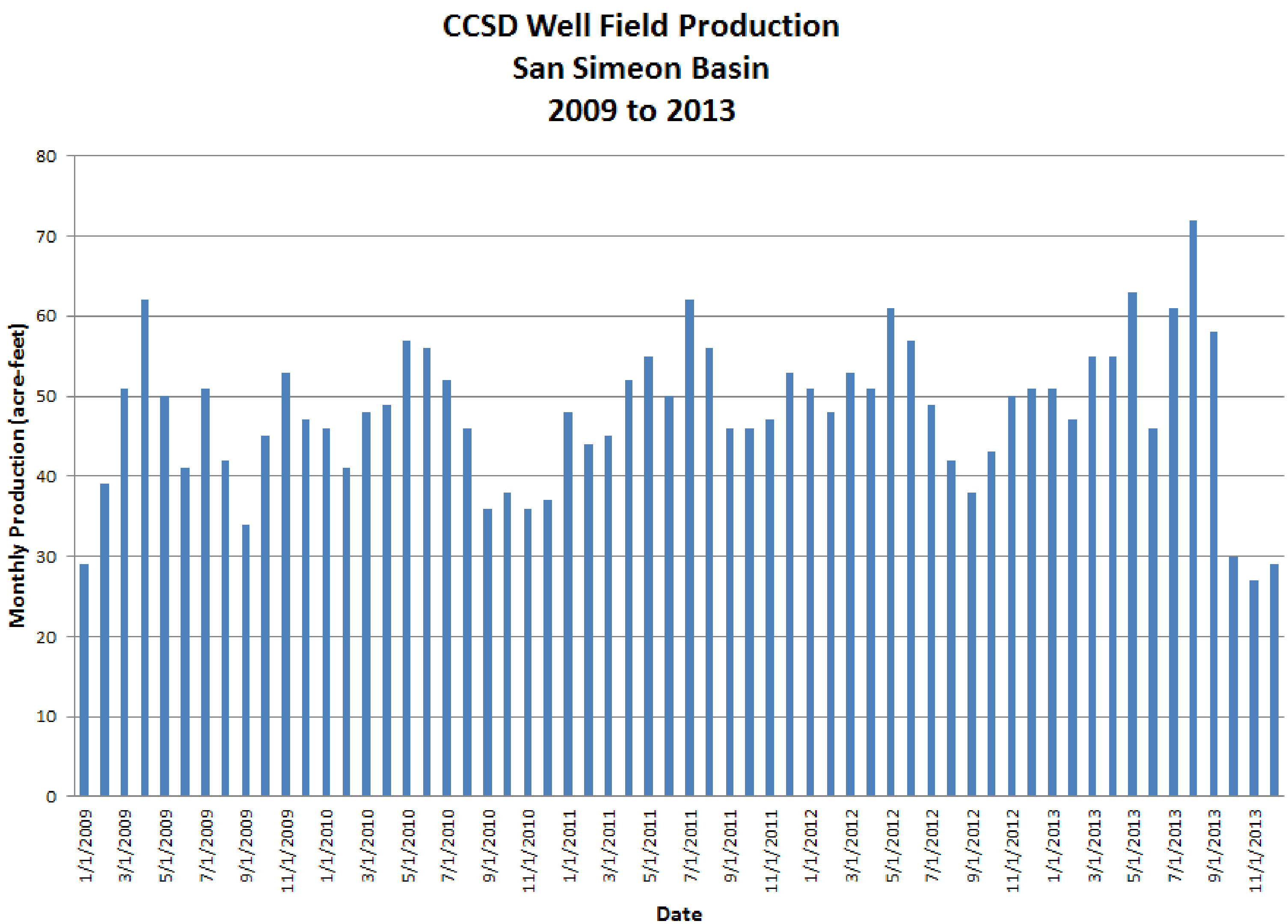

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Figure 2-11
CCSD San Simeon Basin Well Field Production 2009 to 2013

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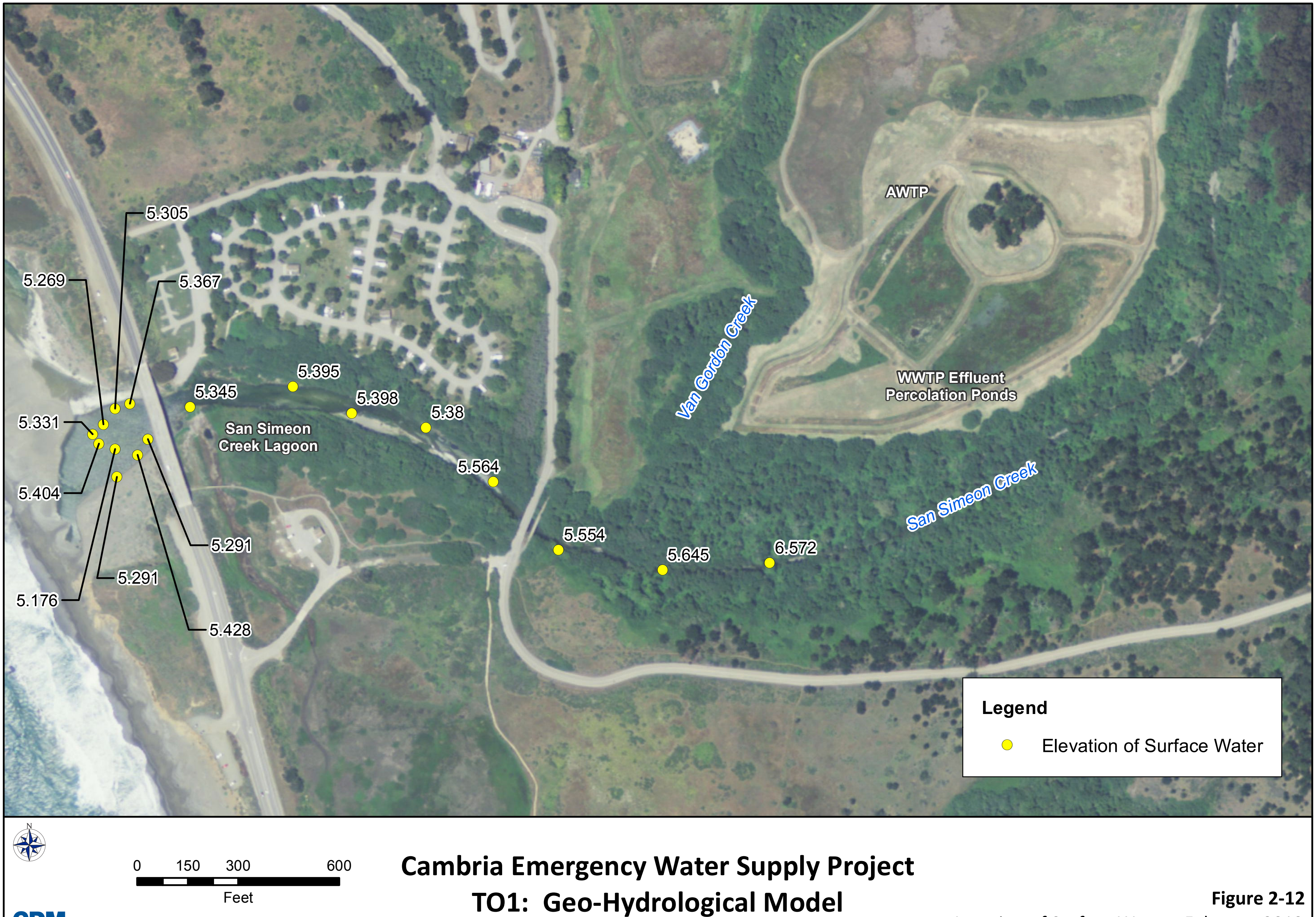

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Figure 2-12
Location of Surface Water - February 2012

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Section 3
Computer Model Code Selection

This modeling evaluation has been conducted using industry standard, open source, government developed computer programs that are able to mathematically represent the processes of interest. Detailed descriptions of these modeling programs are provided in the cited references and will not be repeated. The specific elements that are used in this application are described in the model development section. In addition, preparation of model data sets and post processing of model output was facilitated through use of a commercial graphical user interface. The selected programs are listed below.

MODFLOW-2000 (Harbaugh, 2000), this finite difference model is the most widely used program for modeling of groundwater flow and serves as the basis for flow calculations in the additional programs that are used in the analysis. This program was developed by the US Geological Survey and includes capabilities for simulation of all of the components of interest in this investigation, except for density driven flow, which is handled in the companion program SEAWAT. MODFLOW-2000 is well documented by the USGS.

MT3DMS. (Zheng, 1999), this code was developed under contract from the US Environmental Protection Agency and the US Army Corps of Engineers. This model is an industry standard model used for simulation of transport of dissolved constituents in groundwater. This code is incorporated into the SEAWAT model.

SEAWAT. (Langevin, 2003), SEAWAT is a modification of MODFLOW-2000 and MT2DMS that allow simulation of groundwater flow, including the effects of variable density and transport of solutes. This industry standard model was developed by the USGS. This model was used to assess the importance of density driven flow for comparison with the primary simulations in MODFLOW and MT3DMS.

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Section 4
Ground-Water Flow Model Construction

The basin conceptual model described in Section 2 was used to configure a numerical flow model in MODFLOW-2000 and to set up transport capabilities in MT3DMS and SEAWAT. This section describes the configuration of the model framework, selection of simulation packages to represent the site processes and parameter selection.

4.1 Model Grid

A very fine computational grid was defined to represent the aquifer system at the site, since a major concern is the simulation of transport and consideration of vertical movement of recharge or injected water. The alluvial aquifer is represented by 18 vertical layers at the western limit of the site, decreasing to 8 active layers in the eastern portion of the site where the aquifer is thinner and more distant from the area of interest. The horizontal spacing for grid cells was maintained at a uniform size of 40 by 40 feet, resulting in a grid with 120 rows and 460 columns.

The grid was rotated to approximately parallel the trend of the San Simeon basin. Cells outside of the aquifer footprint and in deeper portions of the grid in the eastern part of the model were inactivated. **Figure 4-1** shows the extent of the model, while **Figure 4-2** shows the model grid in the area of primary concern between the CCSD well field and the wastewater percolation ponds.

4.2 Hydraulic Parameters

A groundwater model must define hydraulic characteristics for each active cell in the grid in order to evaluate flow and transport. These hydraulic characteristics include horizontal and vertical hydraulic conductivity and storage characteristics of the aquifer material. A detailed calibration of hydraulic characteristics was done for a model of the basin in 2007 (Yates, 2007) that was used as the basis for initial configuration of hydraulic characteristics for the alluvial aquifer.

This model was configured in a similar manner to leverage the calibration that was done at that time. Minor refinements were incorporated in some areas, however, variation in hydraulic conductivity during the evaluation of calibration did not result in significant improvements, so the hydraulic conductivity distribution remained very similar to the 2007 configuration. A detailed calibration for development of specific yield, which is important in assessing the volume of water in storage, for assessment of groundwater velocities and estimation of residence time of injected fluids was done.

The hydraulic properties were grouped vertically for definition of hydraulic properties, with an upper zone incorporating layers 1–8, and intermediate zone represented by layers 9–12, and a deep zone for layers 13–18. Properties within each of the layer groupings were uniform. The base of the upper zone was set at an elevation-20, or the bedrock elevation for cases where bedrock was above this elevation. The intermediate zone extended from elevation -20 to elevation -60, again truncating at the bedrock contact if it was shallower. The deep zone extended from -60 to the bedrock contact. In cases where the bedrock contact was above the noted elevations, then underlying layers were inactivated in the model. The active extent of the model grid therefore extended from the water table to the bedrock contact.

Figure 4-3, thru **Figure 4-5** show the distribution of horizontal hydraulic conductivity for the upper, middle and deep zones respectively. The distribution of hydraulic conductivity incorporates the conceptual model characteristic of a lower permeability zone in shallow materials in the western extent of the model down-gradient of the confluence of Van Gordon Creek. A constant ratio of horizontal to vertical hydraulic conductivity of 10:1 was used throughout the model domain. The initial specific yield was set to 0.12, with changes that were incorporated during calibration described in subsequent sections.

4.3 Boundary Conditions

Boundary conditions describe characteristics that control inflow and outflows of water to and from the aquifer system. As described in the conceptual model, the primary sources of water entering the system are recharge from stream seepage, infiltration of precipitation and irrigation return flows, waste water percolation and lateral boundary inflow.

The primary discharge from the aquifer includes stream seepage in the western portion of San Simeon Creek, municipal and agricultural pumping and subsurface discharge to the ocean. These boundary conditions are configured in standard packages within MODFLOW-2000, as described below.

Boundary conditions are specified for individual stress periods, which are a duration over which a given stress is assumed to be constant. For this model, the stress periods for both calibration and assessment of alternatives was specified as a calendar month. These stress periods are subdivided during computations into smaller time increments to facilitate the calculations.

4.3.1 Recharge Package

The recharge package in MODFLOW-2000 allows specification of a time variant rate of flow, expressed as a depth of water per unit of time that is applied to the model at the highest active layer. This model package was used to represent the following sources of recharge:

- Recharge from native precipitation,
- Recharge from irrigation return flows,
- Recharge from lateral boundary inflows, and
- Waste water percolation.

Waste water percolation was the only parameter in the recharge package that incorporated time variation, annual averages for the other parameters were used, since transport time through the unsaturated zone will tend to even out the small surface recharge sources. The recharge from native precipitation and irrigation return flows was evenly allocated through the basin, with an estimated 50 AF of recharge from precipitation, and the irrigation return flows estimated at 15 percent of the applied water. This recharge quantity was set to a constant value of 2.05 inches/year. The lateral boundary inflow component, representing subsurface inflows from surrounding bedrock areas was estimated at 150 AF/year (Yates and Van Konynenburg, 1998), and this quantity was distributed to the outermost cells in the model. During drought simulations, described in later sections, these recharge quantities were reduced.

The CCSD maintains records of discharge to the waste water percolation ponds, see **Figure 4-6**, that were used to determine the recharge quantity infiltrating to the aquifer. These recorded quantities were applied to the entire footprint of the ponds. Some consumptive use of this water would occur due to evaporation, however, it is a relatively small percentage of the applied water, so this was not included. Previously presented Figure 2-10 shows the quantity of wastewater that was discharged to the ponds during the 2009 to 2013 period. This quantity of flow was converted to a depth for use in the model, allocating the flow over the entire area of the pond. Actual operations tend to use only a single pond, moving the discharge to different ponds to maintain infiltration capacity.

4.3.2 Stream Flow Routing Package

The stream flow routing package in MODFLOW-2000 is used to simulate the surface water component in the model. This package maintains a mass balance between the stream flow and gains and losses to groundwater. When the groundwater level is below the stream stage, as occurs during the beginning of the runoff season, water will infiltrate from the stream into groundwater. Conversely, during times when the groundwater level is above the stream stage, groundwater will discharge to the stream. This occurs in the lower reaches of San Simeon Creek as a result of operations at the percolation pond.

Water level observations show that groundwater is rapidly replenished when runoff begins in San Simeon Creek. **Figure 4-7** shows the groundwater elevations at wells 9K2 and 9L1 compared with flows in San Simeon Creek demonstrating this rapid recharge. The stream flow routing package is configured to provide little resistance to flow between groundwater and surface water. **Figure 4-8** shows the location of the stream boundary conditions. Channel and water surface elevations were surveyed to obtain accurate information for the model. Flow rates for San Simeon Creek were obtained from a stream gage maintained by San Luis Obispo County located near the CCSD well field. This flow was assumed to be representative of inflow at the upper reach of the model, since during times when the stream is flowing the discharge rates are significantly higher than potential seepage rates. The stream conductance term was set to a high value based on the observed rapid response of water levels to stream flow. No calibration was done for this parameter.

4.3.3 Lake (Fresh Water Lagoon) Package

The fresh water lagoon is highly connected with the groundwater and surface water systems at the site. Flow in San Simeon Creek discharges to the upper extent of the lagoon. When groundwater is higher than the lagoon stage, discharge will occur from the aquifer to the lagoon. Since the berm impounding the lagoon is periodically breached during higher flow periods or storms, low permeability sediment is potentially eroded from the base of the lagoon, resulting in probable high connectivity between the lagoon and groundwater in some areas.

The lake package was configured to reflect a high degree of connection between the lake and groundwater. Figure 4-8 shows the location of the fresh water lagoon and associated streams. An outlet stream was used to simulate conditions when the lagoon discharges to the ocean. The water surface and lagoon bottom was surveyed to obtain accurate location and elevation information. No data were available to allow calibration of leakage parameters for the lagoon. During transport and variable density simulations the stream package was used to represent this feature to maintain compatibility with the model codes.

4.3.4 Constant Head Package

The hydraulic connection with the ocean is simulated using constant head boundary conditions in the off-shore area. The boundary associated with the ocean was simulated using the equivalent fresh water head to account for the density difference with sea water. For the SEAWAT simulations, the density is internally accounted for in the program. **Figure 4-9** shows the location of the constant head boundaries. The constant head in layer 1 was set over the off-shore portion of the model, while deeper zones were represented as line sources at the western extent of the model. Since sea water is denser than fresh water, the pressure in deeper zones is greater than would be present if the overlying water were fresh. For example, the equivalent fresh water head in the aquifer at a depth of 100 feet in the sea water saturated portion of the aquifer would be 2.57 feet higher.

4.3.5 Well Package

Pumping of groundwater for irrigation and municipal use is simulated using the MODFLOW-2000 well package. This package removes a specified quantity of water that is distributed across model layers corresponding to well screen intervals. The flow was specified proportional to the hydraulic conductivity and thickness of individual layers that correspond to the reported screen intervals.

Estimates of agricultural pumping were developed in the 2007 study based on land use and water user interviews (Yates, 2007). Production records from CCSD were used for the municipal pumping rates. **Figure 4-10** shows the location of pumping wells that were included in the model. Total agricultural pumping occurs during the growing season from June through October, with an average of 180 AF per year of groundwater produced. The CCSD production from the San Simeon basin is limited to 454 gpm (0.635 MGD) during the dry season. The recent pumping was previously presented on Figure 2-11. Well 9P7, located in the percolation pond area, is periodically pumped to maintain a seaward gradient from the well field. However, detailed records of pumping from this well are not available.

4.4 Transport Packages

Analysis of transport of dissolved constituents was conducted using MT3DMS, which uses information from MODFLOW to define flow terms and physical characteristics. The primary additional parameters necessary for transport analysis include effective porosity, which is important in determine groundwater velocity, and dispersivity. Dispersivity is a parameter used to describe the spread of a solute in three dimensions due to small scale variations in groundwater velocity and localized flow directions.

Literature data were used to estimate the dispersivity parameter as a function of transport distance for sensitivity analysis. The selected value for longitudinal dispersivity was 67 feet, 6.7 feet for transverse dispersivity and .67 feet for vertical dispersivity. Effective porosity, which is a measure of the open pore space through which water actively flows, was estimated based on specific yield, which provides a lower limit estimate of the effective porosity.

Simulation of the selected emergency water supply alternative using the variable density package in SEAWAT was also conducted to assess the importance of variable density flow to confirm results of fresh water equivalent head simulations.

4.5 Selection of Calibration Targets

Model calibration is the process of adjustment of model parameters to match model results with field observations. The available information at the site was assessed to identify field measurements that can be used to assess model calibration. The model is configured with known information, as identified in the site conceptual model and in the descriptions provided above.

Parameters in the model that have the greatest uncertainty are selected for adjustment in the process of calibration. The principal data available for comparisons between field measurements and model calculated results are water levels at wells. The CCSD has a comprehensive water level monitoring program in place that records water levels twice per month at available wells. Climatic information was examined to select a period that encompassed a range in rainfall quantity during a period where information on pumping and wastewater discharge was available, along with water level measurements.

The 2001–2002 period was selected for this analysis. **Figure 4-11** shows the location of wells with water level measurement. The water level records were screened to remove wells that had been recently pumped to obtain a data set representative of aquifer conditions for use in the calibration process. This resulted in a total of 411 water level measurements at 13 wells distributed in the San Simeon basin.

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Figure 4-1
Model Grid

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TO1: Geo-Hydrological Model

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Figure 4-2
Detail Area Showing Model Grid

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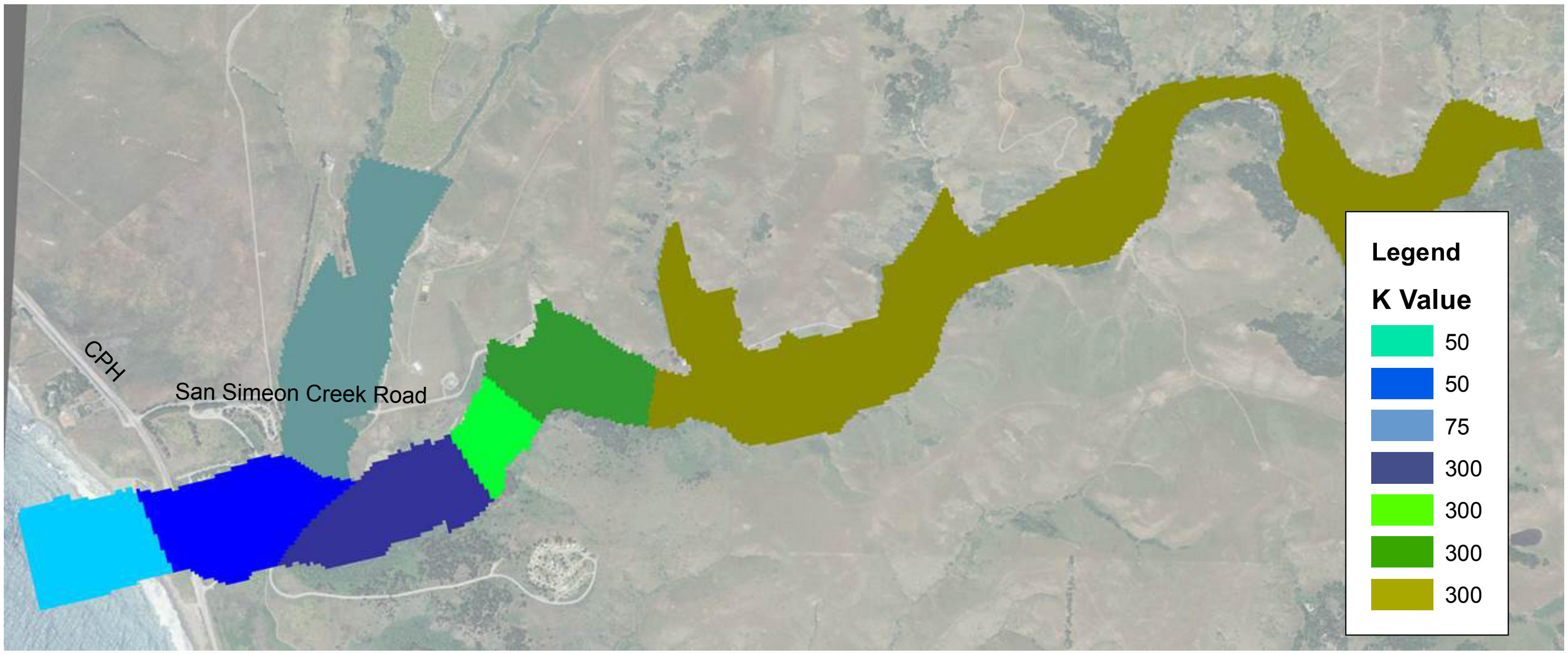

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Figure 4-3
Upper Zone Hydraulic Conductivity Distribution

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Figure 4-4
Middle Zone Hydraulic Conductivity Distribution

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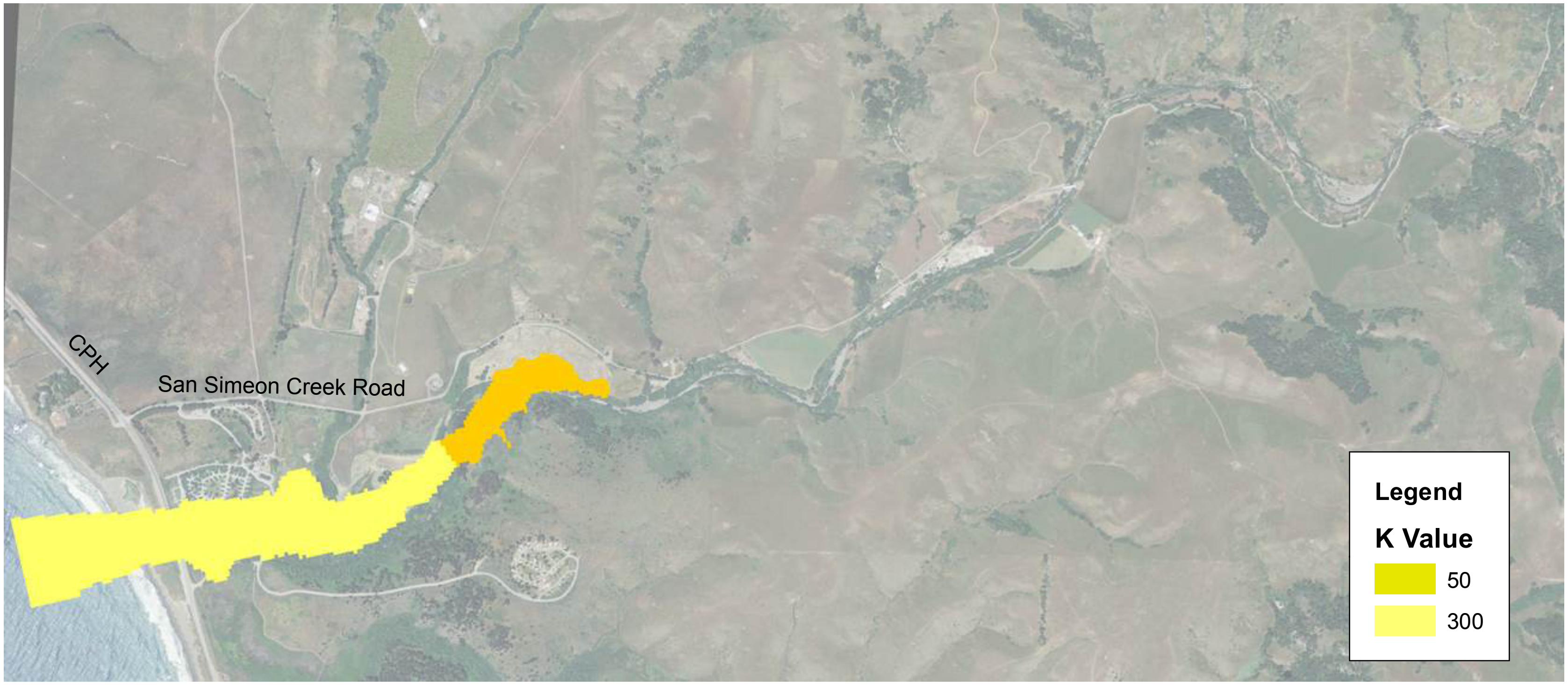

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Figure 4-5
Deep Zone Hydraulic Conductivity Distribution

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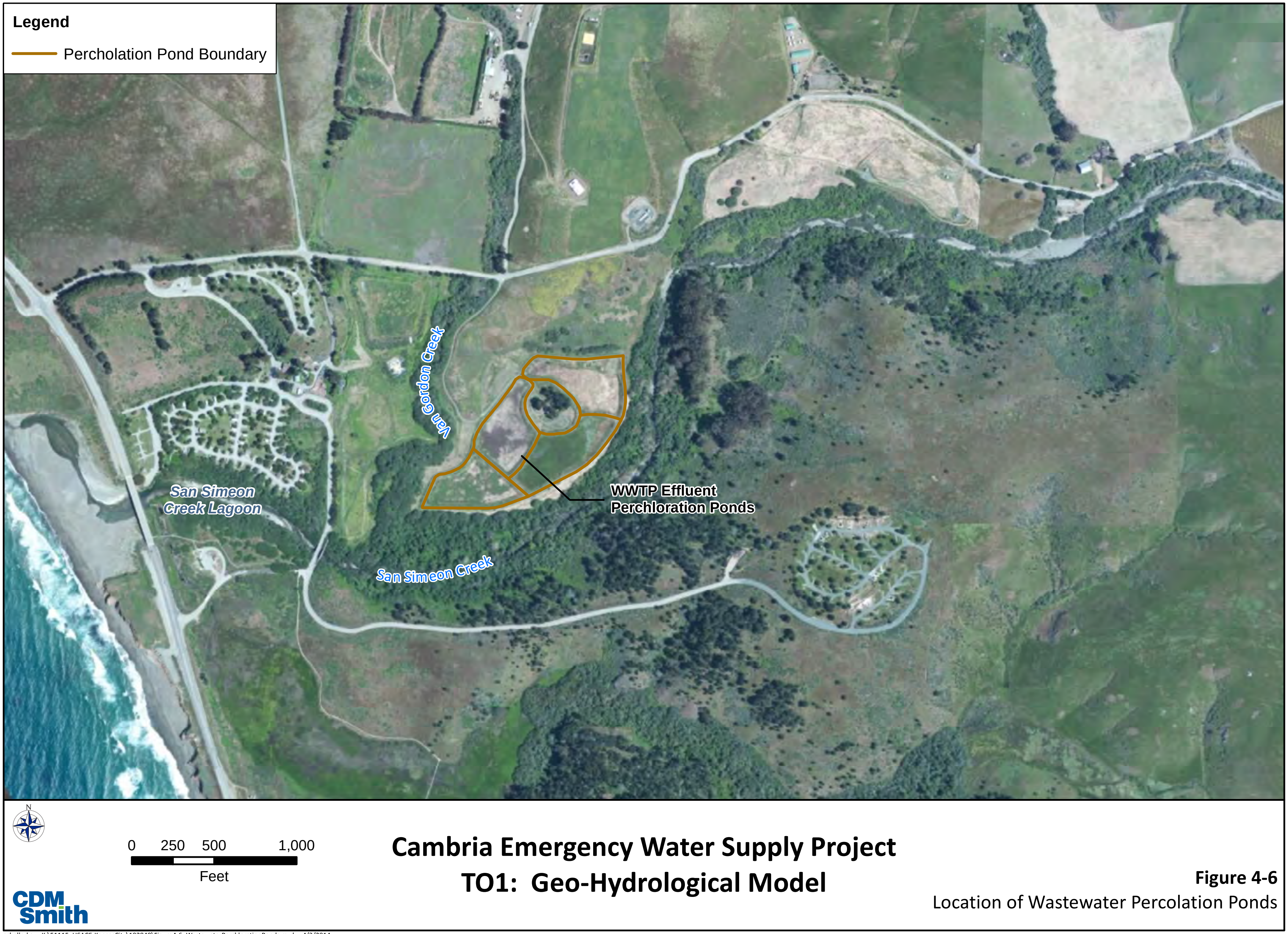

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Figure 4-6
Location of Wastewater Percolation Ponds

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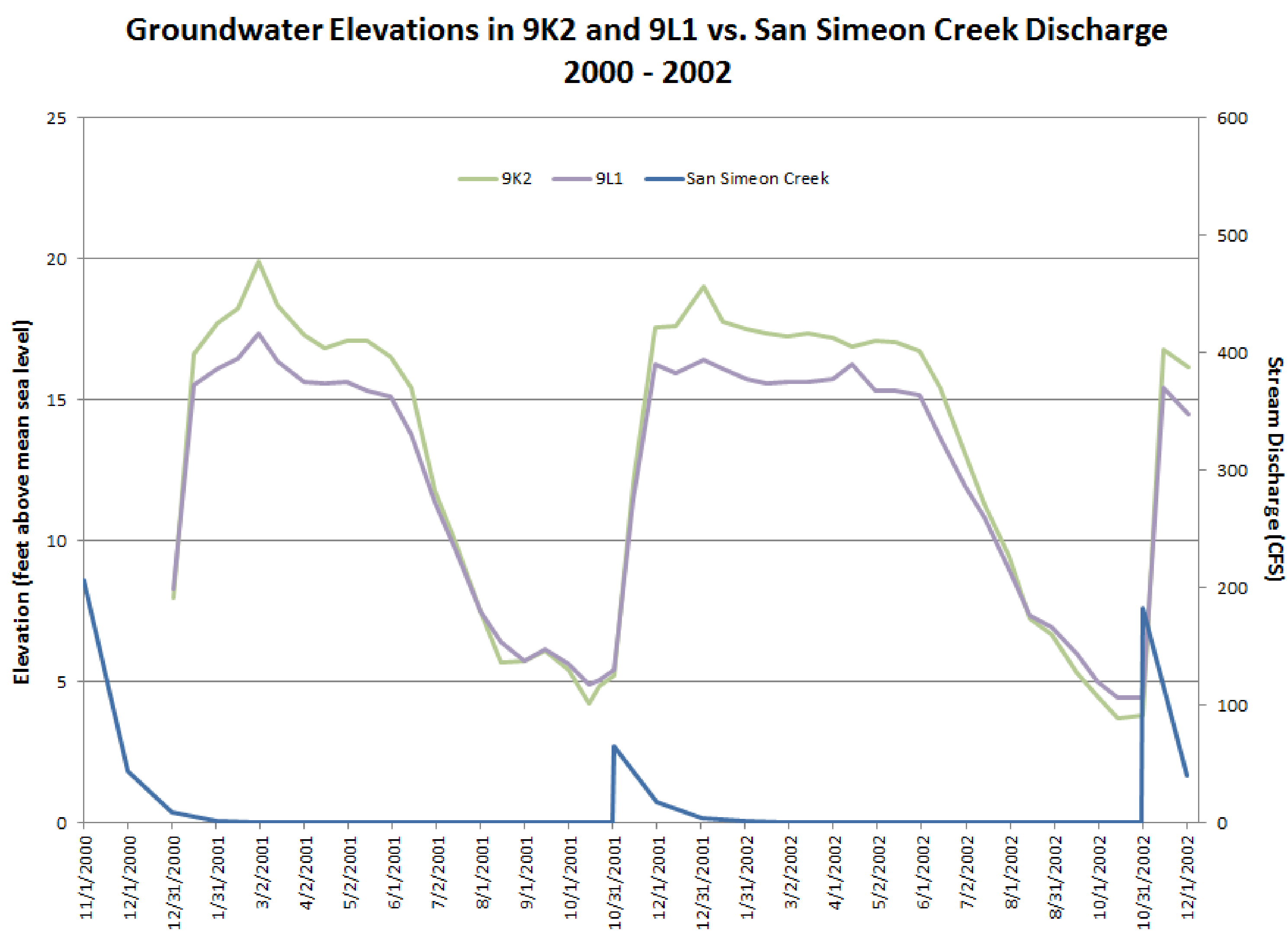

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Figure 4-7
San Simeon Creek, 9K2 and 9L1 Hydrographs

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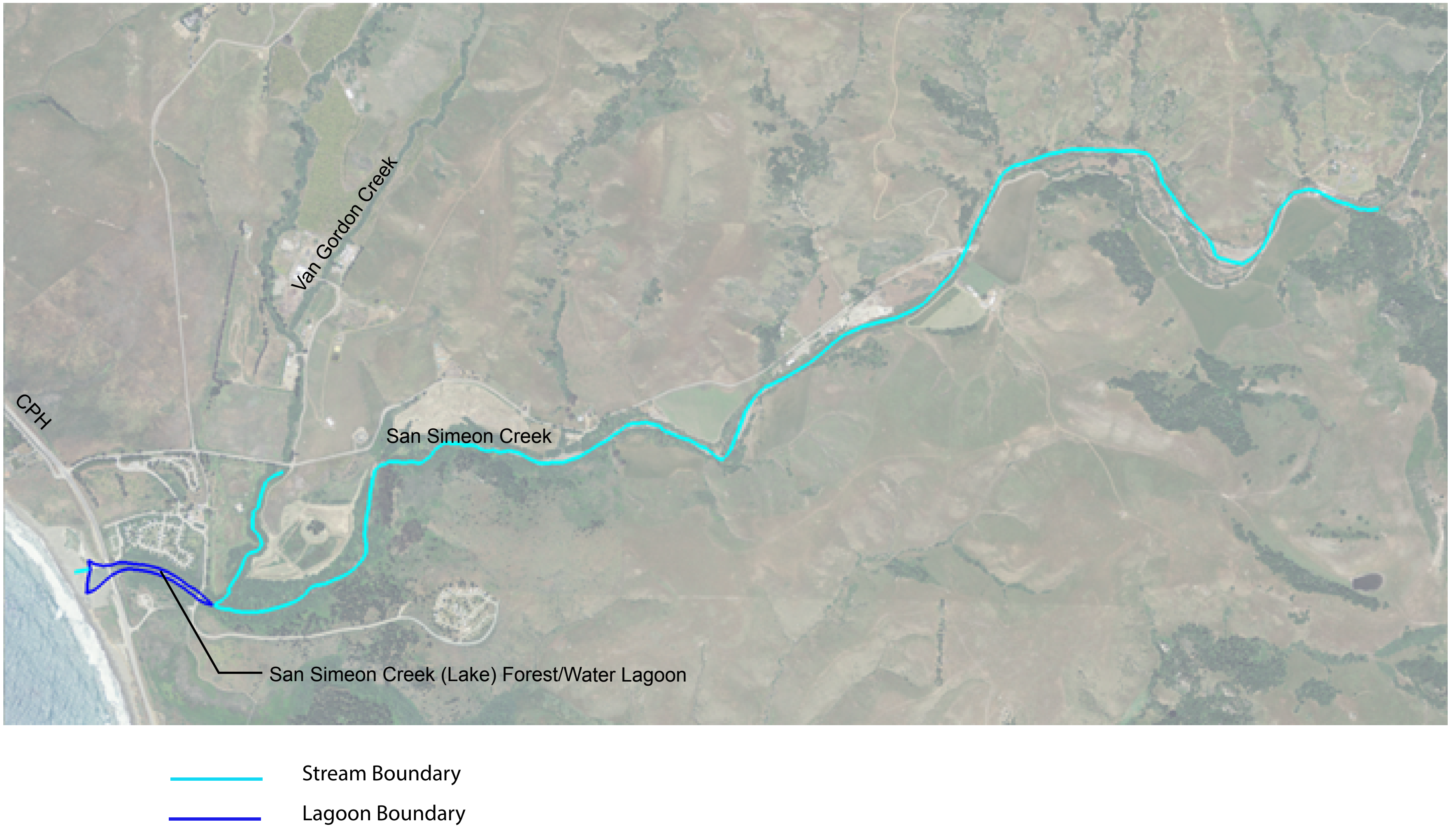

Cambria Emergency Water Supply Project
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Figure 4-8
Location of Stream and Lake Boundary Conditions

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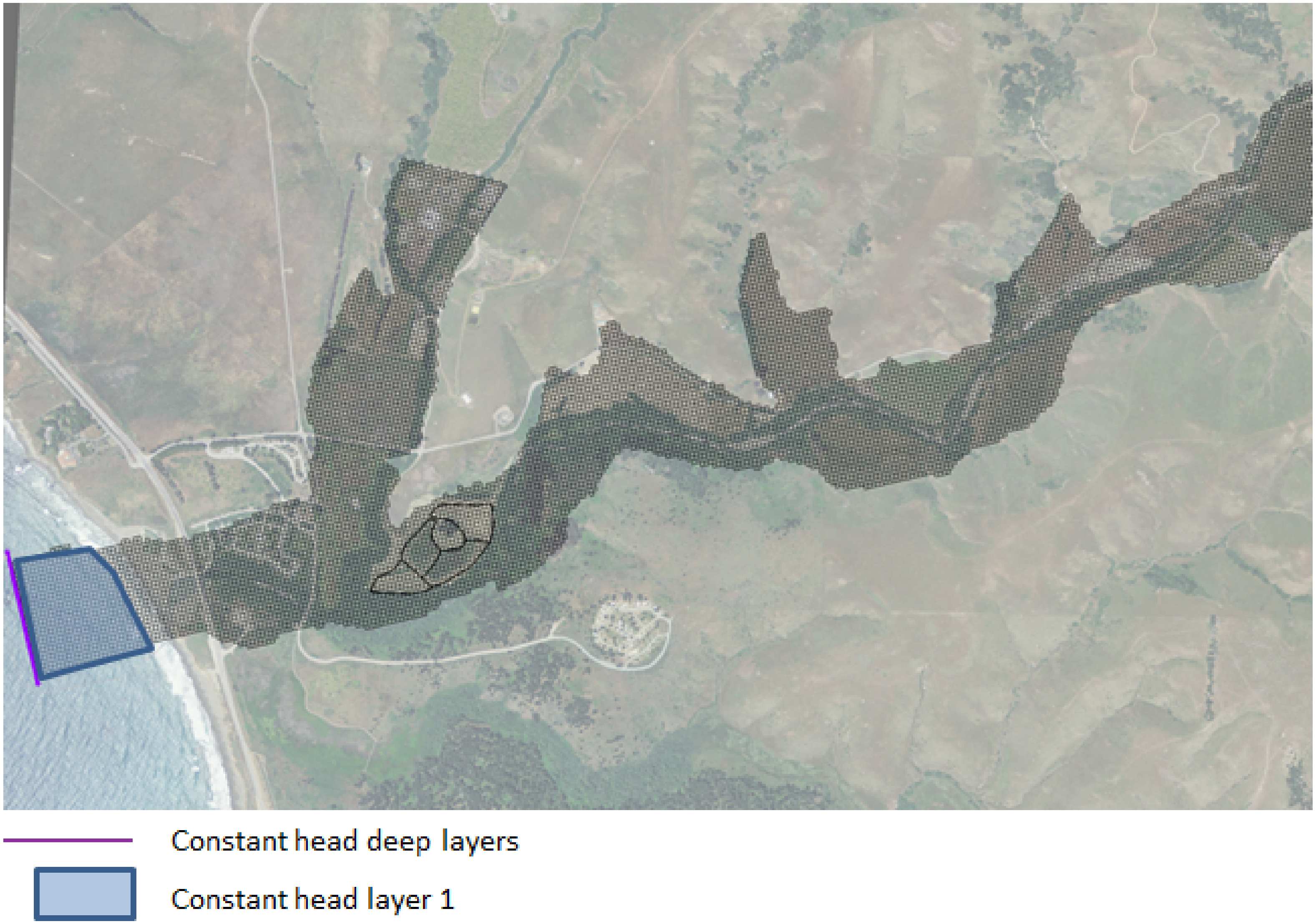

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CDM Smith

Figure 4-9
Location of Constant Head Boundary Conditions

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Figure 4-10
Location of Pumping Wells

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Figure 4-11

Location of Wells with Water Level Measurements

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Section 5 Calibration

5.1 Model Calibration

A well calibrated model was developed in 2007 (Yates and Van Konynenburg, 1998) that was used as the basis for development of the current model. The groundwater flow model was calibrated by identifying sensitive characteristics with the greatest uncertainties, and varying those parameters systematically within this range of uncertainty to obtain a reasonable match between field observations and model simulated results. Hydraulic characteristics have the greatest uncertainty, since initial estimates are made at a limited number of locations, using a variety of testing methods. The initial distribution of hydraulic conductivity from the 2007 provided a reasonable match to field observations and was largely retained for this model. Additional calibration was conducted for specific yield, due to its importance for this project.

Conditions for the 2000 to 2002 period for pumping and recharge were configured from the site data and used to simulate the corresponding period. Since stream-flow occurred during 2000, prior to the formal calibration period, stable conditions prevailed in the model for the 2001 and 2002 periods that were used for the calibration. Simulations were run varying hydraulic characteristics and no significant improvement was obtained by changing hydraulic conductivity from the configuration consistent with the 2007 model.

Figure 5-1 shows a sensitivity analysis for variation of specific yield, which indicates a minimum error measure (mean of absolute value of residuals) was obtained at a specific yield of 0.16. The current model has considerably greater discretization to facilitate the transport analysis, but retains many of the characteristics of the 2007 model. A significant update included the incorporation of surveyed elevations for stream channels and the lagoon area.

5.2 Calibration results

Figure 5-2 provides an overall comparison of the final calibrated model results for corresponding field measurements. This figure plots model calculated water levels versus the field measurements for the corresponding locations and times. The 45 degree line shows a perfect agreement between the model and field measurements, while the actual scatter around this line represents the difference between modeled and measured conditions. This difference is the residual. **Figure 5-3** shows a histogram of the residuals (modeled – measured) for the calibration data set.

Several statistical measures of residuals were computed to summarize the ability of the model to represent field conditions. The mean residual value (Σ(modeled – observed)/n) was -0.48 feet, with a standard deviation of 1.72 feet. The median residual value was -0.2 feet. The range in water levels observed in the data set was from 5.4 to 57.8 feet. A standard measure of calibration is given by the RMS error/ data range, which should be less than ten percent. The RMS error in the calibration data set is 1.78, yielding a value for RMS error/data range of 3.4 percent, which meets the acceptance criteria.

Another comparison measure for the calibration is comparisons of observed water levels and modeled water levels plotted as hydrographs at individual wells. These hydrographs are available at the locations previously shown on Figure 4-11**. Figures 5-4** through **Figures 5-15** provide hydrographs from the eastern portion toward the western limit just upgradient of the fresh water lagoon.

The irrigation wells in the eastern portion of the basin typically show the greatest residuals, particularly during the later portion of 2002. This may be due to overestimation of the quantity of lateral boundary inflow or underestimation of the quantity of pumping in the upper basin. These wells are upgradient of the area of primary concern where water supply alternatives will be implemented. The area from immediately upgradient of the CCSD well field to the fresh water lagoon show very good agreement between the model and observed water levels. Limited data were available in the upper reaches of Van Gordon Creek. However, inconsistencies between estimated pumping and responses at the single well with periodic measurements indicate that a reliable calibration of this drainage is not possible. This area also has minimal interaction with the area of interest due to the lower permeability and limited groundwater flow.

The model calibration is acceptable for use in the assessment of alternatives.

5.3 Water Budget

The water budget for the model for the 2001–2002 period is summarized in **Table 5-1.** The components that are specified input values are in a bold font on this table. A negative value, (in parenthesis), indicates a net removal from the aquifer, while a positive is an inflow to the aquifer.

Table 5-1 Summary of Water Budget Components for 2001-2002 Calibration Period

Component	Annual Volume (AF)
Storage	(315)
Ocean Boundary	(251)
Recharge	**881**
Stream Seepage	806
Fresh Water Lagoon Seepage	(103)
Well Pumping	**(1015)**
Difference	2

During the calibration period, the sources of recharge, including precipitation recharge, irrigation return flows, percolation pond infiltration, lateral boundary inflow and seepage from San Simeon Creek, was 1687 AF/year. The primary outflow from the aquifer was associated with pumping for municipal and agricultural use. Outflows of groundwater to the ocean and to the fresh water lagoon were 354 AF/year, with a decrease in storage of 315 AF/year during this period.

On a long-term average basis, the change in storage is expected to be negligible, since the basin is recharged each season from stream seepage. The water budget components differ from the 1988-1989 conditions simulated in the USGS report, since many of the model inputs, including stream flow duration and pumping rates were updated.

5.4 Sensitivity Analysis

A sensitivity analysis was conducted assessing sensitivity to specific yield and to hydraulic conductivity. As noted above, specific yield was a sensitive parameter and a value of 0.16 was selected since this resulted in the minimum RMS error. A sensitivity run was also conducted to assess the impact of decreasing hydraulic conductivity throughout the model by 20 percent. This sensitivity test showed that when the hydraulic conductivity was decreased by 20 percent, the average absolute value of the residuals increased by 16 percent compared to the selected calibration values.

5.5 Model Uncertainties and Limitations

All mathematical models are simplified representations of very complex natural systems. The model is configured using a limited number of borings to assess the distributions of lithologies in the subsurface. Factors such as the lateral boundary inflow, connection with the ocean, configuration of the aquifer west of the shoreline and other factors are uncertain and have no direct field data for their characterization. The model provides a reasonable approximation of the aquifer response during calibration periods and provides a tool for assessing alternatives. The model should be refined in the future when significant changes in water use in the basin occur after implementation of the selected emergency water supply alternative to refine operational parameters.

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