Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning:

Green Valley\Atascadero and Dutch Bill Creek Watersheds, Sonoma County, California
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Document Organization

This document is organized in four parts as follows:

1. The Executive Summary provides an overview of the project with a moderate level of technical detail.

2. Chapters 1 through 10 comprise the main body of the report with a high level of technical detail.

3. Appendix A contains the project summary that was distributed at two public meetings held in February and March of 2016 and is intended to provide an overview of the project for less technical readers.

4. Appendix B provides a summary of the key restoration recommendations developed from the project and is intended to serve as a reference guide for restoration practitioners working in the watershed.
Executive Summary

Introduction

The Dutch Bill and Green Valley Creek watersheds (Figure E1) have been identified by state and federal fisheries agencies as providing some of the best remaining habitat for coho salmon in the Russian River watershed. Several factors have been identified as limiting coho survival in these watersheds including lack of quality pool habitat, lack of winter refugia, and insufficient summer stream flow (CDFG, 2004; NMFS, 2012). Numerous restoration projects have been implemented in the watersheds in recent years primarily aimed at improving pool conditions and reducing fine sediment inputs, and increasing effort has recently been devoted by the Russian River Coho Water Resources Partnership to address the problem of insufficient summer stream flow. Owing to drought conditions in 2015, the California State Water Resources Control Board (SWRCB) implemented an emergency order intended to maintain or improve stream flows in these watersheds (SWRCB, 2015). The order required water conservation and water use data from rural residents using surface and/or groundwater in these watersheds, for the most part without regard to specific circumstances such as well depth, well location, diversion location and quantity of use. When this project was initiated in 2012, it was evident that better understanding of the spatial and temporal distribution of stream flow and groundwater and the various natural and man-made controls on the hydrologic systems in these watersheds was needed to better inform management of water resources for recovery of endangered coho salmon. Statewide drought and State-level water resources policy changes have magnified the need for this project.

In light of ongoing drought conditions and climate change coupled with an increasing demand for water, developing strategies to sustain or improve summer stream flow conditions is of paramount importance for coho restoration. The goal of this project was to perform a comprehensive analysis of the spatial and temporal distribution of stream flow throughout the watersheds relative to coho habitat requirements to assist in prioritizing restoration efforts and developing strategies to maintain or improve summer stream flow. Although this project has limited immediate objectives, much additional information regarding hydrologic processes and conditions in these watersheds has been developed and is applicable to a wide range of water resources management objectives.
Figure E1 - Map of the study area showing locations of towns, streams, and sub-watersheds.

Hydrologic Modeling

The focus of this project was the development, calibration, and application of a distributed hydrologic model (MIKE SHE, Graham and Butts, 2005; DHI, 2015) capable of simulating surface water/groundwater interactions and quantifying the distribution of summer baseflows. The model utilized available data characterizing the climate, topography, land cover, soils, water use, and hydrogeology of the watershed and provided estimates of the annual and seasonal water balance, stream flow hydrographs, and groundwater levels throughout the watersheds. The model simulated all major land-based processes of the hydrologic cycle on a daily or sub-
daily time-step for Water Years 2010 through 2014 (corresponding to the period from October 1, 2009 through September 30, 2014) and was successfully calibrated to stream flow data at seven locations throughout the Green Valley and Dutch Bill Creek watersheds and to groundwater elevation data from seven monitoring wells used for by a State-sponsored groundwater management program (CASGEM, 2014). Additionally, the model results were validated against detailed stream flow depth measurements at riffle crests and maps prepared by California Department of Fish & Wildlife and University of California Cooperative Extension (UCCE) documenting the spatial distribution of stream reaches where summer stream flows were observed to be absent or intermittent in the principal fish-bearing reaches in the watersheds.

**Hydrologic Characterization**

The model results revealed significant spatial and temporal variability of water balance components and stream flow conditions throughout the watersheds (Figure E2). For example, groundwater recharge in the Atascadero/Green Valley Creek watershed ranged from 2.0 inches in the dry Water Year 2014 to 10.5 inches in the above average Water Year 2011 and varied spatially from near zero to more than 22 inches during Water Year 2010. Surface water/groundwater exchange, which is a major factor determining the persistence of stream flow and wetted habitat throughout the summer and fall, also exhibited significant variability with seepage loses from channels to groundwater occurring in certain (losing) stream reaches and significant gains to stream flow from groundwater discharge occurring in other (gaining) stream reaches. Some reaches, such as portions of upper Green Valley Creek, which were gaining reaches in wetter Water Years became losing reaches during drier Water Years. The patterns of summer stream flow exhibited significant variability as well. Stream flow disappeared completely in some reaches while in other reaches minimum flows exceeded one cubic foot per second (cfs). Stream flow also varied considerably in relation to annual variation in climate. Summer stream flow in much of Dutch Bill and Purrington Creeks was comparable during wet and dry years. In contrast, there were substantial differences in summer stream flow during wet and dry years in portions of upper Green Valley, Atascadero and West Fork Atascadero Creeks.

**Habitat Characterization**

This study focuses on evaluating habitat conditions only with respect to the quantity (depth) of summer stream flow required for rearing of juvenile coho salmon. Existing and/or future studies examining the distribution and quality of rearing habitat, water quality conditions, and other factors should be synthesized with these findings in order to develop a more comprehensive understanding of habitat conditions.

The primary means of relating the hydrologic model results to habitat suitability was to apply the critical riffle depth concept to the model simulated water depths. This approach assumes that the model cross sections represent riffle locations (shallowest portions of the stream between adjacent pools). This assumption is reasonable given the fact that the cross sections
are developed using LiDAR (Light Detection and Ranging) technology which does not penetrate water and therefore does not directly identify deeper water rearing habitat (pools) and by the generally high degree of agreement between model simulated depths and riffle depth measurements collected by UCCE. The concept of “critical riffle depth” (CDFG, 2013) is based on defining minimum flow depth criteria for fish passage through riffles. In essence these criteria represent the minimum flow condition where fish are able to move between pools (the primary habitat areas for juvenile coho). A minimum passage depth of 0.3 feet has been estimated for juvenile coho (R2 Resource Consultants, 2008; CDFG, 2013). This depth criteria is somewhat conservative by design and fish passage and over-summer survival has been observed with shallower riffle depths therefore it is useful to define a lower criteria below which passage is presumably not possible. For the purposes of this study, a flow depth of 0.3 feet or more was considered an indicator of “optimal” rearing habitat.

Through field monitoring in Green Valley Creek, UCCE has found that coho can survive in pools that become disconnected for short periods of time, however survival decreases sharply as a function of the duration of pool disconnection (UCCE, 2015) largely due to the low dissolved oxygen conditions that develop in disconnected pools. Thus in addition to delineating reaches where passage between pools is possible, this study also delineated reaches that become dry (zero discharge) for short periods of time and reaches that become dry for extended periods of time. A disconnection length of 14 consecutive days was used for this analysis which corresponds to an 85% survival rate and the point beyond which survival begins to decline sharply (UCCE, 2015).

During average Water Years, pools remain connected providing perennial habitat in the lowest 3.4 river miles of upper Green Valley Creek (Figure E3). During dry Water Years only the lowest 2.1 river miles provided perennial habitat with continuous pool connectivity. The entire creek may be considered flow-impaired given that water depths drop below optimal passage depths (0.3-ft) even during average Water Years (Figure E3). The best habitat conditions in upper Green Valley Creek occur within Reach UGV3 (Figures E3 & E5). Reaches UGV1 and UGV2 (Figure E5) are characterized by marginal flow conditions where depths may fall below minimum passage depths and long-term pool disconnection may occur during dry Water Year conditions. Short-term disconnection of pools may also occur in UGV4.

The lowest 5.7 river miles of lower Green Valley Creek provide perennial habitat for juvenile coho during average Water Year conditions, however this extent was reduced to the lower 3.6 river miles during dry Water Year conditions. Reach LGV2 provides some of the best habitat conditions in the entire study area and is one of only a few reaches where minimum water depths exceeded the 0.3-ft optimal passage threshold (Figures E3 & E5). In contrast to the lower reach, the upper 2.1 miles of lower Green Valley Creek (LGV1) were characterized by long-term disconnection of pools during dry Water Year conditions.
During both dry and average Water Year conditions, the lowest 2.8 river miles of Purrington Creek provide perennial habitat for juvenile coho, however the entire creek may be considered flow-impaired given that water depths drop below optimal passage depths even during average Water Year conditions. Reaches PUR2 and PUR4 provide the best habitat conditions in Purrington Creek. Pools in reach PUR1 appear to remain connected even during dry conditions, however depths likely fall below minimum passage depths (Figures E3 & E5). Reach PUR3 represents a potential passage barrier caused by low depth of flow during dry Water Year conditions when conservative assumptions regarding licensed flow diversion operations are used.

During both dry and average Water Year conditions, the 4.3 river miles of Dutch Bill Creek between the confluence with Lancel Creek and the Tyrone Road crossing provide perennial habitat for juvenile coho, however the entire creek may be considered flow-impaired given that water depths drop below optimal passage depths even during average Water Year conditions.
The lowest 2.1 miles (DB2) provide the best habitat conditions, whereas minimum passage depths were not maintained within the upper 2.2 miles (DB1) (Figures E3 & E5).

The extent to which coho salmon use Atascadero Creek is not known, however more than eight river miles within Atascadero Creek and West Fork Atascadero Creek have flow conditions that are better than or equivalent to conditions in the best reaches of upper Green Valley and Purrington Creeks. The lower 1.7 river miles of Atascadero Creek above the confluence with Green Valley Creek (LA2) are characterized by periods of zero discharge even during average Water Year conditions. In contrast, the upper 2.3 river miles below the confluence with West Fork Atascadero Creek (LA1) provides some of the best flow availability conditions in the entire study area (Figures E3 & E5).

**Scenario Analysis**

In addition to simulating existing watershed conditions, the model can be used to test scenarios involving various changes in land and/or water management. For this stage of the modeling work, a scenario for augmenting instream flows by releasing water from existing ponds was evaluated. Two ponds were selected for this analysis based on potential feasibility and their locations within key reaches of upper Green Valley Creek which provide some of the highest quality coho habitat in the Russian River watershed but are considered flow impaired (NMFS, 2012). Based on an analysis of the available pond storage remaining at the end of the dry season (carryover storage), it was determined that 0.1 and 0.5 cfs could be released between July 1st and September 30th from the upper and lower ponds respectively.

This flow augmentation scenario was very effective at increasing water depths and reducing the extent of reaches with disconnected pools in upper Green Valley Creek. The additional flow extended the reach where pools remained connected for an additional 1.3 river miles upstream during Water Year 2010 and for an additional 2.2 miles upstream during Water Year 2014 as compared to existing conditions (Figure E4). This represents a doubling of the length of stream with continuously connected pools during dry Water Year conditions. Although the quantity of additional flow diminished with distance downstream from the source, the effects of the flow releases persisted into the upper portions of lower Green Valley Creek. This was more significant during Water Year 2014 where the additional flow reduced the extent of the reaches experiencing short- and long-term disconnection in lower Green Valley Creek.
Figure E3 - Simulated water depths and extent of disconnected reaches for WY 2010.
Figure E4 - Comparison of longitudinal profiles of simulated water depths and extent of disconnected reaches for upper Green Valley Creek between existing conditions and the pond release scenario for WY 2014. The increase in total discharge under the pond release scenario is shown in the lower plot.

### Restoration Recommendations

Under existing flow conditions, the reaches identified as providing the best stream flow conditions in terms of flow depth and duration even during drought conditions are probably the most important reaches on which to focus habitat enhancement work. It is recommended that restoration projects designed to improve pool habitat be focused in reaches UGV3, LGV2, PUR2, PUR4, and DB2 where pools may be expected to function in concert with sufficient flow availability (Figure E5). If flow augmentation projects similar to those simulated in this study can be implemented, the extents of reaches where restoration projects are recommended would increase based on the modified flow regime.

Efforts to improve stream flow either through releases of stored water or water use modifications (conservation through reduced rates of use or through managed timing of use) would be best focused in the reaches that are currently providing significant habitat value at a marginal level in terms of flow depth and/or duration, particularly during dry Water Year conditions. Small changes in flows within these marginal reaches may be expected to yield significant increases in habitat quality. It is recommended that flow augmentation projects be focused in reaches UGV1, UGV2, PUR1, and DB1 (Figure E5). Reaches UGV4 and PUR 4 are also
Figure E5 - Flow availability-based reach classification and restoration prioritization map. In general, reaches shown as blue have the best existing habitat conditions and should be the focus of instream restoration projects aimed at improving pool conditions, and reaches shown as red, orange, or green are more flow-limited and flow augmentation projects such as intentional flow releases or water use modifications are recommended.
characterized by marginal flow conditions, and flow augmentation efforts in the other reaches may be expected to benefit these downstream reaches as well. PUR4 is located in close proximity to several licensed surface water diversions and it is recommended that diversion operations be reviewed and modified if necessary to avoid impacts to flow availability.

Coho use of Atascadero Creek remains poorly understood, and given that Atascadero and West Fork Atascadero creeks contain more than eight river miles with stream flow conditions better than or equivalent to conditions in the best reaches of Purrington and upper Green Valley creeks, further study of Atascadero Creek is highly recommended. Such a study should investigate the degree to which coho utilize Atascadero Creek under existing conditions and the factors that are limiting that use. The degree to which the stagnant water and associated unfavorable temperature and/or dissolved oxygen conditions in the lower 1.7 miles of Atascadero Creek (LA2) could be limiting coho use of the upper watershed should be a key component of this study.

More detailed descriptions of the various reaches and associated restoration recommendations are provided in Appendix B.

**Data Gaps and Next Steps**

The model presented here provides a powerful tool for understanding hydrologic conditions and prioritizing restoration planning efforts throughout the Green Valley, Atascadero, and Dutch Bill Creek watersheds. The model is flexible and can similarly inform land use management planning with respect to effects on water resources. As in any modeling analysis, there is uncertainty in model results and accuracy of model predictions. In order to better understand uncertainty it is instructive to evaluate the completeness and quality of the input data used to develop the model as well as the degree and quality of the model calibration. Recommended improvements to models are often based on providing improved input data and/or additional calibration that result in improved model accuracy or reduced uncertainty with respect to model predictions used to address key management questions. Ideally the modeling work is not a static product but instead becomes a working management tool where the model is incrementally improved with new data and utilized to address new questions or to meet new objectives.

One of the original objectives of the modeling effort was to gain a better understanding of how surface water and groundwater use in the watershed affect stream flow conditions and to develop strategies for improving stream flows by modifying water use patterns. Although a significant amount of information describing the distribution and volume of water use was available, certain data were unavailable. Consequently, simplifying assumptions were required to simulate the timing and volume of water use. In order to utilize the model to evaluate water use impacts on stream flow and have confidence in the results, some refinements to the model are required. Specifically, data describing the locations, rates, and timing of diversions of water from streams are needed as are specific well locations and well completion details for water wells, particularly those located near stream channels. These data correspond to data
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Submittals required of land owners in much of Dutch Bill and upper Green Valley Creek by the State Water Board in its emergency order issued in summer 2015 (SWRCB, 2015).

Additional refinement of the representation of groundwater conditions in the Franciscan Complex bedrock might be warranted, particularly with respect to the influence of groundwater on stream flow in Dutch Bill Creek. The model has been developed based on available data and calibrated at the scale made possible by stream gauges and monitoring wells. It should still be expected that deviations would exist between local conditions in specific wells or specific stream reaches and model predictions. Hydrologic investigations and analyses conducted at finer spatial scales using local data with greater hydrogeologic detail of aquifer characteristics could produce valid conclusions that are inconsistent with model simulations.

Despite these limitations the model can be used in its current form to inform planning and policy-making processes in relation to a variety of water and land use management issues. The flow augmentation scenario discussed in this report is one such example. The model was able to quantitatively predict the effect on stream flow and coho rearing habitat of water released from ponds in upper Green Valley Creek. If new potential flow augmentation projects are identified, the model can be used to assess their potential impact on coho rearing habitat and optimize their effectiveness. The model is also particularly well-suited for simulating the effects of ongoing climate change given the availability of regional down-scaled climate model data (Flint and Flint, 2012). The model is also capable of examining the effects of land use change (e.g. ongoing conversion of orchards or forest to vineyards), future population increases, and water conservation effects on stream flow. Model scenarios could be used to inform practices and policies regarding the sustainability of both surface water and groundwater resources for human use and ecosystems. Although the focus of this study was on low flow conditions for juvenile coho rearing habitat, the model simulates continuous hydrographs and can be used to examine flow conditions important for other coho life stages and/or other species of interest.
Chapter 1 - Introduction

The project described in this report was completed by O’Connor Environmental Inc. (OEI) in cooperation with the Gold Ridge Resource Conservation District (GRRCD) and was funded by a Fisheries Restoration Grant from the California Department of Fish and Wildlife (CDFW Contract #P1130405).

The Dutch Bill and Green Valley Creek watersheds have been identified by state and federal fisheries agencies as providing some of the best remaining habitat for coho salmon in the Russian River Watershed. Several factors have been identified as limiting coho survival in these watersheds including lack of quality pool habitat, lack of winter refugia, and insufficient summer baseflows (CDFG, 2004; NMFS, 2012). Numerous restoration projects have been implemented in the watersheds in recent years primarily aimed at improving pool and off-channel habitat conditions, however relatively little effort has been spent to address the problem of insufficient stream flow. This is in part due to a lack of data and understanding regarding the distribution of flow conditions and the various natural and man-made controls on these flows.

In light of ongoing drought conditions and climate change coupled with an increasing demand for water, developing strategies for sustaining or improving summer stream flow conditions is of paramount importance for coho restoration. The goal of this project was to perform a comprehensive analysis of the spatial and temporal distribution of flow availability conditions throughout the watersheds relative to coho habitat requirements to assist in prioritizing restoration efforts and developing strategies for protecting summer baseflows.

Specifically, this project involved the development, calibration, and application of a distributed hydrologic model which utilized a wide variety of climate, topographic, land cover, soils, water use, and hydrogeologic data for the watershed and provided estimates of the annual and seasonal water balance, stream flow hydrographs, and groundwater levels throughout the watersheds. The modeling results provided the basis for performing a flow availability analysis, characterizing the distribution and quality of available habitat for juvenile coho, and making recommendations about restoration priorities for various sub-reaches within the study area. Additionally, the model has been applied to evaluate the potential improvements to flow availability and habitat conditions resulting from implementing flow augmentation projects, and the model provides the framework for evaluating the effects of land and water management decisions and global climate change on watershed hydrology and flow availability for salmonids during future work.
Chapter 2 - Study Area Description

Physiography
The Green Valley/Atascadero Creek (GVAC) and Dutch Bill Creek (DBC) watersheds are part of the Northern Coast Range geomorphic province. Atascadero Creek is bounded by relatively steep topography separating the watershed from the Salmon Creek and Dutch Bill Creek watersheds to the south and west and by a gentle ridge associated with the Sebastopol Fault which separates the watershed from the Santa Rosa Plain to the east (Figure 1).

The headwaters of Atascadero Creek are located southwest of Sebastopol at elevations of about 800 feet. The upper 3.6 miles of the creek are characterized by relatively steep gradients and limited floodplain development. From this point at an elevation of about 155-ft, the creek flows through a southeast-northwest trending valley on the order of 2,000 to 4,000-ft wide for another 6.0 mi before joining Green Valley Creek west of Graton at an elevation of about 95 ft. The watershed area above the confluence with Green Valley Creek is approximately 21 square miles.

The headwaters of Green Valley Creek are located northeast of Camp Meeker at elevations of about 800 ft. The Creek flows through a northwest-southeast trending valley on the order of 1,000-ft wide for approximately 6.0 miles before joining Atascadero Creek. Below the confluence, the valley narrows to widths of 500- to 1000-ft and flows northwest for another 5.7 miles where it enters the Russian River west of Forestville at an elevation of about 30 ft. The watershed area of Green Valley Creek excluding Atascadero Creek is approximately 18 square miles (Figure 1).

Dutch Bill Creek is bounded to the south and west by a southeast-northwest trending ridge with elevations ranging from 1,000 - 1,450 ft separating the watershed from the Willow Creek and Salmon Creek watersheds. The watershed is bounded by Green Valley Creek to the east and by Smith Creek to the north. The headwaters of the creek are located east of Occidental at elevations of about 800 ft. The creek flows southwest for approximately 0.6 miles where it bends and flows through a narrow southeast-northwest trending valley on the order of 500-ft wide for about 7.7 miles where it enters the Russian River in Monte Rio at an elevation of about 20 ft. The watershed area of Dutch Bill Creek is approximately 12 square miles (Figure 1).

Climate
The GVAC and DBC watersheds experience a Mediterranean climate characterized by cool wet winters and warm dry summers. Precipitation varies substantially across the study area from an average of about 60 inches per year on the western edge of the DBC watershed to about 41 inches per year on the Atascadero Creek valley floor on the eastern side of the GVAC watershed (PRISM, 2010). In general, mean temperatures do not vary significantly across the watershed, however winter temperatures tend to be slightly warmer with less frost on the western side of the study area where the coastal influence is stronger and summer temperatures tend to be warmer on the eastern side of the study area which also experiences less fog.
Figure 1 - Map of the study area showing locations of streams, towns, and sub-watersheds.
Land Use
Significant changes in land use have occurred in the study area over the past century. Prior to European and American settlement in the late 18th and early 19th centuries much of the area was forested with meadows and natural grasslands occupying valley bottom areas. Extensive timber harvesting occurred during the 1920s and 1950s followed by heavy grazing (CDFG, 2006). Many of the natural grasslands were converted to orchards in the early 20th century (PWA, 2008). Residential development increased substantially beginning in the early 1970s (SCCES, 1978), and orchards have been increasingly converted to vineyards since the early 1980s. From the 1930s through the 1990s, riparian cover and large woody debris were periodically mechanically cleared from stream channels in order to maintain channel conveyance and reduce flooding of agricultural lands (GRRCD, 2012). These practices have ceased over the past two decades as regulatory constraints and ecological awareness have increased and there has been a marked increase in the extent of riparian cover particularly in main-stem Atascadero Creek.

Existing land cover in the Dutch Bill Creek watershed is primarily forest (73%), with the remainder divided between grassland (12%), shrubland (6%), mixed (4%), vineyards (3%), and riparian vegetation (2%). The Mixed category consists primarily of rural residential areas that are non-forested, not used for agriculture, and are not primarily hardscape. In the Green Valley Creek watershed, the primary land cover is also forest (48%) with 27% mixed, 12% vineyards, and less than 3% each of the following land cover types: orchard, riparian vegetation, grassland, hardscape, and shrubland. Existing land cover is more evenly distributed in the Atascadero Creek watershed with 46% mixed, 22% forest, 10% vineyard, 10% orchard, 7% grassland, 3% riparian vegetation, and 2% hardscape.

Geology
The majority of the Atascadero Creek watershed is underlain by the late Pliocene to late Miocene Wilson Grove Formation (WGF). The WGF is a fine- to medium-grained sandstone and serves as the primary aquifer in the study area. The WGF also outcrops in portions of the Green Valley Creek watershed including much of the Purrington Creek watershed and the lower portions of upper Green Valley Creek above the confluence with Atascadero Creek. The remainder of the Green Valley Creek watershed is underlain by various rocks of the Franciscan Complex and to a lesser degree by various rocks of the Great Valley Sequence. The WGF only outcrops in a small area near the headwaters of Dutch Bill Creek and the majority of the DBC watershed is underlain by various rocks of the Franciscan Complex and the Great Valley Sequence. Relatively shallow Quaternary alluvium occupies the valley floor along most of the length of Atascadero and Green Valley creeks and the lowest reach of DBC.
Chapter 2 - Conceptual Model

Prior to developing a numerical hydrologic model it is useful to develop a conceptual model of the hydrologic system to aid in understanding the movement of water throughout the study area and provide a framework for developing the numerical model. A conceptual model was developed using measured and estimated physical and hydrologic characteristics of the hydrologic system to describe how these characteristics influence the flow and storage of water. Following Markstrom et al., (2008) and Nishikawa et al. (2013) the watershed was divided into four hydrologic zones (Figure 2):

- Zone A - the Land Surface Zone which includes the plant canopy and the land surface;
- Zone B - the Surface Water Zone which includes the surface water features of the watershed;
- Zone C - the Unsaturated Zone which includes the soil zone; and
- Zone D - the Saturated Zone which includes the groundwater system

Water is held in storage within each of the three regions and water flows into, out of, and within each region by a variety of flow processes. The primary goal of the conceptual model was to identify and characterize the inflow, outflow, and storage characteristics of each region as described in greater detail below. This conceptual model was then used as a guide for developing the numerical model as described in Chapter 4.

Zone A - Land Surface Zone

Zone A Inflows
Precipitation falling primarily as rainfall is the dominant source of inflow to Zone A. Mean annual precipitation for 1981 - 2010 was about 55.5 inches for the DBC watershed, 47.7 inches for the GVC watershed, and 45.0 inches for the AC watershed. Over the entire study area this precipitation represents about 129,314 acre-feet per year (acre-ft/yr).

Applied water for irrigation and frost protection represents another important source of water for Zone A. The vast majority of the applied water in the watersheds is for the ~2,947 acres of vineyards under cultivation. Additional irrigation water is applied for orchards, pasture, and other crop types. Review of the California State Water Resources Control Board's Electronic Water Rights Information Management System (eWRIMS) suggests that approximately 549 acres of vineyards are irrigated at least partially with surface water with the irrigation for the remaining 2,398 acres presumably sourced from groundwater. Based on a review of the eWRIMS, vineyard irrigation rates in the study area average about 3.6 inches per unit land surface area. This represents a total annual irrigation volume of approximately 884 acre-ft/yr.

Review of the Sonoma County Frost Protection Database reveals that approximately 1,157 acres of vineyards (39% of total vineyard acreage) use water for frost protection in the study area (SCDA, 2014). Of these, approximately 796 acres or 69% utilize groundwater for frost protection with the remainder relying on surface water. Frost protection demand was
estimated for 2008 through 2014 based on an analysis of hourly temperature records during the frost protection season (CIMIS, 2005), a compilation of acreages with regular versus micro sprinklers from the Frost Protection Database, and stated average sprinkler flow rates. This analysis suggests that total water use for annual frost protection varied from 81 acre-ft/yr in 2014 to 716 acre-ft/yr in 2008; 2008 was the most recent year when significant frost protection demands occurred.

Applied water in the study area displays a high degree of temporal variability with irrigation occurring primarily July through October and frost protection occurring primarily March 15 through May 15. At other times of the year applied water for commercial agricultural operations is minimal to non-existent.

Natural groundwater discharge generally flows directly to a surface water feature (Zone B), however, during especially wet conditions groundwater may discharge to the soil zone or directly to the land surface. Such groundwater discharge may serve to replenish soil moisture and water availability for Evapotranspiration (ET). At certain times groundwater discharge may be a significant inflow component to Zone A, particularly in low-lying areas with a shallow water table such as the marshy low-lying areas along the main-stem of Atascadero Creek.
Zone A Outflows
Actual evapotranspiration and runoff are the primary outflows from Zone A. Actual evapotranspiration (AET) is a function of potential evapotranspiration (PET), water availability, and vegetation characteristics. Hourly PET data are available at the California Irrigation Management Information System (CIMIS) station for Santa Rosa located just east of Sebastopol (CIMIS, 2005). The Turc Method (Turc, 1961) was used in conjunction with solar radiation data, mean monthly temperature data (PRISM, 2010), and DEM-derived landscape attributes (slope and aspect) to compute a spatially-distributed map of mean monthly PET for the study area. The resulting maps were calibrated to match the observed mean monthly PET for the CIMIS station. This analysis revealed that mean annual PET varies from 25 in/yr on north facing slopes in the higher elevations of the DBC watershed to 49 in/yr on south facing slopes in the lower portions of the GVC and AC watersheds. Averaged across each watershed, mean annual PET was 42.0 in/yr in the DBC watershed, 43.3 in/yr in the GVC watershed, and 44.1 in/yr in the AC watershed.

In the adjacent Santa Rosa Plain (SRP), AET was recently estimated to be ~40% of PET (Woolfenden and Hevesi, 2014). Assuming a similar ratio holds for the DBC and GVAC watersheds suggests that AET is on the order of 17.2 inches per year or 45,877 ac-ft/yr over the entire study area. This figure is likely too low because due to the higher rainfall in the study area relative to the SRP, there would presumably be more soil water available to plants. Woolfenden and Hevesi also found that mean annual ET was ~49% of the mean annual precipitation in the SRP. Using this ratio suggests that ET is on the order of 23.9 in/yr or 63,805 ac-ft/yr over the entire study area.

Runoff varies as a function of the precipitation, topography, and land cover and soil characteristics. Runoff potential is classified as high for most of the DBC watershed and the western portions of the GVAC watershed and medium for most of the eastern portions of the GVAC watershed (USDA, 2007). Runoff was estimated to be ~43% of the mean annual precipitation in the SRP (Woolfenden and Hevesi, 2014). Assuming a similar ratio for the study area suggests that runoff is on the order of 21.0 in/yr or 56,012 ac-ft/yr across the entire study area.

Zone A Storage
Water can be stored temporarily in various storage elements in Zone A. These include water stored in the vegetation canopy through interception storage, water stored on the land surface through depression storage, and water stored in the soil zone. Interception storage may be relatively significant in areas of dense vegetation such as the forested areas of the study area which are primarily located in DBC watershed and the western portions of the GVAC watershed, and is important primarily during small rainfall events with limited effect during large, long-duration rain storms. Depression storage may be significant in some areas, particularly the low-lying marshy areas along the main-stem of Atascadero Creek. Soil moisture storage is expected to vary widely across the study area as a function of soil type with thicker soils and soils with higher clay contents retaining more water than thinner soils with lower clay contents. Zone A
storage is expected to exhibit a strong seasonality with storages replenished during the rainy season and depleted during the dry season.

**Zone B - Surface Water Zone**

**Zone B Inflows**

Runoff and groundwater discharge (the source of baseflow in surface streams) are the primary inflows to Zone B. Wastewater treatment plant discharges are an additional inflow component but are expected to be minimal relative to runoff and baseflow. Runoff is described above in greater detail under Zone A outflows. The Green Valley Creek above Atascadero Creek gauge (GV03 in Figure 27) has a complete and reliable flow record for July through September for Water Years 2011 through 2014. Average stream flow during these months (i.e. baseflow) can be used as a proxy for estimating the groundwater discharge to Zone B. Scaling up the average summer discharges at the Green Valley gauge to the full GVAC watershed area yields baseflow estimates ranging from 301 to 1,806 ac-ft/yr depending on rainfall conditions. Given that the gauge location represents only a small portion of the total drainage area, this estimate contains significant uncertainty. Scaling the average summer discharges at the Dutch Bill Creek above Tyrone Road gauge (DB04 in Figure 27) for Water Years 2012 through 2014 yields baseflow estimates ranging from 92 to 588 ac-ft/yr for the DBC watershed.

**Zone B Outflows**

The primary outflow from Zone B is stream discharge flowing from the outlets of Dutch Bill Creek and Green Valley Creek to the Russian River. Additional outflows occur from seepage losses into the subsurface (Zone C), ET, and diversions for irrigation. No long-term stream gauging stations are available in the study area, however a number of short-term stations are available. Among these, Purrington Creek at Graton Road, Green Valley Creek at Bones Road, and Dutch Bill Creek above Tyrone Road are the most useful in that they have the longest periods of record and the best-developed rating equations (GV02, GV01, and DB04 in Figure 27).

Complete flow data at both the Green Valley Creek and Purrington Creek gauges is only available for Water Year 2011. The average 2011 flow rates at these gauges were 10.4 and 8.3 cfs respectively. Although these gauges only capture a small portion of the total GVAC watershed area, scaling the flow rates up to the full watershed area provides a crude approximation of the total surface water outflow from Zone B. This exercise yields an outflow estimate of between 62,595 and 64,985 ac-ft/yr for the GVAC watershed. Water Year 2011 was an average to above average rainfall year with 50.3 inches recorded at Graton compared to the long-term annual average of 40.9 inches.

Complete flow data at the Dutch Bill Creek gauge is available for Water Years 2012 and 2013 and the 2-yr average flow rate was 12.2 cfs. The gauge captures about 80.4% of the total watershed area; scaling the average flow rate up to the full Dutch Bill Creek watershed area suggests that the total Dutch Bill Creek surface water outflow from Zone B is on the order of 11,064 ac-ft/yr. This estimate is likely lower than the long-term average given that the 2012-
2013 average annual rainfall was only 42.3 inches at Occidental compared to the long-term annual average of 53.9 inches.

Examination of the California State Water Resources Control Board's Electronic Water Rights Information Management System (eWRIMS) revealed that during Water Years 2009 through 2013 an average of 85 ac-ft/yr was diverted from ten locations in the AC watershed, 130 ac-ft/yr was diverted from twelve locations in the GVC watershed, and 115 ac-ft/yr was diverted from seven locations in the DBC watershed. Most of the diversions are associated with either on-stream or off-stream ponds. An inventory using LiDAR-derived elevation data and aerial photography revealed the presence of more than 130 ponds in the study area. Twenty-three on-stream ponds were identified and the remaining majority of the ponds fill primarily from local surface runoff or groundwater inflow. Direct diversions were a relatively small component of the total surface water use, accounting for 16, 21, and 40 ac-ft-yr in the AC, GVC, and DBC watersheds respectively. Diversions associated with Riparian Water Rights are largely unreported in the eWRIMS and have not been quantified, but may be significant.

**Zone C - Unsaturated Zone**

**Zone C Inflows**
The primary inflows to Zone C are infiltration from Zone A, seepage through the streambeds and ponds of Zone B, and septic tank effluent. Infiltration to the soil zone varies across the study area primarily as a function of precipitation and soil hydraulic conductivity. Although precipitation increases substantially from east to west across the study area, the wide variations in soil conductivities across the study area is expected to be the primary driver of variations in infiltration. Soil conductivities are highest in areas underlain by the Wilson Grove Formation and areas underlain by coarse alluvium such as the alluvium along the lower reaches of Dutch Bill Creek and the upper reaches of Atascadero Creek. Soil conductivities are lowest in the north-central portion of the DBC watershed and in the areas of fine-grained alluvium along Green Valley, Purrington, and lower Atascadero Creeks. During the dry summer months, water tables may drop below streambed elevations in some areas resulting in seepage from streambeds and ponds. Domestic water use is significant in the study area and thus septic effluent is a potentially significant inflow to Zone C, however it is expected to be much less than the infiltration as discussed in greater detail under Zone D Inflows.

**Zone C Outflows**
Transpiration by vegetation and recharge to the saturated zone (Zone D) are the primary outflows from Zone C. Transpiration is discussed in more detail under Zone A Outflows. Recharge varies across the study area as a function of the precipitation, soil conductivity, and vertical hydraulic conductivity in the upper portions of the saturated zone. Recharge is expected to be highest in areas underlain by the Wilson Grove Formation and coarse alluvium and lowest in areas underlain by low-permeability basement rocks (primarily Franciscan Complex) and fine-grained alluvium.
Zone D - Saturated Zone

Zone D Inflows
Inflows to Zone D include recharge from Zone C, recharge from streams, and underflow from adjacent basins. Woolfenden and Hevesi (2014) estimated the long-term average annual recharge from the unsaturated zone for areas within the adjacent Santa Rosa Plain that are underlain by the Wilson Grove Formation. Applying this estimate to the portion of the study area underlain by the Wilson Grove Formation yields an estimate of recharge from the unsaturated zone of 8,373 ac-ft/yr. This is equivalent to ~14% of the mean annual precipitation falling over this area. Boudreau (1978) estimated that recharge of the Wilson Grove Formation was on the order of 25% of annual precipitation as part of a 1978 Groundwater Study of Green Valley. Examination of groundwater elevation data from California Statewide Groundwater Elevation Monitoring (CASGEM) wells (CASGEM, 2014) for the primary aquifer in the study area (the Wilson Grove Highlands) indicates that the gradient direction is away from the study area and towards the adjacent Santa Rosa Plain to the east. Thus underflow is not expected to be a significant component of inflow.

Zone D Outflows
Outflows from Zone D include discharge to surface water features in Zone B, underflow to adjacent basins, ET, groundwater pumping, and discharge to the soil zone (Zone C). As discussed above for Zone B Outflows, groundwater discharge to streams as estimated from available stream gauging data ranges from 301 to 1,806 ac-ft/yr for the GVAC watershed and from 92 to 588 ac-ft/yr for the DBC watershed. CASGEM data from Spring 2012 indicate a groundwater gradient towards the adjacent Santa Rosa Plain of approximately 0.01 ft/ft. Based on borehole log interpretations and the CASGEM data, the average saturated thickness along this 11.3 mile-long boundary is approximately 460-ft. Assuming a hydraulic conductivity of 0.5 ft/day and applying Darcy’s Law yields an estimate of the underflow of 1,152 ac-ft/yr. The Santa Rosa Plain groundwater model simulated a boundary inflow of 5,100 ac-ft/yr to the Wilson Grove subarea which loosely corresponds to the boundary with the GVAC watershed (Woolfenden & Hevesi, 2014). The Santa Rosa Plain estimate is significantly larger than the estimate presented here because of differences in the interpretation of the saturated thickness of the Wilson Grove Formation in the vicinity of the boundary.

Based on 2010 census data and a per capita use assumption, domestic pumping in the study area is on the order of 1,535 ac-ft/yr. Based on examination of the Electronic Water Rights Information Management System (eWRIMS) and the Sonoma County Frost Protection Database, irrigation pumping is on the order of 725 ac-ft/yr and frost protection pumping ranged from 110 to 1,041 ac-ft/yr between 2008 and 2014. The mean annual total groundwater pumping for all uses is approximately 2,519 ac-ft/yr which represents the largest outflow component from Zone D.
Chapter 3 - Numerical Modeling Methodology

The hydrologic model of the GVAC and DBC watersheds was constructed using the MIKE SHE model (Graham and Butts, 2005; DHI, 2014). Model development activities have been ongoing since its inception in 1977, and the model has been applied successfully in hundreds of research and consultancy projects covering a wide range of climatic and hydrologic regimes around the world (Graham and Butts, 2005).

The MIKE SHE model is a fully-distributed, physically-based hydrologic model capable of simulating all of the land-based phases of the hydrologic cycle including overland flow, channel flow, evapotranspiration, infiltration and unsaturated flow, groundwater flow, and stream/aquifer interactions. The distributed nature of the model makes it well-suited for examining the hydrologic impacts of changes in climate, land and/or water management. Complex physics-based watershed models, while potentially powerful tools, require large amounts of input data and ideally should be well-calibrated to observed stream flow and/or groundwater data for a number of years. It is important to bear in mind that a model created with MIKE SHE is a simplification of a real hydrologic system and while it can provide useful estimates of various flows and storages within the system, the estimates contain uncertainty and should not be viewed as a replacement for real data or as static since the model will need to be updated on a periodic basis as new data become available.

Overland Flow

The overland flow component of MIKE SHE solves the 2-dimensional St. Venant equations for shallow free surface flows using the diffusive wave approximation. A finite-difference scheme is used to compute the fluxes of water between grid cells on a 2-dimensional topographic surface. Net rainfall, evaporation, and infiltration are introduced as source/sink terms and the model assumes that a sheet flow approximation is valid for non-channelized surface flows and that roughness is uniform over various flow depths. The primary inputs for the overland flow module include topographic information in the form of a Digital Elevation Model (DEM) and a corresponding spatial distribution of overland roughness coefficients (Manning’s n) which is generally referenced to the model’s land cover categories. Sub-grid scale depressions in the topography and barriers to overland flow are represented conceptually through the use of the detention storage parameter.

Channel Flow

The channel flow component of the model calculates unsteady water levels and discharges using an implicit finite-difference formulation to solve the 1-dimensional St. Venant equations for open channel flow. The model is capable of simulating ephemeral stream flow conditions and backwater effects, and includes formulations for a variety of hydraulic structure types (e.g. bridges, weirs, culverts). Either a no-flow or a discharge boundary can be used as the upstream boundary condition, and the downstream boundary can be represented using a water level or water level/discharge relationship boundary condition. Other than boundary conditions, the
primary inputs for the channel flow model include channel geometry information and a spatial distribution of Manning’s roughness coefficients.

**Channel Flow Interactions**
Interaction between the channel flow and overland flow components of the model is driven by the gradient between the overland water depths in a given grid cell and the head in a corresponding computational node in the channels, and is computed using a broad crested weir equation. Depending on the direction of the gradient, the channel flow component of the model can either receive overland flow during runoff events or release water back onto the floodplain as overbank flow when heads in the channel exceed the adjacent floodplain levels. The model is also capable of simulating backwater effects onto the overland flow plane due to restricted channel flow.

The channel flow component of the model is also coupled to the groundwater component of the model. Stream/aquifer exchanges are driven by the head differences between channel nodes and corresponding watershed grid cells, and fluxes are computed through a bed sediment layer with an associated vertical hydraulic conductivity value. The interaction is computed continuously and fluxes are added or subtracted to the corresponding component of the model at the beginning of each time step.

**Evapotranspiration and Interception**
Evapotranspiration (ET) is handled in the model using a 2-layer water balance approach which divides the unsaturated zone into a root zone from which water can be transpired and a lower zone below the root zone where transpiration does not occur. The model computes the Actual ET (AET) as a function of the Potential ET (PET) by tracking the available moisture content in the vegetation canopy, on the overland flow plain, and in the unsaturated zone. The model first extracts water from interception (based on specified values of the interception storage coefficient and the Leaf Area Index or LAI). Next water is extracted from ponded water (evaporation) on the land surface, and finally water is extracted from the unsaturated zone and/or the saturated zone as transpiration if the rooting depth exceeds the depth to the water table in a given time step. The PET is adjusted for each land cover category in the model through the use of a crop coefficient (Kc). The simulated position of the water table along with the specified rooting depth determines the thickness of the zone of transpiration.

**Unsaturated Flow**
The unsaturated flow component of MIKE SHE functions with the 2-layer water balance method described above for ET. The method considers average conditions in the unsaturated zone and tracks the available soil moisture to regulate ET and groundwater recharge using a 1-dimensional (vertical) formulation. A soil map is used to distribute the primary soil properties used to drive the model including the soil hydraulic conductivity and the moisture contents at saturation, field capacity, and the wilting point. The unsaturated flow component of the model interacts with the overland component of the model by serving as a sink term (infiltration) and with the groundwater flow component by serving as a source term (recharge).
Groundwater Flow
The groundwater component of the model solves the 3-dimensional Darcy equation for flow through saturated porous media using an implicit finite-difference numerical scheme solved using the preconditioned conjugate gradient (PCG) technique which is nearly identical to the one used in the USGS’s groundwater model, MODFLOW. The primary inputs to the model are the horizontal and vertical hydraulic conductivities, specific yield, and storage coefficients, as well as the upper and lower elevations of each layer(s) considered in the model. External boundary conditions can be no-flow, head, or gradient boundaries, and pumping wells can be added as internal sink terms. The lower boundary of the model can either be a zero-flux or a specified-flux boundary, and the upper boundary condition is a flux term calculated by the unsaturated flow component of the model (recharge). If the water table reaches land surface, the unsaturated flow calculations are disabled and the groundwater component of the model interacts directly with the overland flow plane.
Chapter 4 - Model Construction

Model Overview
The Green Valley/Atascadero and Dutch Bill Creek hydrologic model covers the full extent of these watersheds upstream of their confluences with the Russian River. The model is discretized onto a 50-meter by 50-meter grid and includes a total of 53,158 cells covering an area of approximately 51.3 square miles. The grid resolution was selected so as to represent the watershed in as much detail as was possible consistent with the overall resolution of input data while ensuring reasonable computation times for the model runs.

The model simulates a continuous 5-yr simulation period from 10/1/2009 through 10/1/2014. This period was selected because it is relatively recent, it corresponds to the period with the most data available for model calibration, and it includes a wide variety of precipitation conditions ranging from the relatively wet Water Year of 2011 where annual precipitation at Graton and Occidental was 50.3 and 61.5 inches respectively to the very dry Water Year of 2014 where annual precipitation at Graton and Occidental was 22.7 and 34.2 inches respectively.

Climate
The Graton and Occidental precipitation records were used to provide daily precipitation inputs to the model (Figure 4). Based on the PRISM data set (PRISM, 2010) which provides gridded average annual precipitation data for the period 1981-2010 for the continental U.S., a significant east-west gradient in precipitation occurs across the basin with precipitation increasing from approximately 41 in/yr in the eastern portion of the AC watershed to 60 in/yr in the western portion of the DBC watershed (Figure 5).

In order to capture the spatial variability of precipitation conditions, the watershed was divided into twenty precipitation zones based on one-inch annual average precipitation contours derived from the PRISM data. A scaling factor for each zone was determined by calculating the difference between the 1981-2010 average annual precipitation from the station records and the corresponding value from each PRISM zone. The Graton record was applied for the 41 to 52 in/yr zones and scaled by factors ranging from 0.99 to 1.26 and the Occidental record was applied for the 53 to 60 in/yr zones and scaled by factors ranging from 0.98 to 1.11. The transition from 52 to 53 in/yr roughly corresponds to the watershed divide between the GVAC and DBC watersheds such that the Graton record is used for the GVAC watershed and the Occidental record is used for the DBC watershed.

The California Irrigation Management Information System (CIMIS) station at Santa Rosa (located near eastern Sebastopol) was used to provide daily PET inputs to the model (CIMIS, 2005). In order to capture the spatial variation in PET across the study area, we applied the Turc Method (Turc, 1968) to compute PET using gridded solar radiation data from the National Solar Radiation Database (NSRD, 2010), and mean monthly temperature data from PRISM (PRISM, 2010). We compared the mean annual PET predicted from the Turc Method with the mean annual PET computed from the CIMIS stations at Santa Rosa and Windsor and globally scaled the Turc Method results to conform with the CIMIS data. The resulting PET grid shows
that mean annual PET in the GVAC and DBC watersheds was 43.7 and 42.0 in/yr respectively but that locally, PET was as low as 25 in/yr on steep north facing slopes and as high as 49 in/yr in exposed areas with higher temperatures (Figure 6). The gridded PET results were used to divide the study area into twenty-five PET zones (25 to 49 in/yr). A scaling factor for each zone was determined by calculating the difference between the 1990-2014 average annual PET from the Santa Rosa CIMIS station and the corresponding value from each PET zone. The CIMIS record was scaled by factors ranging from 0.56 to 1.10 to produce daily PET time series for each PET zone in the model (Figure 7). Crop coefficients were then used to modify this PET time series for each of the land cover categories in the model as described below in the Land Cover section.

**Topography**

A 3-ft resolution Sonoma County LiDAR dataset from autumn 2013 (SC LiDAR) was used to represent the topography in the watershed by re-sampling the data to conform to the 50-meter resolution model domain. Elevations in the GVAC watershed range from 600 to 900-ft above sea level (asl) along the ridges forming the western and southern watershed boundaries to ~30-ft asl at the confluence of Green Valley Creek and the Russian River. In the DBC watershed, elevations range from 1,000 to 1,450-ft asl along the ridge forming the western watershed boundary to ~20-ft asl at the confluence of Dutch Bill Creek and the Russian River (Figure 8).

![Figure 3 - Mean annual precipitation at Graton and Occidental (black and red values indicate wet and dry years defined as +/- 25% of the long term average as shown with the dashed line).](image-url)
Figure 4 - Daily Precipitation at Graton and Occidental for the WY 2010 - 2014 simulation period.
Figure 5 - Spatial variation of mean annual Precipitation used in the hydrologic model.
Figure 6 - Spatial variation of mean annual Potential Evapotranspiration (PET) used in the hydrologic model.
Land Cover
The available land cover datasets for the study area included a parcel-based Sonoma County PRMD Land Use Area map, the 30-m resolution National Land Cover Dataset, and a map showing vineyard areas in Upper Green Valley Creek (Deitch, 2010). Given that a highly accurate land cover data set is one of the most important inputs for the hydrologic analysis, a revised land cover data set was developed by digitizing polygons over a 2009 aerial photograph and using the existing land cover and vineyard datasets as a guide. This revised land cover data set includes the following categories: Forest, Vineyard, Orchard, Mixed, Hardscape, Riparian, Shrubland, Grassland, and Water (Figure 9). The Mixed category consists primarily of rural residential areas that are non-forested, not used for agriculture, and are not primarily hardscape. The hardscape category consists of large building footprints, major paved and unpaved roads, and other areas relatively free of vegetation. Field reconnaissance was performed to verify the suitability of the land cover categories and adjust the land cover map where feasible.

In the GVAC watershed, the dominant land cover categories are Mixed (37%) and Forest (34%), with most of the remaining area consisting of Vineyard (11%), Orchard (7%), and Grassland (5%). In the DBC watershed, the dominant land cover is Forest (73%), with most of the remaining area consisting of Grassland (12%), Shrubland (6%), Mixed (4%), and Vineyard (3%). More details on the distribution of land cover types in the various sub-watersheds is provided in Table 1.

A series of model parameters are utilized in the model based on the land cover map. These parameters include the Manning’s roughness coefficient, detention storage, interception coefficient, crop coefficient, Leaf Area Index, and rooting depth. For land cover types with a deciduous vegetation component, the crop coefficient, Leaf Area Index, and rooting depth were assigned two values, one corresponding to the growing season (March 15th - October 15th) and one corresponding to the dormant season. Many of these parameters are difficult to measure...
in the field and site-specific values are generally unavailable. Thus a typical approach for populating the model with these parameter values is to use literature values from similar land cover types initially and adjust them within the range of reasonable limits as part of the calibration process (Table 2).

Figure 8 - Hydrologic model topography.
Figure 9 - Hydrologic model land cover.
Table 1 - Distribution of land cover types by subwatershed.

<table>
<thead>
<tr>
<th>Subwatershed</th>
<th>Dutch Bill</th>
<th></th>
<th>Green Valley</th>
<th></th>
<th>Atascadero</th>
<th></th>
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<td>2,947</td>
<td>9.2%</td>
</tr>
<tr>
<td>Orchard</td>
<td>19</td>
<td>0.2%</td>
<td>391</td>
<td>3.4%</td>
<td>1,366</td>
<td>10.5%</td>
<td>1,777</td>
<td>5.6%</td>
</tr>
<tr>
<td>Mixed</td>
<td>277</td>
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<td>3,067</td>
<td>26.9%</td>
<td>5,913</td>
<td>45.6%</td>
<td>9,257</td>
<td>28.9%</td>
</tr>
<tr>
<td>Hardscape</td>
<td>28</td>
<td>0.4%</td>
<td>204</td>
<td>1.8%</td>
<td>318</td>
<td>2.5%</td>
<td>550</td>
<td>1.7%</td>
</tr>
<tr>
<td>Riparian</td>
<td>135</td>
<td>1.8%</td>
<td>321</td>
<td>2.8%</td>
<td>395</td>
<td>3.0%</td>
<td>851</td>
<td>2.7%</td>
</tr>
<tr>
<td>Shrubland</td>
<td>436</td>
<td>5.7%</td>
<td>113</td>
<td>1.0%</td>
<td>0</td>
<td>0.0%</td>
<td>549</td>
<td>1.7%</td>
</tr>
<tr>
<td>Grassland</td>
<td>951</td>
<td>12.4%</td>
<td>381</td>
<td>3.3%</td>
<td>839</td>
<td>6.5%</td>
<td>2,171</td>
<td>6.8%</td>
</tr>
<tr>
<td>Water</td>
<td>16</td>
<td>0.2%</td>
<td>30</td>
<td>0.3%</td>
<td>56</td>
<td>0.4%</td>
<td>101</td>
<td>0.3%</td>
</tr>
<tr>
<td>Total</td>
<td>7,654</td>
<td></td>
<td>11,387</td>
<td></td>
<td>12,961</td>
<td></td>
<td>32,002</td>
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Table 2 - Land cover-based hydrologic and vegetation properties used in the hydrologic model.

<table>
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<tr>
<th>Land Cover Type</th>
<th>Manning's Roughness Coefficient</th>
<th>Detention Storage (in)</th>
<th>Interception Coefficient (in)</th>
<th>Leaf Area Index</th>
<th>Rooting Depth (in)</th>
<th>Crop Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>0.60</td>
<td>0.30</td>
<td>0.05</td>
<td>7.0</td>
<td>60</td>
<td>1.25</td>
</tr>
<tr>
<td>Vineyard</td>
<td>0.15</td>
<td>0.05</td>
<td>0.01</td>
<td>2.0 - 2.5</td>
<td>16 - 32</td>
<td>0.85 - 0.95</td>
</tr>
<tr>
<td>Orchard</td>
<td>0.18</td>
<td>0.05</td>
<td>0.02</td>
<td>2.0 - 4.5</td>
<td>16 - 70</td>
<td>0.90 - 1.20</td>
</tr>
<tr>
<td>Mixed</td>
<td>0.23</td>
<td>0.05</td>
<td>0.01</td>
<td>3.0 - 4.0</td>
<td>20 - 28</td>
<td>0.90 - 1.10</td>
</tr>
<tr>
<td>Hardscape</td>
<td>0.08</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>0</td>
<td>0.60</td>
</tr>
<tr>
<td>Riparian</td>
<td>0.60</td>
<td>0.30</td>
<td>0.05</td>
<td>3.0 - 7.0</td>
<td>16 - 70</td>
<td>0.80 - 1.30</td>
</tr>
<tr>
<td>Shrubland</td>
<td>0.38</td>
<td>0.05</td>
<td>0.02</td>
<td>2.0 - 4.5</td>
<td>20 - 40</td>
<td>0.90 - 1.10</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.18</td>
<td>0.05</td>
<td>0.01</td>
<td>2.0 - 3.0</td>
<td>16</td>
<td>1.00</td>
</tr>
<tr>
<td>Water</td>
<td>0.08</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>0</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Surface Water

Streams

A tributary stream channel network was extracted from the 3-ft resolution SC LiDAR dataset by computing flow directions and flow accumulations using standard ArcGIS techniques. Various drainage area thresholds were explored for defining channel head locations. Based on field observations a threshold of five acres was selected. A length threshold of 1,000-ft was applied to thin the resulting drainage network; this resulted in a stream network that was quite detailed but not overly complicated such that it would lead to excessive computational requirements. A separate LiDAR dataset (high-res LiDAR) of higher resolution (1.6-ft) was
obtained for this project in autumn 2012 for the riparian corridor of the main-stem streams in the GVAC watershed. This dataset was used to delineate the streamlines for the main-stems of Atascadero, West Atascadero, Green Valley, and Purrington Creeks. Field reconnaissance was performed to map the major road-side ditches in the study area and refine the LiDAR-derived stream network where necessary. A length threshold of 500-ft was applied to the mapped ditches.

The main-stem, tributary, and ditch networks were combined to produce a final stream network for the model (Figure 10). In the GVAC watershed, the stream network includes 11.0 miles of Atascadero Creek, 4.7 miles of West Atascadero Creek, 11.8 miles of Green Valley Creek, 4.3 miles of Purrington Creek, 132.1 miles of tributary streams, and 19.2 miles of road-side ditches. In the DBC watershed, the stream network includes 8.3 miles of Dutch Bill Creek, 48.5 miles of tributary streams, and 1.5 miles of road-side ditches (Table 3). Routing of concentrated runoff in smaller stream channels that are not represented in the model stream network is handled by the overland flow component of the model which utilizes the model DEM as described above under Topography.

For the four main-stem streams in the GVAC watershed described above, cross sections were extracted from the high-res LiDAR at 328-ft (100-m) intervals; Dutch Bill Creek cross sections were extracted from the SC LiDAR. Comparisons between surveyed cross sections and LiDAR-derived cross sections in Green Valley, Purrington, and Dutch Bill Creeks were used to evaluate the LiDAR accuracy and suitability for hydrologic modeling in previous work (OEI, 2013). For the tributary streams, relationships between drainage area and average channel dimensions (Figure 11) were developed from field measurements and used in conjunction with thalweg elevations extracted from the SC LiDAR to construct channel cross sections at the same 328-ft interval. Ditches were classified into two size categories with characteristic cross section dimensions based on field measurements (small: 2.5-ft x 1.1-ft and large: 5.0-ft x 1.5-ft). The model includes a total of 3,885 cross sections. For more details on the two LiDAR datasets and their accuracy, please refer to OEI (2013).

For reaches not mapped as containing alluvium, river/aquifer exchange was driven by the vertical hydraulic conductivity of the underlying hydrogeologic material as described below in the Hydrogeology section. For the reaches underlain by alluvium, streambed leakage coefficient values were assigned and used to derive the conductance term for simulating river/aquifer exchange. A value of 0.0001 (1/seconds) was used for most of these reaches with the exception of the lowest reach of upper Green Valley Creek below the lowest Green Valley Road crossing and the lowest alluvial reach of Dutch Bill Creek where a value of 0.0002 (1/seconds) was used.

**Ponds**

More than 130 ponds were identified from examination of the SC LiDAR and aerial photography. Of these, 23 were identified as on-stream ponds having either a surface water right and/or a surface area of greater than 0.5 acres (Figure 10). These 23 ponds were added to
the model by extracting additional cross sections from the SC LiDAR to represent the pond storage and spillway elevations.

**Stormwater Drainage**
Maps of stormwater inlets and pipes were obtained from the City of Sebastopol and Sonoma County. Any erroneous surface water features were removed for these areas and the areas drained by stormwater drainage systems were simulated conceptually by applying a 'paved area runoff coefficient' such that 80% of the runoff generated from these areas flows directly to the nearest surface water feature (Figure 10).

**Diversions**
Review of the Electronic Water Rights Information Management System (eWRIMS) revealed that there are 51 active surface water rights in the study area. Monthly diversion rates are available for one or more years within the reporting period of 2008 through 2013. An average monthly diversion rate was calculated from the years with available data and these averages were then applied for the years without reported rates to construct a continuous time-series of diversion rates for the model simulation period. Of the 51 active water rights, 18 of them reported either no use or very small use (<10 gal/day) and were thus not considered in the analysis. Examination of the remaining 33 water rights indicate that on average 330 ac-ft/yr was diverted from 29 locations in the study area over the 2008 through 2013 reporting period (Figure 10). These diversions varied spatially as follows: 85 ac-ft/yr was diverted from ten locations in the AC watershed, 130 ac-ft/yr was diverted from twelve locations in the GVC watershed, and 115 ac-ft/yr was diverted from seven locations in the DBC watershed.

Most of the diversions are associated with either on-stream or off-stream ponds and direct diversions were a relatively small component of the total surface water use accounting for 16, 21, and 40 ac-ft-yr in the AC, GVC, and DBC watersheds respectively. It is important to note that only one riparian water right in the study area is included in the eWRIMS and the model. Additional diversions associated with riparian water rights may be significant, however given that no information is available to describe the majority of these diversions, they have not been included in this analysis.

**Boundary Conditions**
Upstream boundary conditions are zero discharge inflows due to the fact that all surface water inflows are generated by other components within the MIKE SHE model. Downstream boundary conditions consist of rating curves which were developed by solving Manning's equation for the downstream cross sections on Dutch Bill Creek and Green Valley Creek.

**Soils**
A soil series map of the watershed was obtained from the USDA’s SSURGO database (USDA, 2007). Soil series with similar hydraulic properties were aggregated to produce a simplified soils map for the model which includes 15 soil types named by texture (Figure 12 & Table 4). The dominant soil type in the GVAC watershed is Fine Sandy Loam C (57%), with 17% Very
Figure 10 - Stream network and locations of on-stream ponds, points of diversion, and stormwater drainage areas included in the hydrologic model.
Flow Availability Analysis for Restoration Prioritization Planning

Figure 11 - Relationships between drainage area and bankfull width, bottom width, and bankfull area used to construct tributary channel cross sections for the hydrologic model.
Gravelly Loam A, 8% Fine Sandy Loam B, 6% Loam A, 4% Loam B, and the remaining 8% of the watershed consisting of eight other soil types (Table 5). The dominant soil type in the DBC watershed is Very Gravelly Loam A (54%), with 19% Fine Sandy Loam C, 10% Gravelly Loam, 7% Clay Loam, 5% Cobbly Clay Loam, and the remaining 5% of the watershed consisting of seven other soil types (Table 5).

Initial estimates of the saturated hydraulic conductivity and the moisture contents at saturation, field capacity, and the wilting point for each of these soil types were made from the physical properties report in the SSURGO database and final values were determined through model calibration. Initial values were taken as the weighted average of all soil horizons and values were adjusted during calibration by scaling the initial values up or down by a uniform factor. The calibrated saturated hydraulic conductivity values ranged from 0.006 ft/day for Clay to 0.6 ft/day for the Alluvium (Table 6). Soil moisture contents at saturation, field capacity, and the wilting point ranged from 0.32 to 0.44, 0.12 to 0.37, and 0.06 to 0.25 respectively.

Drainage parameters were assigned to represent interflow processes in the model. Drainage occurs in the model when groundwater elevations exceed a specified depth threshold, and drain flow is routed to surface water features in the model based on the surface topography and a specified time constant. When the drainage parameters are properly calibrated, the drainage term serves to represent the interflow component of the stream flow hydrograph. Drainage was included for all areas with slopes greater than 20%. In the GVAC watershed, a drainage level of 3.5-ft below land surface was used and in the DBC watershed a drainage level of 5-ft below land surface was used. A drainage time constant of $1e^{-7}$ was used throughout the model domain. Both the drainage levels and time constant values were determined through the calibration process.
Figure 12 - Hydrologic model soil types.
Table 4 - SSURGO soil series represented by each of the soil types in the hydrologic model.

<table>
<thead>
<tr>
<th>Model Soil Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock</td>
<td>Rock Land</td>
<td>Rock Land</td>
<td>Rock Land</td>
<td>Rock Land</td>
<td>Rock Land</td>
</tr>
<tr>
<td>Clay</td>
<td>Raynor Clay</td>
<td>Los Osos Clay Loam (thin solum)</td>
<td>Yorkville Clay Loam</td>
<td>Suther Loam</td>
<td>Clear Lake Clay</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>Atwell Clay Loam</td>
<td>Atwell Clay Loam</td>
<td>Atwell Clay Loam</td>
<td>Atwell Clay Loam</td>
<td>Atwell Clay Loam</td>
</tr>
<tr>
<td>Cobble Clay Loam</td>
<td>Montara Cobbly Clay Loam</td>
<td>Goulding Cobbly Clay Loam</td>
<td>Montara Cobbly Clay Loam</td>
<td>Montara Cobbly Clay Loam</td>
<td>Montara Cobbly Clay Loam</td>
</tr>
<tr>
<td>Fine Sandy Loam A</td>
<td>Pajaro Fine Sandy Loam</td>
<td>Pajaro Fine Sandy Loam</td>
<td>Pajaro Fine Sandy Loam</td>
<td>Pajaro Fine Sandy Loam</td>
<td>Pajaro Fine Sandy Loam</td>
</tr>
<tr>
<td>Fine Sandy Loam B</td>
<td>Steinbeck Loam (&lt;15% slopes)</td>
<td>Goldridge Fine Sandy Loam (eroded &lt;15% slopes)</td>
<td>Steinbeck Loam (&gt;15% slopes)</td>
<td>Steinbeck Loam (&gt;15% slopes)</td>
<td>Steinbeck Loam (&gt;15% slopes)</td>
</tr>
<tr>
<td>Fine Sandy Loam C</td>
<td>Goldridge Fine Sandy Loam</td>
<td>Josephine Loam</td>
<td>Blutcher Fine Sandy Loam</td>
<td>Blutcher Fine Sandy Loam</td>
<td>Blutcher Fine Sandy Loam</td>
</tr>
<tr>
<td>Loam A</td>
<td>Blutcher Loam</td>
<td>Blutcher Clay Loam</td>
<td>Mendocino Sandy Clay Loam</td>
<td>Mendocino Sandy Clay Loam</td>
<td>Mendocino Sandy Clay Loam</td>
</tr>
<tr>
<td>Loam B</td>
<td>Steinbeck Loam (&gt;15% slopes)</td>
<td>Steinbeck Loam (&gt;15% slopes)</td>
<td>Steinbeck Loam (&gt;15% slopes)</td>
<td>Steinbeck Loam (&gt;15% slopes)</td>
<td>Steinbeck Loam (&gt;15% slopes)</td>
</tr>
<tr>
<td>Loam C</td>
<td>Empire Loam</td>
<td>Yolo Loam Overwash</td>
<td>Empire Loam</td>
<td>Yolo Loam Overwash</td>
<td>Empire Loam</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>Sebastopol Sandy Loam</td>
<td>Yolo Sandy Loam</td>
<td>Hely Silt Loam</td>
<td>Hely Silt Loam</td>
<td>Hely Silt Loam</td>
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<tr>
<td>Gravelly Loam</td>
<td>Henneke Gravelly Loam</td>
<td>Henneke Gravelly Loam</td>
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<td>Henneke Gravelly Loam</td>
<td>Henneke Gravelly Loam</td>
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<td>Hugo Loam</td>
<td>Hugo Very Gravelly Loam</td>
<td>Hugo Very Gravelly Loam</td>
<td>Hugo Very Gravelly Loam</td>
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<tr>
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<td>Aruckle Gravelly Loam</td>
<td>Maymen Gravelly Sandy Loam</td>
<td>Maymen Gravelly Sandy Loam</td>
<td>Maymen Gravelly Sandy Loam</td>
<td>Maymen Gravelly Sandy Loam</td>
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<td>Alluvial Land</td>
<td>Alluvial Land</td>
<td>Alluvial Land</td>
<td>Alluvial Land</td>
</tr>
<tr>
<td></td>
<td>Dutch Bill</td>
<td></td>
<td>Green Valley</td>
<td></td>
<td>Atascadero</td>
</tr>
<tr>
<td>------------------</td>
<td>------------</td>
<td>------------------</td>
<td>--------------</td>
<td>------------------</td>
<td>------------</td>
</tr>
<tr>
<td></td>
<td>Acres</td>
<td>Percent</td>
<td>Acres</td>
<td>Percent</td>
<td>Acres</td>
</tr>
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</tr>
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<td>0.0%</td>
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<tr>
<td>Clay Loam</td>
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<tr>
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<td>77</td>
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</tr>
<tr>
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<td>0</td>
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<td>0</td>
<td>0.0%</td>
<td>476</td>
</tr>
<tr>
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<td>33</td>
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<td>543</td>
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<td>1,515</td>
</tr>
<tr>
<td>Fine Sandy Loam C</td>
<td>1,462</td>
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<td>5,616</td>
<td>49.3%</td>
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</tr>
<tr>
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<tr>
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<td>15</td>
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<td>1,008</td>
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<td>99</td>
<td>0.9%</td>
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<tr>
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<td>0.0%</td>
<td>309</td>
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<td>Gravelly Loam</td>
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<td>95</td>
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<td>0</td>
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<tr>
<td>Very Gravelly Loam A</td>
<td>4,165</td>
<td>54.4%</td>
<td>4,001</td>
<td>35.1%</td>
<td>83</td>
</tr>
<tr>
<td>Very Gravelly Loam B</td>
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<td>126</td>
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</tr>
<tr>
<td>Very Gravelly Loam C</td>
<td>39</td>
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<td>0</td>
<td>0.0%</td>
<td>0</td>
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<tr>
<td>Alluvium</td>
<td>82</td>
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<td>0.0%</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>7,654</td>
<td></td>
<td>11,387</td>
<td></td>
<td>12,961</td>
</tr>
</tbody>
</table>
Table 6 - Soil properties used in the hydrologic model.

<table>
<thead>
<tr>
<th></th>
<th>Saturated Hydraulic Conductivity (ft/day)</th>
<th>Moisture Content at Saturation</th>
<th>Moisture Content at Field Capacity</th>
<th>Moisture Content at the Wilting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock</td>
<td>0.00</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Clay</td>
<td>0.01</td>
<td>0.44</td>
<td>0.37</td>
<td>0.25</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>0.01</td>
<td>0.39</td>
<td>0.34</td>
<td>0.20</td>
</tr>
<tr>
<td>Cobbly Clay Loam</td>
<td>0.01</td>
<td>0.37</td>
<td>0.28</td>
<td>0.19</td>
</tr>
<tr>
<td>Fine Sandy Loam A</td>
<td>0.15</td>
<td>0.41</td>
<td>0.25</td>
<td>0.11</td>
</tr>
<tr>
<td>Fine Sandy Loam B</td>
<td>0.06</td>
<td>0.41</td>
<td>0.26</td>
<td>0.11</td>
</tr>
<tr>
<td>Fine Sandy Loam C</td>
<td>0.08</td>
<td>0.41</td>
<td>0.25</td>
<td>0.11</td>
</tr>
<tr>
<td>Loam A</td>
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<td>0.39</td>
<td>0.29</td>
<td>0.12</td>
</tr>
<tr>
<td>Loam B</td>
<td>0.08</td>
<td>0.39</td>
<td>0.26</td>
<td>0.12</td>
</tr>
<tr>
<td>Loam C</td>
<td>0.06</td>
<td>0.39</td>
<td>0.30</td>
<td>0.12</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>0.02</td>
<td>0.41</td>
<td>0.25</td>
<td>0.10</td>
</tr>
<tr>
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<td>0.37</td>
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<td>0.09</td>
</tr>
<tr>
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<td>0.09</td>
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<tr>
<td>Very Gravelly Loam C</td>
<td>0.13</td>
<td>0.37</td>
<td>0.18</td>
<td>0.09</td>
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<tr>
<td>Alluvium</td>
<td>0.62</td>
<td>0.32</td>
<td>0.12</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Hydrogeology

Hydrogeologic Units

The Late Pliocene to Late Miocene Wilson Grove Formation (WGF) which consists of fine-grained loosely consolidated sandstone with layers of beach or dune sand is the primary aquifer in the study area. The WGF underlies much of the GVAC watershed (67%) as well as a small (7%) portion of the DBC watershed along its south and eastern boundaries. Underlying the WGF and exposed in most of the remainder of the watershed are a series of rocks of the Franciscan Complex and to a lesser extent the Great Valley Sequence. The rocks of the Franciscan Complex include sandstone and shale, a mélange of clastic rocks, serpentinite, basaltic pillow lava and breccias, and a mélange of metamorphic rocks. The rocks of the Great Valley Sequence are primarily siltstones.

In general the Franciscan Complex and the Great Valley Sequence are considered poor aquifer materials with limited groundwater available in bedrock fractures. Wells drilled in these bedrock units are often unsuccessful, and wells that do produce useful quantities of water typically have low capacities. The hydraulic properties of these rock types are highly variable depending on rock type and the degree of fracturing. The hydraulic characteristics of these primarily fractured bedrock units are not well known, and are expected to be spatially
discontinuous. Consequently, for the purposes of this analysis, the fractured bedrock units have all been lumped into a single unit and termed the Franciscan Complex (FC). This simplified representation characterizes the FC with aquifer parameters that contrast distinctly with the WGF where groundwater is generally available without attempting to describe the variability within the FC. Holocene Alluvium is present along most of the length of main-stem Atascadero Creek, West Atascadero Creek, Green Valley Creek, lower Purrington Creek, and the lowest reaches of Dutch Bill Creek.

Model Discretization

Several thousand driller’s logs (Well Completion Reports) were obtained from the State of California Department of Water Resources for the study area. The number of logs was reduced substantially by selecting the deepest logs with the greatest amount of stratigraphic detail, while simultaneously seeking to obtain good spatial coverage throughout the study area. Two hydrogeologic contacts were identified from these logs to constrain the structure of the simulated aquifers: the base of the WGF, and the base of the Alluvium. An isopach map of the WGF was interpolated from 111 driller’s logs that fully penetrated the formation. This map indicates that the WGF thickens from west to east from less than 100-ft in the western portions of the GAVC watershed to more than 650-ft along the divide with the Santa Rosa Plain (Figure 13).

An isopach map of the Alluvium was interpolated from 31 driller's logs that fully penetrated the alluvium. This map indicates that the Alluvium is relatively thin (20 - 40-ft) along lower Dutch Bill Creek, most of Green Valley Creek, and the upper reaches of Atascadero Creek. Above the confluence of Atascadero and West Fork Atascadero Creeks, the alluvium thickness along both creeks increases in the downstream direction from approximately 40- to 100-ft. Below this confluence the alluvium reaches a maximum thickness of ~150-ft upstream of Occidental Road, then decreases in thickness in the downstream direction to less than 40-ft at the confluence with Green Valley Creek. Along Purrington Creek the alluvium increases in thickness in the downstream direction from approximately 40- to 100-ft in the vicinity of Graton Road, then decreases sharply back to ~40-ft at the confluence with Green Valley Creek (Figure 14).

A two-layer groundwater model was developed based on the isopach maps described above. MIKE SHE requires that all layers be continuous across the entire model domain, thus Layer 1 represents the alluvium where present and either the WGF or FC elsewhere. Where the alluvium is present, Layer 2 represents the underlying WGF or FC and outside of the alluvium areas, the WGF or FC are represented in both Layers 1 and 2. The bottom of Layer 2 was developed first by subtracting the WGF isopach map from the surface topography and assuming
Figure 13 - Isopach map of the Wilson Grove Formation and geologic cross section locations.
Figure 14 - Isopach map of the Holocene Alluvium.
a minimum thickness of 100-ft for the WGF and for the areas underlain by the FC. To develop the bottom of Layer 1, two surfaces were developed individually and then combined to generate the final surface. The first surface was developed by subtracting the Alluvium isopach map from the surface topography and assuming a minimum thickness of 20-ft for the Alluvium. A second surface was developed for areas not underlain by Alluvium by halving the thickness of Layer 2 such that the thicknesses of the non-alluvial materials are approximately equal in Layers 1 and 2. The two surfaces were then mosaiced and the transition between them was smoothed by interpolation of thicknesses around the margins of the Alluvium to produce a final surface for the bottom of Layer 1. The thicknesses and materials represented by the resulting layers are summarized in Table 7 and two geologic cross sections through the model domain are shown in Figure 15.

**Hydraulic Properties**

Aquifer test data are available for eleven wells completed in the WGF in the adjacent Santa Rosa Plain. These data indicate a range of hydraulic conductivity (K) values of 3 to 65 ft/day (Kadir and McGuire, 1987; Nishikawa et al., 2013). Additionally, Cardwell (1958) estimated a range of K values for the WGF of 2 to 33 ft/day. Although no long duration aquifer test data was available, short-duration test data is recorded on many of the driller’s logs. This data can be used to derive estimates of the specific capacity (Sc) which can be related to transmissivity (T) using the empirical relationship: \( T = 1500 \times (Sc) \) (Driscoll, 1986), and then to K by dividing by the saturated thickness. This exercise was performed for 24 wells that fully penetrated the WGF in the watershed and the resulting values of K ranged from 0.03 to 2.9 ft/day with a mean value of 0.5 ft/day, significantly lower than previous estimates. A K value of 0.25 ft/day was determined for the WGF as part of the calibration process (Figure 16 & 17; Table 7). Although this value is lower than estimates derived from aquifer test data in the Santa Rosa Plain, this is consistent with descriptions of the formation from Cardwell (1958) where wells tapping the lower portion of the formation west of the Santa Rosa Plain were found to have specific capacity values significantly lower than wells tapping the upper portion of the formation within the Santa Rosa Plain.

No estimates of K were available for the FC or the Alluvium in the study area so initial model values were taken from literature values for similar materials (Freeze and Cherry, 1979). The driller’s logs indicate a wide variation in sediment sizes for the Alluvium ranging from sand and gravel to clay. Most logs (28 of 31) indicate the presence of at least some significant clay strata. Static water levels from logs penetrating through the Alluvium and into the underlying WGF indicate that confined or partially confined conditions are present in the WGF aquifer where it is overlain by alluvium. This is consistent with the description of confined conditions within the WGF in this area given by Cardwell (1958). The presence of confined conditions suggests that the Alluvium likely has a fairly low K value, and a value 2.5e-4 ft/day was determined through calibration for most of the Alluvium in the GVAC watershed. The single driller’s log penetrating the alluvium in lower Dutch Bill Creek indicates primarily sand and gravel, and the saturated K value for the soils in this area is the highest in the entire study area, thus a higher initial K
estimate of 1 ft/day was assumed for the Alluvium in the DBC watershed. The soils data also indicate an area of high saturated K for the area underlain by alluvium in a portion of central Atascadero Creek, thus a higher K estimate of 0.001 ft/day was assumed for this area (Figure 16 & 17; Table 7). A K value of 2.5e⁻⁵ ft/day was assumed for the FC which is consistent with previous findings that characterized the FC as non-water-bearing (Cardwell, 1958; Kunkel and Upson, 1960; Nishikawa et al., 2013).

Herbst et al. (1982) estimated a range of Specific Yield (Sy) values of 10 to 20% for the WGF. A value of 15% was assumed for the model (Table 7). Sy was estimated to be less than 3% for the FC (Herbst el al., 1982) and a value of 2% was used in the model. No estimates of Sy for the Alluvium in the study area were available, thus initial estimates were based on literature values from similar materials (Freeze and Cherry, 1979). Storativity (S) is only used by the model when confined conditions are present. Given the discretization and hydraulic properties used in the

Figure 15 - Geologic cross sections through the lower Atascadero Creek Watershed (top) and the upper Green Valley Creek Watershed (bottom), cross section locations are shown in Figure 13.
model, confined conditions are only possible for portions of the WGF overlain by Alluvium, thus the WGF is the only hydrogeologic unit requiring an estimate of S. Estimates of S for the WGF formation are available from aquifer tests at 5 wells in the adjacent Santa Rosa Plain (Kadir and McGuire, 1987; Nishikawa et al., 2013). These estimates were converted to an equivalent value for the model of 0.0005 based on the relative thicknesses of the aquifers from the test data and the model aquifer thickness.

**Boundary Conditions**

A no-flow boundary condition was applied for the bottom of Layer 2 based on the assumption that the interface between the WGF and the underlying low-permeability FC represents the depth of the active aquifer system such that only minor amounts of groundwater are exchanged across this boundary. Similarly, the margins of the model domain that consist of FC were simulated as no flow boundaries based on the assumption that only limited groundwater flow is transmitted into or out of the study area within the low-permeability FC.

Groundwater elevation data for Spring 2012 was available at twelve California Statewide Groundwater Elevation Monitoring (CASGEM) wells completed in the WGF in the GVAC watershed and in the western-most portion of the adjacent Santa Rosa Plain (CASGEM, 2014). Groundwater elevation contours derived from interpolation of the CASGEM data indicate that groundwater flows from west to east across the GVAC watershed and towards the Santa Rosa Plain (Figure 18). The contours indicate a flow direction roughly parallel to the GVAC/Santa Rosa Plain watershed divide and a gradient of ~0.01 ft/ft. Thus a constant gradient boundary of -0.01 ft/ft was applied for the boundary cells underlain by the WGF (Figures 16 and 17). This is consistent with the findings from the recent Santa Rosa Plain Groundwater Model which represented this watershed divide using boundary conditions that permitted inflow from the GVAC watershed to the Santa Rosa Plain (Woolfenden, 2014).

**Table 7 - Layer thicknesses and aquifer properties used in the hydrologic model.**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Total Thickness (ft)</th>
<th>Layer 1 Thickness (ft)</th>
<th>Hydraulic Conductivity (ft/day)</th>
<th>Specific Yield (%)</th>
<th>Layer 2 Thickness (ft)</th>
<th>Hydraulic Conductivity (ft/day)</th>
<th>Specific Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>20 - 151</td>
<td>20 - 151</td>
<td>0.00025 - 1</td>
<td>8 - 23</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wilson Grove</td>
<td>50 - 654</td>
<td>20 - 327</td>
<td>0.25</td>
<td>15</td>
<td>50 - 593</td>
<td>0.25</td>
<td>15</td>
</tr>
<tr>
<td>Franciscan</td>
<td>50 - 232</td>
<td>20 - 115</td>
<td>0.000025</td>
<td>2</td>
<td>50 - 205</td>
<td>0.000025</td>
<td>2</td>
</tr>
</tbody>
</table>
Figure 16 - Distribution of Hydraulic Conductivity (K) and locations of boundary conditions for groundwater Layer 1.
Figure 17 - Distribution of Hydraulic Conductivity (K) and locations of boundary conditions for groundwater Layer 2.
Groundwater Pumping

Domestic Pumping
In order to estimate the distribution and rates of domestic groundwater pumping, we first identified the portions of the study area receiving water from sources outside the study area and excluded them from the analysis. These areas include western Sebastopol which receives water from municipal wells located in the Santa Rosa Plain, Forestville and Monte Rio and surrounding areas, and portions of Camp Meeker and Occidental which all receive water from the Russian River (Figure 19).

The study area includes all or portions of 315 census blocks and the total population in each census block was tabulated from the 2010 census data. The census data indicate that a total of 15,028 people reside in the study area. Of these 4,465 are served by water delivery from external sources. The remaining population of 10,563 was assumed to rely on groundwater for domestic use. An assumption was made that each parcel in the study area (excluding the water delivery areas) contains one domestic well; it was thus estimated that there are 4,352 domestic wells in the study area (Figure 20). The total population within each of the 315 census blocks was divided by the number of wells within each block to determine the number of people served by each well which ranged from 1.0 to 9.8 with an average of 2.4.

Per capita water use data was obtained for the City of Sebastopol for 2010 through 2013 indicating an average per capita use of 129 gallons per day (gal/d). Dry weather water treatment plant flow data was also obtained from the City of Sebastopol which indicated that 54% of the total use for 2010-2013 represented outdoor use with the remaining 46% representing indoor use. This outdoor use was assumed to occur between May and October in proportions that were based on irrigation data described in greater detail below for irrigation pumping. The Sebastopol data was used to develop a per capita time series of domestic groundwater pumping (Figure 21) which was then scaled based on the number of people served by each well and applied to the 4,352 domestic wells added to the model.

Irrigation Pumping
To estimate the distribution and rates of groundwater pumping for irrigation, each parcel corresponding to vineyard in the land cover map was assumed to contain one irrigation well. This resulted in an estimated 217 irrigation wells in the study area (Figure 20). The number of acres of vineyard served by each well (total vineyard acreage within each parcel) ranged from 0.6 to 101.9 with an average of 10.9 acres. Vineyards are the dominant irrigated crop in the study area. Some orchards and other crop types also receive irrigation water, however many orchards are not irrigated and insufficient data was available to delineate irrigated areas for other crop types, thus only vineyard irrigation was included.

All active surface water rights in the study area were compiled from the California State Water Resources Control Board's (SWRCB) Electronic Water Rights Information Management System (eWRIMS). From among these, nine water rights were identified where monthly water use was reported for 2008 through 2013 and vineyard irrigation was the only stated use. The average
Figure 18 - Groundwater elevation contours based on Spring 2012 measurements from CASGEM wells completed in the Wilson Grove Formation.
irrigation rate calculated from these nine water rights was 3.7 in/yr/ac. The reported water use data also provided a means of estimating the temporal distribution of irrigation which ranged from 0.21 inches in October to 1.15 inches in July (Figure 22). These average rates were scaled based on the number of acres served by each irrigation well and applied to the 217 irrigation wells added to the model. The temporal distribution of irrigation was also used to distribute the outdoor domestic use as described above for domestic pumping.

**Frost Protection Pumping**

All vineyards with frost protection systems that use water are required to register with the Sonoma County Agricultural Commissioner. A review of these registrations as compiled in the Sonoma County Frost Protection Registration Database revealed that 1,052 acres of vineyards in the study area were registered as using water for frost protection (SCDA, 2014). The registration compliance was estimated to be 90% (SCDA Staff, 2014), thus approximately 1,157 acres (39% of the total vineyard acreage) of vineyards in the study area use water for frost protection. The frost protected vineyards were located based on the parcel numbers provided in the frost protection database; the model land cover distribution of vineyards required some adjustments so that total frost protected acreage in the model agreed with the database. All of these vineyards are located in lower elevation areas within the GVAC watershed which are more prone to heavy frost (Figure 23).

The frost protection database also provides the number of acres using regular sprinklers versus micro-sprinklers and average application rates for each sprinkler type, however this data is not given for all of the registrations. Based on the reported proportions using each sprinkler type, an average application rate of 36.9 gal/min/ac was applied for all of the frost protected areas. Hourly temperature data was compiled for the Santa Rosa California Irrigation Management Information System (CIMIS) station located east of Sebastopol (CIMIS, 2005) which experiences temperatures similar to temperatures in the low-lying areas of the GVAC watershed (PRISM, 2010). The number of hours where temperatures were below 35 degrees between March 15th and May 15th of each year were tabulated to estimate the number of hours of frost protection application which ranged from 14 hours in 2014 to 110 hours in 2008. A time series of frost protection pumping was then developed from the temperature data and the average application rate (Figure 25).

**Summary of Groundwater Pumping**

Total estimated domestic groundwater pumping demand in the study area was 1,546 ac-ft/yr. Total estimated irrigation groundwater pumping demand was 726 ac-ft/yr. The frost protection groundwater pumping demand ranged from 81 ac-ft/yr in 2014 to 595 ac-ft/yr in 2008. Averaged over Water Years 2010 – 2014, domestic pumping represented 61% of the total demand, irrigation represented 28% of the total demand, and frost protection represented 11% of the demand (Figure 26). It is important to bear in mind that these breakdowns of demand by use category represent total annual demands and that the demands and distribution of demands by use category exhibit significant seasonal variability.
Figure 19 - Locations of water delivery areas and included in the hydrologic model.
Figure 20 - Locations of groundwater pumping wells included in the hydrologic model.
Figure 21 - Timeseries of per capita domestic groundwater pumping used in the hydrologic model.

Figure 22 - Timeseries of groundwater pumping for irrigation used in the hydrologic model.
Figure 23 - Distribution of irrigation and frost protection used in the hydrologic model.
Figure 24 - Distribution of Irrigation sources used in the hydrologic model.
Figure 25 - Timeseries of groundwater pumping for frost protection used in the hydrologic model.

Figure 26 - Summary of groundwater pumping by use category and subwatershed.
Chapter 5 - Model Calibration

Overview
The available stream flow gauging data consists of data from three stations operated by the Center for Environmental Management and Restoration (CEMAR) in the DBC watershed, five stations operated by CEMAR in the GVC watershed, and three stations operated by the National Marine Fisheries Service (NMFS) in the AC watershed. The periods of record are short (Water Year 2010 or 2011 to present) at all of these gauges and complete rating curves extending throughout the range of recorded flow were not available for any of them. We obtained all of the available gauging measurements and selected seven of the eleven gauges for rating curve development (Table 8 & Figure 27). The rating curves generally consist of a single power-law relationship for higher flows and between two and four separate power-law relationships for lower flows with temporal shifts corresponding to larger flow events and associated changes in channel bed configurations. Confidence in the high flow rating curves was sufficient to develop continuous flow records for Dutch Bill Creek above Tyrone Road (DB04), Green Valley Creek at Bones Road (GV01), and Purrington Creek above Graton Road (GV02). At the remaining stations flow records were only calculated for flows less than or equal to the highest measured flow.

In addition to the gauging data, wet/dry mapping of portions of Dutch Bill, Green Valley, and Purrington Creeks was available from the University of California Cooperative Extension (UCCE). This data consists of maps showing flow conditions (flowing, dry, intermittent flow) during September of 2013 and 2014. UCCE has also performed periodic measurements of summer riffle depths in two short reaches each in Dutch Bill Creek and Green Valley Creek. Both the wet/dry mapping and the riffle depth measurements provided a means of validating the surface water component of the model once calibration to the gauging data was complete.

Bi-annual groundwater elevation measurements are available for six wells in the AC watershed and one well in the GVC watershed (Figure 27). All seven wells are part of the California Statewide Groundwater Elevation Monitoring (CASGEM) program (CASGEM, 2014) and all are completed in the Wilson Grove Formation. At most locations measurements were taken in the Fall and Spring with data available between Fall 2011 and Fall 2014 (Table 8). A groundwater elevation contour map was interpolated for Spring 2012 using data from these wells and several others located in the adjacent Santa Rosa Plain (Figure 18) to assist in validating the groundwater component of the model.

Calibrating a complex integrated hydrologic model such as MIKE SHE can be difficult owing to the large number of model parameters and long model run-times. The calibration process involved running an initial sensitivity analysis to identify a subset of parameters that the model results are most sensitive to. An upper and lower bound for each parameter was then defined based on a review of literature values and available watershed data. The model was then calibrated by adjusting one or more parameters in order to achieve a reasonable water balance and optimum fit between measured and simulated stream flows and groundwater elevations. Given the focus of this study on quantifying stream flow conditions to assist in fisheries habitat
restoration planning, the bulk of the calibration emphasis was on simulating summer base flow conditions as accurately as possible. The parameters that were adjusted during calibration included the following: horizontal and vertical hydraulic conductivities, streambed leakage coefficients, unsaturated hydraulic conductivities, overland Manning's roughness coefficients, drainage levels, and drainage time constants.

Table 8 - Summary of available stream flow gauges for the study area.

<table>
<thead>
<tr>
<th>Gauge Name</th>
<th>Symbol</th>
<th>Type</th>
<th>Period of Record</th>
<th>% Complete</th>
<th># Rating Curve Observations</th>
<th>Highest Gauged Flow (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purrington Creek at Graton Road</td>
<td>GV02</td>
<td>Continuous</td>
<td>2/2010 - 3/2014</td>
<td>89</td>
<td>32</td>
<td>134</td>
</tr>
<tr>
<td>Green Valley Creek at Bones Road</td>
<td>GV01</td>
<td>Continuous</td>
<td>1/2010 - 7/2014</td>
<td>89</td>
<td>25</td>
<td>156</td>
</tr>
<tr>
<td>Dutch Bill Creek above Tyron Road</td>
<td>D804</td>
<td>Continuous</td>
<td>6/2011 - 10/2013</td>
<td>97</td>
<td>19</td>
<td>365</td>
</tr>
<tr>
<td>Green Valley Creek above Atascadero</td>
<td>GV03</td>
<td>Low Flow Only</td>
<td>6/2010 - 7/2014</td>
<td>93</td>
<td>29</td>
<td>399</td>
</tr>
<tr>
<td>Green Valley Creek at Martinelli Road</td>
<td>GV06</td>
<td>Low Flow Only</td>
<td>4/2011 - 6/2011</td>
<td>100</td>
<td>6</td>
<td>27</td>
</tr>
<tr>
<td>Atascadero Creek at Watertrough Road</td>
<td>AT01</td>
<td>Low Flow Only</td>
<td>11/2010 - 6/2013</td>
<td>65</td>
<td>16</td>
<td>51</td>
</tr>
<tr>
<td>Atascadero Creek at Mill Station Road</td>
<td>AT02</td>
<td>Low Flow Only</td>
<td>11/2010 - 6/2013</td>
<td>65</td>
<td>14</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 9 - Summary of available groundwater observation data for the study area.

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Symbol</th>
<th>Period of Record</th>
<th># Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>383588N1228706W001</td>
<td>UA1</td>
<td>10/2011 - 10/2014</td>
<td>7</td>
</tr>
<tr>
<td>383971N1228879W001</td>
<td>MA1</td>
<td>11/2011 - 10/2014</td>
<td>7</td>
</tr>
<tr>
<td>383998N1228713W001</td>
<td>MA2</td>
<td>10/2011 - 10/2014</td>
<td>7</td>
</tr>
<tr>
<td>384111N1228448W001</td>
<td>MA3</td>
<td>4/2012 - 10/2014</td>
<td>6</td>
</tr>
<tr>
<td>384351N1228597W001</td>
<td>LA1</td>
<td>10/2011 - 10/2014</td>
<td>7</td>
</tr>
<tr>
<td>384505N1228683W001</td>
<td>LA2</td>
<td>4/2012 - 10/2014</td>
<td>6</td>
</tr>
<tr>
<td>384387N1229005W001</td>
<td>GV1</td>
<td>10/2011 - 10/2014</td>
<td>3</td>
</tr>
</tbody>
</table>
Surface Water Calibration

Three goodness-of-fit statistics were used to evaluate the agreement between model simulated stream discharges and measured stream discharges. These statistics included the Mean Error (ME), Root Mean Square Error (RMSE), and the Nash-Sutcliffe model efficiency coefficient (NSME) (Nash and Sutcliffe, 1970). ME and RMSE provide an overall measure of the model bias and have been calculated for the full period of record at the three gauges with sufficient high flow rating curves and for all seven gauges for the May through September low flow period.
The NSME provides an overall measure of the predictive capability of the model. A NSME value of zero indicates that model predictions are as accurate as the mean of the measured data and a value of one indicates a perfect calibration. NSME has only been calculated for the three gauges with high flow rating curves deemed sufficient for developing continuous flow records. Given the uncertainties in the high flow rating curves, the NSME calculations excluded days when observed discharges exceeded the highest gauged flow (see Table 8).

Due to the limited periods of record at the available gauging locations it was deemed more appropriate to calibrate the model to all of the available data rather than divide the simulation into calibration and validation periods as is more typically done when long-term gauging data is available. Figures 28 through 31 show the comparison between model simulated and measured discharges for the three gauges with continuous flow records. Figures 32 through 35 show the comparison between model simulated and measured discharges for all of the selected gauges focusing on the low flow period that is most critical from a coho habitat perspective. Calibration statistics are presented in Table 10.

The match between simulated and measured stream flows was generally good at all three of the continuous gauging locations. The model reproduces the quick responses in stream flow during runoff events that is characteristic of the watersheds as well as the overall shape of rising and receding flows. RMSE values ranged from 6.7 to 7.8 cfs and NSME values ranged from 0.67 to 0.73. The largest errors occur during the largest runoff events where the model sometimes significantly over-predicts peak flows and significantly under-predicts at other times. Given the uncertainties in the high flow rating curves at these gauges and the fact that the bulk of the calibration effort was focused on low flow periods most critical for understanding coho habitat, these differences are not surprising.

During low flow periods most critical for understanding coho habitat, the model performance is generally very good. Both the shape and timing of the spring flow recessions as well as the magnitudes of summer baseflow are generally well-represented by the model. RMSE values for the May through September low flow period ranged from 0.1 cfs at the Purrington Creek at Graton Road and Green Valley Creek at Bones Road gauges to 1.6 cfs at the Atascadero Creek at Mill Station Road gauge. The overall tendency of the model is to over-predict low flows somewhat particularly during the spring flow recession and in the late summer and early fall when stream flows drop close to zero.

The model appears to significantly over-predict flows during certain runoff events including three events in October of 2010, 2011, and 2012, however closer examination of the precipitation data suggests that these differences may be an artifact of inaccuracies in the rainfall records. For example, the model predicts a large peak on October 24, 2010 and the Graton rainfall gauge recorded 5.5 inches of precipitation on this date whereas the Occidental gauge recorded zero rainfall. Similar discrepancies were found for events on October 5, 2011 and October 22, 2012 where the model predicts significant peak discharge, the Graton gauge recorded 1.2 inches of precipitation, and the Occidental gauge recorded zero or 0.1 inches. Additionally, significant runoff is recorded at several of the stream gauges between October 26,
2011 and October 29, 2011 which the model does not capture because both rainfall gauges recorded zero rainfall on these dates. General consistency between the two rainfall records and generally good agreement between the timing of model simulated and measured stream flow events suggests that these problems with the rainfall records are relatively isolated.

Table 10 - Stream flow calibration results.

<table>
<thead>
<tr>
<th>Gauge Name</th>
<th>Time Period</th>
<th>ME (cfs)</th>
<th>RMSE (cfs)</th>
<th>NSME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purrington Creek at Graton Road</td>
<td>Continuous</td>
<td>-0.1</td>
<td>6.7</td>
<td>0.73</td>
</tr>
<tr>
<td>Green Valley Creek at Bones Road</td>
<td>Continuous</td>
<td>1.2</td>
<td>7.8</td>
<td>0.67</td>
</tr>
<tr>
<td>Dutch Bill Creek above Tyrone Road</td>
<td>Continuous</td>
<td>2.4</td>
<td>7.8</td>
<td>0.76</td>
</tr>
<tr>
<td>Purrington Creek at Graton Road</td>
<td>May - Sept</td>
<td>0.3</td>
<td>0.1</td>
<td>-</td>
</tr>
<tr>
<td>Green Valley Creek at Bones Road</td>
<td>May - Sept</td>
<td>0.0</td>
<td>0.1</td>
<td>-</td>
</tr>
<tr>
<td>Dutch Bill Creek above Tyrone Road</td>
<td>May - Sept</td>
<td>-0.2</td>
<td>0.8</td>
<td>-</td>
</tr>
<tr>
<td>Green Valley Creek above Atascadero</td>
<td>May - Sept</td>
<td>0.5</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>Green Valley Creek at Martinelli Road</td>
<td>May - Sept</td>
<td>0.6</td>
<td>1.1</td>
<td>-</td>
</tr>
<tr>
<td>Atascadero Creek at Watertrough Road</td>
<td>May - Sept</td>
<td>0.6</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Atascadero Creek at Mill Station Road</td>
<td>May - Sept</td>
<td>1.6</td>
<td>1.6</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 28 - Comparison of measured and simulated stream flows for WY 2010 - 2013 for Purrington Creek at Graton Road.
Figure 28 (continued)

Figure 29 - Comparison of measured and simulated stream flows for WY 2010 - 2013 for Green Valley Creek at Bones Road.
Figure 29 (continued)
Figure 30 - Comparison of measured and simulated stream flows for WY 2012 - 2013 for Dutch Bill Creek above Tyrone Road.
Figure 31 - Comparison of measured and simulated flow durations curves for Purrington Creek at Graton Road, Green Valley Creek at Bones Road, and Dutch Bill Creek above Tyrone Road.
Figure 32 - Comparison of measured and simulated stream flows for the WY 2010 summer baseflow period at all gauging locations with available data.
Figure 33 - Comparison of measured and simulated stream flows for the WY 2011 summer baseflow period at all gauging locations with available data.
Figure 33 (continued)
Figure 33 (continued)
Figure 34 - Comparison of measured and simulated stream flows for the WY 2012 summer baseflow period at all gauging locations with available data.
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Figure 34 (continued)
Figure 35 - Comparison of measured and simulated stream flows for the WY 2013 summer baseflow period at all gauging locations with available data.
Figure 35 - (continued)
Comparisons between riffle depth measurements collected by UCCE between June and October and simulated water depths at model cross sections within the ~1,000-ft long measurement reaches are shown in Table 11 and Figures 36 & 37. The simulated model depths show overall agreement with the measured riffle depths in terms of the timing and degree of depth declines as the dry season progresses. MEs ranged from -0.15 to 0.14 ft and RMSEs ranged from 0.08 to 0.16 ft. Depths were predicted best at the Green Valley - Upper and Dutch Bill - Lower sites where MEs ranged from -0.01 to -0.06 ft. The model over-predicts (ME of 0.14 ft) depths at the Green Valley - Lower site particularly during the driest conditions and under-predicts (ME of -0.15 ft) depths at the Dutch Bill - Upper site.

Comparisons between reaches mapped as wet, dry, and intermittent and corresponding simulated flow conditions during September of 2013 and September of 2014 are shown in Figures 38 & 39. For the purposes of this comparison, the simulated discharges were used to define dry reaches as those with zero discharge and intermittent reaches as those with discharges of less than 0.05 cfs. There is overall agreement between the patterns of wet and dry reaches. In the upper reaches of Upper Green Valley Creek the model predicts drier conditions than the observations, however the transition to mostly flowing conditions occurs at a similar position in the watershed. In Dutch Bill Creek both the simulated and observed maps show transitions to dry conditions occurring at similar positions in the watershed in both the upper and lower reaches of the creek.

Table 11 - Riffle depth calibration results.

<table>
<thead>
<tr>
<th>Reach Name</th>
<th>ME (ft)</th>
<th>RMSE (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Valley Creek - Lower</td>
<td>0.14</td>
<td>0.16</td>
</tr>
<tr>
<td>Green Valley Creek - Upper</td>
<td>-0.06</td>
<td>0.10</td>
</tr>
<tr>
<td>Dutch Bill Creek - Lower</td>
<td>-0.01</td>
<td>0.08</td>
</tr>
<tr>
<td>Dutch Bill Creek - Upper</td>
<td>-0.15</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Figure 36 - Comparison of measured riffle depths and simulated water depths for two reaches in upper Green Valley Creek.
Figure 37 - Comparison of measured riffle depths and simulated water depths for two reaches in Dutch Bill Creek.
Figure 38 - Comparison between September 2013 wet/dry mapping and the extent of wet/dry reaches simulated with the hydrologic model.
Figure 39 - Comparison between September 2014 wet/dry mapping and the extent of wet/dry reaches simulated with the hydrologic model.

**Groundwater Calibration**
In order to evaluate the agreement between model simulated groundwater elevations and measured groundwater elevations, Mean Error (ME) and Root Mean Square Error (RMSE) were calculated for the residuals (difference between simulated and observed groundwater elevations) at each of the seven monitoring wells. Due to the limited periods of record at the available monitoring locations it was deemed more appropriate to calibrate the model to all of the available data rather than divide the simulation into calibration and validation periods as is more typically done when long-term gauging data is available. The composite comparison of simulated and measured groundwater elevations is shown in Figure 40. Figure 41 shows the
comparison between model simulated and measured groundwater elevations for each of the seven monitoring wells with available data and calibration statistics are presented in Table 12.

It should be noted that six of the seven monitoring wells used for model calibration are drilled in the WGF aquifer. The WGF aquifer has relatively consistent hydraulic properties and the groundwater calibration using these data provides a regionally-representative estimate of WGF hydraulic characteristics. Well GV1 is located in the FC at the edge of a thin, isolated outcrop of the WGF and should not be considered to provide adequate representation of groundwater conditions in the FC.

Overall, groundwater elevations are reasonably well-predicted by the model. MEs range from -3.7 to 7.7-ft at the UA1, GV1, MA1, and MA2 stations. At the remaining stations (MA3, LA1, LA2), groundwater elevations are over-predicted and MEs range from 12.1 to 35.1-ft. These three wells are all located relatively close to the boundary separating the study area from the Santa Rosa Plain where simulated groundwater elevations would be expected to be influenced by the assumptions made to represent the boundary. Additional monitoring data in this vicinity could be used to refine the model representation of the boundary, possibly leading to improved calibration at wells MA3, LA1, and LA2 and refined estimates of groundwater outflows to the Santa Rosa Plain. Both the simulated and measured data show minor seasonal fluctuations in groundwater elevations on the order of 2 to 5-ft and either a stable or slight negative trend in elevations between 2011 and 2014.

Table 12 - Groundwater calibration results.

<table>
<thead>
<tr>
<th>Well</th>
<th>ME</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA1</td>
<td>-3.7</td>
<td>4.1</td>
</tr>
<tr>
<td>MA1</td>
<td>2.7</td>
<td>4.7</td>
</tr>
<tr>
<td>MA2</td>
<td>7.7</td>
<td>9.7</td>
</tr>
<tr>
<td>MA3</td>
<td>12.1</td>
<td>12.2</td>
</tr>
<tr>
<td>LA1</td>
<td>35.1</td>
<td>35.2</td>
</tr>
<tr>
<td>LA2</td>
<td>30.3</td>
<td>30.4</td>
</tr>
<tr>
<td>GV1</td>
<td>1.8</td>
<td>2.1</td>
</tr>
</tbody>
</table>
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Figure 40 - Composite of simulated and measured groundwater elevations at seven monitoring wells for WY 2011 - 2014.

Figure 41 - Comparison of measured and simulated groundwater elevations for WY 2011 - 2014.
Figure 41 (continued)
Chapter 6 - Results

Water Budgets
A description of the water balance is one of the most fundamental outputs from the model. Water balance information can be extracted for the full study area or for any subarea. Water balances can be highly detailed (e.g. decompose ET into interception, evaporation, transpiration from the unsaturated zone, and transpiration from groundwater) or more general. For the purposes of this preliminary modeling effort, a basic overall annual water budget and a groundwater budget are presented for the GVAC and DBC watersheds for each of the simulated Water Years of 2010 - 2014. A monthly water budget is also presented for selected water budget terms as are maps depicting the spatial variations of key water budget components.

Hydrologic Water Budgets
The primary inflow in the GVAC watershed was precipitation, which ranged from 25.7 inches in the dry Water Year of 2014 to 56.3 inches in the moderately wet Water Year of 2011 (Table 13). Irrigation is a much less significant additional source of inflow (0.5 to 0.6 in/yr) and it was relatively uniform between Water Years owing to the way the irrigation demands were calculated. Except for the moderately wet year of 2011, ET was the largest outflow from the watershed. Variations in ET were significantly less than the variations in precipitation and ranged from 18.1 inches in 2014 to 25.1 inches in 2011. Stream flow was the next largest outflow from the watershed and it varied substantially and in a similar fashion to precipitation ranging from 10.0 inches in 2014 to 27.3 inches in 2011. Groundwater pumping was more than an order of magnitude less than ET or stream flow (1.1 to 1.2 in/yr) and was relatively uniform owing to the way input water demands were calculated. Groundwater boundary outflows were a constant 0.3 in/yr. Increases in storage of 3.0 to 3.1 inches occurred during Water Years 2010 and 2011 and decreases in storage of 0.3 to 3.4 inches occurred during Water Years 2012 -2014.

Nearly all of the inflow in the DBC watershed was precipitation, which ranged from 35.0 inches in the dry Water Year of 2014 to 67.5 in the moderately wet Water Year of 2011 (Table 13). Irrigation is a much less significant additional source of inflow (0.1 in/yr). ET was the largest outflow from the watershed during the driest two Water Years and stream flow was the largest outflow during the three other Water Years. Variations in ET were significantly less than the variations in precipitation and ranged from 18.9 inches in 2014 to 26.7 inches in 2011. Stream flow varied substantially and in a similar fashion to precipitation ranging from 16.8 inches in 2014 to 40.3 inches in 2011. Groundwater pumping was a very small component of the water budget (0.2 in/yr). Decreases in storage of 0.7 to 0.8 inches occurred during the two driest Water Years 2012 and 2014 and increases in storage of 0.2 to 0.4 inches occurred during the remaining three Water Years.

Groundwater Budgets
Infiltration recharge represented the largest source of groundwater recharge to the GVAC watershed in 2010, 2011, and 2013, however during the driest two years 2012 and 2014,
streambed recharge was the dominant component of total recharge (Table 14). Annual infiltration recharge varied from 2.0 inches during the dry Water Year of 2014 to 10.5 inches during the moderately wet Water Year of 2011. Streambed infiltration varied much less than infiltration ranging from 4.8 to 6.4 inches. Baseflow discharge to streams was the largest source of groundwater outflow and it was relatively uniform between Water Years, ranging from 5.5 to 6.7 inches. Groundwater discharge directly to the land surface varied from 1.4 inches in WY 2014 to 3.5 inches in WY 2011. ET from groundwater was relatively uniform and ranged from 2.1 to 2.4 inches. Groundwater pumping and groundwater boundary outflows were both relatively uniform and were 1.1 and 0.3 inches per year respectively.

Infiltration recharge represented the largest source of groundwater recharge to the DBC watershed and varied from 2.0 inches during the dry Water Year of 2014 to 5.4 inches during
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the moderately wet Water Year of 2011 (Table 14). In contrast to the GVAC watershed, streambed infiltration was highest during the dry Water Year of 2014 (1.3 inches) and lowest during the average Water Year of 2010 (0.6 inches). Baseflow discharge to streams was the largest source of groundwater outflow and it ranged from 1.9 to 3.4. Groundwater discharge directly to the land surface varied from 0.6 to 1.7 inches. ET from groundwater was relatively uniform and ranged from 0.7 to 0.8 inches. Groundwater pumping was a small component of the groundwater budget and was a uniform 0.2 inches per year.

Spatial and Temporal Variations of Water Budget Components

ET was generally lowest during the winter months, highest during May when potential ET was relatively high and available soil moisture was plentiful, and progressively decreasing throughout the summer months as available soil moisture diminished (Figure 42). Groundwater recharge only occurred during months with significant precipitation. During Water Year 2010 recharge occurred every month between November and April whereas during the dry Water Year of 2014 recharge only occurred during March and April. Small negative recharge values (indicating groundwater discharge to the land surface in excess of infiltration recharge) occurred between May and October of most years, however exceptionally dry conditions resulted in negative recharge persisting for 12 of 13 months between February of 2013 and February of 2014. These effects are more pronounced in the GVAC watershed where a larger proportion of the watershed is characterized by high water table conditions and consequently transpiration from groundwater and rejected recharge are higher.

Figure 43 shows the monthly variations in the different components responsible for stream flow generation. On an overall annual basis, runoff was the largest component of stream flow (62%), with interflow (drainage) being the next most significant component (36%), and baseflow accounting for only 2%. Despite being dwarfed by runoff and interflow on an annual basis, between May and October of most years, baseflow is the dominant source of stream flow. During months of high precipitation, a net loss of stream flow to groundwater occurs (streambed losses exceed gains). Some losses continue throughout the year, however a net gain of stream flow from groundwater occurs throughout the summer months. These effects are more pronounced in the GVAC watershed where the degree of surface water/groundwater interaction tends to be greater than in the DBC watershed. The pattern of interflow tends to follow that of runoff but with some temporal lag resulting in a situation where interflow becomes the dominant component of stream flow during March and/or April of some years. This effect is most pronounced in the DBC watershed.

Significant variations in groundwater recharge across the watersheds occurs as the result of numerous landscape factors, most notably soil hydraulic conductivity, geology, topographic position, land cover and ET, and the east to west precipitation gradient. Recharge ranged from as low as -1 inches to more than 23 inches during Water Year 2010 and from -2 to 13 inches during the dry Water Year of 2014 (Figures 44 & 45). Recharge was lowest in the valley-bottom areas with extensive clay soils along Atascadero Creek, lower Green Valley Creek, and lower Purrington Creek and in other areas with clayey soils scattered throughout the watershed.
Highest recharge values occurred throughout the higher elevation areas of the watersheds that are underlain by coarser soils.

Surface water/groundwater interactions defined as losses from streams to groundwater (losing stream reaches) and gains to streams from groundwater (gaining stream reaches) vary substantially across the study area and through time. On an average annual basis lower Atascadero and lower Green Valley Creeks were losing reaches with seepage losses of up to 30 cubic feet per day per foot of channel length (Figures 46 & 47). Surface water/groundwater interaction was minimal throughout most of the DBC watershed and in upper Purrington Creek owing to the low-permeability bedrock in those areas. In Water Year 2010 when conditions were relatively wet, the lower main-stem of Dutch Bill Creek and most of upper Green Valley, lower Purrington, Atascadero, and West Fork Atascadero Creeks were gaining reaches with gains of between 0.3 and 15 cubic feet per day per foot of channel length. During the dry Water Year of 2014, the extent of gaining reaches decreased dramatically compared to 2010 and many reaches that were gaining in 2010 were losing reaches in 2014 (Figure 48).
Transpiration varies across the watershed from less than 2 inches per year to more than 30 inches per year (Figures 49 & 50). The variations appear to be driven primarily by the distribution of land cover types, soil moisture capacity, and potential ET. Comparing the simulated Water Year 2014 transpiration with 2010 transpiration reveals that transpiration values are lower in 2014 than in 2010 in many areas, however values remain relatively unchanged in other areas. In particular the areas along the reaches of lower Atascadero and Green Valley Creeks that were shown to be net losing reaches have very high transpiration that persists even in dry 2014 conditions. This can be attributed to the presence of willows and other phreatophytes that are able to maintain access to the shallow water table in this area even under drought conditions.

Figure 43 - Simulated monthly water budget for the various components of total stream flow for WY 2010 - 2014.
Figure 44 - Simulated annual groundwater recharge for WY 2010.
Figure 45 - Simulated annual groundwater recharge for WY 2014.
Figure 46 - Simulated mean annual surface water/groundwater exchange for WY 2010.
Figure 47 - Simulated mean annual surface water/groundwater exchange for WY 2014.
Figure 48 - Comparison of mean annual surface water/groundwater exchange for WY 2010 and WY 2014 in Purrington Creek and upper Green Valley Creek.
Figure 49 - Simulated annual transpiration for WY 2010.
Figure 50 - Simulated annual transpiration for WY 2014.
Streamflow

Mean Annual Discharge
Mean annual discharges varied from <1 cfs in headwater reaches to 25 to 50 cfs in lower Green Valley Creek depending on the Water Year (Figures 51 & 52). Mean annual discharge in Atascadero Creek and West Fork Atascadero Creek increased in the downstream direction from <1 to 15 cfs during WY 2010 and from <1 to 10 cfs during WY 2014. Below the confluence of those two creeks and upstream of Occidental Road, mean annual discharges in Atascadero Creek ranged from 20 to 30 cfs in WY 2010 and from 10 to 15 cfs in WY 2014. Between Occidental Road and the confluence with Green Valley Creek, flows decreased to 10 to 20 cfs in WY 2010 and to 5 to 15 cfs in 2014.

In Purrington Creek, mean annual discharge increased in the downstream direction from <1 cfs to 10 cfs in WY 2010 and from <1 to 5 cfs in WY 2014. During WY 2010, mean annual discharge in upper Green Valley Creek increased in the downstream direction from <1 to 15 cfs at the confluence with Purrington Creek and to 20 cfs at the confluence with Atascadero Creek. During WY 2014 flows ranged from <1 to 10 cfs throughout the reach upstream of the Atascadero confluence. Lower Green Valley Creek had the highest mean annual discharges which ranged from 40 to 60 cfs in WY 2010 and from 15 to 30 in WY 2014. Discharges in Dutch Bill Creek increased progressively in the downstream direction from <1 to 30 cfs in WY 2010 and from <1 to 20 cfs in WY 2014.

Mean Summer Discharge
Mean June 15th to September 15th baseflow discharges (hereafter referred to as summer discharge) varied from zero in headwater reaches to 1.3 cfs in portions of Atascadero, West Fork Atascadero and Green Valley Creeks (Figures 53 and 54). Mean summer discharge in West Fork Atascadero Creek increased in the downstream direction from zero to 1.0 cfs during WY 2010 and from zero to 0.5 cfs during WY 2014. Above the confluence with West Fork Atascadero Creek, Atascadero Creek summer discharges ranged from zero to 0.3 cfs in WY 2010 and from zero to 0.2 cfs in WY 2014. Below the confluence of those two creeks and upstream of Occidental Road, discharges in Atascadero Creek ranged from 0.7 to 1.3 cfs in WY 2010 and from 0.3 to 0.5 cfs in WY 2014. The reach of Atascadero Creek between Graton Road and the confluence with Green Valley Creek was particularly dry with mean summer flows ranging from zero to 0.2 cfs.

In Purrington Creek, mean summer discharges increased from zero to 1.0 cfs in WY 2010 and from zero to 0.5 cfs in WY 2014. During WY 2010, mean summer discharges in upper Green Valley Creek increased in the downstream direction from zero to 0.5 cfs at the confluence with Purrington Creek and to 1.3 cfs at the confluence with Atascadero Creek. During WY 2014 flows ranged from zero to 0.2 cfs above the Purrington Creek confluence and to 0.7 cfs at the confluence with Atascadero Creek. Lower Green Valley Creek was characterized by declining flows in the downstream direction ranging from 0.3 cfs to 1.3 cfs in WY 2010 and from <0.05 to 1.3 cfs in WY 2014. With the exception of the lowest alluvial reach where conditions were very
dry (<0.05 cfs), discharges in Dutch Bill Creek increased progressively in the downstream direction from zero to 0.3 cfs in WY 2010 and from zero to 0.2 cfs in WY 2014.

**Minimum Summer Discharge**
The patterns of minimum summer discharge are generally similar to those of mean summer discharge. The following discussion focuses on describing the extent of reaches with very dry minimum discharge conditions and any significant differences between mean and minimum summer discharges. A short reach of Atascadero Creek just upstream of the confluence with West Fork Atascadero Creek was dry during both WY 2010 and WY 2014 as was most of the reach extending from ~1,000-ft upstream of Graton Road to the confluence with Green Valley Creek (Figures 55 & 56).

In Purrington Creek, flows remained perennial for the most part with the exception of a short reach upstream of the lowest Graton Road crossing that was dry in WY 2014. Upper Green Valley Creek was dry upstream of the upper Green Valley Road crossing in WY 2010 and for an additional 1,500-ft below the crossing in WY 2014 (Figures 55 & 56). Small flows persisted throughout lower Green Valley Creek in WY 2010, however the creek was dry between the confluence of Atascadero Creek downstream to a point 1,200-ft upstream of the Highway 116 crossing in WY 2014. The extent of perennial flow in Dutch Bill Creek is very similar in both WY 2010 and 2014. The creek was dry upstream of the confluence with Lancel Creek and for the lowest 9,500-ft above the confluence with the Russian River.
Figure 51 - Simulated mean annual discharge for WY 2010.
Figure 52 - Simulated mean annual discharge for WY 2014.
Figure 53 - Simulated mean June 15th - Sept 15th discharge for WY 2010.
Figure 54 - Simulated mean June 15th - Sept 15th discharge for WY 2014.
Figure 55 - Simulated minimum discharge for WY 2010.
Figure 56 - Simulated minimum discharge for WY 2014.
Groundwater
Simulated Layer 1 groundwater elevations for April 1st, 2010 and October 1st, 2010 are shown in Figures 57 and 58. These elevations represent a composite of all of the geologic materials represented by Layer 1 (Alluvium, Wilson Grove Formation, Franciscan Complex). Groundwater flow directions generally follow topographic patterns with elevations in the GVAC watershed ranging from 700 to 1,000-ft asl in the headwaters of Atascadero, upper Green Valley and Purrington Creeks to less than 100-ft asl in lower Green Valley Creek. Groundwater gradients are much steeper in the DBC watershed with elevations ranging from 1,400-ft asl along the eastern watershed divide to less than 100-ft asl near the confluence with the Russian River. Throughout the study area groundwater gradients generally converge towards the major stream channels, and in lower Atascadero Creek, groundwater also flows southwest to northeast towards the adjacent Santa Rosa Plain. Groundwater elevations are slightly lower in October than in May, however the overall directions of groundwater flow are very similar seasonally and throughout the five year simulation period.

Figure 59 shows the change in groundwater elevations between October 1st, 2010 and October 1st, 2014. Areas underlain by rocks of the Franciscan Complex exhibited relatively small changes in groundwater elevations whereas areas underlain by the Wilson Grove Formation exhibited larger changes. Within the Franciscan Complex, changes were generally less than 2-ft and within the Wilson Grove Formation changes ranged from slight increases to decreases of up to 14-ft. The largest changes occurred along the western edges of the upper Atascadero and West Fork Atascadero creek watersheds, and in smaller areas in the lower Purrington Creek watershed and near the watershed divide between the lower portion of upper Green Valley Creek and lower Green Valley Creek. Decreases in elevations of up to 10-ft also occurred along the eastern-side of lower Atascadero and lower Green Valley Creeks.
Figure 57 - April 2010 simulated groundwater elevations. Note that areas underlain by the Franciscan Complex have been simulated using a simplified representation of aquifer characteristics and that simulated groundwater elevations in these areas may not be representative of local conditions.
Figure 58 - October 2010 simulated groundwater elevations. Note that areas underlain by the Franciscan Complex have been simulated using a simplified representation of aquifer characteristics and that simulated groundwater elevations in these areas may not be representative of local conditions.
Figure 59 - Simulated change in groundwater elevations from October 1, 2009 to October 1, 2014. Note that areas underlain by the Franciscan Complex have been simulated using a simplified representation of aquifer characteristics and that simulated groundwater elevations in these areas may not be representative of local conditions.
Chapter 7 - Habitat Characterization

Approach
A lack of adequate stream flow to support juvenile rearing habitat during the summer months has been identified as a primary limiting factor for coho survival in Russian River tributaries in general (CDFG, 2004; NFMS, 2012) and in Green Valley Creek specifically (GRRCD, 2010; GRRCD, 2013). Numerous methods have been developed to relate stream flow conditions to habitat quality and define minimum flow requirements for a specific species and life stage of interest. These methods include applying regional regression equations that have been developed from multiple habitat suitability curve studies (e.g. Hatfield and Bruce, 2000), wetted perimeter and critical riffle depth methods (e.g. Swift, 1979, R2 Resource Consultants, 2008), and direct habitat mapping approaches (e.g. McBain and Trush, 2010).

Regional regression equations produce discharge estimates for Green Valley and Dutch Bill Creeks that are an order of magnitude higher than those observed during the summer months at the stream flow gauges in the watersheds. Given that these streams provide some of the best remaining coho habitat in the Russian River watershed despite these very low flow conditions, application of these regional equations may be of limited value for delineating the extent and quality of existing habitat availability with respect to base flow. Direct habitat mapping approaches require detailed fieldwork which is beyond the scope of this study, however these approaches could be utilized in future work. Perhaps the most straightforward way to utilize the hydrologic model results to delineate habitat availability is by applying the critical riffle depth concept to the model simulated water depths. The application of this approach assumes that the modeled cross sections represent riffle locations. This assumption is reasonable given the fact that the cross sections are developed from LiDAR which does not penetrate water and therefore would not be expected to capture pool geometry and by the good agreement between model simulated depths and riffle depth measurements collected by UCCE.

The critical riffle depth concept is based on defining minimum flow depth criteria for fish passage through critical riffles. In essence these criteria represent the minimum flow condition where fish are able to move between pools. A minimum passage depth of 0.3 feet has been estimated for juvenile coho (R2 Resource Consultants, 2008; CDFG, 2013). This depth criteria is somewhat conservative by design and fish passage has been observed at shallower depths therefore it is useful to define a lower criteria below which passage is presumably not possible. For the purposes of this study, that depth was defined as 0.1 feet.

Through field monitoring in Green Valley Creek, UCCE has found that coho can survive in pools that become disconnected for short periods of time, however survival decreases sharply as a function of the length of pool disconnection (UCCE, 2015) largely due to the low dissolved oxygen conditions that develop in disconnected pools (Figure 60). Thus in addition to delineating reaches where passage between pools is possible it is useful to delineate reaches that become dry for short periods of time and reaches that become dry for extended periods of time. A disconnection length of 14 consecutive days was used for this analysis which
corresponds to an 85% survival rating and the point beyond which survival begins to decline sharply (UCCE, 2015).

Extensive characterization of pool availability has been conducted in these watersheds and numerous instream restoration projects designed to enhance pool habitat have been implemented in recent years. This analysis assumes that pool habitat availability is adequate and instead focuses on characterizing the degree of connectivity between pools. Future work to combine the flow connectivity results produced here with pool inventory data could be used to develop a more comprehensive analysis that considers both pool availability and connectivity, however such work is beyond the scope of this analysis.

Figure 60 - Relationship between coho survival and the length of pool disconnection established by UCCE in Green Valley Creek.
Results
Flow availability-based habitat maps depicting the minimum water depths and extent of short- and long-term disconnected reaches for WY 2010 and WY 2014 are presented in Figures 61 and 62. Longitudinal profiles of flow-availability based habitat showing both minimum and average June 15 - September 15th conditions for Upper Green Valley, Purrington, and Dutch Bill creeks are presented in Figures 63 through 65. The flow-availability conditions discussed in detail below are summarized on a reach-by-reach basis in Table 15.

Upper Green Valley Creek
Long-term disconnection of pools is predicted to occur during both dry and average flow conditions throughout the reach extending from the headwaters of upper Green Valley Creek through the middle Green Valley Road crossing. Pools within the reach between the middle Green Valley Road crossing and the Bones Road crossing remained connected during WY 2010 but long-term disconnection occurred throughout the reach during WY 2014. During WY 2010, minimum water depths were below the minimum passage threshold (0.1-ft) and summer average water depths were approximately equal to the threshold indicating that passage between pools within this reach was marginal and likely only possible during the early summer months.

Pools within the reach between the Bones Road crossing and the confluence with Purrington Creek remained connected during both dry and average flow conditions with the exception of the ~1,900-ft reach below Bones Road where pools became disconnected during WY 2014. Water depths remained above the 0.1-ft minimum passage threshold but below the 0.3-ft optimal passage threshold during both dry and average flow conditions. This suggests that aside from the ~1,900-ft reach below Bones Road, passage between pools was adequate throughout the reach even during dry Water Year conditions.

The reach between the confluence with Purrington Creek and the confluence with Atascadero Creek remained connected with flow depths near the 0.3-ft optimal passage threshold during WY 2010 and between the minimum and optimal passage threshold during WY 2014. It should be noted that the model calibration shows that the model over-predicts depths in the lowest portion of this reach above the Atascadero Creek confluence and that some disconnected pools have been observed in this reach during dry Water Year conditions.

Lower Green Valley Creek
Pools remained connected throughout lower Green Valley Creek during WY 2010 with flow depths above the 0.3-ft optimal passage threshold except in a few short reaches where depths remained well above the minimum passage threshold. During WY 2014, the reach between the confluence with Atascadero Creek and a point ~1,600-ft upstream of the Hwy 116 crossing was characterized by alternating reaches of short- and long-term disconnection of pools indicating that passage in this reach was marginal and likely only possible during the early summer months. Downstream of this reach through the confluence with the Russian River, pools in lower Green Valley Creek remained connected even in dry Water Year flow conditions with
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water depths well above the minimum passage threshold and exceeding the optimal passage threshold in much of the reach.

**Purrington Creek**
Long-term disconnection of pools is predicted to occur between the headwaters of Purrington Creek through a point ~2,700-ft downstream of the upper-most Graton Road crossing. Between this point and the third Graton Road crossing (just downstream of Green Hill Road) pools remained connected, however water depths were generally below the 0.1-ft minimum passage threshold even during average Water Year conditions. This suggests that passage between pools was likely possible only during early summer conditions in this reach.

Between the third Graton Road crossing and the confluence with Green Valley Creek, pools remained connected during both WY 2010 and WY 2014 with the exception of a ~400-ft reach immediately upstream of the downstream-most Graton Road crossing where short-term disconnection occurred in WY 2014. Excluding this short reach, water depths were between the minimum and optimal passage threshold during both dry and average Water Year conditions indicating that passage between pools was adequate throughout this reach even during dry Water Year conditions.

**West Fork Atascadero Creek**
With the exception of the upper-most ~1,300 feet, pools in West Fork Atascadero Creek remained connected during both dry and average Water Year conditions. Upstream of the Wagnon Road crossing (1,800-ft upstream of the upper-most Hwy. 12 crossing) water depths were below the 0.1-ft minimum passage threshold for the most part indicating that passage between pools was generally not adequate. Between the Wagnon Road crossing and the second Hwy. 12 crossing, water depths were generally between the minimum and optimal passage depths during both dry and average Water Year conditions. Between the second Hwy. 12 crossing and the confluence with Atascadero Creek, passage depths were above the 0.3-ft optimal passage threshold during WY 2010 and either close to or above the threshold in WY 2014 as well.

**Upper Atascadero Creek**
Long-term disconnection of pools occurred throughout the upper-most ~4,300-ft of upper Atascadero Creek. Between this point and the Barnett Valley Road crossing pools remained connected, however water depths were below the 0.1-ft minimum passage threshold in some reaches indicating that passage between pools was likely only possible during the early portion of summer. Between the Barnett Valley Road crossing and the Hwy. 12 crossing, pools remained connected with water depths between the minimum and optimal passage thresholds with the exception of the 1,600-ft reach below Barnett Valley Road which experienced short-term disconnection during WY 2014. Short-term disconnection of pools occurred in the lower-most ~2,400-ft reach between the Hwy. 12 crossing and the confluence with West Fork Atascadero during WY 2010, and long-term disconnection of pools occurred within this reach during WY 2014.
Lower Atascadero Creek
Pools remained connected with passage depth generally above the 0.3-ft optimal passage depth threshold between the confluence of Atascadero and West Fork Atascadero creeks and a point ~1,200-ft upstream of the Graton Road crossing during both dry and average Water Year conditions. The reach between this point and the confluence with Green Valley Creek was characterized by alternating reaches of short- and long-term periods of zero discharge indicating the potential for temperature and/or dissolved oxygen problems to develop.

Dutch Bill Creek
Between the headwaters of Dutch Bill Creek and the confluence with Lancel Creek, long-term disconnection of pools occurred during both dry and average Water Year conditions. Between the Lancel Creek and Grub Creek confluences, pools remained connected, however water depths were generally below the 0.1-ft minimum passage threshold indicating that passage between pools was likely only possible during the early summer months. Between the confluence with Grub Creek and a point ~600-ft upstream of the Tyrone Road crossing, pools remained connected with water depths close to but generally above the 0.1-ft minimum passage threshold indicating that passage conditions were adequate even during dry Water Year conditions in this reach. Long-term disconnection of pools occurred throughout the lowest reach of Dutch Bill Creek from ~600-ft upstream of the Tyrone Road crossing to the confluence with the Russian River.
Table 15 - Summary of flow-availability based habitat conditions for various sub-reaches within Green Valley, Atascadero, Purrington, and Dutch Bill creeks. Reach codes refer to the reaches delineated on Figure 70.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Green Valley</td>
<td>Headwaters to middle Green Valley Rd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Continuous Pool Connection</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>UGV1 - Harrison Creek to Bones Rd*</td>
<td>13,300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>UGV2 - Bones Rd to 1,900-ft below Bones Rd</td>
<td>6,900</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>UGV3 - 1,900-ft below Bones Rd to Green Valley Rd</td>
<td>1,900</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>UGV4 - Green Valley Rd to Atascadero Ck**</td>
<td>2,650</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>A1 - Atascadero Ck to 1,600-ft above Hwy 136</td>
<td>10,900</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>A2 - 1,600-ft above Hwy 136 to Russian River</td>
<td>10,000</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>8</td>
</tr>
<tr>
<td>Purrington</td>
<td>Headwaters to 2,700-ft below 1st Graton Rd</td>
<td>3,200</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>PUR 1 - 2,700-ft below Graton Rd to 3rd Graton Rd</td>
<td>4,900</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>PUR 2 - Graton Rd to 400-ft above 4th Graton Rd</td>
<td>8,200</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PUR3 - above 4th Graton Rd to 4th Graton Rd</td>
<td>400</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PUR4 - 4th Graton Rd to Green Valley Ck</td>
<td>1,350</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td>West Fork Atascadero</td>
<td>Headwaters to 1,300-ft below headwaters</td>
<td>1,300</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>WFA1 - 1,300-ft below headwaters to Wagnon Rd</td>
<td>7,050</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>WFA2 - Wagnon Rd to 2nd Hwy 12</td>
<td>5,500</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>WFA3 - 2nd Hwy 12 to Atascadero Ck</td>
<td>10,650</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>8</td>
</tr>
<tr>
<td>Upper Atascadero</td>
<td>Headwaters to 4,300-ft below headwaters</td>
<td>4,300</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td></td>
<td>UA1 - 4,300-ft below headwaters to Barnett Vly Rd</td>
<td>6,800</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>4</td>
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<tr>
<td></td>
<td>UA2 - Barnett Vly Rd to 1,600-ft below Barnett Vly Rd</td>
<td>1,600</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>UA3 - 1,600-ft below Barnett Valley Rd to Hwy 12</td>
<td>11,750</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>UA4 - Hwy 12 to 2,400-ft above WF Atascadero Ck</td>
<td>2,450</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>UA5 - 2,400-ft above WF Atascadero Ck to WFAC</td>
<td>4,400</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>1</td>
</tr>
<tr>
<td>Lower Atascadero</td>
<td>LA1 - WF Atascadero Ck to 1,200-ft above Graton Rd</td>
<td>12,250</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>LA2 - 1,200-ft above Graton Rd to Green Valley Ck</td>
<td>8,900</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>1</td>
</tr>
<tr>
<td>Dutch Bill</td>
<td>Headwaters to Lancel Ck</td>
<td>8,150</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>DB1 - Lancel Ck to Grub Ck</td>
<td>11,400</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>DB2 - Grub Ck to 600-ft above Tyrone Rd</td>
<td>11,200</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>600-ft above Tyrone Rd to Russian River</td>
<td>12,750</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>0</td>
</tr>
</tbody>
</table>

* long-term pool disconnection does occur in average water years within the upper portion of this reach (Harrison Creek confluence to middle Green Valley Road crossing), however UGV1 was extended to include this area owing to the significant coho use documented in the reach

** although the model did not predict disconnection in this reach, field observations indicate some disconnection does occur during dry Water Year conditions
Figure 61 - Simulated water depths and extent of disconnected reaches for WY 2010.
Figure 62 - Simulated water depths and extent of disconnected reaches for WY 2014.
Figure 63 - Longitudinal profiles of simulated water depths and extent of disconnected reaches for upper Green Valley Creek. Horizontal dashed lines show depth thresholds and vertical dashed lines show locations labeled on the top of the plots.
Figure 64 - Longitudinal profiles of simulated water depths and extent of disconnected reaches for Purrington Creek. Horizontal dashed lines show depth thresholds and vertical dashed lines show locations labeled on the top of the plots.
Figure 65 - Longitudinal profiles of simulated water depths and extent of disconnected reaches for Dutch Bill Creek, horizontal dashed lines show depth thresholds and vertical dashed lines show locations labeled on the top of the plots.
Chapter 8 - Scenario Analysis

Overview
Several types of scenarios focused on enhancing flow availability conditions for juvenile coho were envisioned. These included reducing or eliminating direct diversions that may be reducing summer base flow, reducing or eliminating groundwater pumping that may be reducing summer base flow, and augmenting stream flows via intentional releases from existing on-stream ponds. Although the model represents all direct diversions listed in the eWRIMS and reporting of diversions is now required for all riparian diversions, only one riparian diversion is listed in the database for the entire study area. There are almost certainly additional riparian diversions in the watersheds, however no information is available about diversion locations or rates. Also there are no direct diversions listed in the eWRIMS in upper Green Valley Creek which is of particular interest as a key stream for providing coho habitat. Given the incomplete knowledge of existing diversion operations, the decision was made to delay evaluating the effects of stream flow diversions on flow availability conditions in order to avoid coming to possibly incorrect conclusions about diversion impacts due to incomplete data.

Similarly, although the model represents rates and locations of groundwater pumping based on reasonably good information, wells were located based on parcel centroids and generalized well completion information was used in the model. Given that the effects of pumping on stream flows is likely to be very sensitive to the distance of the wells from streams, local hydrogeologic conditions, and the specific well completion details, the decision was made to delay evaluation of the effects of groundwater pumping on flow availability conditions in order to avoid coming to possibly incorrect conclusions about pumping impacts due to incomplete data. The specific types of data needed to refine the model such that it is ready for evaluation of diversion and groundwater pumping impacts are discussed in the Data Gaps and Recommendations for Future Work section of this report.

A single model scenario involving augmenting flows through intentionally releasing water from existing ponds was evaluated. Two ponds were selected for this analysis based on potential or demonstrated landowner cooperation and their locations within key reaches of upper Green Valley Creek which are considered to be flow impaired yet still provide some of the best remaining coho habitat in the Russian River watershed. The existing conditions model was used to estimate the carryover storage in these two ponds (the available storage on October 1st after accounting for evaporation and existing water use). These storages represent an estimate of the volume of water that could be released downstream during the summer months while still allowing the ponds to serve their existing water use functions. The storages were estimated following the end of WY 2010 which represents near average Water Year conditions. The storage volumes were converted to a constant flow rate that could be maintained for the 92-day period from July 1st through September 30th. These flow rates were 0.1 cfs for the upper pond and 0.5 cfs for the lower pond. Water was released from both ponds during this time window during each of the five Water Years simulated with the model, and the results
were tabulated and compared to the existing conditions results in order to quantify the potential for improving stream flow and habitat conditions via intentional pond releases.

**Results**
The pond release scenario was very effective at increasing water depths and reducing the extent of reaches with disconnected pools in upper Green Valley Creek. Approximately 0.08 of the 0.10 cfs released from the upper pond reached Green Valley Creek. This additional flow extended the reach where pools remained connected for an additional 1.3 river miles upstream during Water Year 2010 and for an additional 2.2 miles upstream during Water Year 2014 as compared to existing conditions (Figures 66 & 67; Table 16). This represents a doubling of the length of continuously connected pool habitat during dry Water Year conditions. Average summer water depths remained close to the minimum passage threshold (0.1-ft) within these reaches.

A significant portion of the flow released from the lower pond infiltrated into the streambed and only 0.21 to 0.24 of the 0.50 cfs release reached Green Valley Creek. This additional flow was enough to increase depths by ~0.05-ft from where the lower pond discharges to Green Valley Creek (~0.4 miles downstream of Bones Road) downstream to the confluence with Purrington Creek. Below the Purrington Creek confluence, the additional flow resulted in smaller increases in average summer water depths. Although the quantity of additional flow diminished with distance downstream, the effects of the flow releases persisted into the upper portions of lower Green Valley Creek (Figures 68 & 69). This was more significant during Water Year 2014 where the additional flow reduced the extent of the reaches experiencing short- and long-term disconnection in lower Green Valley Creek.

**Table 16 - Comparison of flow-availability based habitat conditions in upper Green Valley Creek between existing and pond release scenario conditions.**

<table>
<thead>
<tr>
<th></th>
<th>WY 2010</th>
<th>WY 2014</th>
<th>WY 2010</th>
<th>WY 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>River miles with continuously connected pools</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing Conditions</td>
<td>3.4</td>
<td>2.2</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Pond Release Conditions</td>
<td>4.7</td>
<td>4.4</td>
<td>3.8</td>
<td>3.6</td>
</tr>
</tbody>
</table>
Figure 66 - Comparison of simulated water depths and extent of disconnected reaches in Green Valley Creek for WY 2010 between existing conditions and the pond release scenario.
Figure 67 - Comparison of simulated water depths and extent of disconnected reaches in Green Valley Creek for WY 2014 between existing conditions and the pond release scenario.
Figure 68 - Comparison of longitudinal profiles of simulated water depths and extent of disconnected reaches for upper Green Valley Creek between existing conditions and the pond release scenario for WY 2010. The increase in total discharge under the pond release scenario is shown in the lower plot.
Figure 69 - Comparison of longitudinal profiles of simulated water depths and extent of disconnected reaches for upper Green Valley Creek between existing conditions and the pond release scenario for WY 2014. The increase in total discharge under the pond release scenario is shown in the lower plot.
Chapter 9 - Restoration Recommendations

The delineation of flow availability conditions relative to coho habitat requirements presented here provides a means of prioritizing restoration actions on a reach by reach basis. Specifically, the reaches identified as providing the best flow availability conditions and those that maintain habitat value even during drought conditions are probably the most important reaches to focus habitat enhancement work aimed at addressing limiting factors other than flow (e.g. ensuring quality pool habitat). Efforts to improve flow availability conditions either through intentional flow releases or water use modifications would be best focused in the reaches that are currently providing significant habitat value but at a more marginal level, particularly during dry Water Year conditions. Small changes in flows within these marginal reaches may be expected to yield significant increases in habitat value.

Finally reaches where existing flow availability conditions generally are not suitable can be identified as reaches that do not provide significant juvenile rearing habitat and where restoration efforts should probably be given low priority. It is important to note that if flow augmentation projects similar to those simulated in this study can be implemented, the extents of reaches where restoration projects are recommended would increase based on the new modified flow regime. The reaches described below are shown and color coded based on existing flow availability and recommended restoration actions in Figure 70. More detailed reach maps and recommendation summaries are provided in Appendix B.

Upper Green Valley Creek

The lower-most 3.8 river miles of upper Green Valley Creek from the Harrison Creek confluence downstream to the confluence with Atascadero Creek appears to be the extent of the reach with suitable flow conditions for providing juvenile coho rearing habitat. Upstream of the Harrison Creek confluence, pools become disconnected for extended periods of time even under average Water Year conditions indicating limited rearing habitat potential. Pools also become disconnected in the 0.4 mile reach between the Harrison Creek confluence and the middle Green Valley Road crossing, however significant coho use has been documented in this reach so it has been included in the mapping of suitable habitat extent.

The reach with suitable flow conditions can be divided into four reaches as follows: UGV1 - upper 1.3 river miles from the Harrison Creek confluence to the Bones Road crossing, UGV2 - 0.4 river miles below the Bones Road crossing, UGV3 - 1.6 river miles from 0.4 miles below the Bones Road crossing to the lower Green Valley Road crossing, UGV4 - lower 0.5 river miles above the confluence with Atascadero Creek (Figure 70).

All four reaches can be considered flow-impaired given that, with a few exceptions, water depths dropped below optimal passage threshold depths even under average Water Year conditions. UGV3 provides the best flow conditions, maintaining minimum passage depths even under dry Water Year conditions. Under the present flow regime, restoration projects aimed at improving juvenile habitat conditions would be most beneficial within this 1.6 river
Figure 70 - Flow availability-based reach classification and restoration prioritization map. In general, reaches shown as blue have the best existing habitat conditions and should be the focus of in-stream restoration projects aimed at improving pool conditions, and reaches shown as red, orange, or green are more flow-limited and flow augmentation projects such as intentional flow releases or water use modifications are recommended.
mile reach. UGV1 did not maintain minimum passage depths under average Water Year conditions and long-term disconnection of pools occurred during dry water conditions in both UGV1 and UGV2. UGV4 is also flow-impaired, but not to the degree of UGV1 and UGV2 and disconnection in this reach may be related to the ongoing sand and gravel deposition and associated aggradation of the channel in this reach. Restoration focused on flow augmentation would be most beneficial within UGV1 and UGV2 (1.3 river miles total); such efforts may be expected to benefit UGV4 as well.

Augmenting flows by intentionally releasing water from existing ponds was shown to be a very effective strategy for improving flow availability conditions. If such flow release projects can be implemented, the extent of the creek with suitable flow conditions for providing juvenile coho rearing habitat could be extended significantly farther upstream. Under the flow regime simulated with the pond release scenario (described in the Scenario Analysis section of this report), restoration projects aimed at improving juvenile habitat conditions would also be recommended in reaches UGV1 and UGV2 and possibly even farther upstream.

**Lower Green Valley Creek**

Lower Green Valley Creek can be divided into two reaches: LGV1 - upper 2.1 river miles from the Atascadero Creek confluence to ~1,600-ft upstream of the Highway 116 crossing, and LGV2 - lower 3.6 river miles above the Russian River confluence (Figure 70).

LGV2 provides some of the best flow conditions for juvenile coho in the study area maintaining depths above the optimal passage threshold during average water year conditions and depths above the minimum passage threshold during dry water year conditions. LGV1 is characterized by favorable flow conditions during average water year flows but periods of long-term pool disconnection during dry water year conditions. Given the lack of adequate flow availability in LGV1 during dry water years under the present flow regime, restoration projects aimed at improving juvenile rearing habitat would be most beneficial within LGV2. Flow augmentation efforts in lower Green Valley Creek should be focused on LGV1 and could potentially provide an additional 2.1 river miles of dry year rearing habitat. Pond releases in upper Green Valley Creek may improve conditions in LGV1 somewhat, however additional flow augmentation is likely needed in this reach in order to eliminate disconnection of pools during dry Water Year conditions.

There is some evidence that water quality conditions may be limiting habitat quality within both LGV1 and LGV2. It is recommended that water quality conditions in these reaches be evaluated and that efforts to improve water quality be pursued as appropriate.

**Purrington Creek**

The lower-most 2.8 river miles of Purrington Creek from ~0.5 miles downstream of the upper-most Graton Road crossing to the confluence with Green Valley Creek appears to be the extent of the reach with suitable flow conditions for providing juvenile coho rearing habitat. Upstream
of this reach, pools become disconnected for extended periods of time even under average Water Year flow conditions indicating limited rearing habitat potential.

The reach with suitable flow conditions can be divided into four reaches as follows: PUR1 - upper 0.9 river miles upstream of the 3rd Graton Road crossing, PUR2 - 1.5 river miles between the 3rd and 4th Graton Road crossings, PUR3 - 0.1 river miles upstream of the 4th Graton Road crossing, and PUR4 - lower 0.2 river miles above the confluence with Green Valley Creek (Figure 70).

All four reaches can be considered flow-impaired given that water depths dropped below optimal passage threshold depths even under average water year conditions. Reaches PUR2 and PUR4 provide the best flow conditions, maintaining minimum passage depths even under dry water year conditions. Under the present flow regime, restoration projects aimed at improving juvenile habitat conditions would be most beneficial within these two reaches (1.7 river miles total).

In contrast to upper Green Valley Creek, none of the reaches experienced long-term disconnection of pools under dry water year conditions, however PUR3 did experience short-term disconnection and water depths fell below minimum passage depth thresholds in PUR1 even under average Water Year conditions. Flow augmentation efforts should be focused on PUR1 and PUR3. Small increases in flow within PUR1 could potentially provide an additional 0.9 miles of available rearing habitat and PUR3 essentially represents a depth passage barrier during dry years which should be verified and removed if possible. PUR3 appears to be influenced by the diversions located in this vicinity. These diversions were modeled using the maximum diversion rates reported in the eWRIMS which may overstate the effects of the diversions depending on the details of the actual diversion operations which are not completely known.

**Upper Atascadero Creek and West Fork Atascadero Creek**

Coho use has not been documented in upper Atascadero Creek, however reaches with flow conditions suitable for providing juvenile coho rearing habitat are present throughout much of the upper watershed, and juvenile steelhead do currently utilize these areas. In particular the lowest 2.0 river miles of West Fork Atascadero Creek and a 0.5 river mile reach of upper Atascadero Creek have flow conditions that are better than any of the reaches in Upper Green Valley or Purrington Creek. A total of 3.1 river miles of West Fork Atascadero Creek and 2.7 river miles of upper Atascadero Creek have flow conditions that maintain minimum passage threshold depths even under dry water year conditions.

The 0.5 river mile reach upstream of the confluence of Atascadero and West Fork Atascadero Creeks (UA5) becomes disconnected even under average water year conditions. This essentially represents a depth passage barrier which should be verified and removed if possible. UA5 appears to be influenced by the diversions located in this vicinity. These diversions were modeled using the maximum diversion rates reported in the eWRIMS which may overstate the effects of the diversions depending on the details of the actual diversion operations which are
not completely known. Given the availability of extensive reaches with suitable flow conditions for juvenile coho in Upper Atascadero Creek, additional effort to understand the extent of coho presence in Atascadero Creek and the factors limiting access to and survival in the upper watershed is highly recommended.

**Lower Atascadero Creek**
Lower Atascadero Creek can be divided into two reaches: LA1 - upper 2.3 river miles from the West Fork Atascadero Creek confluence to ~1,200-ft upstream of Graton Road, and LA2 - lower 1.7 river miles above the Green Valley Creek confluence (Figure 70). LA1 provides some of the best flow conditions for juvenile coho in the study area, maintaining depths above the optimal passage threshold during average water year conditions and depths above the minimum passage threshold during dry water year conditions. Small water depths persist in LA2, however, a stagnant water (zero discharge and velocity) condition develops during the late summer even during average water year conditions.

As discussed above for upper Atascadero Creek, the degree to which coho use Atascadero Creek and the factors limiting that use have not been studied in detail. This analysis suggests that the stagnant water conditions in LA2 may result in temperature and/or dissolved oxygen conditions that limit access to the upper portions of the watershed. Given that more than eight river miles of habitat better than or equivalent to the best reaches of upper Green Valley and Purrington Creeks lie upstream of this reach, further investigation of the role of LA2 in limiting coho use of Atascadero Creek is highly recommended. Flow augmentation efforts focused on LA2 may improve access to the upper watershed and would be expected to also improve flow conditions in LA1 of lower Green Valley Creek located immediately downstream.

**Dutch Bill Creek**
The 4.3 river miles of Dutch Bill Creek between the confluence with Lancel Creek and a point ~600-ft upstream of the Tyrone Road crossing appears to be the extent of the reach with suitable flow conditions for providing juvenile coho rearing habitat. Upstream and downstream of this reach, pools become disconnected for extended periods of time even under average water year flow conditions indicating limited rearing habitat potential. The reach with suitable flow conditions can be divided into two reaches as follows: DB1 - upper 2.2 river miles between the Lancel Creek confluence and the Grub Creek confluence, and DB2 - 2.1 river miles downstream of the Grub Creek confluence (Figure 70).

Both reaches can be considered flow-impaired given that water depths dropped below optimal passage threshold depths even under average water year conditions. DB2 provides the best flow conditions, maintaining minimum passage depths even under dry water year conditions. Under the present flow regime, restoration projects aimed at improving juvenile habitat conditions would be most beneficial within this 2.1 river mile reach. Pools in DB1 remain connected, however water depths drop below minimum passage depths even in average water year conditions. Flow augmentation efforts should be focused on DB1 as small increases in flow within this reach could potentially provide adequate passage depths throughout this 2.2 river mile reach. In the summer of 2015, the Camp Meeker Recreation and Park District
released about 0.1 cfs into Dutch Bill Creek which appears to have been very effective at increasing stream flow and preventing downstream pool disconnection. This effort demonstrates the efficacy of flow augmentation efforts for improving habitat conditions during critically dry periods.
Chapter 10 - Data Gaps and Recommendations for Future Work

The model presented here provides a powerful tool for understanding hydrologic conditions and informing water resource and land use management policies and restoration planning efforts throughout the Green Valley, Atascadero, and Dutch Bill Creek watersheds. Like any modeling analysis, there is uncertainty in the model results and the accuracy of model predictions. In order to better understand this uncertainty it is useful to examine the completeness and quality of the input data that went into developing the model and the degree and quality of the model calibration. Recommended improvements to the model are based on areas where better input data and/or additional calibration would be expected to lead to improved model performance and/or increased suitability for addressing key management questions. Ideally the modeling work would not be a static product but instead represent a working management tool where the model is periodically improved as new data becomes available and new questions arise.

Although a significant amount of information describing the distribution and volumes of water use was available, certain data was missing requiring simplifying assumptions be made regarding the details of water use patterns. In particular, the model includes all known surface water diversions as reported in the California State Water Resources Control Board’s eWRIMS, however it is believe that the vast majority of diversions associated with Riparian Water Rights (formalized by a Statement of Use) are not reported. Data describing the locations, rates, and timing of these riparian diversions is required in order for the model to be used to more accurately quantify the effects of surface water diversions in the watershed and the potential habitat benefits of changing diversions patterns. The considerable degree to which model predictions are correlated with observed flows suggests that the un-quantified surface diversions may not be of enormous significance.

Groundwater wells were represented in the model by locating them at the center or each parcel, and well completion details were generalized from Well Completion Reports. This representation of wells provides a reasonable approximation of pumping distributions, however it is not suitable for examining the potential effects of pumping on stream flow conditions in detail. Thousands of driller’s reports are available providing valuable information regarding well completion details, however the usefulness of these reports is limited by several factors. Perhaps most significantly, the reports generally only locate wells based on the parcel number or address, and in many cases there are multiple logs for a given parcel or no parcel identification making it difficult or impossible to assign a single log to each parcel. Many parcels within the study area are very large and the parcel centroid could be hundreds or thousands of feet away from the actual well location.

From an overall water balance and recharge perspective, these approximations of well characteristics are probably not significant, however it is critical for understanding potential stream flow impacts of pumping in cases where wells are located in close proximity to streams. Pumping rates for short-duration pump tests performed at the time of well completion are often reported in Well Completion Reports, however these rates are often not reflective of
actual pumping operations and virtually no information regarding pumping volumes or
durations for individual wells is readily available short of a lengthy effort to obtain pump test
data from County files. The recent California State Water Resources Control Board Emergency
Drought Regulation for four lower Russian River tributaries (SWRCB, 2015) may provide some of
the missing information. Near the completion of this study, two relatively detailed
groundwater assessment reports completed by a Sonoma County hydrogeologist (Eugene
Boudreau) were obtained from a resident of upper Green Valley Creek. These reports locate
wells (subject to similar uncertainty with respect to actual location) and provide associated
driller's log (Well Completion Report) information for many of the wells in upper Green Valley
Creek. These reports along with a landowner outreach effort related to the SWRCB Emergency
Order could provide the basis for refining the model representation of groundwater pumping
and increase the model's utility as a tool for understanding the effects of groundwater pumping
on stream flow and habitat conditions.

Although the model was calibrated to a significant amount of stream flow and groundwater
observation data, the periods of record for all of the stream gauges and observation wells was
relatively short (2-5 years). Ideally the model would be calibrated over a longer time period
and a separate multiple year validation period would be used to validate the model's predictive
capabilities. Most of the calibration gauges and observation wells remain active and it is
recommended that an updated model calibration and validation be performed following the
collection of several more years of data. Additional groundwater elevation monitoring data in
the vicinity of the watershed divide separating the GVAC watershed from the Santa Rosa Plain
may enable refinement of the model representation of groundwater outflows along this
boundary. Groundwater calibration errors were largest at observation wells located close to
this boundary suggesting that better characterization of the boundary may lead to improved
model performance in this area.

Despite these limitations, the model can be used in its current form to address a wide variety of
water and land use management issues. The flow augmentation scenario discussed in this
report is one such example, and the model was able to quantify the amount of water released
from ponds that reaches Green Valley Creek and the significance of this additional water in
terms of improvements to habitat conditions. As new potential flow augmentation projects are
identified in the watersheds, the model can be used to test and optimize their effectiveness.

The model is also particularly well-suited for simulating the effects of ongoing climate change
given the availability of regional downscaled climate model data (Flint and Flint, 2012). The
model is also well-suited for examining the effects of land use change (e.g. ongoing conversion
or orchards to vineyards) and future population increases and could be a valuable asset to
Sonoma County staff tasked with reviewing permit applications for vineyard, winery, and
residential development projects. These types of scenarios can be used to guide policies
designed to ensure the sustainability of both surface water and groundwater resources for
people and ecosystems. Lastly, although the focus of this study was on low flow conditions for
juvenile rearing habitat, the model simulates continuous hydrographs and as such is well-suited
for examining flow conditions important for other coho life stages, other species of interest, or other types of management questions.
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