Date: 2/27/2020

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Project: SLO Basin Groundwater Sustainability Plan

Subject: **Draft** Surface Water/Groundwater Modeling Approach Technical Memorandum (Modeling TM No.1)

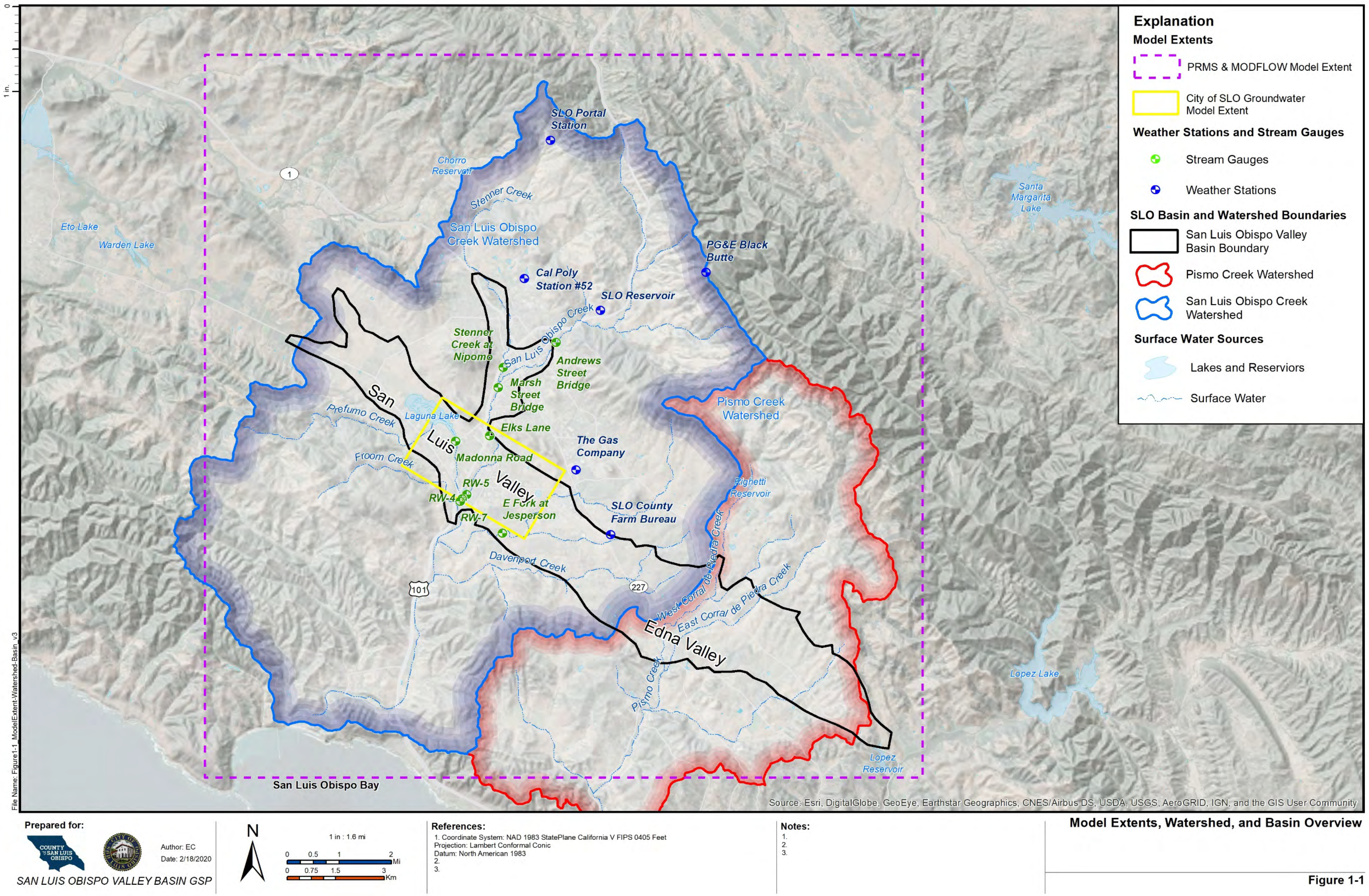
Section 1. Introduction

This draft Technical Memo (TM No.1) is prepared by Water Systems Consulting, Inc. (WSC) and GSI Water Solutions, Inc. (GSI), for the San Luis Obispo (SLO) County Groundwater Sustainability Agency (GSA) and the City of SLO GSA. As part of the Groundwater Sustainability Plan (GSP) for the SLO Valley Groundwater Basin (Basin), the consultant team is developing an integrated surface water-groundwater numerical model for the objective of evaluating the potential impacts of proposed projects and management actions associated with the GSP. The objective of this TM is to document the modeling approach and hydrogeologic conceptual model (HCM) associated with the construction of the integrated numerical model of the SLO Basin.

The Basin covers approximately 20 square miles in central San Luis Obispo County (County). The Basin extents are defined as the contact of water-bearing sediments with the non-water-bearing formations of the Santa Lucia Range to the northeast, and the San Luis Range and the Edna Fault Zone to the southwest. Annual average precipitation in the Basin is approximately 18 to 22 inches (GSI Water Solutions, Inc., 2018). The Basin is commonly divided into two sub-areas: the San Luis Valley and the Edna Valley. The San Luis Valley occupies approximately the northwestern half of the Basin; it includes the City of San Luis Obispo (City), and the primary land uses are municipal and industrial. Most water supply in the San Luis Valley is from both in-basin groundwater sources and imported surface water sources (Whale Rock Reservoir, Salinas Reservoir, and Nacimiento Reservoir). The Edna Valley occupies the southeastern half of the Basin. The primary land use is agriculture, with wine grapes as the dominant crop type. Groundwater is the major source of water supply in the Edna Valley.

To date, a watershed scale groundwater or integrated surface water-groundwater model has not been published for the entire Basin. In 1997, the California Department of Water Resources (DWR) performed initial work on a basin groundwater model, but the model was never published. A groundwater model was developed within a portion of the Basin that encompasses the San Luis Valley (the City of SLO model)(Cleath-Harris Geologists, 2018) and a surface water hydraulic model has been developed for the San Luis Obispo Creek watershed (Questa Engineering Corp., 2007). Figure 1-1 shows the watershed and Basin boundaries, and the proposed model extent for both PRMS and MODFLOW.

GSI developed a TM to evaluate multiple integrated surface water-groundwater modeling systems and identified the best modeling system to achieve compliance and project objectives for the SLO GSP (GSI Water Solutions, Inc., 2019). GSFLOW, a fully integrated hydrologic model (IHM) developed by the United States Geological Survey (USGS) (Markstrom, Niswonger, Regan, Prudic, & Barlow, 2008), was recommended to the GSP Groundwater Sustainability Commission (GSC) to be selected as the model system to be used for the GSP. IHM models like GSFLOW can provide important information about water resources and are often used as decision support tools for resource management (Laniak, et al., 2013). GSFLOW integrates the Precipitation-Runoff Modeling System (PRMS) watershed model code with the MODFLOW groundwater model code.



Model Extents, Watershed, and Basin Overview

Figure 1-1

Section 2. Hydrogeologic Conceptual Model

This section of the TM summarizes the HCM for the San Luis Obispo Valley Groundwater Basin (Basin) (DWR Basin 3-09), including summary discussion of both geologic formations and hydrogeologic conditions significant to the development of the numerical model. These subjects are evaluated in greater detail in the Basin Characterization Report (GSI Water Solutions, Inc., 2018), and the reader is directed to that report for a more comprehensive discussion of relevant topics.

2.1. Geologic Formations and Water Bearing Properties

For the purpose of the GSP, the rocks in the Basin vicinity may be considered as two basic groups; the water-bearing sediments of the SLO Basin, and the consolidated bedrock of the surrounding hills and watershed. Compared to the saturated sediments that comprise the Basin aquifers, the consolidated bedrock formations are not considered to be water-bearing. Although bedding plane and/or structural fractures in these rocks may yield small amounts of water to wells, they do not represent a significant portion of the pumping in the area. In fact, the DWR Bulletin 118 delineation of the Basin boundaries is defined both laterally and vertically by the contacts of the Basin sediments with the surrounding and underlying consolidated bedrock formations.

Figure 2-1 displays a stratigraphic column of the significant local geologic units. Figure 2-2 presents a geologic map of the Basin vicinity (assembled from a mosaic of the Dibblee maps from the San Luis Obispo, Pismo Beach, Lopez Mountain, and Arroyo Grande NE quadrangles) showing where the various formations crop out at the surface.

Figure 2-2 also displays the Basin boundaries defined in DWR Bulletin 118. Inspection of Figure 2-2 indicates that the existing DWR GIS shapefiles for the Basin boundary do not match up precisely with the mapped extent of the water-bearing formations. This is likely an artifact of previous mapping being performed at a larger statewide scale.

The water-bearing sedimentary formations and the non-water-bearing bedrock formations are briefly described below, from the youngest to the oldest.

2.1.1. Basin Sedimentary Formations

Recent Alluvium

The Recent and Older Alluvium is the mapped geologic unit composed of unconsolidated sediments of gravel, sand, silt, and clay, deposited by fluvial processes along the courses of San Luis Obispo Creek, Davenport Creek, East and West Corral de Piedras Creeks, and their tributaries. Lenses of sand and gravel are the productive strata within the Alluvium. There is no significant difference in hydrogeologic properties between Recent and Older Alluvium. These strata have no significant lateral continuity across large areas of subsurface within the Basin. Thickness of Alluvium may range from just a few feet to greater than 50 feet.

Paso Robles Formation

The Paso Robles Formation underlies the Recent Alluvium throughout most of the Basin and overlies the Pismo Formation where present. It is composed of poorly sorted, unconsolidated to mildly consolidated sandstone, siltstone, and claystone, with thin beds of volcanic tuff in some areas. The Paso Robles Formation is exposed at the surface through much of the Edna Valley, except in areas where existing streams have deposited Recent Alluvium on top of it. Wells that screen both the Recent Alluvium and Paso Robles Formation have reported yields from less than 100 to over 500 gallons per minute (gpm). There is no laterally extensive fine-grained confining unit separating the Paso Robles formation from the Recent Alluvium in the Basin.

Pismo Formation

The oldest geologic water-bearing unit with significance to the hydrogeology of the Basin is the Pismo Formation. The Pismo Formation is a Pliocene-aged sequence of unconsolidated to loosely consolidated marine deposited sedimentary units composed of claystone, siltstone, sandstone, and conglomerate. There are five recognized members of the Pismo Formation (Figure 2-1). While all are part of the Pismo Formation, the distinct members reflect different depositional environments, and the variations in geology may affect the hydrogeologic characteristics of the strata. From the bottom (oldest) up, these are:

- The Edna Member, which lies unconformably atop the Monterey Formation, and is locally bituminous (hydrocarbon-bearing)
- The Miguelito Member, primarily composed of thinly bedded grey or brown siltstones and claystones
- The Gragg Member, usually described as a medium-grained sandstone
- The Bellview Member, composed of interbedded fine-grained sandstones and claystones
- The Squire Member, generally described as a medium- to coarse-grained fossiliferous sandstone of white to grey sands.

Previous reports have identified the significant thicknesses of sand at depth beneath the Paso Robles Formation in the Edna Valley as the Squire Member of the Pismo Formation. However, ambiguities exist in the identification of the individual Pismo Formation members, so for the purposes of this report, these sediments will be referred to more generally as the Pismo Formation. The Pismo Formation is extensive below the Paso Robles Formation in the Edna Valley. There is no laterally extensive fine-grained confining layer separating the Pismo Formation from the Paso Robles Formation in the Basin. Thicknesses of Pismo Formation up to 400 feet are reported or observed in well completion reports.

Wells that are completed in both the Paso Robles and Pismo Formations are reported to yield from less than 100 gpm to approximately 700 gpm.

2.1.2. Bedrock Formations

Monterey Formation

The Monterey Formation is a thinly bedded siliceous shale, with layers of chert in some locations. In other areas of the County outside of the Basin, the Monterey Formation is the source of significant oil production. While fractures in consolidated rock may yield small quantities of water to wells, the Monterey Formation is not considered to be a Basin aquifer for the purposes of this Study. Some wells in the Basin screen both Basin sediments and the upper portion of the Monterey Formation. Of the bedrock formations discussed here, the Monterey Formation is the one most often used for water supply in the Basin. There are no paired wells that provide specific data comparing water levels in wells screening the Monterey Formation and the Basin sediments. However, the Monterey Formation is assumed to receive rainfall recharge in the mountains at higher elevations than the Basin. For this reason it is assumed that an upward vertical flow gradient exists between the Monterey Formation and the overlying Basin sediments. Because the Monterey formation is significantly less productive than the Basin sediments, the rate of this flux is not expected to be significant.

Obispo Formation

The Obispo Formation and associated Tertiary volcanics are composed of materials associated with volcanic activity along tectonic plate margins approximately 20 to 25 million years ago. Although fractures in consolidated volcanic rock may yield small quantities of water to wells, the Obispo Formation is not considered to be an aquifer for the purposes of this Study.

Franciscan Assemblage

The Franciscan Assemblage contains the oldest rocks in the Basin area, ranging in age from late Jurassic through Cretaceous (150 to 66 million years ago). The rocks include a heterogeneous collection of basalts, which have been altered through high-pressure metamorphosis associated with subduction of the oceanic crust beneath the North American Plate before the creation of the San Andreas Fault. Although fractures may yield small quantities of water to wells, the Franciscan Assemblage is not considered to be an aquifer for the purposes of this Study.

2.2. Geologic Structure

The primary geologic structures of significance to the hydrogeology of the Basin are the Edna Fault Zone and the adjacent Los Osos Fault Zone, which together form the southwestern boundary of the Basin through the uplift of the Franciscan and Monterey strata southwest of the faults. The Edna Fault is identified as a normal fault, extending from southeast of the Edna Valley to the vicinity of the town of Edna (Figure 2-2). There are some disconnected and unnamed fault splays mapped in the area south of the San Luis Obispo County Regional Airport. The Los Osos Fault Zone is mapped along the southwest edge of the Los Osos Valley. Movement along the Edna and Los Osos Valley Fault Zones has brought the water-bearing sediments of the Basin into contact with the bedrock formations of the San Luis Range. No available water level or other data indicate that the faults have any significant effect on the movement or quality of groundwater in the Basin.

2.3. Lithologic Data

All readily available lithologic data were obtained for the preparation of the Characterization Report (GSI Water Solutions, Inc., 2018) and updated for this TM. Sources of data included Well Completion Reports on file with the County and DWR, boring logs documented in published government reports or private consultant reports, geophysical boring logs, and various other sources. In all, 405 data points with lithologic information were collected for use in the GSP. (The reader is referred to the Characterization Report to evaluate the details of twelve cross sections generated in the Basin, which will not be duplicated herein.) Lithologic data were assigned spatial coordinates based on available mapping, and descriptions of geologic materials were recorded in a database for reference in future Sustainable Groundwater Management Act management activities. Lithologic data point locations are presented in Figure 2-3.

Available lithologic data, cross sections, and land surface elevation data were evaluated to identify probable contacts between geologic formations. Based on these data, GSI developed a map of total thickness of combined Basin sediments (Alluvium, Paso Robles Formation, and Pismo Formation), presented in Figure 2-4. This figure indicates that the Basin sediments are significantly thicker in the Edna Valley than in the San Luis Valley. Lithologic data were reviewed to identify contacts between the Recent Alluvium, Paso Robles Formation, and Pismo Formation. Based on these contacts, twelve cross sections were developed and presented in the Characterization Report (GSI Water Solutions, Inc., 2018); the reader is directed to that report to review details of the cross sections. Based on this data, a 3-D lithologic model of the SLO Basin sediments was developed using the software package Leapfrog©. Leapfrog 3D is a geologic modeling platform that incorporates and processes data from multiple sources including boreholes, GIS, grids, mesh/surface information, and historical cross section data. The Leapfrog model can be used as a basis to develop a numerical groundwater model grid and/or for 3D visualization and presentation purposes (Figure 2-5).

2.4. Hydrogeologic Setting

This section of the TM presents a summary discussion of hydrogeologic conditions in the SLO Basin as they pertain to the integrated model development. These subjects are evaluated in greater detail in the Basin Characterization Report (GSI Water Solutions, Inc., 2018), and the reader is directed to that report for a more comprehensive discussion of relevant topics. This TM will present an overview of the hydrogeology but will not duplicate the level of detail provided in the Characterization Report.

2.4.1. Hydrogeologic Units

Although there are significant intervals of clay evident in boring logs throughout the Basin, the clay lenses are not consistent across large areas. There is no evidence of laterally extensive impermeable strata that vertically isolates the geologic formations from one another. As a result, it appears that in the San Luis Valley, the Recent Alluvium and the Paso Robles Formation function as a single hydrogeologic unit. Work performed for the City indicates that alluvial deposits have a significantly higher hydraulic conductivity than the Paso Robles Formation and the Pismo Formation (Cleath, 2019). It does not appear that wells in the San Luis Valley are screened exclusively in either the Recent Alluvium or the Paso Robles Formation. Similarly, in the Edna Valley, there is no laterally extensive impermeable strata separating the Paso Robles and Pismo Formations. Frequently, the sand of one formation is in contact with the sands of the other formation. Therefore, it appears that in the Edna Valley, the Paso Robles Formation and the Pismo Formation function as a single hydrogeologic unit. Therefore, the modeling approach will be to represent each of the geologic units separately in the model, but no discrete barriers to vertical flow between the units will be simulated.

2.4.2. Recharge

The primary mechanisms for recharge in the Basin occur via infiltration of rainfall, percolation of seasonal streamflow from the alluvial sediments to underlying formations, deep percolation of applied irrigation water, and mountain front recharge. Mountain front recharge has not been specifically discussed or quantified in previous studies.

DWR (Department of Water Resources, 1958) estimated that average recharge to the Basin was 2,250 acre-feet per year (AFY). Working with data from a longer period of record, Boyle (Boyle Engineering Corp., 1991) estimated total recharge to the Basin from 1978-1990 was 3,650 AFY (1,510 acre-feet from irrigation percolation, 1,450 acre-feet from rainfall, 430 acre-feet from stream seepage losses, 300 acre-feet from reclaimed wastewater). In its draft report, DWR (Department of Water Resources , 1997), using a groundwater model approach, estimated combined recharge from precipitation, agriculture return flows, and incidental urban recharge, to average 4,560 AFY and range from 2,300 AFY in a drought year to 9,590 AFY in a wet year (As discussed previously, the groundwater model was never published). It should be noted that DWR (Department of Water Resources , 1997) estimates aquifer recharge from stream seepage only during dry years; in wet years, DWR estimated that the aquifer discharges to streams.

Cleath-Harris Geologists (CHG), a member of the consultant team developing the SLO Basin GSP, is preparing estimates of a historical water budget simultaneously with the development of the Basin numerical model. Estimates for each of the components of recharge discussed herein will be utilized during the calibration of the model.

2.4.3. Groundwater Pumping

Patterns and quantities of groundwater use in the Basin have varied depending on the period of record. The City of San Luis Obispo did not begin using groundwater until the late 1980s. In the 1990s, the City relied on significant groundwater use, particularly during the drought of the early 1990s. Today, by contrast, the City's potable water wells are used only for emergency standby due to groundwater contamination. The City does have plans to utilize groundwater as a drinking water supply in the future.

Agricultural groundwater use in the Edna Valley has changed in recent decades in response to market drivers, with the total irrigated acreage expanding significantly, and the crop types changing. Currently, wine grapes are the dominant crop type. No continuous estimates of groundwater pumpage in the Basin are available. Agricultural wells have not been metered in the past, and methods to estimate agricultural pumpage indirectly may vary. However, various published estimates have been presented in past reports and are briefly discussed below.

DWR (Department of Water Resources, 1958) estimates that 1,900 acre-feet of groundwater was pumped at that time. No details on this estimate are evident in the report text.

Boyle (Boyle Engineering Corp., 1991) reports an estimate of agricultural groundwater pumpage of 5,200 AFY, based on evaluation of irrigated acreage of various crop types, unit water use for each crop type, and irrigation efficiency. It is noteworthy that there is no reported irrigated vineyard acreage reported for their study period (1978-1990). Municipal and industrial pumpage is estimated to average 600 to 800 AFY during that period but was reported to be as high as 2,600 AFY during the drought year of 1990. Resultant total groundwater pumpage estimates for the Basin range from 5,690 to 7,810 AFY.

In its draft report, DWR (Department of Water Resources , 1997) presents some estimates for groundwater pumpage in the Basin. For years ranging from 1970 to 1995, groundwater pumpage estimates for all water user groups from the San Luis Valley range from 1,900 to 3,300 AFY, with the maximum estimate in the drought year of 1990. Pumpage estimates from the Edna Valley range from 2,330 to 4,340 AFY. Resultant total groundwater pumpage estimates for the Basin range from 4,380 to 7,640 AFY.

CHG is developing estimates of historical pumping as part of the water budget analysis. The results of that analysis will be incorporated into the historical calibration of the groundwater model.

2.4.4. Evapotranspiration

Evapotranspiration refers to the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants. This mechanism for outflow from the Basin may be significant in areas where the water table is near the land surface, such as along the stream corridors in the Basin. Transpiration of applied irrigation water to agricultural crops is also a significant process in the hydrology of the Basin. The details of the evapotranspiration processes will be represented in the integrated model.

2.4.5. Surface Water/Groundwater Interaction

Surface water/groundwater interactions represent a significant portion of the water budget of SLO Basin. In the Basin, these interactions occur primarily at streams and lakes.

Laguna Lake is the only lake in the Basin. The downstream outlet of the lake is dammed to artificially impound water to maintain water elevation in the lake to preserve and enhance the wildlife habitat and recreational purposes. The water in the lake is partially supplied by seasonal flow in Prefumo Creek, which flows into Laguna Lake. During dry periods, the lake may remain at least partially full, although it may dry up during extended drought. This appears to indicate that in addition to surface water inflow, the water in the lake is at least partially supplied by subsurface groundwater inflow.

Groundwater interaction with streams in the Basin is not well quantified, but it is recognized as an important component of recharge in the water budget. During the dry season when many streams have no flow, the groundwater elevation is below the streambed. Therefore, it is generally understood that San Luis Obispo Creek discharges to the underlying aquifer, at least in the first part of the wet-weather flow season. If there is constant seasonal surface water flow, it is possible that groundwater elevations may rise to the point that they are higher than the stream elevation, and the creek may become a seasonally gaining stream, but there are no data to corroborate this. It may remain a losing stream throughout most or all years.

The amount of flow in surface water/groundwater interaction is difficult to quantify. Boyle (Boyle Engineering Corp., 1991) assumed that 10 percent of the measured surface water flow coming into the Basin in San Luis Obispo Creek and Stenner Creek was recharged to the aquifer and at an average rate of 430 AFY. In its draft report, DWR (Department of Water Resources , 1997) reports model-generated estimates ranging from streams gaining 2,700 AFY from the aquifer, to streams losing 680 AFY to the aquifer.

The County, through its Water Resources Division coordination with Zone 9 and the City, maintains a network of five stream gages in the San Luis Valley of the Basin to record heights of flow throughout the year for flood warning purposes. The gages were constructed in November 2001 and have periods of record from 2005 to the present. Continuous monitoring of the height of flow at the gages is recorded, but equivalent discharge (e.g. cubic feet per second) is not recorded. Partial rating curves have recently been developed for some of the gages based on field measurements of discharge for observed flows. Additionally, estimated theoretical rating curves for each gage based on hydraulic modeling using HEC-RAS have been developed (Questa Engineering Corp., 2007).

2.4.6. Groundwater Flow Patterns

Groundwater flow in the Basin is predominantly from the Edna Valley toward the San Luis Obispo Creek alluvium, at which point the flow direction leaves the Basin through the alluvium. Groundwater in the northwestern areas of the Basin near the City boundary and Los Osos Valley Road flows southeastward toward the San Luis Obispo Creek alluvium. In the Edna Valley, there are also local areas of flow leaving the Basin along the Corral de Piedras Creek and alluvium of other smaller tributaries, in the southeastern portion of the Basin.

DWR (Department of Water Resources, 1958) published a series of maps depicting groundwater elevation maps for the various parts of its study area, including groundwater elevations in the Basin for Fall 1954. This map displays dominant groundwater flow direction from higher elevations in the Edna Valley (over 280 feet relative to mean sea level [msl]) to lower elevations (less than 110 feet msl) where San Luis Obispo Creek exits the Basin (GSI Water Solutions, Inc., 2018).

Boyle (Boyle Engineering Corp., 1991) presents water level elevation contour maps for the spring of 1986 and 1990. Contours for spring of 1990 display a pattern of groundwater flow in the Basin very similar to that exhibited in the DWR map. Contours for the spring of 1986 are not presented in this report, but 1986 represents wetter conditions than the 1990 map, and it is noted in Boyle (Boyle Engineering Corp., 1991) that there is a difference of approximately 10 feet of elevation between the two maps, representing the variation in water levels that may be observed between wet and dry weather cycles (GSI Water Solutions, Inc., 2018).

In its draft report, DWR (Department of Water Resources , 1997) used a computer groundwater model developed for its study to generate a series of modeled water level maps representing wet, dry, and average conditions. The model results are not re-presented in this Study, but the maps display the same general flow patterns as the DWR (Department of Water Resources, 1958) and Boyle (Boyle Engineering Corp., 1991) maps based on field data. Water level elevations in what DWR defines as the San Luis sub-basin in wet years were approximately 10 to 20 feet higher than in dry years. In what DWR defines as the Edna sub-basin, the difference in groundwater elevations between wet and dry years was approximately 20 to 30 feet.

Recent groundwater level data collected as a part of the District's voluntary monitoring network were obtained and used to generate a water table map to evaluate more recent conditions. Figure 2-6 presents the contours generated from the data for the October 2019 monitoring event. Because there are no significant or extensive aquitards separating the Alluvium, Paso Robles Formation, and Pismo Formation, the water level maps assume that all three formations function as a single hydrogeologic unit. This map confirms the previously estimated primary direction of groundwater flow from the Edna Valley to the San Luis Valley, but several new features are apparent. First, a pronounced mound is evident at the location where Corral de Piedras Creek enters the Basin in Edna Valley, near the corner of Biddle Ranch Road and Orcutt Road. This indicates that this is a groundwater recharge area, and that the recent rains of 2016-2017 have elevated water levels in this area. Secondly, a depression in the water table surface is evident in the area near Edna Road and Biddle Ranch Road, likely due to agricultural pumping in the area in recent years. The southeast and northwest extents of the Basin had no wells monitored during this event to calculate water levels in these areas.

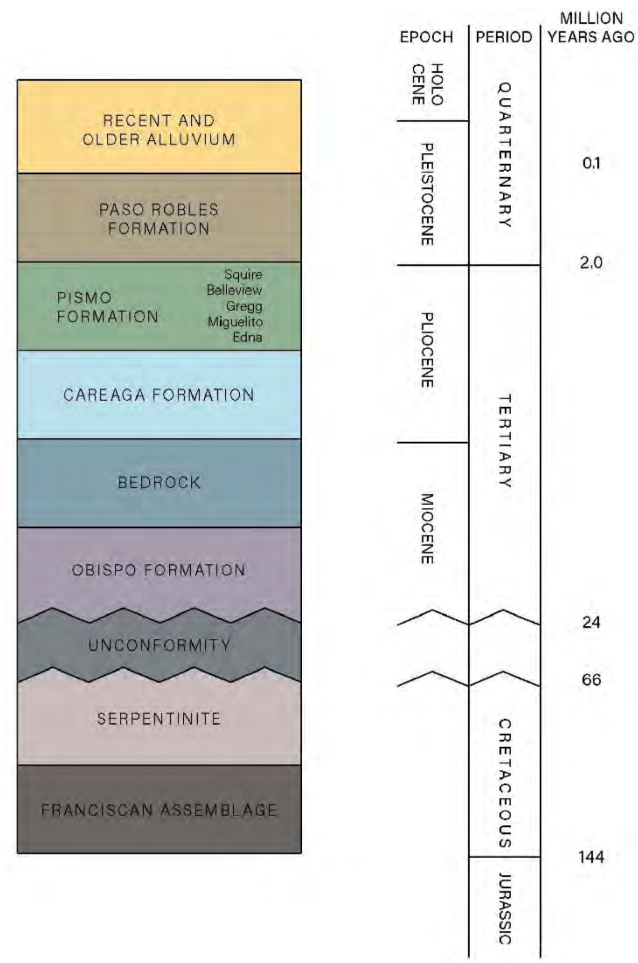
The San Luis Valley and the Edna Valley are characterized by different patterns of groundwater use. In the San Luis Valley, groundwater use has been dominated by municipal and industrial use. In the Edna Valley, groundwater use is dominated by agricultural use. During the past 20 to 25 years, vineyards have supplanted other crop types as the dominant agricultural use. Available water level data were reviewed, and data from wells with the longest period of record are presented here.

Figure 2-7 presents long-term groundwater elevation hydrographs for ten wells throughout the Basin. Three main patterns of water level change are evident in these hydrographs. The hydrographs for the wells in the San Luis Valley indicate that water levels in these wells, although somewhat variable in response to seasonal weather and water use fluctuations and longer-term drought cycles, are essentially stable. There are no long-term trends indicating steadily declining water levels in this area. By contrast, several wells in the Edna Valley display steadily declining water levels during the past 20 to 25 years.

Two wells in close proximity to the groundwater recharge area in Edna Valley where Corral de Piedras Creek enters the Basin display much greater volatility in response to drought cycle fluctuations than the wells in San Luis Valley but appear to rebound to pre-drought levels when the drought cycle ends; water levels in these wells do not display a long-term decline of water levels.

2.4.7. Hydraulic Properties

During the preparation of the Basin Characterization Report (GSI, 2018), all available data on constant rate aquifer tests and specific capacity tests in the Basin were collected, reviewed, and presented in the report. Seventy-seven well locations in the Basin were identified that had an estimate of aquifer hydraulic parameters, indicating reasonable data density in the Basin. Wells screened in the Alluvium and Paso Robles Formation have reported transmissivities ranging from about 5,000 to 158,000 gallons per day per foot (gpd/ft), and averaging over 42,000 gpd/ft. Wells screened in Paso Robles and Pismo Formations have transmissivities ranging from less than 1,000 to about 40,000 gpd/ft, and average about 10,000 gpd/ft. These data are presented in a summary table in Chapter 4 of the GSP.



Prepared for:

Author: EC
Date: 1/13/2020

SAN LUIS OBISPO VALLEY BASIN GSP

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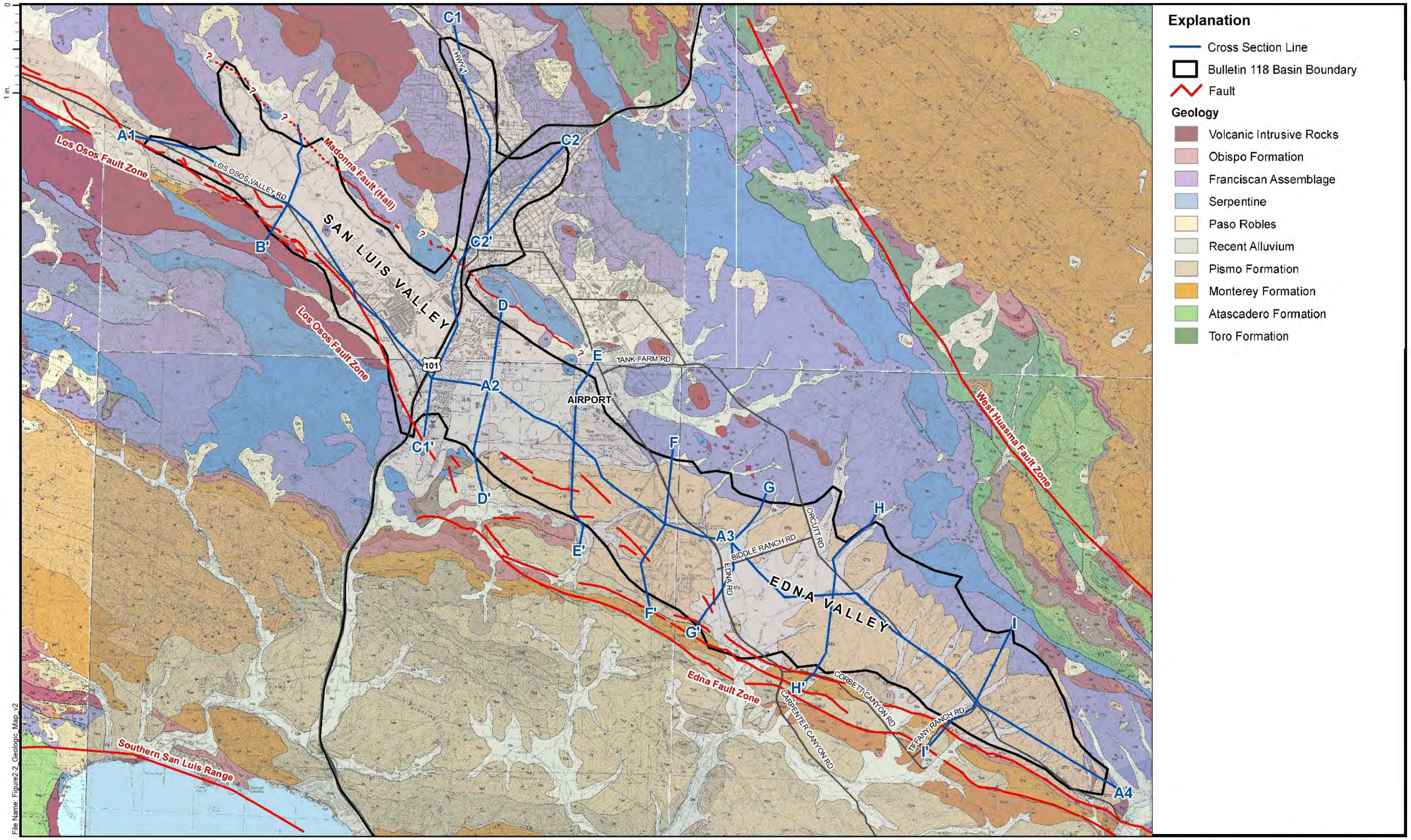
Local Geologic Stratigraphic Column

Figure 2-1



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SAN LUIS OBISPO VALLEY BASIN GSP

Author: EC
Date: 1/13/2020

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1. Coordinate System: NAD 1983 StatePlane California V FIPS 0405 Feet
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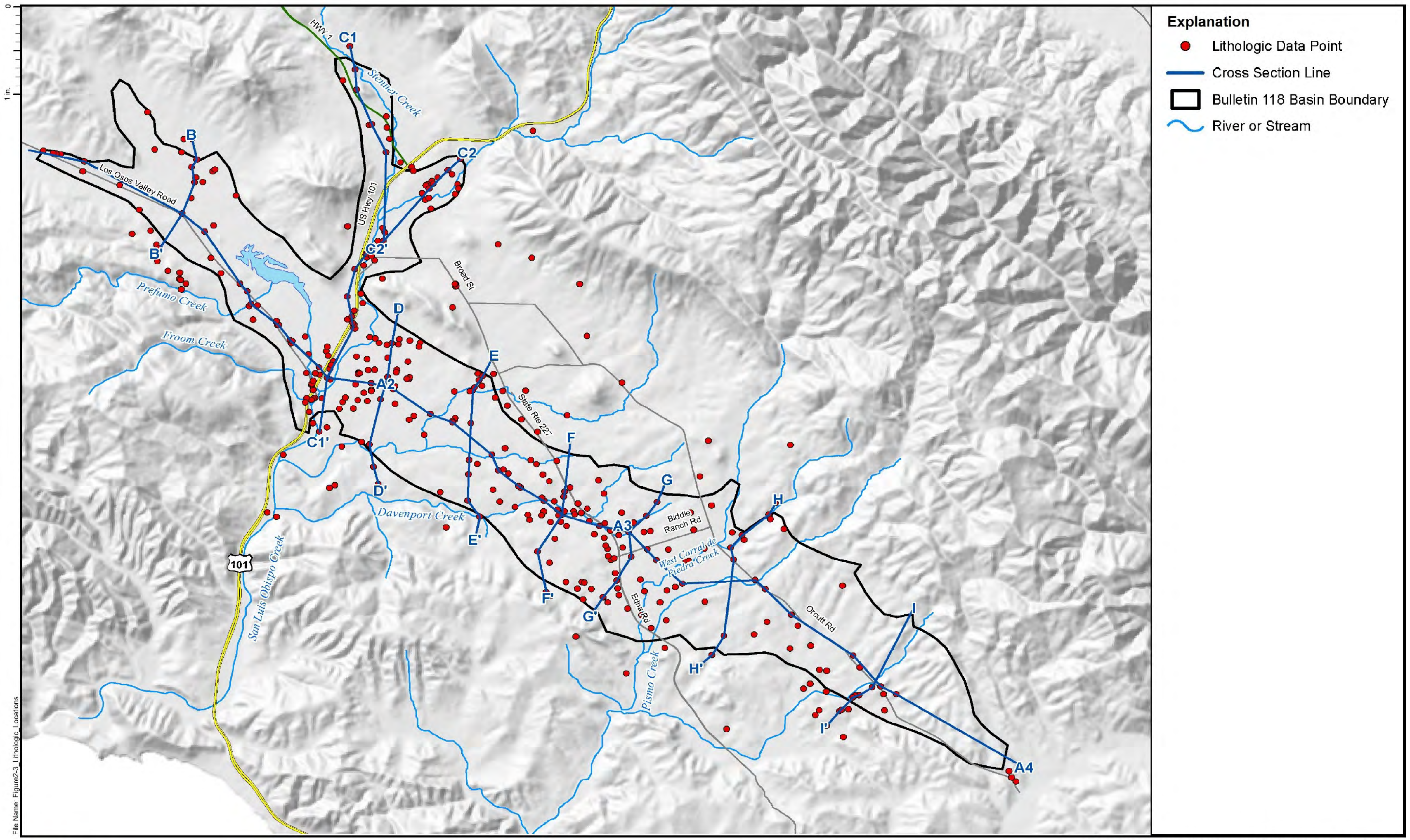
San Luis Obispo Valley Basin Geologic Map

Figure 2-2



Prepared for:

Author: EC
Date: 10/15/2019

SAN LUIS OBISPO VALLEY BASIN GSP

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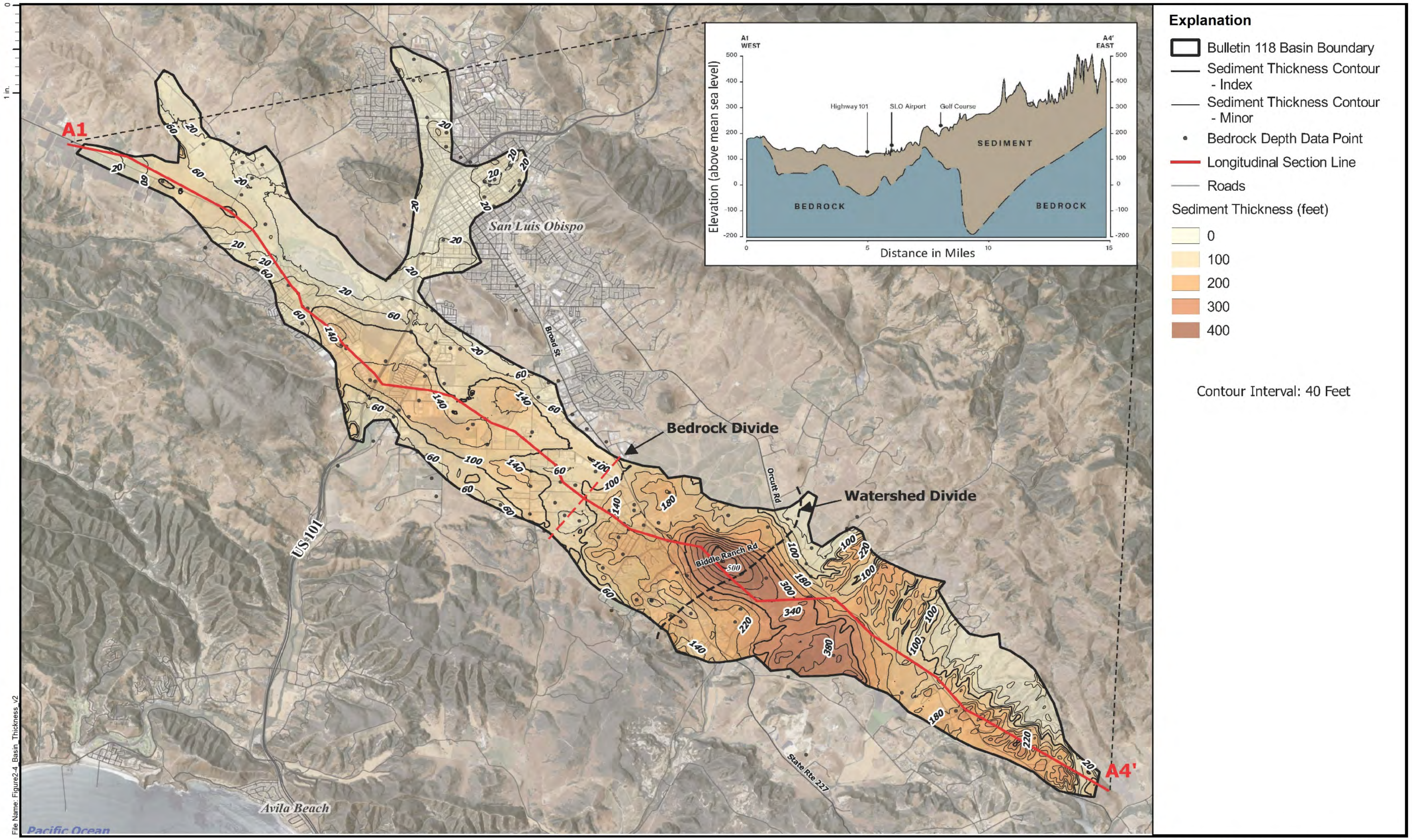
San Luis Obispo Valley Basin Cross Section Lines and Lithologic Data Points

Figure 2-3



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Author: EC
Date: 1/13/2020

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1. Vertical Exaggeration = 57x for inset cross section
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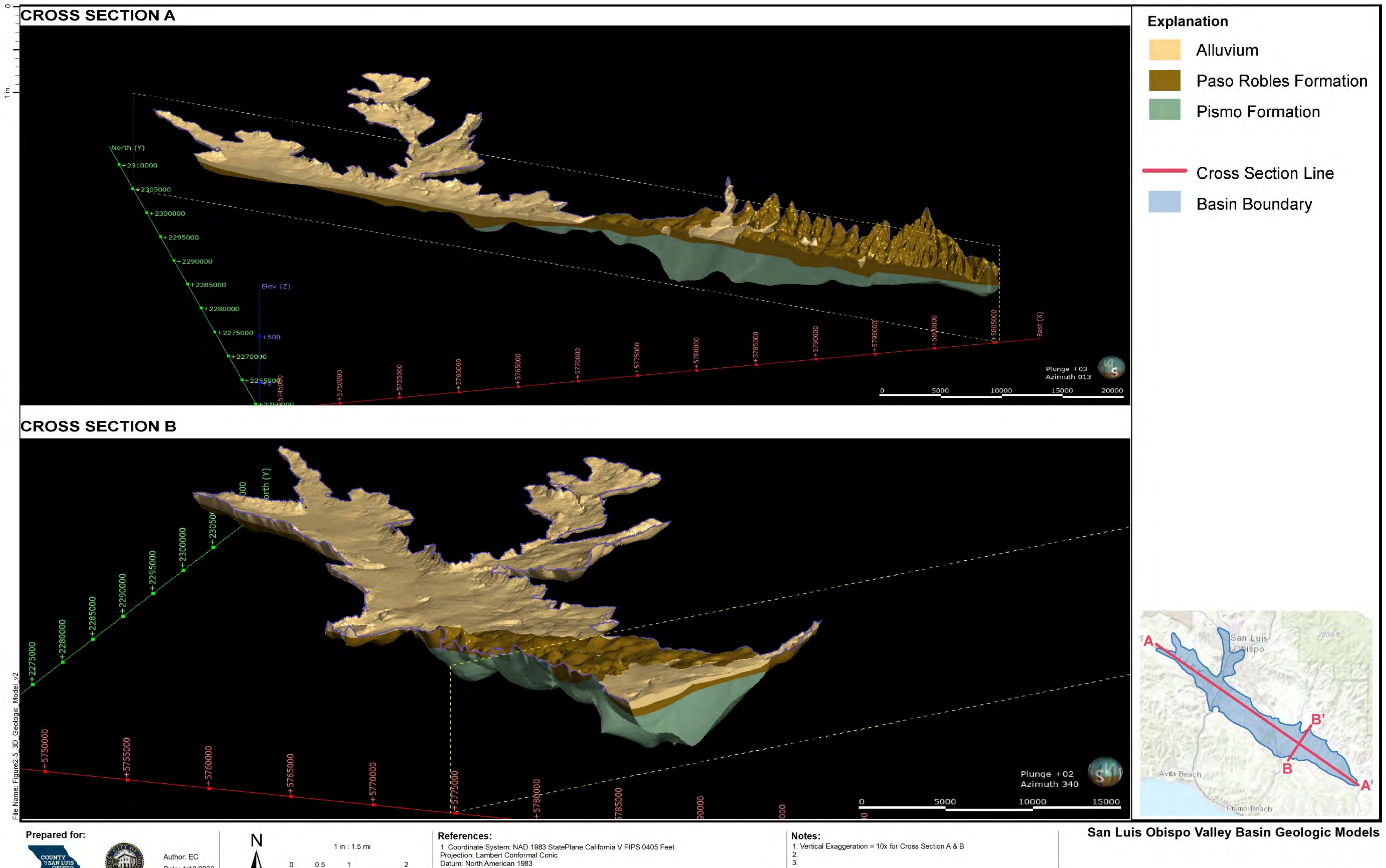
San Luis Obispo Valley Basin Sediment Thickness

Figure 2-4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CROSS SECTION B
Explanation
Alluvium
Paso Robles Formation
Pismo Formation
Cross Section Line
Basin Boundary
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Plunge +02
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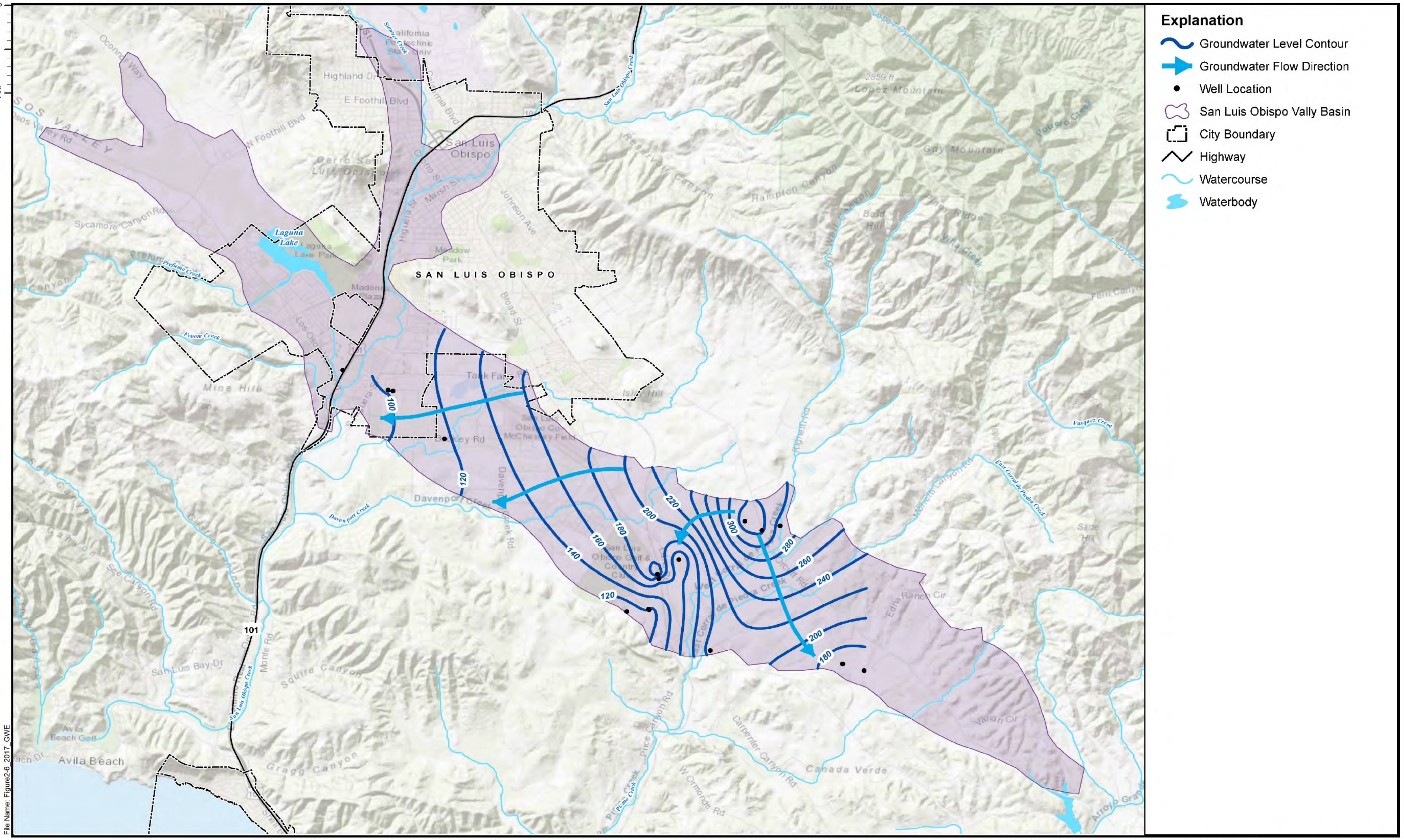
San Luis Obispo Valley Basin Geologic Models

Figure 2-5



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Author: EC
Date: 10/14/2019

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References:
1. Coordinate System: NAD 1983 StatePlane California V FIPS 0405 Feet
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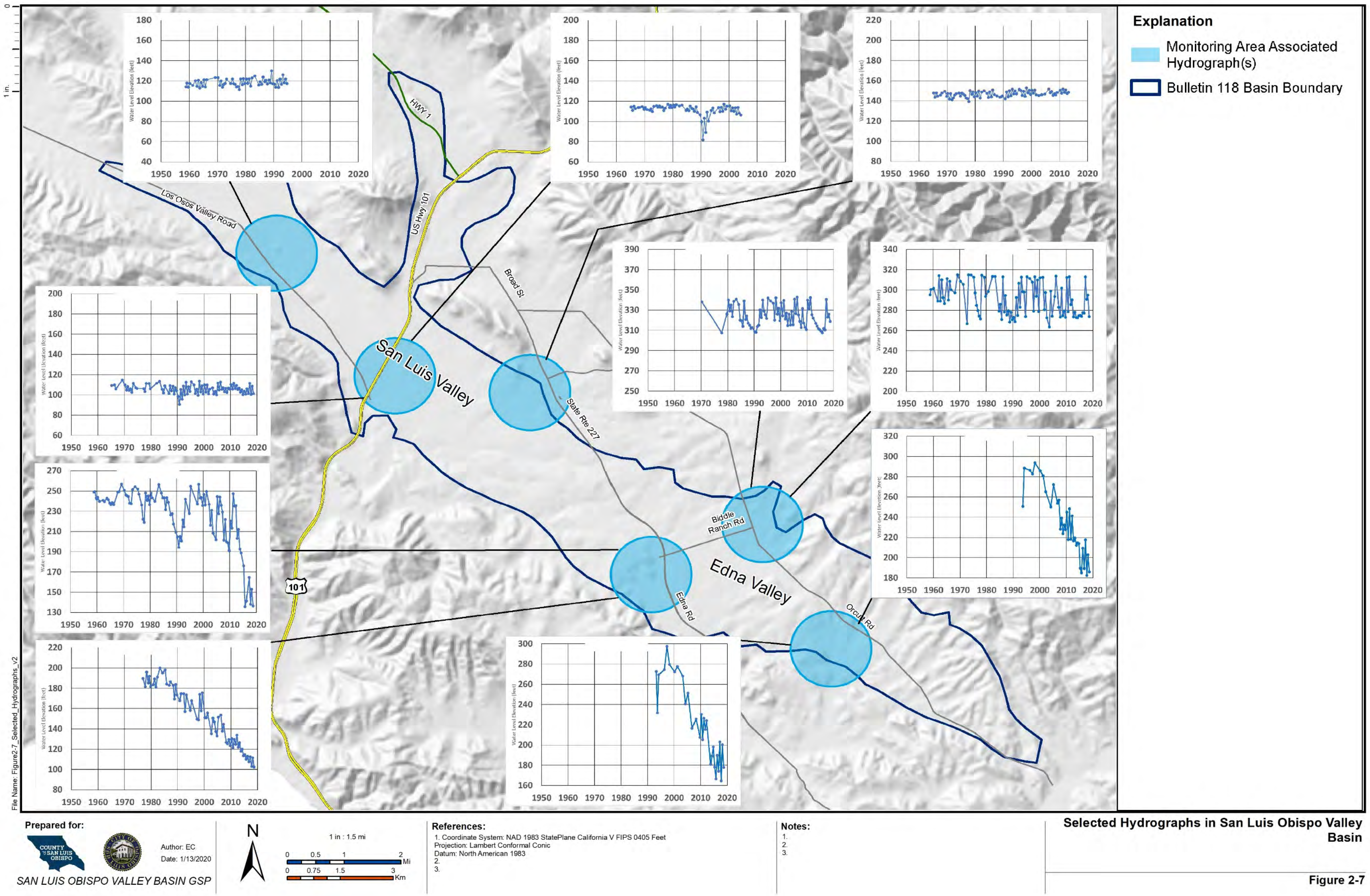
October 2017 Groundwater Elevations

Figure 2-6

File Name: Figure2-6_2017_GWE



Selected Hydrographs in San Luis Obispo Valley Basin

Figure 2-7

Section 3. Modeling Approach

The GSA expressed a preference for an integrated surface water-groundwater model to be used to support the GSP, rather than a traditional groundwater model limited to the extents of the Basin. An integrated model simulates surface water processes in the contributing watershed as well as groundwater flow within the basin and incorporates results of the surface water simulation as input into the groundwater flow model. There are numerous approaches and available modeling codes capable of achieving this objective. GSI and WSC evaluated four options for development of an integrated numerical model and documented the results in a TM prepared for GSA staff (GSI Water Solutions, Inc., 2019), and presented the results to the GSC in a public meeting. The four options considered were:

- MODFLOW + HSPF (coupled model)
- MODFLOW-One Water (OWHM)
- IWFM – DWR Integrated Flow Model
- GSFLOW

For reasons documented in the supporting TM (GSI Water Solutions, Inc., 2019), the decision was made to use GSFLOW as a platform for the integrated model.

GSFLOW is a fully integrated watershed-groundwater model (Markstrom et al., 2008) that has been used throughout the United States by the USGS and other hydrologic professionals to model surface water and groundwater conditions in various geologic settings. GSFLOW is a coupled groundwater and watershed flow model based on integration of the USGS watershed model PRMS and groundwater model MODFLOW. The PRMS and MODFLOW models can be developed separately, with initial parameter estimation performed in the two models separately, before integrating the two component models. Then the integrated model is calibrated and run using GSFLOW to complete the model development process.

GSFLOW was developed to simulate coupled groundwater – surface water flow in one or more watersheds by simultaneously simulating flow across the land surface, within subsurface saturated and unsaturated materials, and within streams and lakes (Markstrom et al., 2008). GSFLOW uses physically based processes and empirical methods with user inputs of air temperature and precipitation (i.e., snow/rain) to simulate the distribution of precipitation into runoff, evapotranspiration, infiltration, groundwater flow, and surface-water flow.

Details of the modeling approach for PRMS and MODFLOW are presented in the following sections.

Section 4. PRMS: Surface Water-Component Model

The modeling software that will be used to simulate the watershed-scale surface water component of the integrated model is PRMS version 5.0.0. PRMS is a deterministic, distributed-parameter, physical-process hydrologic model used to simulate and evaluate the watershed response of various combinations of climate and land use (Markstrom, et al., PRMS-IV, the Precipitation-Runoff Modeling System, Version 4, 2015).

In the PRMS model, climate data, including precipitation and temperature, are applied to simulate hydrologic water budgets based on spatially defined watershed-component model parameters such as plant canopy and soil zone properties. Surface and subsurface flow is calculated through the cascading of rain-generated runoff. When run in PRMS-only simulations, runoff that infiltrates into the soil zone is distributed to the subsurface reservoir and groundwater reservoir where it can interflow to streams or lakes. When run in a coupled GSFLOW simulation, groundwater flow routing is simulated in MODFLOW rather than PRMS. Initial parameter estimation of the PRMS model will be performed in PRMS-only mode prior to integration into GSFLOW and final calibration of the integrated model.

4.1. Model Discretization

Model discretization is performed using Gsflow-Arcpy (Gardner, Morton, Huntington, Niswonger, & Henson, 2018), a toolkit of ArcGIS Python codes. Gsflow-Arcpy consists of a series of python scripts that, when run in succession, produce model-ready PRMS parameter files and a parameter shapefile for visual representation of all inputs.

Prior to performing the model discretization, the watershed boundary, or model domain, for PRMS and GSLFOW was delineated. The model domain was defined by all land area that drains surface runoff into the San Luis Obispo Valley Groundwater Basin. The two primary watersheds that make up this area are the San Luis Obispo Creek and Pismo Creek watersheds. The two pre-delineated watersheds were trimmed at the south-west boundary of the Basin. A topographic analysis was then performed along the south-west boundary to capture all sub-watersheds that drain to the Basin, including the Prefumo Creek and Froom Creek sub-watersheds. Figure 4-1 presents the PRMS model domain.

4.1.1. Hydrologic Response Unit Discretization

The first step in preparation of the PRMS model is the spatial discretization of the watershed into individual hydrologic response units (HRU). This is performed to allow for spatial variability in model inputs (elevation, slope, vegetation type, etc.) and reporting of the simulation results, as a water balance and energy balance are computed at each timestep at each HRU. A grid-based approach, which entails the delineation of the watershed into square grid-cell HRUs, was selected for both the PRMS and MODFLOW models. Various grid cell sizes were evaluated, ranging from 250-foot (ft) to 1,000-ft. Sample grids at differing cell sizes were overlaid onto aerials and base maps to evaluate grid cell density. GSI and WSC performed a brief literature review to assess what grid cell size has been used in comparison to the entire modeled area for other GSFLOW modeling studies documented in the state. The ratios of cell size to watershed size were assessed in comparison to other GSFLOW models, including the Santa Rosa Plain Model (Woolfenden & Nishikawa, 2014) and the Santa Cruz Mid-County Basin Model prepared by HydroMetrics Water Resources, Inc. (Huntington, King, & Tana, 2016). This comparison indicated that 500-foot grid cells for the model yielded a grid cell to model area ratio within the bounds of those from other documented GSFLOW modeling studies. Therefore, a uniform grid cell size of 500 ft x 500 ft, totaling 21,462 cells, was adopted for the initial model development.

The delineation of the watershed into HRUs for the PRMS model was performed using the Gsflow-Arcpy toolkit. Limitations of the ArcInfo grid format is that it will only perform raster-based calculations on vertical-horizontal oriented grid cells (Environmental Systems Research Institute (ESRI), 2013). Additionally, GSFLOW requires that the grid cells in PRMS output files match those in the MODFLOW files or if the PRMS and MODFLOW grid cells orientation and total model extents differ, HRU's assigned in PRMS and their associated gravity reservoirs are reassigned proportionally to each MODFLOW grid cell. To resolve this limitation, the vertical oriented PRMS grid and its populated input data fields will be used for PRMS calibration. Once PRMS and MODFLOW have been initially run separately, PRMS HRU's and their associated gravity reservoirs will be reassigned to the MODFLOW grid. This combined grid will create the final grid to be used for GSFLOW calibration and multiple model runs assessing various scenarios. This approach will maintain the integrity of the developed PRMS input files and allows for simplified integration between PRMS and MODFLOW into GSFLOW that does not require custom code integration and use of additional data files.

Once the HRU grid cells are generated, the next step in the discretization is the designation of cells as one of four types: land, lake, swale, or inactive. Two water bodies within the watershed, Laguna Lake and the Righetti Reservoir, were designated in the model input. Swales, which represent a sink without an outlet, were not identified within the watershed and therefore were excluded from the designation in the model input. Inactive cells represent those outside the watershed boundary that are not included in the model simulation.

The last step to the HRU discretization is the designation of sub-basins. Sub-basins were delineated based on the locations of the various stream gages (see Section 4.2.2), the outlet of Righetti Reservoir, and the model outlet points. Figure 4-1 presents the results of HRU discretization and Figure 4-2 presents the locations of model sub-basin points and model outlet points.

4.1.2. Stream Segments

Another spatial unit that is defined as part of the model discretization is the delineation of stream segments throughout the watershed. In PRMS, lateral flows, inflow and outflow are calculated at each stream segment. Delineation of the stream segments began with first assigning mean surface elevations to each HRU grid cell within the watershed using a 10-meter resolution digital elevation model (DEM) from the National Elevation Dataset (National Elevation Dataset, 2019). The mean elevations are then used by the Gsflow-Arcpy script to designate the stream segments locations by creating continuously down-sloping HRUs. Generated stream segments were viewed in comparison to USGS National Hydrography Dataset (NHD) streams in ArcMap (National Hydrography Dataset, 2002 - 2016) and recent satellite imagery from Google Earth to evaluate the accuracy of the stream delineation. Stream segment alignments were iteratively adjusted by manually altering the mean elevation of HRUs and rerunning the Gsflow-Arcpy script. The level of detail with regards to stream order was optimized to be representative of the main branches and the primary tributaries. Figure 4-3 presents the stream segments generated for the PRMS model.

4.2. Model Inputs and Calibration Data

Like the model discretization, Gsflow-Arcpy (Gardner, Morton, Huntington, Niswonger, & Henson, 2018) was used to assign input parameters to the HRUs such that they are formatted and structured for direct use by the PRMS model software.

4.2.1. Climate Input

PRMS requires a variety of climatic data for use throughout the various stages of modeling, including pre-processing of input data (mean monthly precipitation, maximum temperature, and minimum temperature), simulation runs (daily precipitation, maximum temperature, and minimum temperature), and calibration (solar radiation and evapotranspiration). Climatic data, dating back to 1870, was obtained from the Cal Poly Weather Station through the help of the Irrigation Training & Research Center (ITRC). The Cal Poly Weather Station houses not only the ITRC owned gages but also the California Irrigation Management Information System (CIMIS) and National Oceanic and Atmospheric Administration (NOAA) weather stations. While there are other County and privately-owned climate stations throughout the watershed, the Cal Poly Weather Station is the only station that has extensive records spanning the duration of the anticipated calibration period. Furthermore, the ITRC has performed thorough quality control reviews on the data collected from the Cal Poly Weather Station.

As part of the pre-processing and generation of input data, mean monthly precipitation was spatially distributed to each HRU within the model domain using 30-year normal baseline datasets, spanning from 1981 to 2010, from the Parameter-Regression on Independent Slopes Model (PRISM) (NACSE, 2019). Monthly precipitation scaling factors, that act as multipliers to account for changes in elevation, were then calculated for each HRU based on a ratio between the PRISM data and 1870-2018 mean monthly observed precipitation data from the Cal Poly Weather Station. Figure 4-4 and Figure 4-5 show the mean annual precipitation PRISM dataset and mean annual precipitation scaling factors derived from the PRISM and the Cal Poly Weather Station datasets. During PRMS simulations, the HRU precipitation scaling factors will be multiplied by the daily precipitation measurements from the Cal Poly Weather Station to calculate daily precipitation at each HRU. This will be performed using the precip_1sta module, as discussed further in Section 4.3. The accuracy of the precipitation scaling factors will be assessed by comparing the measured precipitation at the three County rain gages (SLO Portal, SLO Reservoir, and The Gas Company) to the modeled rainfall at each respective HRU.

Mean monthly minimum and maximum temperature values were assigned to each HRU using the 30-year normal PRISM dataset, as done with precipitation. Daily minimum and maximum temperature will be calculated at each HRU during PRMS simulations using daily observed maximum and minimum temperature data from the Cal Poly Weather Station and monthly PRISM data assigned to each HRU. PRMS simulations will use the temp_sta module to perform temperature calculations, as discussed further in Section 4.3. The accuracy of the modeled temperature will be assessed by comparing the modeled minimum and maximum temperatures to the measured values at the two nearby weather stations (PG&E Black Butte and SLO County Farm Bureau) with data available on Weather Element (Weather Element, 2014).

4.2.2. Streamflow Data

The County of San Luis Obispo owns and operates five real-time data monitoring stream gages along San Luis Obispo Creek, within the model domain. Each gage station records creek stage (depth) on fifteen-minute intervals. Available stage data at each station dates to 2005. Of the five County stream gages, three have stage-discharge relationships, or rating curves, that were approximated by Central Coast Salmon Enhancement (CCSE) based on recorded stage data and measured flows between 2017 and 2019. These stream gages include the Andrews Street Bridge, Stenner Creek at Nipomo, and Elks Lane (Figure 1-1). The rating curves generated for these gauge stations are considered the best available information for use in converting stage data to flow rate, and therefore are anticipated to be the primary datasets for use in calibrating the PRMS model. As previously mentioned, Questa Engineering Corps also estimated theoretical rating curves for each of the five County gages using a HEC-RAS model (Questa Engineering Corp., 2007). However, preliminary application of these rating curves to the stream gage data resulted in abnormal daily mean hydrographs in comparison to the hydrographs generated using the CCSE rating curves. The Questa rating curves may be used as a secondary dataset for comparison of modeled to observed flows at the Jesperesen and Madonna Road gage stations, where no CCSE rating curves exist.

In addition to the County owned gages, the City of San Luis Obispo collects weekly measurements of stage and flow within San Luis Obispo Creek at the outfall of the Water Resources Recovery Facility (WRRF) during the months of April to September as part of the National Pollutant Discharge Elimination System (NPDES) permitting program. It is not anticipated that this data will be used for calibration purposes given the apparent daily and monthly data gaps.

Lastly, monthly diversion data, dating back to 2010, is available for the 500-acre-foot Righetti Reservoir located along West Corral De Piedra Creek. A sub-basin, or sub-watershed, was designated at this reservoir in the model so that simulated flows can potentially be calibrated to observed monthly data. The efficacy of calibration at this location will be dependent on the capabilities of the PRMS routing modules and the limited information available on the day-to-day operations of the reservoir. At the very least, the Righetti Reservoir diversion data may be used to incorporate future diversion flows into modeling scenarios.

4.2.3. Additional Parameters

Vegetation, soil, and impervious land cover surfaces play important roles in routing and distributing runoff throughout PRMS. Vegetation is used by relating vegetation type to root depth and evapotranspiration to model water balances within the soil zone, and vegetation's various roles in runoff processes. Vegetation data was retrieved from the LANDFIRE datasets available through the United States Department of Agriculture, Forest Service (LANDFIRE, 2019). The vegetation parameters are calculated and populated before the soil parameters in order to establish root depths for each vegetation type. Soil data from SSURGO and STATSGO (Soil Survey Staff, 2019) are used to extract available water content (AWC), saturated hydraulic conductivity (Ksat), soil type, and percentages of sand, silt, and clay values throughout the watershed. These values are then assigned to various soil parameters used in PRMS to model flux's between vegetation and the soil-root zone. Impervious land cover surfaces are used to model surface runoff in areas that have no infiltration or in areas with different infiltration rates then can be expected from certain vegetated areas or soil types. The National Land Cover Database (Homer, Fry, & Barnes, 2012) data is used to derive these areas within each HRU grid cell represented as percentages. Figure 4-6 shows the National Land Cover Database data showing land cover types in the Basin derived from the impervious Arcpy script.

4.3. PRMS Modules

PRMS simulates the hydrologic cycle through various processes, each with one or more modules available for use. Table 4-1 presents the modules that have been selected for use in this model.

Table 4-1. PRMS Modules to Be Used

Module Name	Process	Description[1]
basin	Basin Definition	Defines shared watershed wide and HRU physical parameters and variables.
cascade	Cascading Flow	Determines computational order of the HRUs and groundwater reservoirs for routing flow downslope.
soltab	Solar Table	Computes potential solar radiation and sunlight hours for each HRU for each day of the year.
obs	Time Series Data	Reads and stores observed data from all specified measurement stations.
temp_sta	Temperature Distribution	Distributes maximum and minimum temperatures to each HRU by using temperature data measured at one station.
precip_1sta	Precipitation Distribution	Determines the form of precipitation and distributes it from one or more station to each HRU by using monthly correction factors to account for differences in altitude, spatial variation, topography, topography, and measurement gage efficiency.
ddsolrad	Solar Radiation Distribution	Distributes solar radiation to each HRU and estimates missing solar radiation data using a maximum temperature per degree-day relation.
transp_tindex	Transpiration Period	Determines whether the current time step is in a period of active transpiration by the temperature index method.
potent_jh	Potential Evapotranspiration	Computes the potential evapotranspiration by using the Jensen-Haise formulation (Jensen & Haise, 1963)
intcp	Canopy Interception	Computes volume of intercepted precipitation, evaporation from intercepted precipitation, and throughfall that reaches the soil.
srunoff_smidx	Surface Runoff	Computes surface runoff and infiltration for each HRU by using a nonlinear variable-source-area method allowing for cascading flow.
soilzone	Soil-Zone	Computes inflows to and outflows from soil zone of each HRU and includes inflows from infiltration, groundwater, and upslope HRUs, and outflows to gravity drainage, interflow, and surface runoff to down-slope HRUs.
gwflow	Groundwater	Sums inflow to and outflow from PRMS groundwater reservoirs. Used in the PRMS-only model, not the integrated GSFLOW model.
strmflow	Streamflow	Computes flow in the stream network using the Muskingum routing method and flow and storage in on-channel lake using several methods. Used in the PRMS-only model, not the integrated GSFLOW model.
[1] (Markstrom, et al., PRMS-IV, the Precipitation -Runoff Modeling System, Version 4: Updated Tables from Version 4.0.3 to Version 5.0.0, 2019; Markstrom, Niswonger, Regan, Prudic, & Barlow, 2008)		

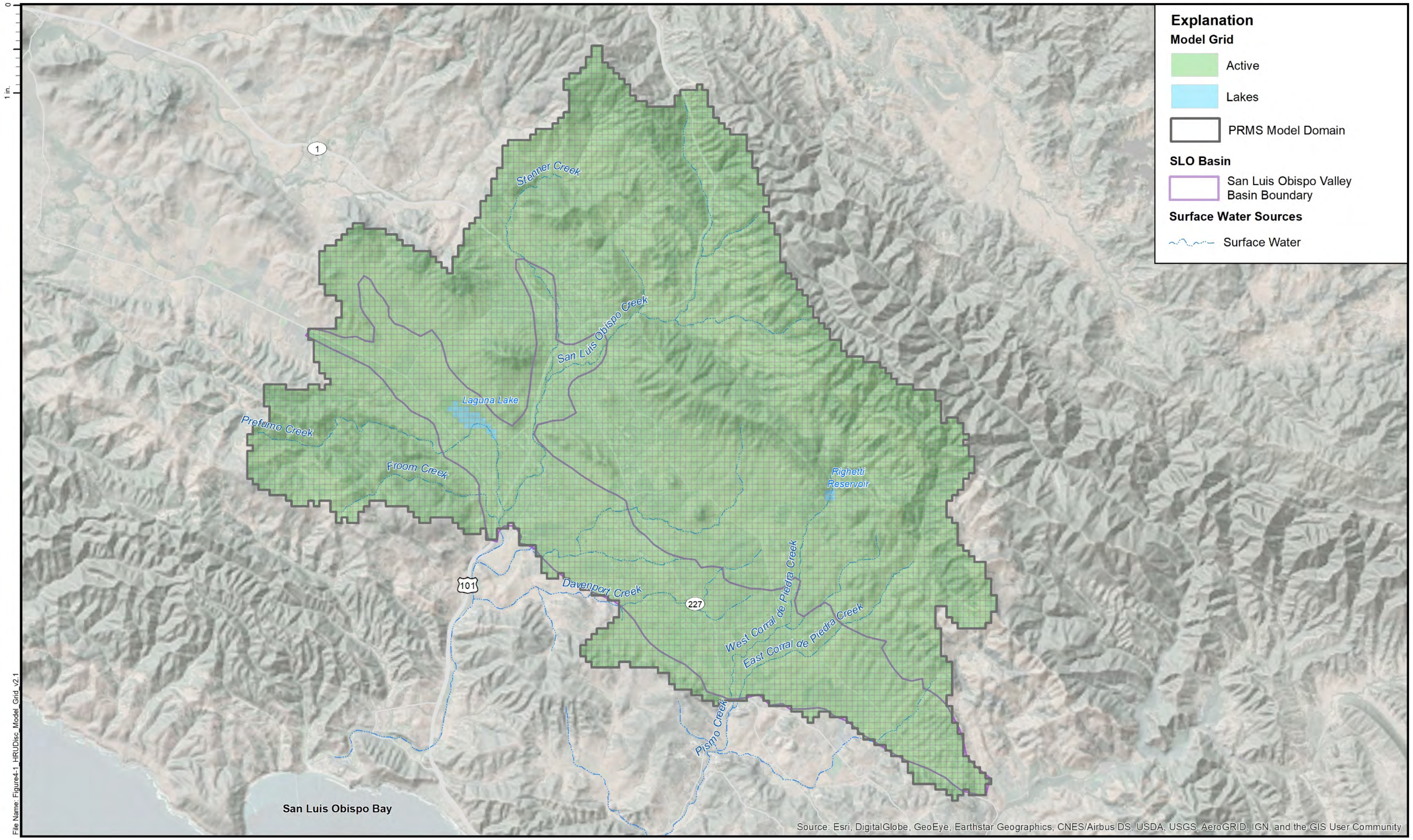
4.4. Calibration Approach

The PRMS model will be calibrated using the USGS Luca software (Hay & Umemoto, 2007) and a step-wise approach that includes the optimization of the following data sets: mean monthly solar radiation, mean monthly potential evapotranspiration, streamflow volume (annual mean, mean monthly, and monthly mean), and streamflow timing (daily and monthly mean). Simulated values and model outputs will be compared to calibration data sets generated from measured data. Data sets for solar radiation and potential evapotranspiration will be derived from measurements recorded at the Cal Poly CIMIS Weather Station 52. Calibration data sets for streamflow volume and timing will be derived from the CCSE and Questa Engineering Corps rating curves and measured stage data at the five County stream gages, as discussed in Section 4.2.2. The Madonna Road stream gage will be used for calibration of the integrated GSFLOW model but not for initial calibration of the PRMS model, as it is located downstream of Laguna Lake which will be modeled in MODFLOW using the Lake Package. The PRMS calibration simulation period will be based on the available stream gage data, which spans from July 2006 to August 2019.

Modeled and measured streamflow will be evaluated in the integrated model via comparison of daily and mean monthly hydrographs as well as using goodness-of-fit statistics. Goodness-of-fit statistics that will be considered for use include the percent-average-estimation-error (PAEE), the absolute-average-estimation-error (AAEE), and the Nash-Sutcliffe model efficiency (NSME). Table 4-2 presents the range of goodness-of-fit criteria as outlined for the Santa Rosa Plain Model (Woolfenden & Nishikawa, 2014). The optimal goal is to achieve calibration results within the “Very Good” or “Excellent” range, however, this may not be feasible at each stream gage location due to limitations associated with the accuracy of the rating curves and stream gage stage data.

Table 4-2. Goodness-of-fit Statistics

Goodness-of-fit Category	PAEE (%)	AAEE (%)	NSME
Excellent	-5 to 5	≤0.5	≥0.95
Very Good	-10 to -5 or 5 to 10	0.5 to 1.0	0.85 to 0.94
Good	-10 to -5 or 5 to 10	10 to 15	0.75 to 0.84
Fair	-10 to -5 or 5 to 10	15 to 25	0.6 to 0.74



Prepared for:

COUNTY OF SAN LUIS OBISPO

SAN LUIS OBISPO VALLEY BASIN GSP

Author: EC
Date: 12/18/2019

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References:
1. Coordinate System: NAD 1983 StatePlane California V FIPS 0405 Feet
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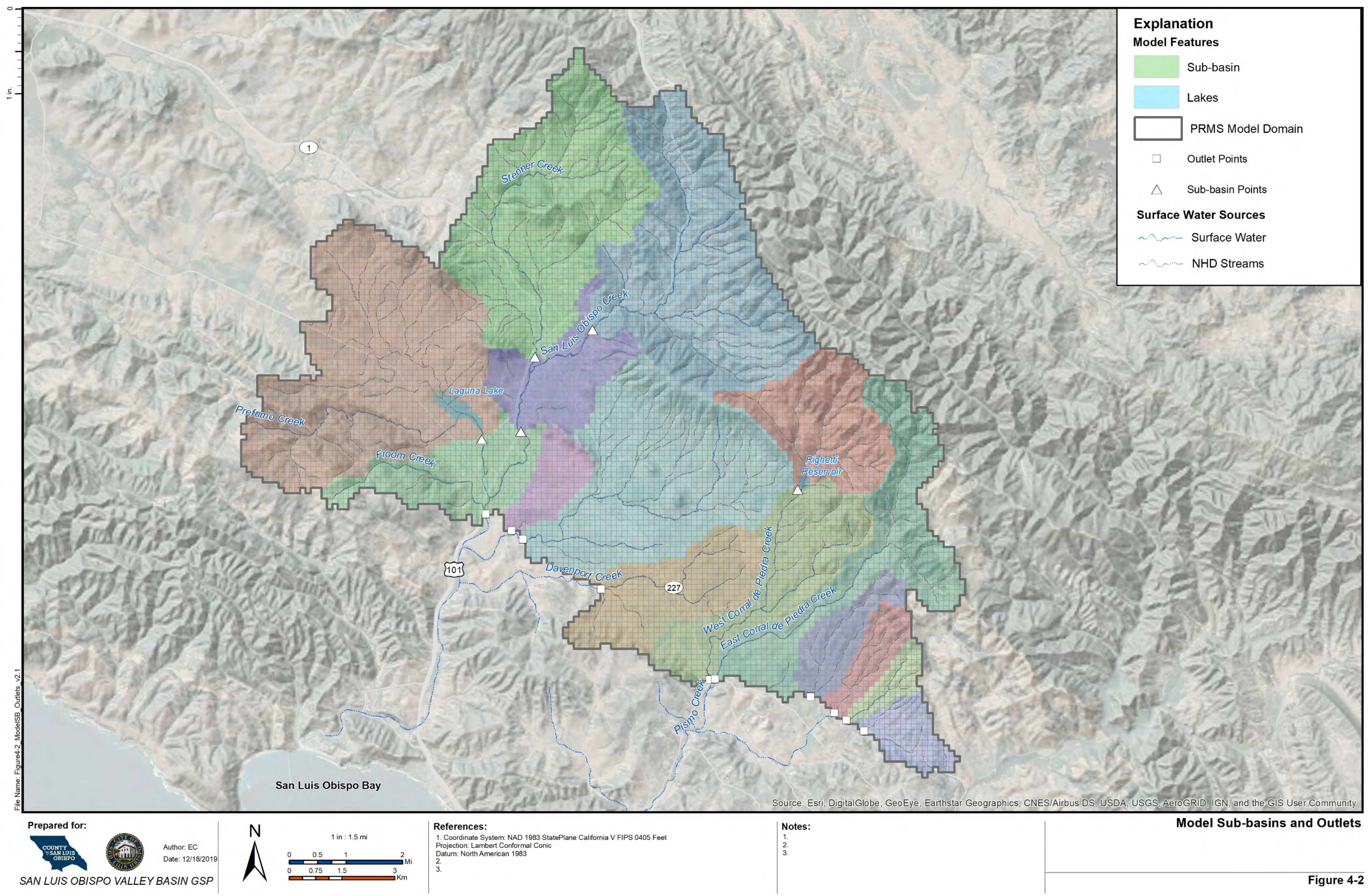
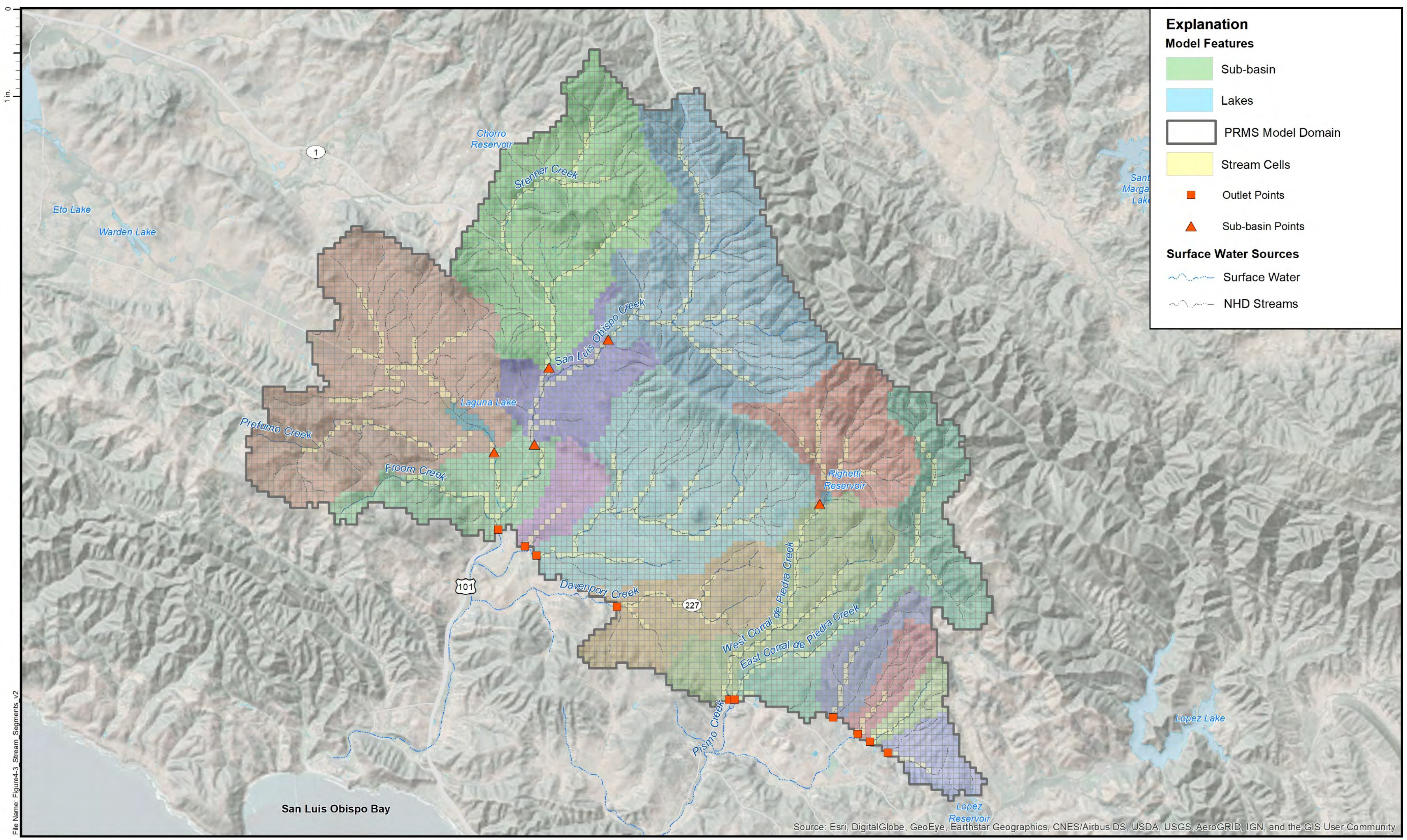
HRU Discretization of Model Grid

Figure 4-1



Model Sub-basins and Outlets

Figure 4-2



Prepared for:

SAN LUIS OBISPO VALLEY BASIN GSP

Author: EC
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1. Coordinate System: NAD 1983 StatePlane California V FIPS 0405 Feet
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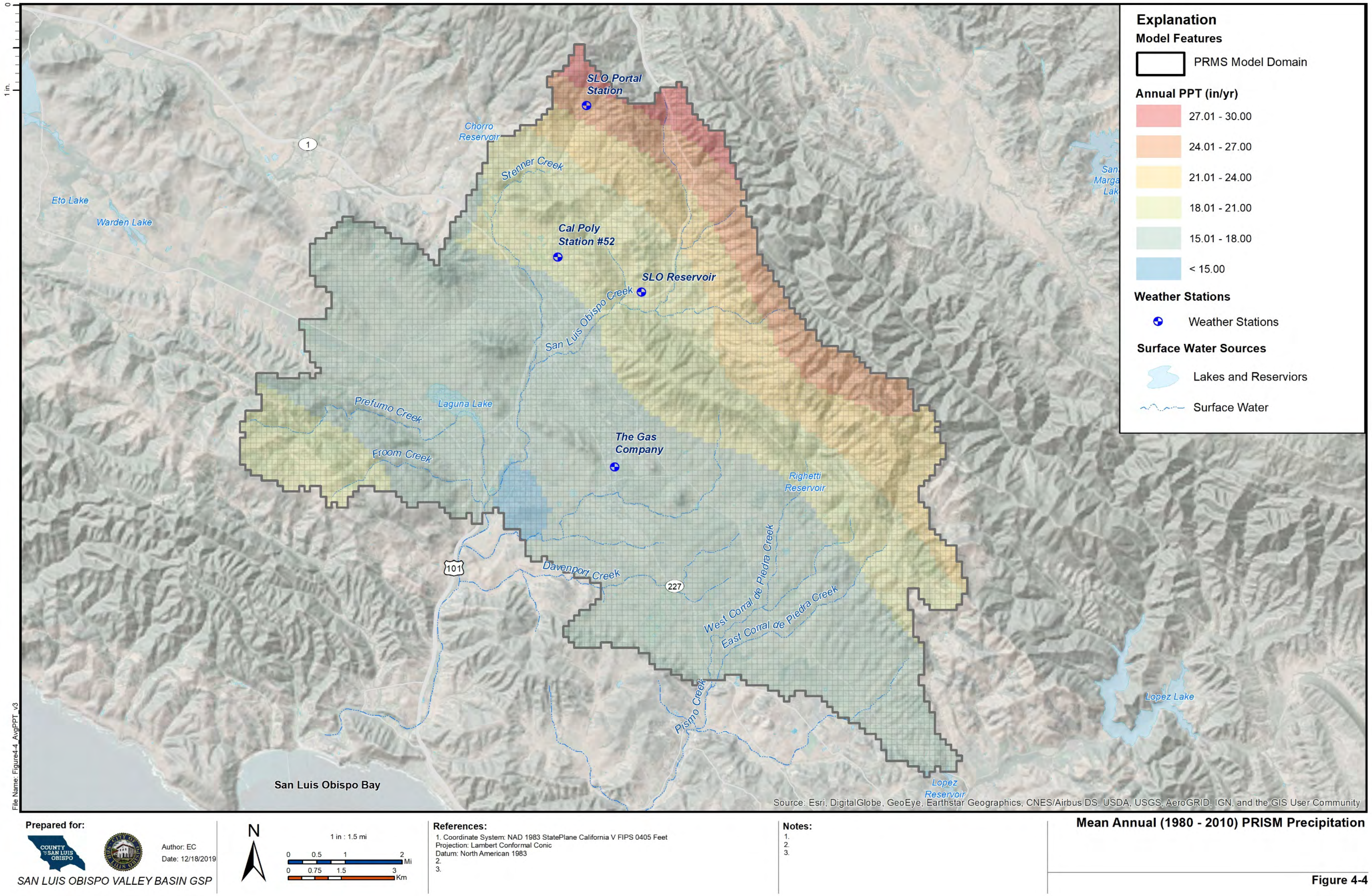
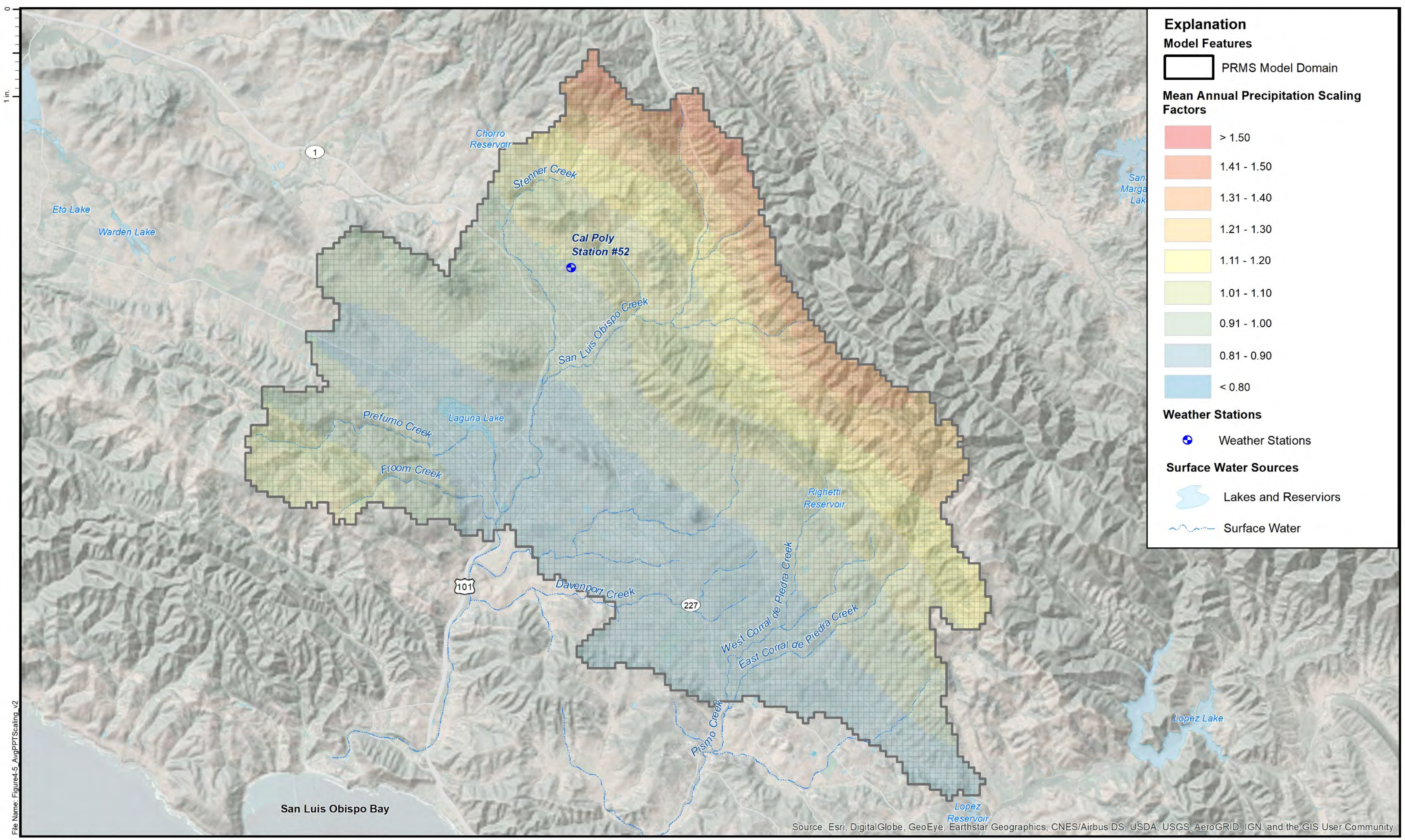
Model Stream Segments and Sub-basins

Figure 4-3



Mean Annual (1980 - 2010) PRISM Precipitation

Figure 4-4



Prepared for:

SAN LUIS OBISPO VALLEY BASIN GSP

Author: EC
Date: 10/10/2019

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1. Coordinate System: NAD 1983 StatePlane California V FIPS 0405 Feet
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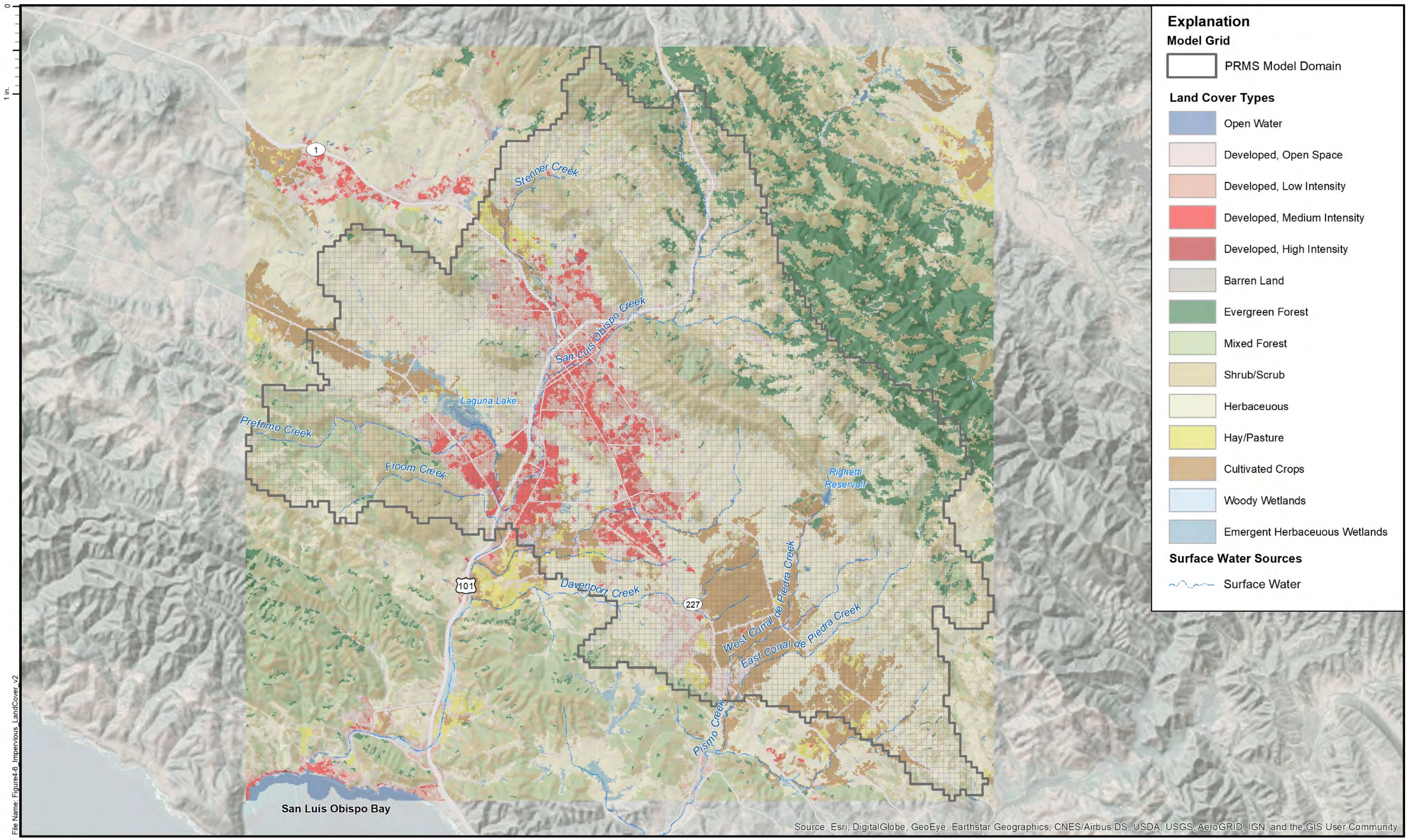
Mean Annual Precipitation Scaling Factors

Figure 4-5



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Author: EC
Date: 12/18/2019

SAN LUIS OBISPO VALLEY BASIN GSP

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References:
1. Coordinate System: NAD 1983 StatePlane California V FIPS 0405 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983
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Land Cover Types

Figure 4-6

Section 5. MODFLOW: Groundwater Flow Model

MODFLOW is a publicly available groundwater modeling code developed by the USGS. It is the most used groundwater modeling code in the world and is considered an industry standard. MODFLOW-NWT is the most recent version of MODFLOW that is compatible with GSFLOW; this is the version of MODFLOW that is being implemented. This section of the TM summarizes the modeling approach for the MODFLOW portion of the GSFLOW model.

5.1. Model Discretization

Model grid discretization for the areas represented by both PRMS and MODFLOW were discussed in the previous discussion of PRMS model approach. A uniform grid cell size of 500 feet by 500 feet was adopted for model development.

Vertical discretization of the model (i.e., model layering) will be implemented based on the dominant geologic formations in the Basin (Figure 5-1). One layer each will be assigned to the Recent Alluvium, Paso Robles Formation, and Pismo Formation. In addition, because there are wells identified within the Basin that draw from both the Basin sediments and the underlying Monterey Formation bedrock, a fourth model layer will be added to represent undifferentiated bedrock (i.e., both Franciscan and Monterey Formation represented with a single layer) beneath the Basin, and extending up to the watershed boundaries.

5.1.1. Lateral Boundaries

Groundwater elevations at the northwest extent of the Basin where it bounds with the Los Osos Valley Basin, and at the southeast extent of the Basin where it bounds with the Arroyo Grande sub-basin, are assumed to be coincident with divides in the groundwater surface between the adjacent basins. These lateral boundaries of the Basin will be represented with Constant Head Boundaries (CHBs) with elevations assigned using the most accurate estimate of groundwater elevations in these areas that can be developed from available data.

5.1.2. Mountain Front Recharge

Groundwater elevations in the bedrock formations of the mountains surrounding the Basin are higher than the groundwater elevations within the Basin. Since groundwater flows from areas of higher head to areas with lower head, it is assumed that some amount of inflow to the Basin sediments occurs through the mechanism of mountain front recharge. Subsurface inflow to the Basin through mountain front recharge will be estimated as part of CHG’s water budget analysis. It is not expected that this will comprise a significant portion of the Basin water budget. The estimates that will be generated for this component of inflow to the Basin will be represented using General Head Boundaries (GHBs) along the lateral boundaries of the Basin.

5.1.3. Recharge

In a traditional MODFLOW model, various components of recharge to the aquifer such as infiltration of precipitation, irrigation and municipal return flow, etc., are estimated and implemented into the model via the MODFLOW Recharge Package. With the integrated modeling approach provided by GSFLOW, these components of recharge are explicitly simulated using the physically-based processes simulated in PRMS, and the results are transmitted for use by MODFLOW in the groundwater flow simulations. Initial estimates of these recharge components will be made based on water budget analysis and calibration of the MODFLOW model to observed historical water levels. Refinement and revision of these estimates will occur during the combined calibration process using both PRMS and MODFLOW.

5.1.4. Infiltration of Streamflow

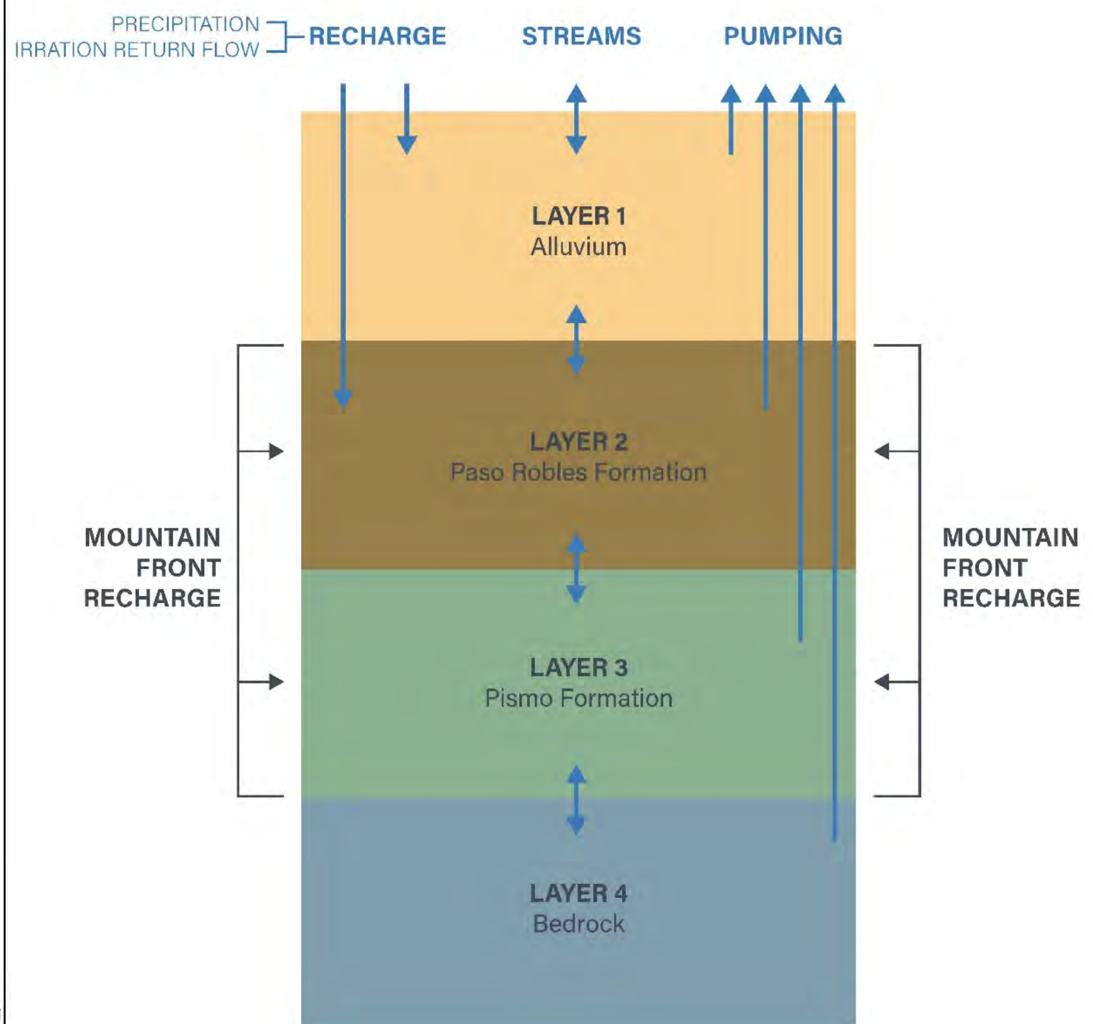
As discussed previously, seasonal infiltration of streamflow to the underlying aquifers is a significant component of the Basin water budget. Streamflow processes within the Basin will be represented using the Streamflow Routing packages available in MODFLOW (SFR and SFR2). Estimates of streamflow infiltration into the underlying aquifers in the Basin provided by the CHG water budget analysis and by previous studies will be used as general guides during historical calibration. Parameters of the SFR package will be adjusted until the quantities of flux between the streams and the aquifers are consistent with the available data.

5.1.5. Well Pumpage

CHG estimates of historical well pumpage developed for the water budget analysis will be incorporated into the historical calibration of the groundwater model. Municipal pumpage by the City will be represented in the specific wells owned and operated by the City. For representation of agricultural pumpage in MODFLOW, there is often not adequate information on well location or pumpage amounts to attempt to explicitly represent pumpage from individual wells. A common approach is to spread estimated agricultural pumping amounts over the entire area of irrigated fields. GSI anticipates that given the amount of data available on well locations in the irrigated areas of the Basin and estimates of historical agricultural pumpage generated by CHG's water budget analysis, it may be feasible to apply irrigation pumpage to specific wells located within the irrigated field areas. Pumpage from de minimis well owners will be estimated based on County data and spread across the areas where the wells are located; no effort to identify specific de minimis wells will be made.

5.2. Calibration Approach

As discussed previously, PRMS and MODFLOW may be run separately during the early stages of model development. It is anticipated that GSI will conduct initial parameter estimation using a long-term historical simulation in MODFLOW-only mode, prior to and separate from the PRMS initial calibration. Because PRMS must be run using daily time steps, it is not necessarily the most efficient tool to perform a long-term simulation to generate initial parameter estimates. Evaluation of the hydrographs in Figure 2-7 indicate that water levels were in approximate equilibrium prior to 1980. The drought of the late 1980s and early 1990s is clear in the hydrographs of some of these wells. In addition, water level declines in Edna Valley wells beginning in the 1990s is evident. In order to capture these significant trends in water levels over the years, the initial parameter estimation of the MODFLOW model will be performed to simulate the 40-year period from 1980 to 2019 using quarterly or monthly stress periods, before the MODFLOW and PRMS models are combined for the integrated model. Annual values provided by the CHG water budget analysis will be used to guide model inputs for such model parameters as pumping and recharge. Aquifer hydraulic properties such as transmissivity and storativity will be varied within ranges indicated by available data (GSI 2018). After the initial parameter estimates of the groundwater flow model are complete, the MODFLOW model will be combined with the PRMS model to perform a joint calibration in which the points of contact between the surface water model and the groundwater flow model are adjusted over the calibration period. All the hydrographs displayed in Figure 2-7 will be used as calibration targets for the MODFLOW model. A commonly referenced metric for groundwater model calibration is to achieve a scaled root mean square error less than 10% for water level calibration targets. GSI and WSC will attempt to meet this calibration standard for modeled groundwater elevations.



Prepared for:

Author: EC
Date: 10/15/2019

SAN LUIS OBISPO VALLEY BASIN GSP

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Model Layering and Hydrologic Conceptual Model

Figure 5-1

Section 6. Summary and Next Steps

This TM has presented the data summary, HCM, and anticipated modeling approach for the development of an integrated surface water-groundwater model of the SLO Basin and its contributing watersheds. After approval by the GSA staff, the next step is to perform calibration of the model, discussed in Section 5.2. After separate initial runs of PRMS and MODFLOW are completed, the two models will be joined in GSFLOW, and a combined calibration will be implemented in which parameters of both models will be adjusted to achieve a good fit between observed and modeled water levels, stream flow, and other water budget components.

After calibration of the integrated model is completed, a sensitivity analysis will be performed. The purpose of a sensitivity analysis to identify parameters or boundary conditions to which model forecasts are particularly sensitive. Sensitivity analysis provides a measure of the influence of parameter uncertainty on model predictions. During the sensitivity analysis, key model input parameters and boundaries (such as pumping, recharge, transmissivity, etc.) are systematically varied on the calibrated model simulation, and the resulting impact on the modeled heads are quantified. Calibration and sensitivity analyses will be documented in a separate Technical Memo.

After the completion of the sensitivity analysis, if the model is judged to be adequate for the purposes of the GSP, it will be used to run predictive scenarios simulating projects and management actions to be specified by the GSAs. When the predictive scenarios are complete, an uncertainty analysis will be performed. The purpose of the uncertainty analysis is to identify the impact of parameter uncertainty on the use of the model's ability to effectively support management decisions. This can inform the interpretation of the model results to identify high priority locations for recharge projects, expansion of monitoring networks, and other management actions. The uncertainty analysis is like the sensitivity analysis in that key model parameters are systematically varied and resultant impacts on modeled heads are quantified. However, the uncertainty analysis is performed on the predictive scenario runs rather than the calibration simulation.

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