TECHNICAL MEMORANDUM

IMPLEMENTATION OF GROUNDWATER AND SURFACE WATER MODEL INPUTS FOR SIMULATIONS IN SUPPORT OF GROUNDWATER SUSTAINABILITY PLAN DEVELOPMENT BY THE MOUND, FILLMORE AND PIRU GROUNDWATER SUSTAINABILITY AGENCIES

UNITED WATER CONSERVATION DISTRICT

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This document describes selected modeling stresses and assumptions used by United Water Conservation District to conduct simulations of future hydrologic conditions considered in the Groundwater Sustainability Plans prepared by the Mound Basin Groundwater Sustainability Agency and the Fillmore and Piru Basins Groundwater Sustainability Agency that may not be described in detail in the Groundwater Sustainability Plans.

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1 INTRODUCTION

The Fillmore and Piru Basins Groundwater Sustainability Agency (FPBGSA) and the Mound Basin Groundwater Sustainability Agency (MBGSA), with the assistance of their consultants, Daniel B. Stephens and Associates and INTERA Incorporated, respectively, are developing the Groundwater Sustainability Plans (GSPs) for the Piru, Fillmore, and Mound subbasins of the Santa Clara River Valley groundwater basin (Figure 1) in compliance with the 2014 Sustainability Groundwater Management Act (SGMA). The United Water Conservation District (UWCD or United) is supporting the analysis of the GSPs for the Piru, Fillmore, and Mound subbasins by using its recently expanded MODFLOW-based Regional Groundwater Flow Model ("Regional Model") (UWCD, 2021; 2018).

In supporting the GSP development efforts of the FPBGSA and MBGSA, this document details the implementation of selected modeling stresses used for the GSP simulations for three future scenarios: (1) future baseline reference, (2) near future (2030 climate change factors), and (3) late future (2070 climate change factors). All future scenarios use the period 1943-2019 as the past reference period for hydrological inputs, the longest period possible with good recorded hydrologic data. The document contains two main sections which describe selected processes and assumptions used in the simulations by UWCD to conduct simulations for the Groundwater Sustainability Plans: Section 3 *Groundwater Flow Modeling Inputs*, and Section 4 *Surface Water Hydrology Modeling*. Section 4 details the modeling of several surface water hydrology spreadsheet models that provide input data to the groundwater model. The groundwater model reports (UWCD, 2021, 2018) detail the construction and calibration of the Regional Model. Specific to the GSP modeling presented here, this document provides additional detail regarding how the surface water and groundwater forecasting for the future runs requested by FPBGSA and MBGSA was implemented into the Regional Model.

2 INTERACTIONS BETWEEN GROUNDWATER FLOW MODEL AND SURFACE WATER HYDROLOGY MODELS

Surface water hydrology inputs to the Regional Model (UWCD, 2021) were determined using a number of hydrological models used for reservoir operations, streamflow routing and Freeman Diversion operations. Figure 2 provides a schematic of the model integration employed for the GSP supporting work. Figure 3 shows the streamflow locations used in Figure 2, as well as stream gages described in Section 4. A more detailed explanation of each surface water hydrology model is also provided in Section 4. The modeling workflow consists of the following four elements:

1) Groundwater Flow Model upstream of Freeman Diversion facility.

The Regional Model simulates streamflow, groundwater levels and water balances for the Piru, Fillmore and Santa Paula basins. Hydrological models are used to calculate Lake Piru outflows (including spills), Castaic Lake reservoir releases, and streamflow in the Santa Clara River (SCR) upstream of the confluence with Castaic Creek. Estimated future discharges from water reclamation facilities (WRFs) in the Santa Clarita Valley (SCV) are combined with simulated Castaic Lake releases and streamflow in the SCR upstream of Castaic Creek to calculate streamflow in the SCR upstream of the confluence with Piru Creek. Lake Piru outflows and streamflow in the SCR upstream of Piru Creek are used as inputs to the Regional Model. Additionally, the Regional Model incorporates inputs for tributary flows, weather, recharge, pumping, diversions and WRF discharges in Ventura County.

2) Diversions and bypass flows at the Freeman Diversion

Stream flow in the Santa Clara River just upstream of the Freeman Diversion facility was calculated using United’s Upper Basins Routing Model. Diversions and Santa Clara River flows just downstream of the Freeman Diversion (“bypass flows”) were calculated by United’s Hydrological Operations Simulation System (HOSS). The HOSS requires inputs for groundwater elevations for selected wells in the Oxnard Forebay. Since the HOSS is not integrated with the Regional Model, the first HOSS model run for a scenario is generally run using historical groundwater elevations or estimates from a prior run. Model outputs are then input to the Oxnard Plain Surface Water Distribution Model (SWDM, see below), which provides inputs to the Regional Model. Selected groundwater elevation outputs from the Regional Model are then used as inputs for a second run of the HOSS, the SWDM and the Regional Model. This iterative process is repeated until groundwater elevations converge.

While the Regional Model also calculates streamflow at the Freeman Diversion, its simulated streamflow at the Freeman Diversion was not able to adequately reproduce the historical daily flow magnitudes and trends during model calibration, although the simulated monthly-average streamflow was close to the historical monthly records. The MODFLOW Stream Package (STR) used by the Regional Model is based on a simplistic concept of stream routing which does not include the streamflow travel time in the stream channel, leading to the limitation that the STR package is more suitable for the relatively stable streams. Although the Reginal Model may not be able to adequately simulate the daily SCR streamflow rates, it should be noted that the Regional Model was able to simulate the groundwater levels in the basins of the SCR valley with good calibration.

3) Artificial recharge and surface water deliveries by United

The Oxnard Plain Surface Water Distribution Model (SWDM) was used to calculate the volumes of artificial recharge to each of United's recharge basins and surface water deliveries to the Pumping-Trough-Pipeline (PTP) and the Pleasant Valley (PV) pipeline, based on diversions calculated by the HOSS. The SWDM also calculates pumping demands in United's surface water delivery service areas (PTP and PV) as the deficit between total demand and surface water deliveries. Conejo Creek diversions are also incorporated in the SWDM, and are an important water supply to the PV service area. The SWDM requires inputs for groundwater elevations for selected wells in the Oxnard Forebay. Since the SWDM is not integrated with the Regional Model, iterative runs are performed in a similar manner as with the HOSS model.

4) Groundwater Flow Model downstream of Freeman Diversion Facility.

The Regional Model uses inputs provided by the upgradient portion of the model (groundwater fluxes from Santa Paula basin), the SWDM (artificial recharge, surface water deliveries, pumping) and HOSS (diversions, bypass flows) to simulate streamflow, groundwater levels and water balances for the Mound, Oxnard, Pleasant Valley and western Las Posas Valley basins. Selected groundwater elevations from wells in the Oxnard Forebay are exported to the HOSS and SWDM operations models for iterative runs until groundwater elevations for wells in the Oxnard Forebay and fluxes to Mound basin converge (as described in the previous paragraphs and in Sections 4.6 and 4.7). Generally two-to-four model runs are required, depending on how well initial water levels assumed for the HOSS and SWDM runs match the Regional Model outputs.

3 GROUNDWATER FLOW MODELING INPUTS

This section describes the various data inputs that were required for simulations by the Regional Model in support of the GSP analysis in cooperation with FPBGSA and MBGSA and their consultants. Some of these components have previously been described within the Regional Model documentation (UWCD, 2021, 2018), while some are specific to the scenarios simulated for the GSP development.

3.1 WEATHER DATA

Precipitation used over the model domain and reference evapotranspiration (ET) used in riparian stream channel reaches were estimated based on the California Department of Water Resources (DWR) datasets and guidelines for the preparation of GSPs (DWR, 2018a). DWR provided Variable Infiltration Capacity (VIC) model output for precipitation and reference ET at 1/16th degree resolution spatial resolution and monthly temporal resolution (monthly totals) for a reference simulation over 1915-2011 that represents a historical simulation with the temperature detrended as well as monthly total change factors for each month for two future climate periods representing the near future (2030) and the late future (2070).

United, FPBGSA, and MBGSA selected three weather datasets based on a single historical climate cycle (1943-2019). The historical climate cycle was adjusted by the two DWR climate factors provided for precipitation and reference ET corresponding to the DWR baseline reference simulation and recommended central tendency scenarios for each climate periods for the near future (2030) and the late future (2070). This resulted in a total of three 77-year climate datasets to be used for model simulations.

Using the monthly totals for precipitation and reference ET from the DWR baseline reference simulation, near future (2030) and late future (2070) estimates were calculated for input into the Regional Model future climate simulations. A crop coefficient of 1.0 was used for riparian vegetation. Monthly total values for precipitation and ET were then mapped from the VIC grid cells to MODFLOW grid cells based on the VIC grid cell that the center of a MODFLOW grid cell was determined to be located within (Figure 4). Monthly totals of precipitation and ET were then uniformly distributed across each month.

Lastly, as the DWR precipitation and reference ET change factors were available for model years 1915-2011 as monthly totals, input for recent model years 2012-2019 were determined by selecting analogous water years in the historical record and applying the precipitation and reference evapotranspiration change factors published for these analogous water years. The analogous year selection criteria were chosen based on streamflow analysis, and more detail related to those methods is presented in Section 4.8.

3.2 RECHARGE

The Regional Model was used to simulate groundwater recharge resulting from various sources and uses of surface water, as described below. The recharge from different sources and/or uses were summed as total recharge in the recharge package (RCH) in the Regional Model. The groundwater recharge from various sources and/or usages of surface water is detailed in the following subsections. The recharge rates used were based on the calibration result of the Regional Model (UWCD; 2021, 2018).

3.2.1 PRECIPITATION

In relation to areal recharge calculations, monthly evapotranspiration (ET) was assumed to be 0.75 inch. If the monthly precipitation was less than 0.75 inch, no recharge from the precipitation was simulated. If the monthly precipitation was greater than 0.75 inch, the recharge was assumed to increase linearly, proportional to the monthly precipitation, with a maximum recharge rate of 30 percent. The recharge from precipitation was implemented as follows:

- If monthly precipitation was less than 0.75 inch, then no recharge was assigned in that area;
- If monthly precipitation was 0.75 to 1 inch, then recharge was assigned from 0 to 10 percent of precipitation (on a sliding scale);
- If monthly precipitation was 1 to 3 inches, then recharge was assigned from 10 to 30 percent of precipitation
- If monthly precipitation was greater than 3 inches, then recharge was assigned as 30 percent of precipitation.

3.2.2 EXTRACTED WATER FROM WELLS

The extracted groundwater from wells serves agricultural need as well as municipal and industrial (M&I) use. The extracted groundwater for agriculture was assumed to have higher recharge rate than M&I use.

The agricultural water recharge rate was assumed to be 25% for Oxnard subbasin and 20% for all other basins (Piru, Fillmore, Santa Paula, Mound, Pleasant Valley, and West Las Posas). If the precipitation recharge rate was higher than the assumed agricultural water recharge rate (20% or 25%) particularly during wet months, the agricultural water recharge rate was replaced by the higher precipitation recharge rate. The M&I water recharge rate was assumed to be 5% (of delivered water) for all basins.

3.2.3 APPLIED WATER

Regardless of the source, for modeling purposes water use is classified so that return flows to the systems can be characterized properly. The recharge rates for agricultural and M&I uses were calculated in the same manner as described in Section 3.2.2 *Extracted Water from Wells*, above. Cities, and various local water companies and mutuals pump and deliver water to users, in addition to a multitude of private groundwater wells that are operated within the model domain. Several surface water diversions are also maintained and operated. Cities on the Oxnard Plain import water from the State Water Project (via Calleguas Municipal Water District (CMWD)), but direct deliveries of State Water does not yet occur in the Piru, Fillmore, Santa Paula or Mound basins. In a few instances extracted water is transported by pipeline to other basins.

3.2.4 UWCD RECHARGE ACTIVITIES AND SURFACE WATER DELIVERIES

UWCD diverts streamflow from the Santa Clara River for artificial recharge within its spreading basins and delivers a portion of diverted SCR water via pipelines to Pumping Trough Pipeline (PTP) users and Pleasant Valley County Water District (PVCWD) users for agricultural irrigation. Additionally, Camrosa Water District (Camrosa) diverts water from Conejo Creek to supply PVCWD users and users within their own service area. The recharge resulting from surface water deliveries from the water diverted and delivered water by UWCD and Camrosa was calculated as agricultural return flow in the same manner as described in Section 3.2.2 *Extracted Water from Wells*, above. The recharge occurring in UWCD's spreading basins was calculated without loss based on a series of surface water hydrology and operational models, as detailed in *Section 4 Surface Water Hydrology Modeling*. United is not currently operating their Piru Spreading Grounds and there are no UWCD surface water deliveries within Piru, Fillmore, or Mound basins. Recharge activities related to conservation releases from Lake Piru and other releases along the Santa Clara River are detailed in *Section 4 Surface Water Hydrology Modeling*.

3.3 MOUNTAIN FRONT RECHARGE

There are some areas outside of the Regional Model domain that are part of surface watersheds associated with the Oxnard, Pleasant Valley, West Las Posas, Mound, Santa Paula, Fillmore, and Piru groundwater basins. Precipitation that falls on these areas may contribute mountain front recharge to the aquifers. The precipitation is calculated based on the surface watershed areas outside of the Regional Model. The sum of precipitation is multiplied by the same precipitation recharge ratio used in calculating the precipitation recharge detailed in Section 3.2.1 *Precipitation*, which is presented above.

3.4 STREAMFLOW, INTER-BASIN SUBSURFACE FLOW, AND DIVERSIONS

The Regional Model simulated flows in the Santa Clara River and several tributaries, Conejo Creek, Arroyo Las Posas, and Calleguas Creek. The streamflow rates at the Freeman Diversion were calculated as detailed in Section 4.5 *Santa Clara River Upstream of Freeman Diversion Facility*, below. UWCD simulated SCR flow from Piru basin to the ocean. The simulated SCR streamflow at the Los Angeles Country boundary in Piru and the simulated streamflows of its tributaries (Piru, Hopper, Pole, Sespe, and Santa Paula Creeks) were calculated as described in

Section 4. *Surface Water Hydrology Inputs*. Diversions along the Santa Clara River and tributaries were implemented similarly as described in the 2020 Regional Model documentation (UWCD, 2021) with future monthly total estimates calculated as the average for the available reported data 2010-2019.

The streamflow in Conejo Creek entering the Regional Model was based on data provided by the Fox Canyon Groundwater Management Agency (FCGMA)'s consultant, DUDEK, for the previous future modeling of the lower basins (UWCD, 2019). Estimates based on a relationship between monthly precipitation for a nearby VIC grid cell (DWR, 2018a) and historical observed Conejo Creek streamflow were previously provided to UWCD. For the future simulations presented here, the relationship was modified slightly using a VIC grid cell (ID 9894) that was within the Conejo Creek watershed and produced a slightly improved relationship between the VIC precipitation and historical observed Conejo Creek streamflow. This relationship was then applied to the 1915-2011 DWR records, adjusted for 2030 and 2070 change factors and the 2012-2019 years were determined by selecting analogous water years in the historical record in the same manner as mentioned in Section 3.1, above, and detailed in 4.8, below. The discharge to Conejo Creek by Camarillo Sanitation District was included in the Stream (STR) package, as was the flow diversion by Camrosa.

The streamflow in Arroyo Las Posas enters the Regional Model from East Las Posas. There was also an inter-basin flow between East Las Posas and the PV basin in the form of subsurface flow (groundwater flux) beneath Arroyo Las Posas. Similar to Conejo Creek, streamflow entering the Regional Model was based on data provided by the FCGMA's consultant, DUDEK for the previous future modeling of the lower basins (UWCD, 2019) based on a relationship between monthly precipitation for a nearby VIC grid cell (DWR, 2018a) and historical observed Arroyo Las Posas Creek streamflow. The same relationship was used and applied to estimated streamflow for the future baseline, 2030 and 2070 simulations, and the 2012-2019 years were determined by selecting analogous water years in the historical record in the same manner as mentioned in Section 3.1, above, and detailed in 4.8, below.

The inter-basin flow between the East Las Posas and the Pleasant Valley basins were previously simulated by a groundwater model developed by CMWD's consultant, INTERA and previously provided to UWCD (UWCD, 2019). The 1930-1979 inter-basin flow for the 2030 and 2070 future climates were used to fill associated years in the 1943-2019 records. 1980-2019 was filled with 1930-1979 monthly averages, adjusted for the difference between the 1970-1979 average and the 1930-1979 average. In the absence of future baseline information, future baseline was filled with estimated 2030 data over 1943-2019.

3.5 PUMPING

Pumping within the Piru, Fillmore, and Mound Basins were prescribed for the future baseline, 2030, and 2070 simulations by FPBGSA and MBGSA. Because the Santa Paula basin is adjudicated, the pumping within the Santa Paula basin uses average 2015-2019 pumping for future baseline, 2030, and 2070 simulations. Future pumping related to the Oxnard basin, Pleasant Valley basin, and Las Posas basin was previously prescribed by FCGMA in accordance with their GSPs (FCGMA, 2019a, 2019b, 2019c), and the implementation in the future scenarios is detailed in previous modeling documentation (UWCD, 2019).

4 SURFACE WATER HYDROLOGY INPUTS

A number of hydrological models were used to simulate reservoir operations, streamflow routing and Freeman diversion operations. All models were run using historical hydrology for the period 1943-2019 for the future baseline scenarios, and with adjustments for climate change according to the DWR Guidance Document for the Sustainable Management of Groundwater. All models were calculated and calibrated in daily time steps. Hydrology models were spreadsheet models, calculated in Microsoft Excel, except for the runoff model used to calculate change factors to account for development in the Santa Clarita Valley. A description of all surface water hydrology models and major assumptions is presented here. More detailed information is available in other published reports, as referenced.

4.1 CASTAIC RESERVOIR RELEASES

The California Department of Water Resources (DWR) completed construction of Castaic Dam in 1973. The current operations of Castaic Reservoir include flood flow releases to the Downstream Water Users (DWUs), of which United is member. Flood flow releases are implemented according to a 1978 agreement between DWR and the DWUs, allowing for storage and later release of natural inflows in excess of 100 cfs into Castaic Reservoir. Storage of flood flows is contingent on availability of sufficient storage volume, and all stored water is to be releases by May 1. Any remaining water can be appropriated by DWR. United coordinates the flood flow release program for the DWUs and makes the requests for water storage and release to DWR.

Simulation of releases from Castaic Reservoir was performed using a Castaic Reservoir operations model. While daily operations logs with releases are available for the 1977-2019 period, an operations model allows calculation of releases for the entire 1943-2019 modeling period, and allows simulated releases for different climate change scenarios.

The Castaic Reservoir model was developed as a simple water balance model in Microsoft Excel. Reservoir inflows were calculated as follows (Figure 3):

- 1/1/1943 – 9/30/1946: estimated based on correlation with gage USGS 11108500 SANTA CLARA RIVER AT L.A.-VENTURA CO. LINE CA
- 10/1/1946 - 12/31/1976: Gage USGS 11108145 CASTAIC C NR SAUGUS CA
- 1/1/1977 – 12/31/2019: natural inflows from DWR Southern Field Division Water Operations Logs.

The following assumptions were made for calculating flood flow releases:

- Inflow-outflow regime is implemented when reservoir inflows are less than 100 cfs.
- Flood flow releases occur between February and April.
- Flood flow releases are initiated when stored flood flows exceed 10,000 acre-feet (February), 4,000 acre-feet (March) or 0 acre-feet (April)

- Maximum flood flow release rates are determined as such that flows in the Santa Clara River downstream of the Castaic Creek confluence do not exceed 75 cfs (February) or 200 cfs (March-April).
- Percolation losses in Castaic Creek during flood flows releases equal 10% of flow.
- When reservoir inflows exceed 5000 cfs (daily), 50% of inflows are released as inflow-outflow and 50% are stored for later release (if storage capacity is available).
- Inflow-outflow regime is implemented when stored flood flows exceed 15,000 to 45,000 acre-feet (depending on month).
- All flood flows are appropriated by DWR when cumulative inflows exceed 40,000 acre-feet (indicating wet years when historically no flood flow releases were requested).

The Castaic Reservoir model was calibrated by comparing modeled and observed annual total releases (including flood flow releases and releases during inflow-outflow operations) for the 1979-2020 period, and by comparing modeled and observed flood flow releases for the 1998-2020 period (Figure 5). Figure 6 shows an example of how simulated reservoir releases differ from historical flows in Castaic Creek before construction of Castaic Reservoir.

4.2 SANTA CLARA RIVER NATURAL RUNOFF UPSTREAM OF CASTAIC CREEK

The historical record of “natural” (no WRF discharges”) streamflow in the Santa Clara River upstream of Castaic Creek was calculated by subtracting historical Valencia WRF discharges and Castaic Creek discharges from the flows at Santa Clara River downstream of Castaic Creek. The latter were compiled using the following records (Figure 3):

- 1943-1946: estimated based on correlations with gage USGS 11108000 SANTA CLARA R NR SAUGUS CA.
- 1947-1952: sum of flows from gages USGS 11108000 SANTA CLARA R NR SAUGUS CA and USGS 11108145 CASTAIC C NR SAUGUS CA.
- 1952-1996: Gage USGS 11108500 SANTA CLARA RIVER AT L.A.-VENTURA CO. LINE CA
- 1996-2019: Gage USGS 11109000 SANTA CLARA R NR PIRU CA.

Significant development occurred in the Santa Clarita Valley between 1943 and 2019. Therefore, for future modeling efforts, the historical flow record for the Santa Clara River upstream of Castaic Creek was adjusted to reflect the current rainfall-to-runoff response associated with a higher degree of urban development and land use with impervious surfaces. It was assumed that future developments will not significantly alter the current percentage of effective impervious area, and therefore the flow record was not further adjusted for future land use changes. This assumption is based on the expectation of infill development and the implementation of stormwater Best Management Practices in most future developments.

Adjustment of historical flows to reflect current levels of impervious area was performed as follows:

1) Daily runoff in the Santa Clara River upstream of Castaic Creek was simulated for 1960-2005 using the calibrated and validated Santa Clara River hydrology model developed by the Ventura County Watershed Protection District using the U.S. EPA Hydrologic Simulation Program – FORTRAN (HSPF) (VCWPD, 2009). This model run used the 2001 Southern California Association of Governments (SCAG) land use data. Flows were simulated for station RCH190 in the HSPF model (Figure 3).
2) The HSPF model was run as before but with impervious area reflecting 1950s, 1970s and 1990s land use. Land use coverage in the HSPF model was adjusted by reducing the impervious land use proportional to the reduction in population in the Santa Clarita Valley between 2000 (pop. 190,000) and the earlier periods. Impervious land use was reduced by 94% (pop. 12,000), 70% (pop. 58,000) and 28% (pop 136,000) for the 1950s, 1970s and 1990s, respectively. The area corresponding to the impervious land use reductions was assigned to open space and agriculture according to available historical land use data (Price et al., 2007, Robson, 1972).
3) For each of the HSPF runs with reduced impervious area (1950s, 1970s, 1990s), the difference in runoff with the 2000s land use run was calculated. The only variables that were different between model runs were the percentages of impervious, agricultural and open space land use. Relationships were established between the reduction in runoff with reduced impervious land use and modeled discharge, separately for peak flows and flows on receding limb of hydrograph, for the 1950s, 1970s and 1990s model runs (Figure 7).
4) The relationships from step 3 for the 1950s, 1970s and 1990s were applied to the historical record of 1943-1959, 1960-1979, and 1980-1999, respectively, effectively increasing daily flows during storm peaks and hydrograph receding limbs (only storm runoff exceeding 50 cfs). The historical record from year 2000 onwards was not adjusted for land use changes. The resulting flow record and a comparison with the historical record is shown in Figure 8.

4.3 SANTA CLARA RIVER DOWNSTREAM OF CASTAIC CREEK

Daily discharge in the Santa Clara River downstream of Castaic Creek (Figure 3) was calculated as the sum of the flows upstream of Castaic Creek (Section 4.2), releases from Castaic Reservoir (Section 4.1) and estimated discharges from the Valencia, Saugus and future Newhall Ranch WRFs. Future discharges from the WRFs were assumed to be constant at 30 cfs, no streamflow losses were applied. United's estimate of WRFs discharges corresponds well with the total WRF discharges assumed by Santa Clarita Valley Water Agency (SCVWA) for their GSPs future water balance (Dirk Marks, personal communications). SCVWA assumes average monthly discharges between 25 and 37 cfs, or 29 cfs on average.

4.4 LAKE PIRU RESERVOIR OUTFLOWS

The Lake Piru reservoir model is a water balance model calculating water levels and storage in Lake Piru based on historical data or assumed scenarios for inputs and outputs. Water inputs include inflows from the Middle Piru Creek watershed (natural flows, State Water imports, releases from Pyramid Lake) and rainfall; outputs include releases through the Santa Felicia Dam (SFD) outlet works (conservation releases, migration releases, habitat releases), spills and evaporation. Inflows from Middle Piru Creek were compiled based on gages USGS 11110000 PIRU C NR PIRU CA (1943-1955) and USGS 11109600 PIRU CREEK ABOVE LAKE PIRU CA (1955-2019) (Figure 3).

Important assumptions and inputs include:

- Lake Piru storage area and volume were gradually decreased to reflect the current rate of sedimentation in the reservoir. Storage capacities and corresponding areas were reduced gradually every 5 years from 82,000 AF (1943-1947 model years) to 69,384 AF (2013-2019 model years). The starting storage capacity was based on a 2020 bathymetry survey, and the 5-year sediment loads to the reservoir were calculated based on the average annual rainfall for each 5-year period using the equation 5-yr sediment load (AF) = 126.5 * average rainfall (inches) – 1,653. This relationship was developed from the 1985, 1996, 2005, 2015 and 2020 Lake Piru bathymetry surveys.
- Historical inflows from Middle Piru Creek includes periods when Pyramid Lake operations were different from current operations (inflow-outflow).
- Habitat and migration releases are simulated using operational rules that mimic releases according to operations specified in the Santa Felicia Water Release Plan (UWCD, 2012).
- Conservation releases are simulated using operational rules that mimic current operations. Conservation releases were started in September with maximum release rates of 400 cfs during dry and normal years, and started in August with a maximum release rate of 300 cfs during wet years. Minimum carry-over storage volumes during dry, normal and wet years were 15,000 AF, 30,000 AF and 50,000 AF, respectively.
- UWCD has a State Water Project Table A allocation of 3,150 AF. Annual allocations of Table A water were based on DWR's modeling of the State Water Project's existing delivery capability, which includes current flow regulations and adjusted to account for land-use changes (DWR, 2018b). To simulate current operations, it was assumed that UWCD would not purchase Table A water during wet years (water year rainfall at Santa Paula gage #245 < 25" or 3-year running average for Sespe runoff > 200,000 AF when rainfall at gage #245 > 10") and during years when the conservation release exceeds 31,000 AF.

4.5 SANTA CLARA RIVER UPSTREAM OF FREEMAN DIVERSION FACILITY

Streamflow in the Santa Clara River at the Freeman Diversion facility was calculated using the Upper Basins Surface Water Model. This model calculates surface flows, recharge to groundwater and rising groundwater for the reaches of the Santa Clara River overlying the Piru, Fillmore and Santa Paula basins (Figure 9). Model inputs include releases from Lake Piru (Section 4.4), Santa Clara River flows from Los Angeles County (Section 4.3), tributary flows (Hopper Creek, Sespe Creek, Santa Paula Creek), and historical available storage in Piru and Fillmore basins. Model outputs include available storage in the Piru and Fillmore basins for model scenarios, and river flows at the Freeman Diversion. Empirical relationships (based on observations) are used to model the following processes: recharge to groundwater in the Piru and Fillmore basins, rising groundwater at the Piru/Fillmore and Fillmore/Santa Paula basin boundaries, underflow between Piru and Fillmore basins, and losses in surface flows across Santa Paula basin. The model calculates the change in available storage in Piru and Fillmore basins for a modeling scenario compared to historical trends in available storage (based on a water mass balance for each basin), and subsequently adjusts fluxes for recharge, rising groundwater and underflow for the modeling scenario based on the calculated available storage and the established empirical relationships. The groundwater basin water balances for Piru and Fillmore only include fluxes for stream recharge, rising groundwater and underflow. Other fluxes including groundwater pumping, recharge not associated with the stream channel and evapotranspiration are assumed to remain unchanged between the historical hydrology and modeled scenarios. The influxes and outfluxes calculated for each reach are summarized in Table 1.

Two additional calculations were included in the model to improve model calibration.

- A multiplication factor of 1.2 was applied to gaged daily streamflows from major tributaries (Hopper Creek, Sespe Creek, and Santa Paula Creek). The correction factor improves calibration by accounting for bank storage and inflows from minor tributaries that were not included in the model.
- Simulated daily streamflow at the Freeman Diversion Facility was adjusted for model bias by subtracting the modeling error obtained from simulating historical hydrology and operations. This bias correction improves the model results when the unadjusted model would consistently over- or under predict streamflow for a period of time (e.g. during a conservation release, or on the receding limb of hydrograph for a specific storm event).

Model calibration results for streamflow just upstream of the Freeman Diversion Facility for the Upper Basins Surface Water Model and the Regional Model, and simulated diversions based on these streamflows, are compared in Figure 10. While both models perform well, the Regional Model underpredicts long-term average streamflow, leading to an underprediction of simulated diversions. Diversions simulated by the HOSS (simulating bypass flows proposed in United’s Multiple Species Habitat Conservation Plan; UWCD, 2020) based on observed historical streamflows are 65,060 AF/yr, while simulated diversions based on streamflows from the Upper

Basins Surface Water Model and the Regional Model are 65,700 AF/yr and 57,300 AF/yr, respectively. Therefore, the Upper Basins Surface Water Model was used to simulate future streamflow at the Freeman Diversions.

4.6 DIVERSIONS AND BYPASS FLOWS AT FREEMAN DIVERSION FACILITY

Diversions are calculated based on total river flows entering the Freeman Diversion facility (imported from the Upper Basins Surface Water Model), and operational simulations using the Hydrological Operations Simulation System (HOSS) model.

The HOSS is a hydrology-based operations model that simulates diversions and flow magnitudes in the Santa Clara River downstream of the Freeman Diversion (bypass flows), and the amount of water that is lost or gained to/from groundwater in the “critical reach” of the SCR in the Oxnard Forebay. The HOSS is based upon several decades of historical flow gage data, groundwater conditions in the Forebay, and diversion flow rates, and has been peer-reviewed by R2 Resource consultants (R2 Resource Consultants, 2016).

Since some modeled operations in the HOSS depend on groundwater levels, iterative runs were performed where diversions from the HOSS were used in the SWDM and Regional Model, and groundwater level outputs from the groundwater model run (forecasted groundwater elevations at three wells) were then used to re-run the same scenario in the HOSS and SWDM until model runs converged (see also Section 4.7).

For groundwater modeling for GSP development, bypass flow and diversion operations were implemented as follows:

- 1943-1945 model years (2020-2022): Bypass flow operations as currently implemented by United, based on the reasonable and prudent alternative 2 (RPA 2(a) and 2(b)) as contained in the 2008 Biological Opinion issued by National Marine Fisheries Service (NMFS, 2008). These operations require increased bypass flows for steelhead migration compared to historical operations. Operations correspond to Scenario 4 (UWCD, 2016).
- 1946-1949 model years (2023-2026): Bypass flow operations proposed by United in its Freeman Diversion Multiple Species Habitat Conservation Plan (UWCD, 2020), without infrastructure improvements. These operations are designed to provide adequate bypass flows for fish migration while increasing diversions compared to the operations based on the Biological Opinion, and represents a realistic scenario for future diversion operations. No updates to United’s facilities are implemented during these years.
- 1950-2019 model years (2027-2096): Bypass flow operations as for the prior period, but with implementation of Freeman Expansion Phase 1 project. This project will connect the Ferro basin and make improvements to the existing desilting basin and headworks. Maximum diversion rates are 375 cfs as before, but diversion of water with higher suspended sediment concentrations is possible (up to 7,000 mg/l total suspended solids compared to 4,000 mg/l prior).

4.7 ARTIFICAL RECHARGE AND SURFACE WATER DELIVERIES ON OXNARD PLAIN

The Oxnard Plain Surface Water Distribution Model was used to calculate the amounts of artificial recharge at UWCD's facilities and surface water deliveries to the PTP and the PVWCD surface water delivery systems. The Oxnard Plain Surface Water Distribution Model is a water routing model that simulates amounts of groundwater recharge and surface water deliveries based on a series of adjustable hydrologic inputs (e.g. total river flow, diversions, obtained from the HOSS model) and operational assumptions. Some modeled operations in the Surface Water Distribution Model depend on available storage in the Oxnard Forebay and groundwater mounding in the vicinity of the Saticoy Recharge Facility, which is determined based on groundwater levels for three wells in the Oxnard Forebay. Therefore, iterative runs were performed where outputs from the Surface Water Distribution Model (spreading at recharge basins and calculated groundwater extractions) were used in the groundwater model, and groundwater level outputs from the groundwater model run were then used to re-run the same scenario in the Surface Water Distribution Model. The model runs were repeated until groundwater elevations in two wells in the Oxnard Forebay (2N22W12R01S and 2N22W12E04S) and fluxes between the Oxnard Forebay and Mound basin converged (daily water levels mostly within 5 ft and monthly fluxes within 20 AF between consecutive runs).

The Surface Water Distribution Model was also used to calculate pumping demands in the PTP and PV service areas, based on the difference between surface water deliveries and total agricultural demands within the respective service areas. Baseline total agricultural demands were based on the average historical demand for the years 2015-2017, and were reduced by 35% in the Oxnard Basin and 20% in Pleasant Valley basin during the first 20-year period. These demand assumptions are the same as those used for the scenario with projects in the Groundwater Sustainability Plans for the Oxnard Basin and Pleasant Valley Basin (FCGMA, 2019a, 2019b).

Water resource inputs to the Surface Water Distribution Model include diversion amounts, pumping from Saticoy wells and Conejo Creek diversions. Operational assumptions govern how the distribution of surface water is prioritized among recharge basins and surface water deliveries, and change based on season and hydrologic conditions (dry, normal or wet years). The following assumptions were made regarding water inputs:

- Surface water from the Freeman Diversion can supply all recharge basins and surface water delivery systems, while water occasionally pumped from UWCD's Saticoy well field is restricted to the PTP and PVCWD surface water delivery pipelines. Surface water from Conejo Creek diversions are restricted to the PVCWD delivery pipeline.
- Diversions calculated in the HOSS were reduced by 10% for days when bypass flows were provided, in order to account for inefficiencies in diversion operations due to flushing, maintenance and other reasons.

- The Saticoy well field is used to pump down the groundwater mound that sometimes develops beneath the Saticoy recharge basins in wet years. The production capacity of the Saticoy well field is dependent upon groundwater elevation. The well field does operate during periods of significant spreading in the recharge basins, because pipeline demands can normally be met with diverted surface water at these times.
- Surface water deliveries to PVCWD from the Conejo Creek diversion were estimated at 4,500 AF/year by Camrosa Water District.

Water routing prioritization indicates the order in which recharge basins and surface water delivery systems receive available water. A priority assignment of 1 is the highest priority. Facilities assigned a priority of 3 or greater often receive no water, as all available surface water has been used by facilities with higher priority. Prioritization rules for water routing are summarized in Table 2, and depend on the following factors:

- Water year hydrology: defined as dry, normal, wet, based on streamflow magnitude (R2 Resource Consultants, 2016).
- Season: summer is defined as beginning on July 1st and continuing to the first significant storm event of the winter (equal to first turn-out of the season); winter is the remaining period. During summer dry and normal conditions, the highest priorities for surface water routing are El Rio, PTP and PV (percentages to each facility are detailed in Table 2). During the winter season and wet summers, the highest priority is surface water deliveries (equally divided between PTP and PV), followed by recharge at El Rio and then other recharge basins.
- Forebay available storage: the estimated volume of additional groundwater that could be stored in the Forebay, calculated based on groundwater elevations in two key wells. Conditions with available storage > 70,000 AF indicate dry conditions, with increased priority for recharge in El Rio.
- Suspended sediment concentrations: when sediment levels in the river exceed 3,000 NTUs, diversions are routed to the Ferro basin (from 2027 onwards), and the Noble and Rose recharge basins first, to avoid clogging of the surface layer in the Saticoy and El Rio recharge basins. Sediment levels in the river were estimated based on a historical empirical correlation between average daily streamflow and sediment concentration.

Water deliveries to recharge basins and surface water delivery pipelines are limited by conveyance capacity, basin infiltration rates and demands for surface water deliveries to the PTP and PV pipelines.

- The modeled instantaneous conveyance capacity limits for facilities are: 350 cfs for Saticoy, 180 cfs for Noble, 80 cfs for Rose, 0 cfs (2020-2026) and 375 cfs (2027-2096) for Ferro, 120 cfs for El Rio, 65 cfs for PTP and PV systems (individually), and 75 cfs for PTP and PV systems combined.
- When modeled groundwater elevations in well 02N22W12R01S were less than 95 ft amsl, the maximum infiltration rates in each of the recharge basins were 145 cfs for Saticoy, 100

cfs for Noble, 52 cfs for Rose, 151 cfs for Ferro and 100 cfs for El Rio, for a maximum combined artificial recharge rate in the Oxnard Forebay of 397 cfs without Ferro basin, and 548 cfs with Ferro basin. When groundwater elevations at well 02N22W12R01S exceeded 95 ft amsl, combined maximum infiltration rates were gradually reduced according to the relationship shown in Figure 11. For example, at a groundwater elevation of 120 ft in well 02N22W12R01S, artificial recharge to the Oxnard Forebay is limited to 191 cfs (without Ferro basin) and 263 cfs (with Ferro basin). These maximum and reduced infiltration rates due to mounding were based on field observations.

- Demand for surface water deliveries was estimated on a daily basis using historical surface water delivery data, and accounts for seasonal, daily and weather-related variability in demand.

4.8 SURFACE FLOW INPUTS UNDER CLIMATE CHANGE SCENARIOS

All hydrology models presented in Section 4 require daily inputs for streamflow. For scenario runs that simulate climate change, daily flows from tributaries and drainage areas that feed into the models were adjusted using the 2030 and 2070 future conditions streamflow change factors provided by DWR. The following historical records were adjusted for climate change (see locations in Figure 3):

- Castaic Reservoir inflows. Historical records were compiled based on USGS gage records and DWR operations logs as detailed in Section 4.1.
- Santa Clara River upstream of Castaic Creek. Historical records were compiled based on USGS gage records and adjusted for current development as detailed in Section 4.2.
- Middle Piru Creek (inflows to Lake Piru). Historical records were compiled based on USGS gage records as detailed in Section 4.4.
- Pole Creek. Historical records were compiled from VCWPD Station 713 Pole Creek at Sespe Ave (1974-2018). Missing data were estimated based on correlations with Hopper Creek. Flows from Pole Creek were exclusively used by the Regional Groundwater Flow Model.
- Hopper Creek. Historical records from USGS gage 11110500 Hopper Creek near Piru CA, and VCWPD Station 701 Hopper Creek at Hwy 126 near Piru. Flows from Hopper Creek were also used by the Regional Groundwater Flow Model.
- Sespe Creek. Historical records are from gage USGS 11113000 SESPE C NR FILLMORE. Flows from Sespe Creek were also used by the Regional Groundwater Flow Model.
- Santa Paula Creek. Historical records are from gage USGS 11113500 SANTA PAULA C NR SANTA PAULA. Flows from Santa Paula Creek were also used by the Regional Groundwater Flow Model.

Daily historical flow records were adjusted to 2030 and 2070 future conditions using the HUC8_18070102 annual and monthly streamflow change factors provided by the DWR, using the methodology for application of time series change factor data described in the Guidance Document for Climate Change Data Use during Groundwater Sustainability Plan Development (DWR, 2018a). The methodology was applied to the daily flow data using the same methods as recommended for monthly data.

DWR streamflow change factors were available for model years 1916-2011. Change factors for model years 2012-2019 were determined by selecting analogous water years in the historical record, and applying the streamflow change factors published for these analogous water years. Analogous water years were determined using the monthly precipitation record for VCWPD rain gage 245 (Santa Paula), which has a complete data record from 1915-2019, and is representative of the average annual precipitation observed in large portions of the watershed. Analogous water years for each of the 2012-2020 water years were determined by calculating the root mean square error (RMSE) based on monthly precipitation with each water year from 1915-2011. Monthly precipitation for each of the 2012-20 water years was compared with the two 1915-2011 water years with lowest RMSE (see example in Figure 12). Generally, the year with the lowest RMSE was selected as the analogous water year, except for WY 2017. For 2017, the year with the lowest RMSE had significantly higher precipitation, and therefore the water year with second-lowest RMSE was selected. The analogous water years, annual precipitation and RMSEs for 2012-2020 are tabulated in Table 3.

5 REFERENCES

DWR (California Department of Water Resources), 2018a, Guidance for Climate Change Data Use during Groundwater Sustainability Plan Development. April 2018.

DWR (California Department of Water Resources), 2018b, The State Water Project Final Delivery Capability Report 2017. March 2018.

FCGMA (Fox Canyon Groundwater Management Agency), 2019a. Groundwater Sustainability Plan for the Oxnard Subbasin, December 2019. Last accessed 16 February 2021: http://www.fcgma.org/groundwater-sustainability-plan

FCGMA (Fox Canyon Groundwater Management Agency), 2019b. Groundwater Sustainability Plan for the Pleasant Valley Basin, December 2019. Last accessed 16 February 2021: http://www.fcgma.org/groundwater-sustainability-plan

FCGMA (Fox Canyon Groundwater Management Agency), 2019c. Groundwater Sustainability Plan for the Las Posas Valley Basin, December 2019. Last accessed 16 February 2021: http://www.fcgma.org/groundwater-sustainability-plan

NMFS (National Marine Fisheries Service), Southwest Region, 2008, Final biological opinion for the Bureau of Reclamation's approval of United Water Conservation District's proposal to operate the Vern Freeman Diversion and fish-passage facility.

Price, C. V., Nakagaki, N., Hitt, K. J., & Clawges, R. M. (2007). *Enhanced historical land-use and land-cover data sets of the US Geological Survey*. US Department of the Interior, US Geological Survey.

R2 Resource Consultants, 2016, Riverine effects analysis of Freeman Diversion flow releases on steelhead and Pacific lamprey; Attachment A, model documentation report. September 2016.

Robson, S.G. 1972. *Water-Resources Investigation Using Analog Model Techniques in the Saugus-Newhall Area, Los Angeles County, California.* U.S. Geological Survey Water Resources Divisions. Prepared in Cooperation with the Newhall County Water District. Open-File Report 72-320, 58p. February 10, 1972.

UWCD (United Water Conservation District), 2012, Santa Felicia Water Release Plan, United Water Conservation District, June 2012.

UWCD (United Water Conservation District), 2016, Forecasted Water Resources Impacts from Changes in Operation of Freeman Diversion, United Water Conservation District Open-File Report 2016-03. Last accessed 29 March 2021: https://www.unitedwater.org/wp-content/uploads/2021/02/UWCD-OFR-2016-03-Water-resource-impacts-from-changes-in-Freeman-Ops.pdf

UWCD (United Water Conservation District), 2018, Ventura Regional Groundwater Flow Model and Updated Hydrogeologic Conceptual Model: Oxnard Plain, Oxnard Forebay, Pleasant

Valley, West Las Posas, and Mound Basins, United Water Conservation District Open-File Report 2018-02, July. Last accessed 16 February 2021: https://www.unitedwater.org/wp-content/uploads/2020/10/VRGWFM_Ver1-0_Documentation_UWCD-OFR2018-02_Complete-Reduced.pdf

UWCD (United Water Conservation District), 2019. Implementation of Groundwater Model Inputs for Simulations in Support of Groundwater Sustainability Plan Development by the Fox Canyon Groundwater Management Agency. Technical Memorandum. November.

UWCD (United Water Conservation District), 2020. Freeman Diversion Multiple Species Habitat Conservation Plan. June 30, 2020.

UWCD (United Water Conservation District), 2021, Ventura Regional Groundwater Flow Model and Updated Hydrogeologic Conceptual Model: Piru, Fillmore, and Santa Puala Groundwater Basins, United Water Conservation District Open-File Report 2021-01, June.

VCWPD (Ventura County Watershed Protection District), 2009. Hydrologic Modeling of the Santa Clara River Watershed with the U.S. EPA Hydrologic Simulation Program – FORTRAN (HSPF). Prepared by Aqua Terra Consultants, November 25, 2009.

6 TABLES

Table 1. Model reaches and influxes/outfluxes for the Santa Clara River Upper Basins Surface Water Model.

Reach No.	Reach Description	Influxes	Outfluxes
1	Piru Creek SFD dam to SCR confluence	- Flows from SFD (from Lake Piru model)	- Piru Creek diversions - Percolation Piru Creek - Piru Creek flow upstream SCR confluence
2	SCR Newhall to Torrey	- Piru Creek flow upstream SCR confluence - SCR flow upstream of Piru Creek	- Percolation Newhall to Torrey - SCR flow Torrey
3	SCR Torrey to Piru/Fillmore basin boundary	- SCR flow Torrey - Hopper Creek flow - Piru basin rising groundwater	- Percolation Torrey to Piru basin boundary - Percolation Hopper Creek - SCR flow Cavin
4	SCR Piru/Fillmore basin boundary to Sespe confluence	- SCR flow Cavin	- Percolation Cavin to Sespe - SCR flow upstream Sespe confluence
5	SCR Sespe confluence to Fillmore/Santa Paula basin boundary	- SCR flow upstream Sespe confluence - Sespe Creek flow - Fillmore basin rising groundwater	- Percolation Sespe Creek - Percolation SCR downstream Sespe - SCR flow at Fillmore basin boundary
6	SCR Fillmore/ Santa Paula basin boundary to Freeman diversion	- SCR flow at Fillmore basin boundary - Santa Paula Creek	- Percolation Santa Paula Creek - Santa Paula basin losses (percolation and diversions) - SCR flows at Freeman

Table 2. Prioritization order for water resources supply to recharge basins and PTP/PV systems. When facilities are assigned identical priorities, the percentages of supply received for each facility are included in parentheses.

Facility	**Summer (dry)**	**Summer (normal-wet), winter**	**Forebay storage > 70,000 AF**	**NTU > 3,000**
El Rio basin	1 (50%)	2	1	5
PTP system	1 (25%)	1 (50%)	2 (50%)	6 (50%)
PV system	1 (25%)	1 (50%)	2 (50%)	6 (50%)
Saticoy basin	2	3	3	4
Noble basin	3	4	4	2
Rose basin	4	5	5	3
Ferro basin	5	6	6	1

Table 3. Summary of analogous water years for water years 2012-2020 for the purpose of calculating streamflow change factors, with annual precipitation for each year and calculated root mean square error (RMSE).

WY	**WY analog**	**WY precip**	**WY analog precip**	**RMSE (monthly)**
2012	1925	10.18	10.01	0.68
2013	2002	6.03	6.98	0.53
2014	1959	6.12	6.67	0.85
2015	1949	10.63	9.79	0.76
2016	1930	9.63	11.59	0.43
2017	1973	21.65	23.32	1.62
2018	1981	8.84	11.88	0.62
2019	1973	22.23	23.32	1.33
2020	1942	15.04	14.19	0.99

7 FIGURES

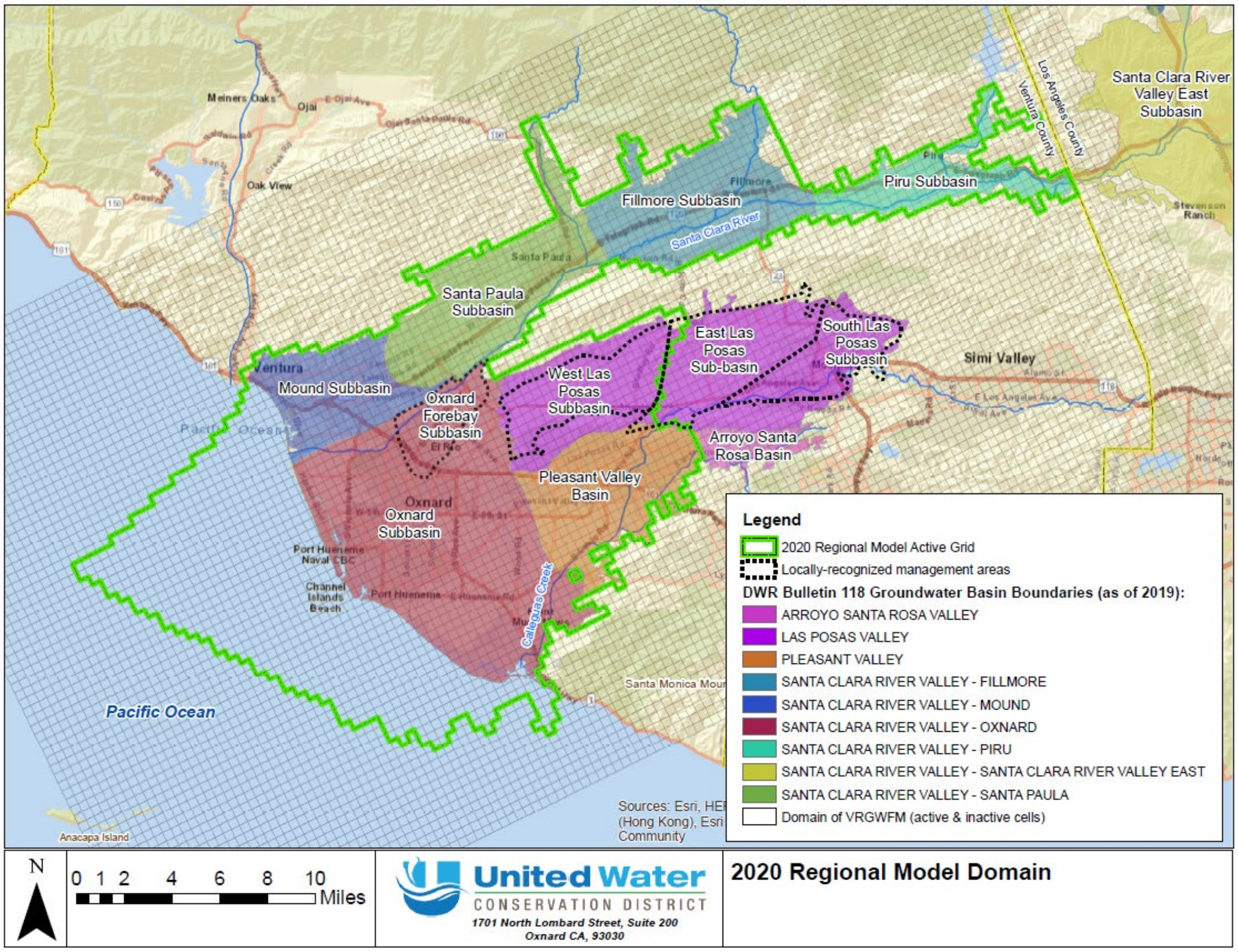

Figure 1. Regional Model Domain with Santa Clara River Valley Expansion.

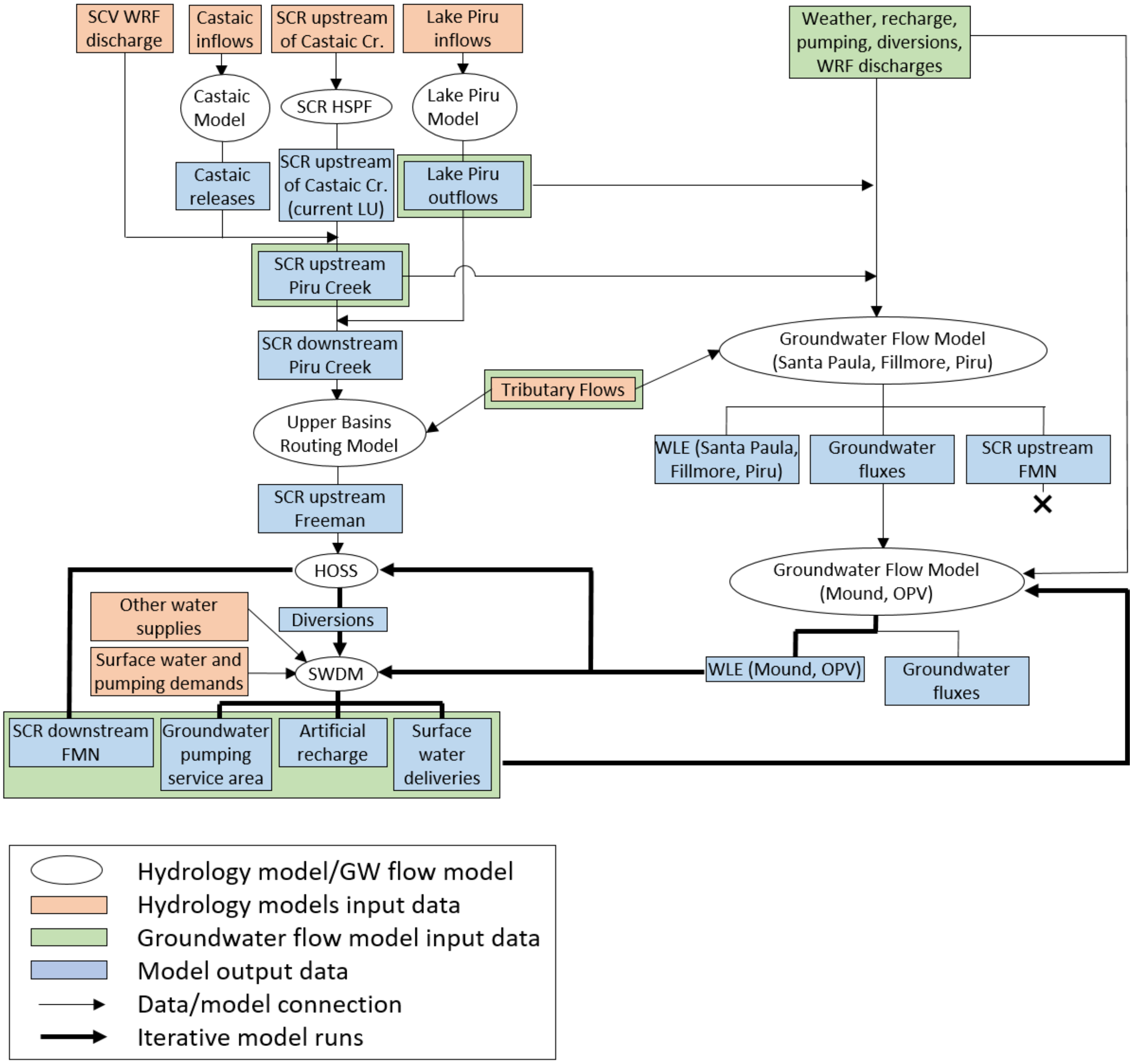

Figure 2. Schematic of the interaction between surface water hydrology models and Ventura Regional Groundwater Flow Model.

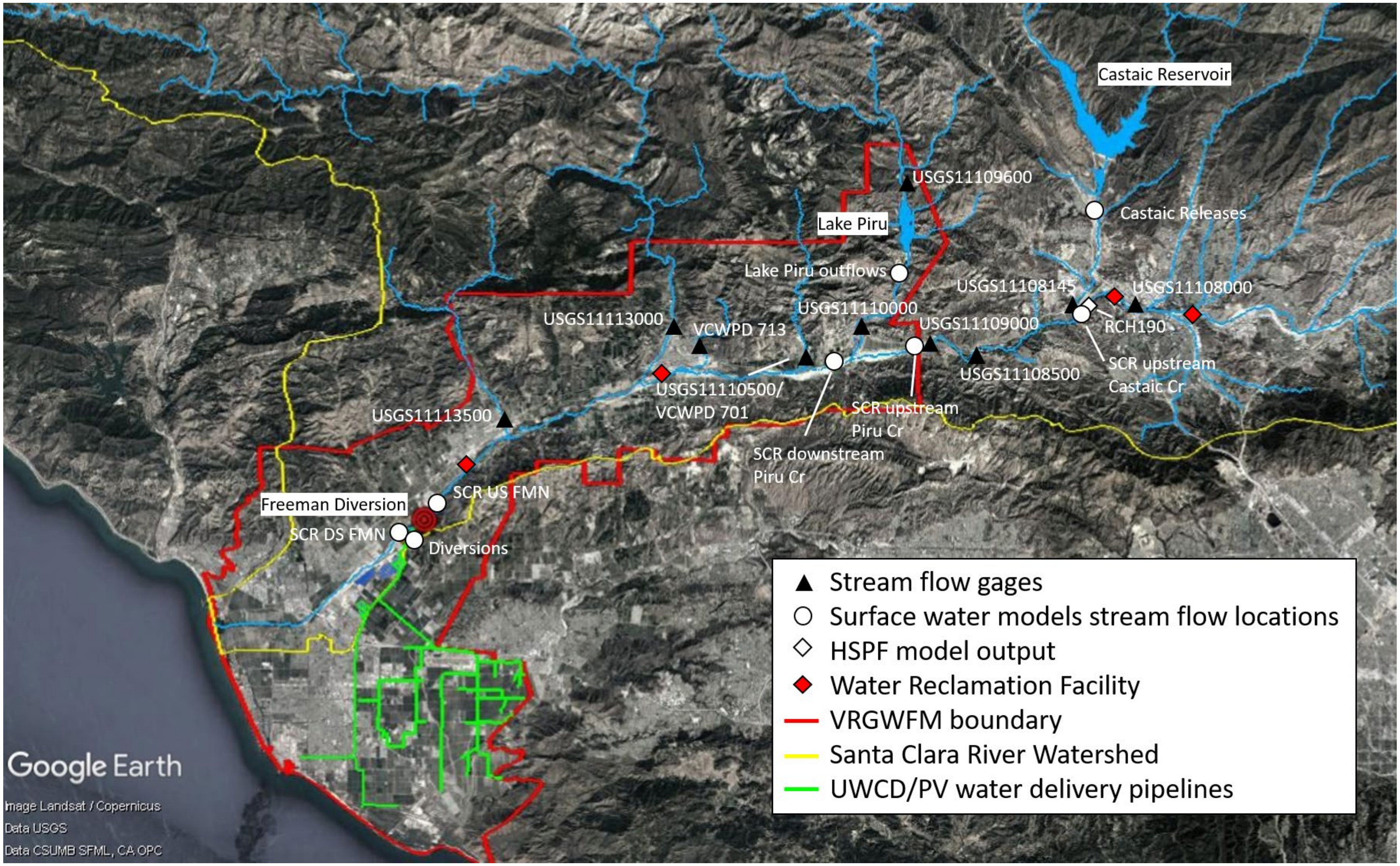

Figure 3. Map of streamflow locations, gages and water reclamation facilities used in surface water hydrology and Regional Model models.

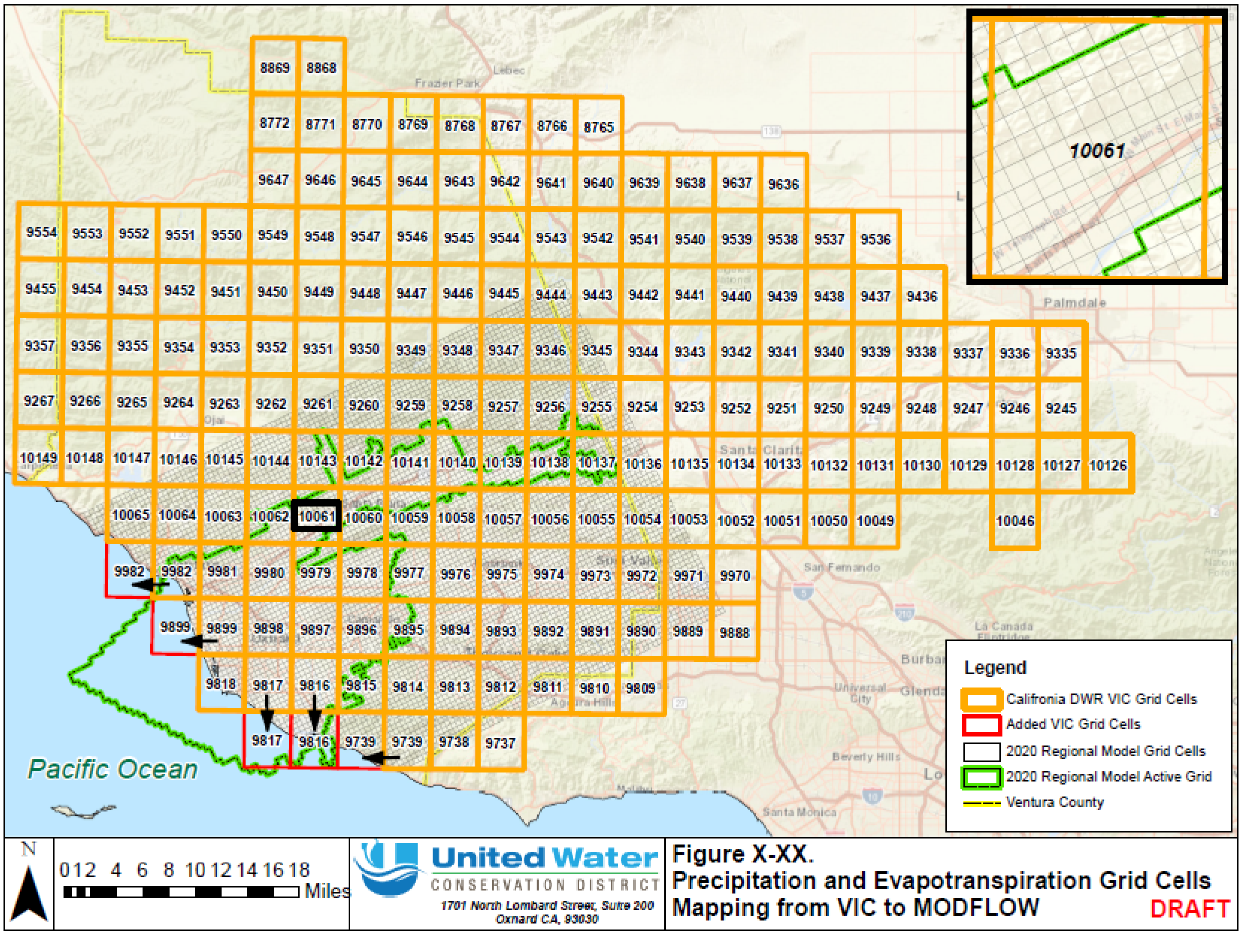

Figure 4: Mapping of California DWR provided Variable Infiltration Capacity (VIC) grid cells to Regional Model MODFLOW grid cell; Additional VIC cells (red) were added for completeness based on neighboring grid cells; Inset figure displays example of Regional Model MODFLOW grid cells located within a single VIC grid cell (ID 10061) within Santa Paula basin.

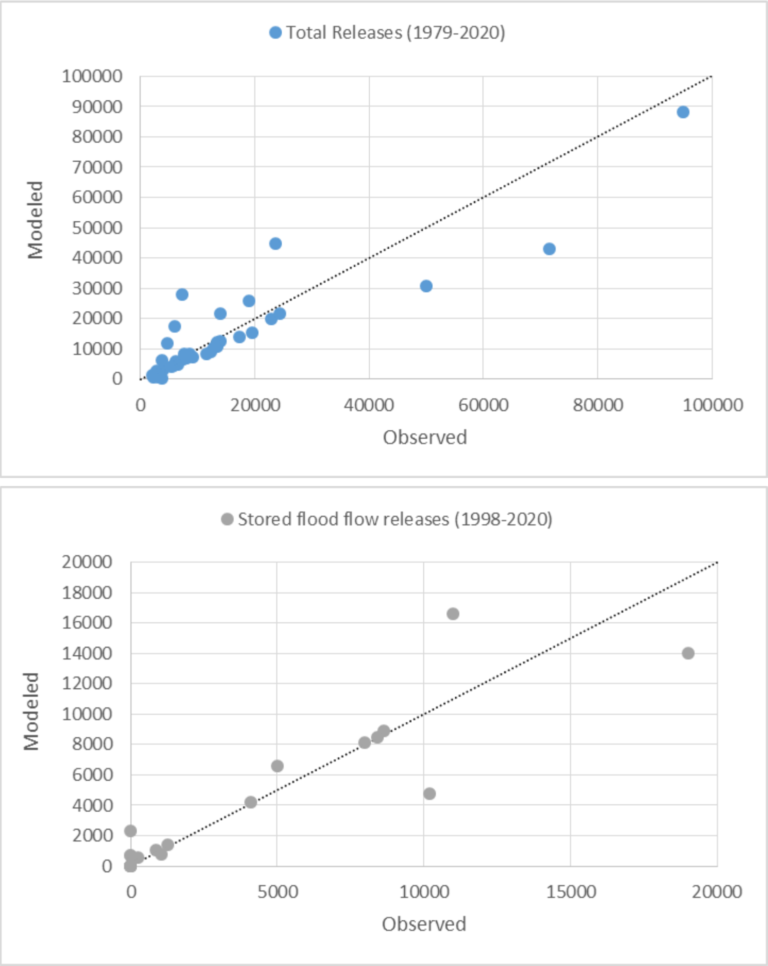

Figure 5. Calibration of Castaic Reservoir Operations Model. Modeled versus observed total releases (top) and flood flow releases (bottom) from Castaic Reservoir.

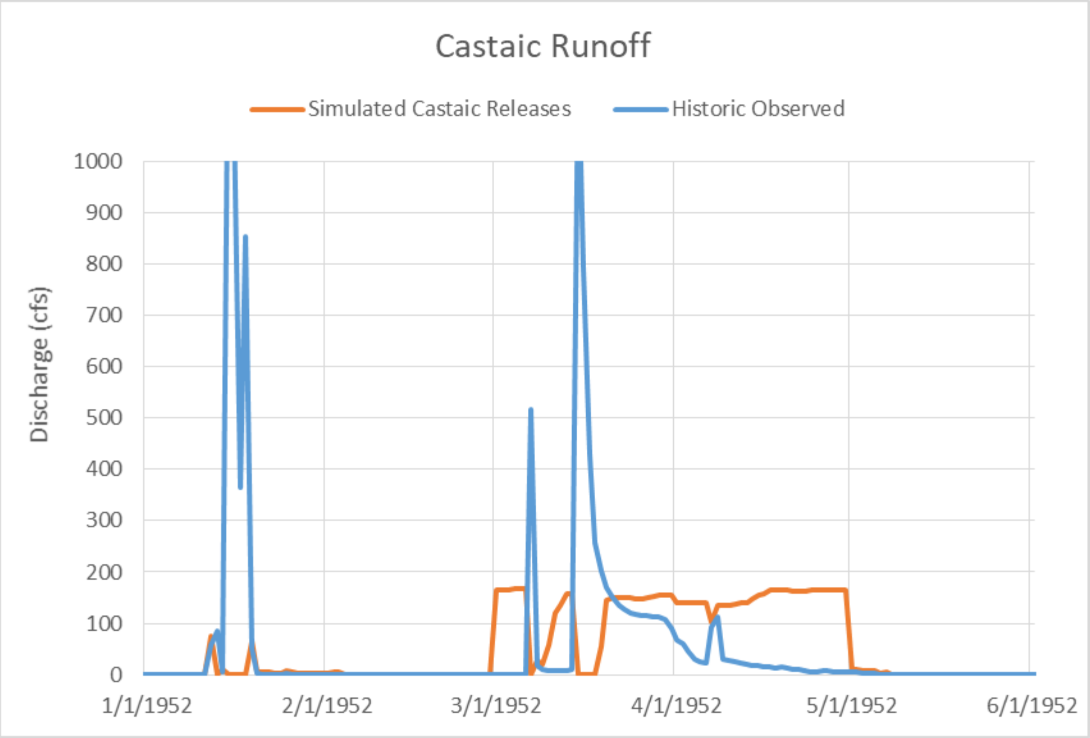

Figure 6. Example of simulated releases from Castaic Reservoir compared to historical flows in Castaic Creek before construction of Castaic Reservoir.

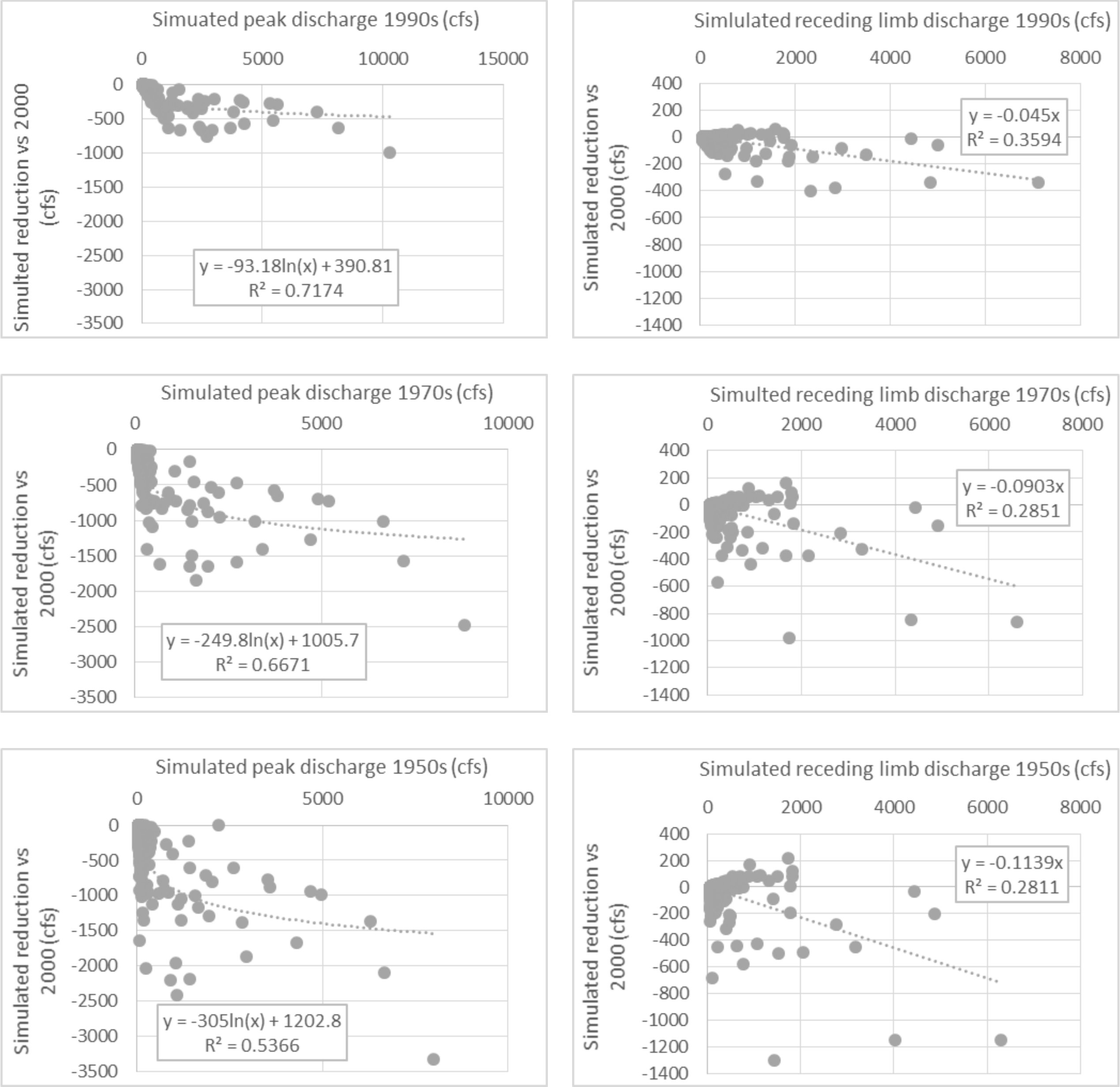

Figure 7. Simulated reduction in daily streamflow for storm peak discharges (left side) and storm flow discharges on receding limb (right side) for the 1950s, 1970s and 1990s simulation periods compared to the model run using 2000s land use. Best fit regression curves and equations are shown for each run.

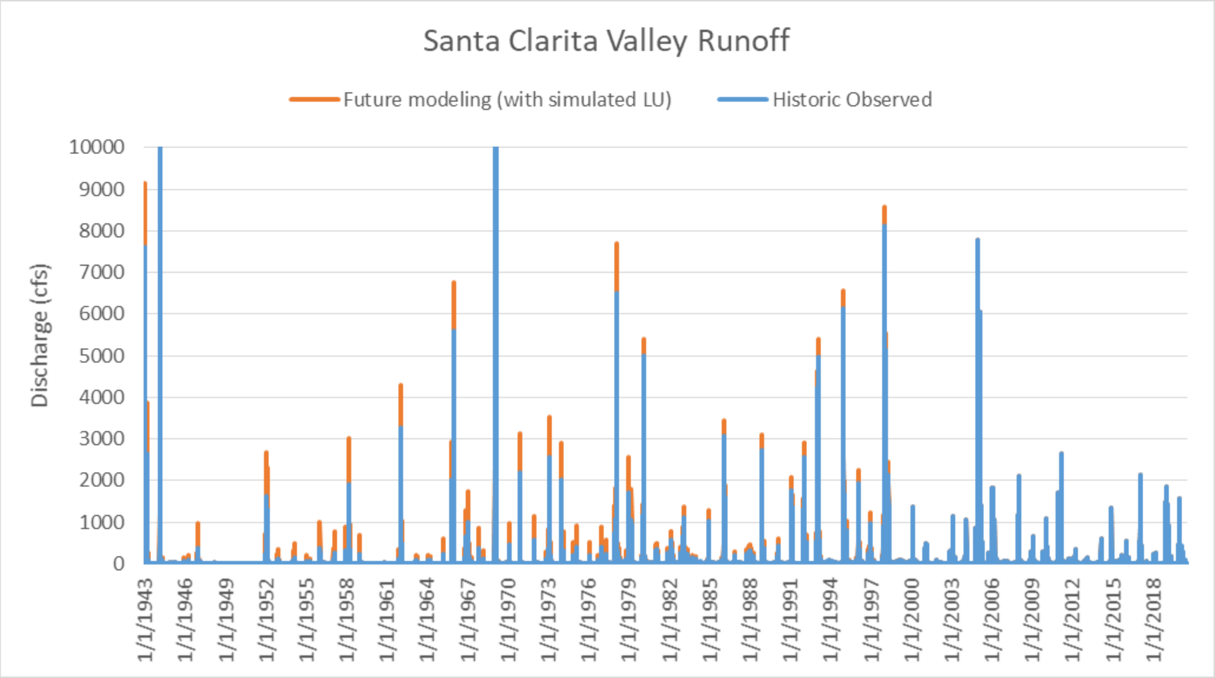

Figure 8. Natural streamflow in the Santa Clara River upstream of Castaic Creek before (historical observed) and after adjustment to reflect current impervious land use (LU). The adjusted record with simulated land use was used in future modeling efforts.

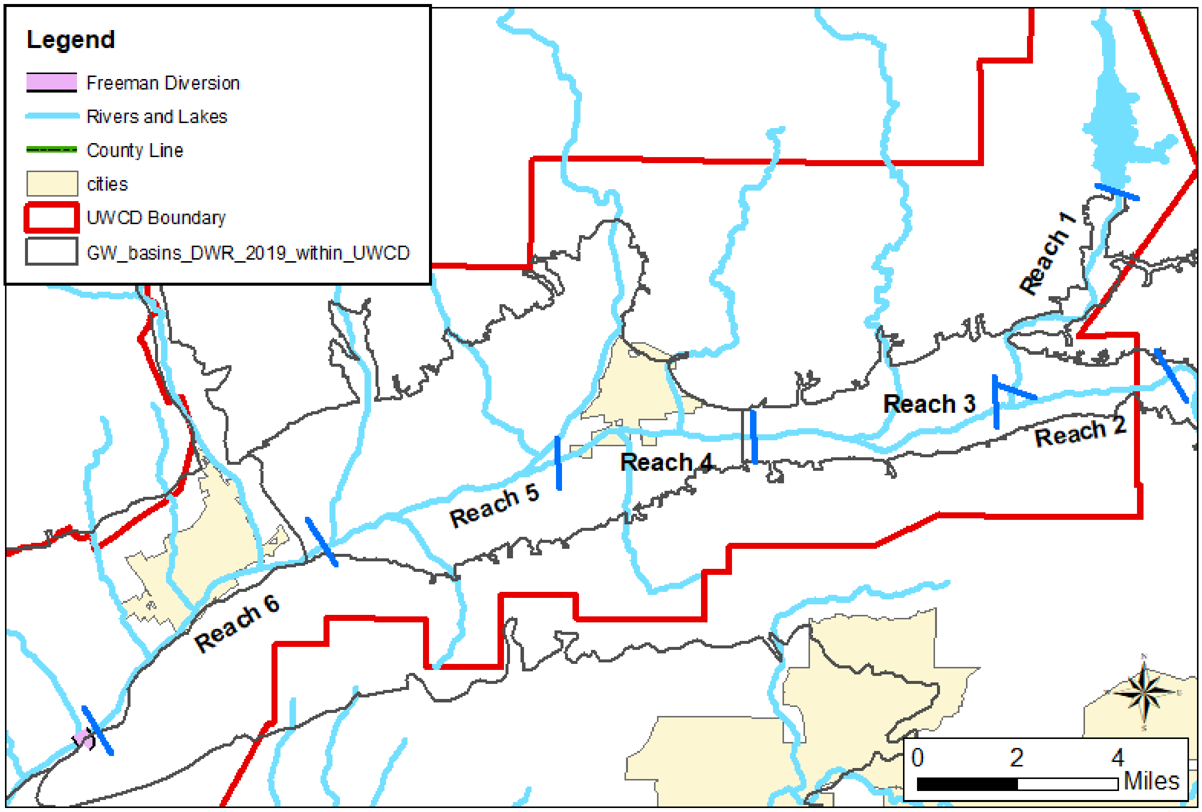

Figure 9. Model reaches for the Santa Clara River Upper Basins Surface Water Model. Reaches are numbered and separated by blue lines.

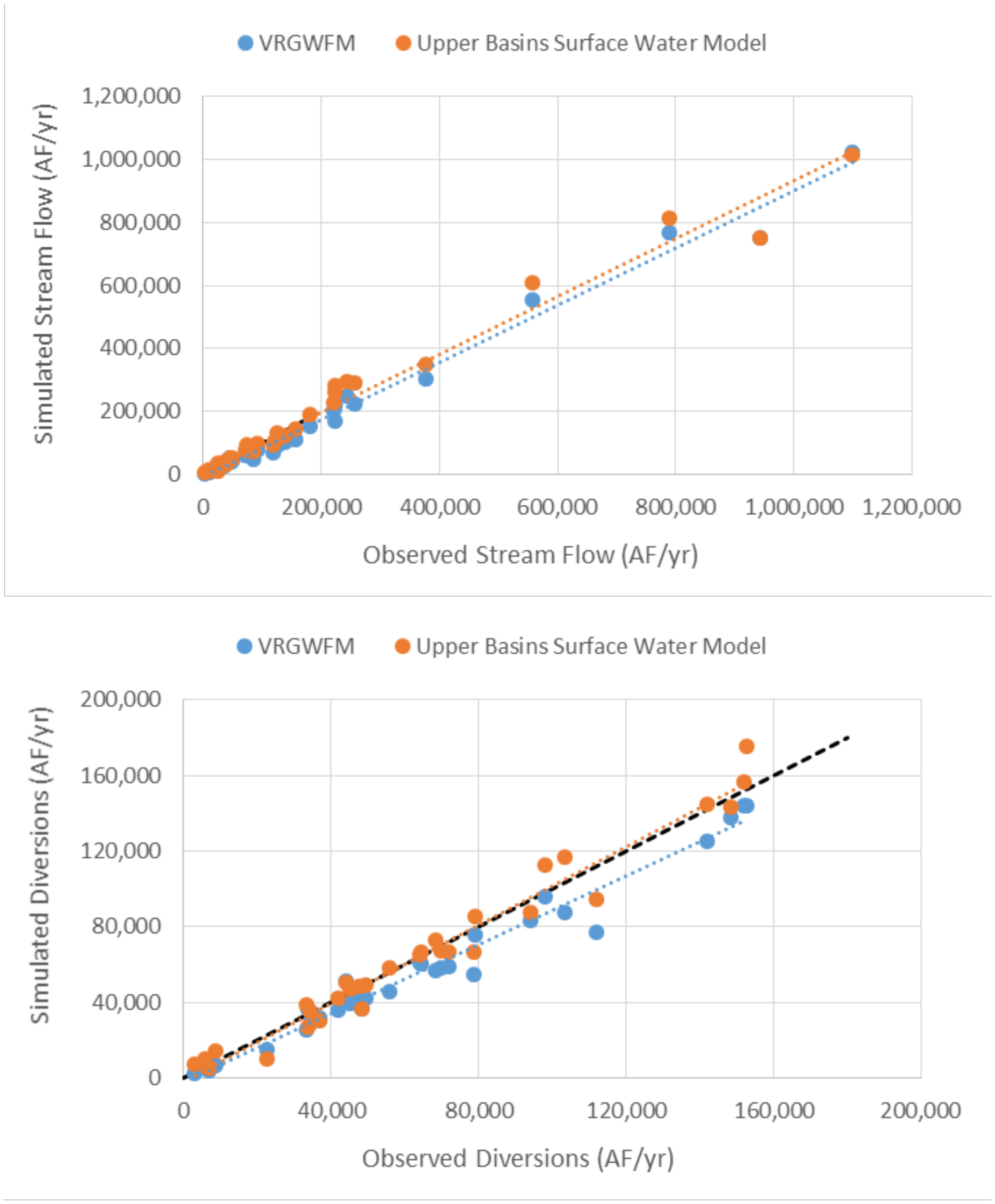

Figure 10. Simulated versus observed historical annual streamflow at the Freeman Diversion (top) and annual diversions based on simulated streamflow (bottom), for the regional groundwater flow model (Regional Model) and the Upper Basins Surface Water Model. Model simulations were performed for the 1985-2015 calibration period, assuming bypass flow operations as proposed in United's Multiple Species Habitat Conservation Plan (UWCD, 2020). Simulations of diversions were performed with the Hydrological Operations Simulation System (HOSS).

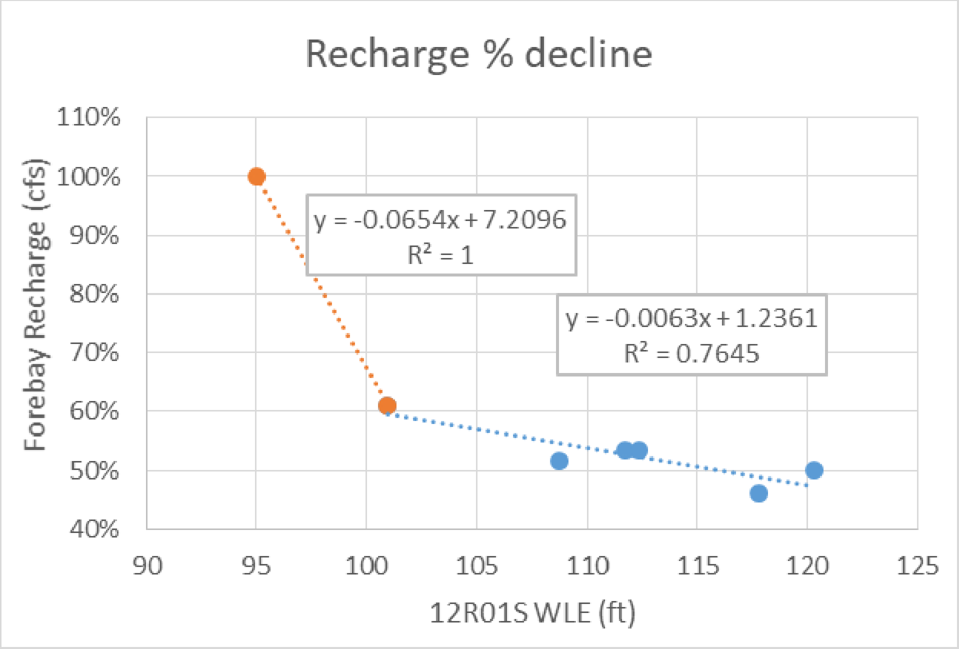

Figure 11. Decrease in maximum infiltration rate for artificial recharge to the Oxnard Forebay as a function of groundwater elevation at well 2N22W12R01S.

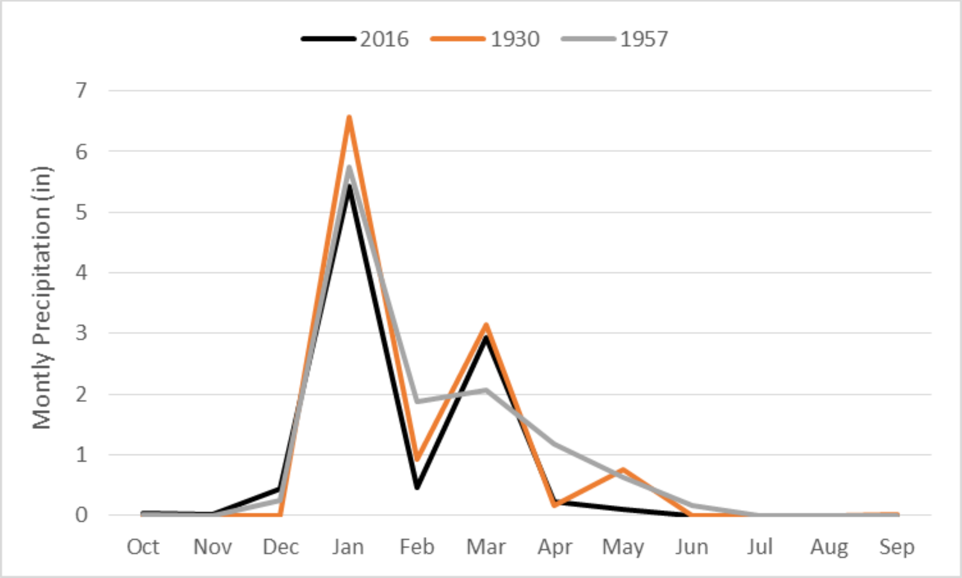

Figure. 12. Comparison of monthly precipitation for VCWPD gage 245 (Santa Paula) for water year 2016 and the two water years with streamflow change factors with the lowest RMSE (0.42 for WY 1930, 0.59 for WY 1957). Water year 1930 was selected as the analogous year for 2016 for the purpose of calculating streamflow change factors.