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Project Progress Report

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In cooperation with Monterey County, Monterey County Water Resources Agency, and the Salinas Valley Basin GSA.

Overview of Salinas Valley Models

Introduction

In January 2016, the U.S. Geological Survey California Water Science Center (USGS CAWSC) began collaborating with Monterey County and the Monterey County Water Resources Agency (MCWRA) to create a suite of geologic and hydrologic models. The primary purpose of these models is to inform the County's five-year (2014 – 2018) hydrologic study of the water supply and groundwater quality in the MCWRA's Zone 2C, within the Salinas Valley Aquifers as part of a settlement agreement (Monterey County 2010). The suite of models include: (1) a geologic model to estimate aquifer properties and aquifer and aquitard extents; (2) a watershed model to simulate surface processes and inflows to the groundwater basin from adjacent catchments; (3) an integrated hydrologic model of the Salinas Valley Groundwater Basin; and (4) an operational reservoir model. The Salinas Valley models will contribute to several other regional modeling efforts: for MCWRA's Interlake Tunnel Project, the development of Groundwater Sustainability Plans under the State's Sustainable Groundwater Management Act (SGMA; CADWR, 2014), and a future water supply risk assessment for the Salinas and Carmel River Basins Study (SCRBS) by the U.S. Bureau of Reclamation (2015) in cooperation with local partners.

Salinas Valley model development and use in these studies are keystones of regional drought planning tools for managing conjunctive use of groundwater and surface water. These models provide vital information for evaluating strategies to achieve groundwater sustainability. These decision tools provide estimates of groundwater storage, surface and subsurface storage and flows, groundwater-surface water (GW-SW) interactions, and hydrologic and agricultural budgets. In addition, the cooperative research partnership between the Monterey County Water Resources Agency and the USGS has resulted in development of model update utilities, cutting-edge reservoir simulation and land use methods, and SGMA reporting utilities that will benefit multiple California modeling efforts.

The purposes of this project update are to (1) describe the model development (2) describe how model results are used to understand seawater intrusion, water levels (hydraulic heads), and land use, (3) provide an overview of the model review process and anticipated completion timeline, and (4) discuss how modeling results and future model updates can be used in ongoing and future hydrologic investigations in the basin.

Model development and Updates

Model development has been a collaborative process with regular guidance and input from Monterey County, MCWRA, and their consultants. Additional guidance and review were provided by an independent Technical Advisory Committee with regional stakeholders, consultants, agricultural commissioners, and the Salinas Valley Basin Groundwater Sustainability Agency.

The models were constructed using published open-source modeling software. The Salinas Valley integrated hydrologic model (SVIHM) and Salinas Valley Operational Model (SVOM) are built using the latest version of MODFLOW-OWHM (Boyce and others, 2020) with the MODFLOW Farm Process (Schmid and others (2006), Schmid and Hanson (2009)). The software can be downloaded in its entirety here, https://code.usgs.gov/modflow/mf-owhm. You can also find helpful information on this webpage https://www.usgs.gov/software/modflow-one-water-hydrologic-flow-model-conjunctive-use-simulation-software-mf-owhm. The SVIHM has been developed using two sub-models, a 3-D geologic framework and texture model (Salinas Valley Geologic Model; SVGM; Sweetkind and others, In Prep), and a Hydrologic Simulation Program – Fortran watershed model (HSPF; Bicknell and others, 1997) for the entire Salinas Valley Watershed (Salinas Valley Watershed Model, SVWM).

Geologic Framework and Texture Model

The geologic framework model was used to define the spatial extent, depth, and distribution of geologic material textures for the offshore region, five major aquifers of the Salinas Valley, aquitards between each aquifer, and the depth to bedrock. The aquifers are defined consistent with previous studies and include the surficial aquifer, 180-ft aquifer, 400-ft aquifer, Purisima aquifer, and Paso Robles aquifer.

Each of the aquifers was explicitly defined using well borehole data, and local geologic investigations (Tinsley, 1975; Feeney and Rosenberg, 2003; Kennedy/Jenks, 2004; Hanson and others, 2002; Colgan and others, 2012; Langenheim and others 2012, Hanson and Sweetkind, 2014; Taylor and Sweetkind, 2014; Hanson and others, 2014a; Baillie and others, 2015;). The distribution of texture in each aquifer was developed for each borehole location and kriged to create a continuous surface. These depth-discrete spatial layers for each aquifer were used to define a geologic texture for each model cell as a percentage of coarse material (K_{coarse}). This method has been widely used in hydrologic models (Faunt and others, 2009a; Faunt and others, 2009b; Faunt and others, 2010) to relate geologic texture to hydraulic properties. This approach defines aquifer properties using a coarse-grained (K_{coarse}) and fine-grained (K_{fine}) end member defined as:

$K_{fine}=1.0-K_{coarse}$

Hydraulic conductivity ranges for each aquifer were defined using data from previous models (Hanson and others, 1990; Hanson and Benedict, 1993; Hanson and others, 2003, 2004, 2014 a,c,d,e; Sweetkind and others, 2013; Phillips and others, 2007; Faunt and others, 2009a,b; Ludington and others, 2007; MCWRA monitoring well database), aquifer tests, and estimated ranges for geologic materials.

The hydraulic conductivity value at the upper extent of the range is assigned to cells in areas where the percentage of coarse material is 100% (K_{coarse} =1.0). Similarly, the hydraulic conductivity value at the lower extent of the range is assigned to cells in areas where the percentage of coarse material is 0% (K_{fine} = 1.0). For all other model cells, a composite hydraulic conductivity was generated using a power law relationship between the values for the K_{coarse} and K_{fine} end members.

Data from previous offshore studies (Johnson and others, 2016) were used to define the structure, distribution, and properties of the offshore region. The offshore region was parameterized similarly to the onshore region of the model domain providing continuity between the offshore and onshore regions of each aquifer that facilitates a robust estimation of fluxes between the offshore and onshore areas of each aquifer.

Climate data

Climate data for the SVWM and SVIHM include minimum and maximum air temperature, precipitation, and potential evapotranspiration. Climate data for both models were developed using the Basin Characteristics Model (BCM) tools (Flint and others, 2004; Flint and Flint, 2007 a,b,c) from national climate data stations (for example, Daly and others, 2004) and data from the California Irrigation Management System stations (CIMIS, 2005). The BCM tools were used to develop daily spatially distributed 270-m resolution climate datasets for the future climate scenarios. Climate input datasets are precipitation, maximum and minimum air temperature, and solar radiation; the latter two are used to compute evapotranspiration.

Climate input were developed as spatially distributed grids. Gridded data were interpolated onto the model grid using an area-weighted approach. For the SVWM, the 270-m climate data were interpolated onto the hydrologic response units (HRUs). For the SVIHM, the 270-m climate grids were interpolated onto the model grid.

Salinas Valley Watershed Model

The (SVWM) simulates watershed processes for the entire Salinas River watershed (figure 1). The model simulates the historical period between 10/1/1948 - 9/30/2018. Each sub-catchment in the domain was defined as a hydrologic response unit (HRU). Hydrologic processes simulated for each HRU include evapotranspiration, runoff, interflow and baseflow. Each HRU is connected to stream segments and tributaries that represent a drainage network to route surface waterthrough the SVWM from upland areas to the Pacific Ocean. Streamflow in each stream segment is simulated using the kinematic wave method. The simulation includes the discharge volume, stream velocity, stage, and water volume for the segment, as well as stream losses from evaporation and streamchannel infiltration.

The SVWM combines the BCM tools and HSPF models to simulate the climate and hydrology for the upland areas and tributaries draining into the alluvial valleys simulated by the SVIHM. The SVWM domain consists of an upper Salinas Valley subarea and lower Salinas Valley subarea simulated as sub-catchments connected at the location of USGS streamgage 11150500 (SALINAS R NR BRADLEY CA, https://waterdata.usgs.gov/nwis/uv?site_no=11150500), with all surface water outflows from the upper SVWM entering the lower SVWM as Salinas River streamflow at the location of the streamgage. The upper SVWM includes five sub-watershed areas that contain most of the Paso Robles area of the Upper Salinas

River Valley in San Luis Obispo County area, while the lower SVWM contains most of the SVIHM area within its five sub-watershed areas.

Salinas Valley Watershed Model Domain

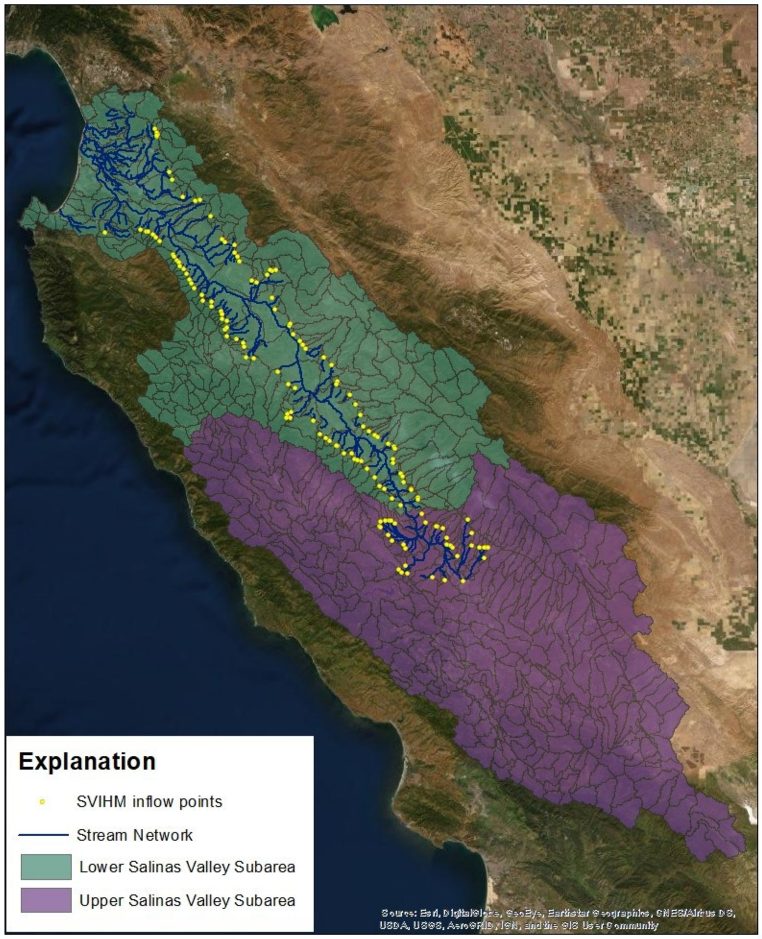

Figure 1: Salinas Valley Watershed Model (SVWM) domain showing Upper and Lower Salinas Valley Subareas, stream network, and inflow points where watershed flows are routed into the Salinas Valley Integrated Hydrologic Model (SVIHM).

Spatial discretization of the SVWM was based on topographically defined watersheds that were subdivided into smaller sub-drainage areas using a combination of surface flow-routing defined by a 10-meter digital elevation model (DEM) and pre-defined sub-drainages (CalWater version 2.2.1, Department of Forestry and Fire Protection, http://frap.fire.ca.gov/data/frapgisdata-sw-calwaterdownload). The smaller sub-drainages were used to (1) represent spatially varying climate and topography in the upland areas of the SVWM model domain, and (2) define pour points to route estimated ungaged flows from the SVWM to the SVIHMstream networks. The SVWM spatial discretization resulted in HSPF segments varying in area from 65 acres to about 25,000 acres and a total of 148 pour-point connections for inflows from upstream drainagesalong the Salinas Valley.

The HSPF model is run as a continuous simulation using an hourly time step; however, in the current

SVWM version, the daily climate inputs are uniformly distributed to hourly values. Therefore, only daily results are used for calibration and for developing SVIHM inflows.

SVWM model parameters were developed using geographic information system (GIS) data sets that included: DEM-derived elevation, slope and aspect, estimated soil water storage capacity (State Soil Survey Geographic ((SSURGO), Web Soil Survey, available online at https://websoilsurvey.nrcs.usda.gov/), percent forest canopy and impervious land cover (National Land Cover Data, NLCD; U.S. Geological Survey, 2007, 2011, 2014). For discrete data such as land cover type, GIS analysis was used to calculate the weighted average values for each HSPF parameter based on the fractional area of a given discrete data value within each HSPF segment. The fractional areas for discrete data are calculated in GIS, and the weighted averages are calculated in spreadsheets, resulting in a unique set of HSPF parameters for each model segment. This method provided a better representation of the physical watershed characteristics for each segment as compared to simply using the dominant discrete data within each segment. Continuous data such as slope and percent canopy cover were mapped directly to HSPF segments as area-average values using GIS.

The SVWM was used to estimate inflows into the Salinas Valley from adjoining ungaged watersheds. These inflows are provided as a monthly inflow time series to the SVIHM. Although the model is only used to estimate ungaged watershed inflows to the SVIHM, the SVWM is calibrated for the entire basin, providing many opportunities for future evaluations where surface water and sediment and nutrient transport are of greater concern than groundwater storage. These potential applications will be discussed in the section on Future model updates, applications, and developments.

Salinas Valley Integrated Hydrologic Model

The Salinas Valley Integrated Hydrologic Model (SVIHM) is an integrated water resources management tool that simulates the conjunctive use of groundwater and surface-water in the Salinas Valley (Figure 2). The Salinas Valley model simulates the period between 10/1/1967 to 9/30/2018 and has been calibrated for the period from 10/1/1967 to 12/31/14. The SVIHM includes explicit representation of climate, groundwater and surface water, recharge, runoff, inflows from ungaged watersheds, reservoir releases, Salinas River diversions, municipal and industrial water supply pumping, and a rigorous simulation of the substantial Salinas Valley agricultural industry.

The SVIHM is built using the latest version of MODFLOW-OWHM (Boyce and others, 2020) with the MODFLOW farm process. OWHM simulates water supply and demand for natural, urban, and cultivated lands. OWHM uses an embedded land use and crop model based on the widely used FAO56 method (Allen and others, 2005) to estimate water demands for a set of user-specified land uses. If precipitation and direct groundwater root uptake are insufficient to meet simulated land use water demands, then additional supplies can be provided to meet the deficit (groundwater pumping, surface water diversions, wastewater reclamation, and reservoirs). Additionally, for cultivated lands, water demand efficiencies can be specified for land-use type, irrigation type, climate regime (wet or dry), and region. This well-developed model framework facilitates evaluation of water demand by region, crop, and climate regime and allows for scenario testing to evaluate the effects of potential changes in agricultural practices, increases in efficiency, and optimization of agricultural development within the basin. This tool is well suited for the analyses that will be needed throughout the next century to manage sustainability of the Salinas Valley aquifer system.

Salinas Valley Integrated Hydrologic Model Domain

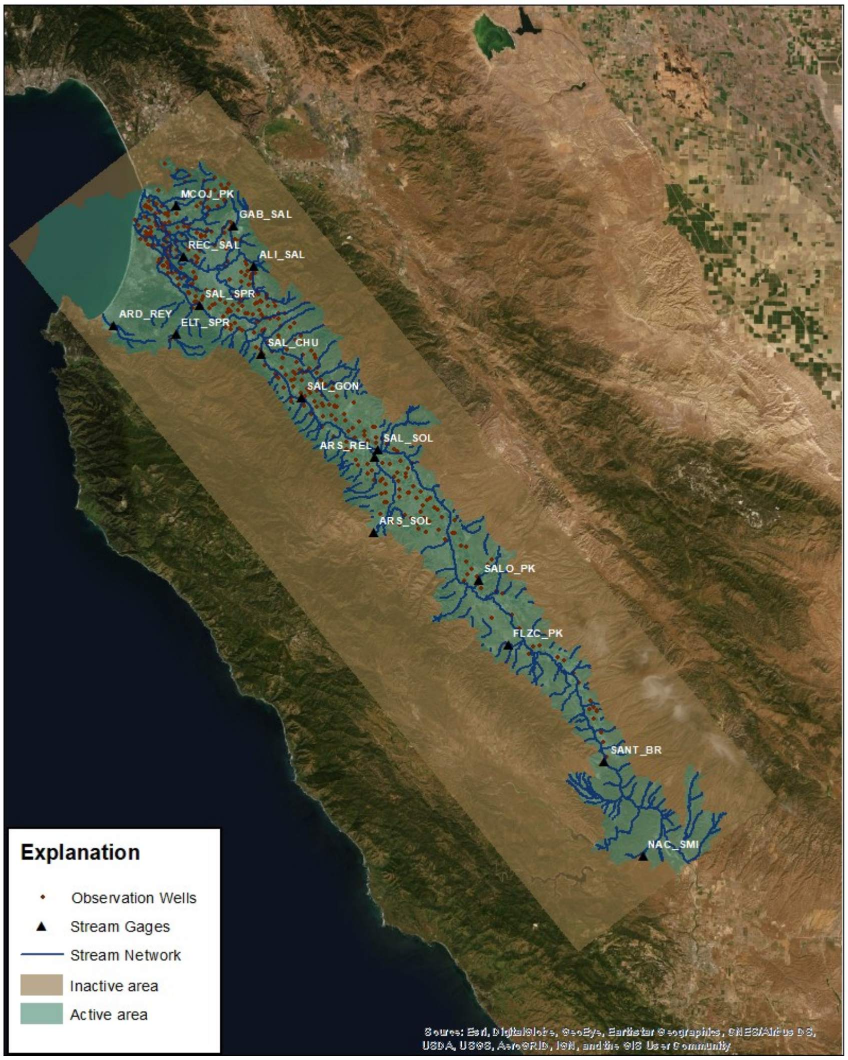

Figure 2: Salinas Valley Integrated Hydrologic Model (SVIHM) showing domain extent with inactive and active areas, stream network, stream gages, and observation wells.

The total active modeled area in the SVIHM is 10,266 mi^2. The model grid is uniform, where each grid cell is approximately 6.42 acres (529-by-529 ft). There are 976 rows, 567 columns, and 9 layers having a varying number of active cells in each layer, for a total of 265,382 active model cells. To assess changes in aquifer storage due to seawater intrusion, the model includes approximately 84,000 active cells onshore and 11,000 active cells offshore. The SVIHM includes nine model layers that correspond to locally defined hydrostratigraphic units such as the defined aquifers (180-Foot and 400-Foot aquifers), confining units, and geologic units (e.g., basement bedrock). The top of SVIHM is represented by the altitude of the land surface, but because hydrostratigraphic units are discontinuous across the study area, the uppermost active layer is a composite of model layers 1, 3, 5, 7, and 9.

The SVIHM is partitioned into 31 water balance subregions (WBS; Figure 3 and Table 1). Each WBS has simulatedwater demands for each land use and a unique set of available water supplies that can be used by the model to meet the demands. The model includes WBS representing the Zone 2C jurisdictional area and associated subareas, the Castroville Seawater Intrusion Project (CSIP) area, Seaside Basin, and areas outside the Zone 2C boundary but within the SVIHM model domain.

Table 1. Summary of water-balance subregions within the Salinas Valley Integrated Hydrologic Model, Monterey and San Luis Obispo Counties, California. (SW= Surface water, GW = Groundwater, None = No Deliveries).

Water Balance Subregion	Region Name	Region Description	Irrigation Water Supply
1	Riparian Corridor	Monterey and SLO Counties	None
2	CSIP Area	Castroville Seawater Intrusion Project Region	GW/SW/recycled water
3	Coastal Urban areas	Salinas, Castroville, Marina, Seaside, Sand City, Monterey, Del Rey Oaks	None
4	Inland Urban areas	Chualar, Gonzales, Soledad, Greenfield, King City, & San Ardo	None
5	Highlands South	North of Eastside outside of Zone 2C	GW
6	Granite Ridge	North of Eastside outside of Zone 2C	GW
7	Corral De Tierra	South of Pressure part within Zone 2C	GW
8	Blanco Drain Area	Drain subarea within Pressure subarea of Zone2C	GW
9	East Side	Remainder of Eastside subarea in Zone2C	GW
10	Pressure Northeast	Pressure subarea NE of Salinas River in Zone 2C	GW
11	Pressure Southwest	Pressure subarea SW of Salinas River in Zone 2C	GW
12	Forebay Northeast	Forebay subarea NE of Salinas River in Zone 2C	GW
13	Forebay Southwest	Forebay subarea SW of Salinas River in Zone 2C	GW
14	Arroyo Seco	Subarea SW of Salinas River outside of Zone 2C	GW
15	Clark Colony	Subarea SW of Salinas River partly outside of Zone 2C	SW/GW
16	Upper Valley Northeast	Upper Valley subarea NE of Salinas River and northeast of King City in Zone 2C	GW
17	Upper Valley Northwest	Upper Valley subarea NW of Salinas River and west of King City in Zone 2C	GW
18	Upper Valley Southeast	Upper Valley subarea SE of Salinas River and east of King City in Zone 2C	GW
19	Upper Valley Southwest	Upper Valley subarea SW of Salinas River and west of King City in Zone 2C	GW
20	Below Dam	Subregion below Nacimiento Dam and within Zone 2C	GW

21	Westside Region	Westside Regions of SVIHM outside of Zone 2C boundary in Monterey County Inland Southwest of Arroyo Seco and Clark Colony subregion	GW
22	Hames Valley	Outside Zone 2C but in Monterey County	GW
23	NE Quarries	Outside Zone 2C but in Monterey County	GW
24	Northeast Region	Northeast Regions of SVIHM outside of Zone 2C on the Northeast side of the Eastside, Granite Ridge, and Highlands South subregions	GW
25	Southwest Region	Southwest regions of SVIHM outside of Coastal Pressure subregion Zone 2C boundary in Monterey County	GW
26	Northeast Region	Northeast Region of SVIHM outside of Zone 2C Forebay subregion in Monterey County	GW
27	Southwest Region	Southwest regions of SVIHM outside of the Upper Valley and Forebay regions subregions of Zone 2C in Monterey County plus outside of Arroyo Seco, Hames Valley, and SLO active subregions	GW
28	Southeast Region	Southeast Region of SVIHM outside of Below Dam and Upper Valley subregions of Zone 2C boundary in Monterey County	GW
29	Paso Robles Region	Remainder of Paso Robles Basin in active model grid in San Luis Obispo County	GW
30	Seaside Basin	Seaside Adjudicated Basin (landward only)	GW
31	Offshore	Offshore (groundwater analysis only)	None

Water Balance Subregions

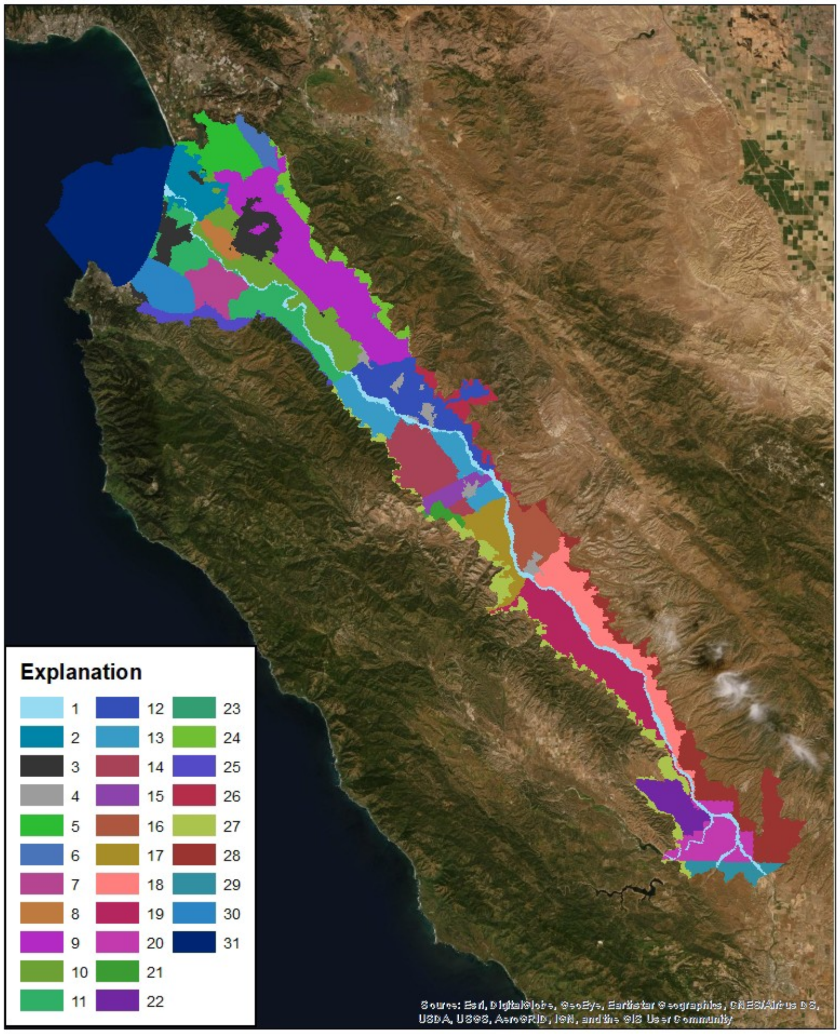

Figure 3: Salinas Valley Integrated Hydrologic Model Water Balance Subregions.

The SVIHM has 56 specified land use types (Table 2), each with defined water sources, irrigation type and efficiency (if applicable), and crop water demand properties (crop coefficients, area, crop development timeline). For each model year, two six-month land use maps were generated using a composite of available land use data from California Department of Water Resources, Monterey County, and the National Land Cover Database (NLCD, U.S. Geological Survey, 2014) and a newly developed method that leverages the California Pesticide Use Reporting (CalPUR) database.

The new CalPUR method is used to provide greater detail about the distribution of crops within areas with vague land use types such as “truck and vegetable crops” (Henson and others, in Prep). This approach captures complex cultivation methods including multi-cropping and crop rotations, providing a rich dataset for estimating agricultural water demands.

Table 2: Salinas Valley Integrated Hydrologic Model (SVIHM) Land Use Types

Land Use Type		Land Use Type		Land Use Type	
1	Celery – coastal	20	Root vegetables – inland	39	Outdoor nurseries – coastal
2	Celery – inland	21	Tomato/pepper – coastal	40	Outdoor nurseries – inland
3	Cucumber/melon/squash – coastal	22	Tomato/pepper – inland	41	Indoor nurseries
4	Cucumber/melon/squash – inland	23	Strawberries – coastal	42	Artichokes
5	Legumes – coastal	24	Strawberries – inland	43	Pasture
6	Legumes – inland	25	Corn – coastal	44	Non-irrigated
7	Lettuce – coastal	26	Corn – inland	45	Semi-agricultural
8	Lettuce – inland	27	Field crops – coastal	46	Idle/fallow
9	Rotational 30-day – coastal	28	Field crops – inland	47	Ag-trees
10	Rotational 30-day – inland	29	Grain crops – coastal	48	Golf course turf/parks
11	Crucifers/cabbages – coastal	30	Grain crops – inland	49	Urban
12	Crucifers/cabbages – inland	31	Cane/bush berries – coastal	50	Quarries
13	Unspecified irrigated row crops – coastal	32	Cane/bush berries – inland	51	Water
14	Unspecified irrigated row crops – inland	33	Deciduous fruits and nuts – coastal	52	Riparian
15	Carrots – coastal	34	Deciduous fruits and nuts – inland	53	Upland grasslands/shrub lands
16	Carrots – inland	35	Citrus/subtropical – coastal	54	Woodlands
17	Onions/garlic – coastal	36	Citrus/subtropical – inland	55	Beach/dunes
18	Onions/garlic – inland	37	Vineyards – coastal	56	Barren/burned
19	Root vegetables – coastal	38	Vineyards – inland		

The SVIHM was calibrated using over 63,098 monthly observations including: 1,738 measurements from the MCWRA observation well network (Figure 2); 6,448 streamflow measurements of at 17 streamgages (Figure 2 and Table 3); 127,683 monthly reported groundwater extraction values; and 162 reported monthly diversions. In addition, calibration included second-order observations of streamflow differences between gages and vertical hydraulic head differences between aquifers with multiple nested observation wells.

Table 3: Stream gage information showing Gage ID, U.S. Geological Survey National Water Information System (NWIS) gage number and gage name.

Gage ID	NWIS Gage Number	Gage Name
ARS_SOL	11152000	ARROYO SECO NR SOLEDAD CA
ARS_REL	11152050	ARROYO SECO BL RELIZ C NR SOLEDAD CA
SAL_SOL	11151700	SALINAS R A SOLEDAD CA
ELT_SPR	11152540	EL TORO C NR SPRECKELS CA
SAL_CHU	11152300	SALINAS R NR CHUALAR CA
ALI_SAL	11152570	ALISAL C NR SALINAS CA
SANT_BR	11150500	SALINAS R NR BRADLEY CA
SAL_SPR	11152500	SALINAS R NR SPRECKELS CA
SALO_PK	11151500	SAN LORENZO C A KING CITY CA
NAC_SMI	11149500	NACIMIENTO R BL NACIMIENTO DAM NR BRADLEY CA
REC_SAL	11152650	RECLAMATION DITCH NR SALINAS CA
GAB_SAL	11152600	GABILAN C NR SALINAS CA
ARD_REY	11143300	ARROYO DEL REY A DEL REY OAKS CA
FLZC_PK	11150700	FELIZ CYN TRIB NR SAN LUCAS CA
MCOJ_PK	11152700	MORO COJO SLOUGH TRIB NR CASTROVILLE CA
SAL_GON	11152200	SALINAS R NR GONZALES CA

In collaboration with MCWRA and the Pajaro Valley Water Management Agency, self-updating model tools have been developed which allow temporal datasets of MODFLOW-OWHM models to be updated using spreadsheets with updated temporal data. This approach is an improvement that allows models to continue to be updated and useful for the wide range of resource questions and scenarios that arise. These self-updating model tools can be used to update or correct input data describing climate data, ungaged inflow data, land use properties, observed hydraulic heads, groundwater extraction, wastewater reclamation, surface water diversions, reservoir releases, and agricultural pumping, irrigation types and efficiencies. All these updates can be completed without rebuilding the entire model. Model updates are described in the section “Future model updates, applications, and developments”.

Salinas Valley Operational Model

The Salinas Valley operational model (SVOM) uses the Surface Water Operations Module of MODFLOW-OWHM. This implementation of reservoir operations is based on a wealth of prior publications (Ferguson and others 2015; Ferguson and others, 2016; Hevesi and others, 2019; Hanson and others, 2020; Boyce and others, 2020). The SVOM is a baseline model that is used to evaluate water supply projects such as the reservoir modification and changes to operations to aide with groundwater sustainability efforts. The SVOM is similar to the SVIHM for simulation of hydrologic processes, surface and subsurface properties, and simulation of agricultural operations. In this model, the land use is fixed to 2014, the time step is shorter, about five to six days, and the reservoir operations are explicitly simulated. The reservoir operations rules are human readable text files that formulate the logic for the current mandated operational rules for conservation, water supply, flood mitigation, and water rights. These operations include fish passage rules that support the life cycle of threatened steelhead fish populations. These input data just translate existing flow charts and figures from the approved operations into text that the model can read in. These data are available from MCWRA upon request, both in the form used in the model and in public documents.

Model Representation of Seawater Intrusion, Groundwater Levels and Land Use

The following descriptions of methods are provided to illustrate how the model will inform future evaluations of Seawater Intrusion, groundwater sustainability evaluations and scenarios, and responses to changes in land use and climate.

Seawater Intrusion

Interactions with onshore freshwater aquifers and near-shore saltwater aquifers are driven by contrast in aquifer hydraulic heads and pore water densities between freshwater and seawater and the distribution of aquifer permeability along the coast. Seawater Intrusion (SWI) is estimated in the SVIHM as flux across the coastal boundary. The monthly elevation of the 9413450 NOAA Station buoy in Monterey Bay is used as a proxy for the sea water elevation (H_{sw}). In the model, the sea level is simulated as an equivalent freshwater head (h_{fw}) using the following relation from Motz (2005):

$$h_{fw} = \frac{\rho_{sw}}{\rho_{fw}} h_{sw} - \left(\frac{\rho_{sw} - \rho_{fw}}{\rho_{fw}} \right) Z$$

where

- h_{fw} is the seawater's equivalent freshwater hydraulic head at elevation Z (L),
- ρ_{sw} is the seawater density (M/L^3),
- ρ_{fw} is the freshwater density (M/L^3), and
- Z is the elevation point where the equivalent freshwater head is calculated (L).

Similar to other models in the region (Hanson, 2003a,b), the freshwater-seawater interface is simulated as general head boundary (GHB), that is, a boundary that depends on the aquifer hydraulic heads along the coast. To specify an ocean boundary condition with the GHB, the sea level is converted to an equivalent freshwater head at the model cell's center. The density of seawater is assumed to have an average value of 1,025 kg/m^3, and the density of freshwater is assumed to be 1,000 kg/m^3 (Motz, 2005). When hydraulic head in an aquifer is greater than h_{fw} along the coast, hydrologic flows are seaward. Conversely, when hydraulic head in an aquifer is less than h_{fw} along the coast, seawater intrusion into the aquifer occurs. The net annual flux values along the coastline for each aquifer are simulated by the SVIHM to inform interpretation of chloride monitoring by MCWRA.

Although these estimates do not provide information about the onshore spatial extent of SWI, the model is well-poised to be used to provide this information in future model updates and applications. These more explicit methods will be described in the Future model updates, applications, and developments section.

Groundwater Elevations

The SVIHM and SVOM estimate groundwater elevations using well-developed methods of the MODFLOW framework. MODFLOW uses the method of finite differences to solve the groundwater flow equation for each model cell. This approach assumes Darcian flow that is based upon hydraulic gradients within and among aquifers and the spatial distribution of hydraulic conductivity. Additional boundary conditions or processes that can increase or decrease hydraulic heads in the model are simulated such as barriers to flow (for example, faults), groundwater extraction (for example, municipal and agricultural pumping), stream-aquiferinteractions, sea water intrusion, and recharge.

After successful calculation of the hydraulic head in each aquifer, well depth-weighted composite heads are developed for wells screened in multiple aquifers. Composite- and single-well aquifer values for the simulated and observed hydraulic heads are compared. If the comparison between simulated and observed hydraulic heads is reasonable, the spatial distribution of simulated aquifer hydraulic heads provides another source for evaluating groundwater elevations and complements independently developed groundwater contour maps by MCWRA.

Land Use

Land use will be updated in future updates of the SVIHM using available spatial datasets and the CalPUR method to attribute vague land use categories. As new spatial data become available, they can be prioritized in the composite land use map and replace co-located data. The process for developing land use input data has four steps: develop a composite map, enhance map with CalPUR data, interpolate onto model grid, and generate the input files. In the future, new land use properties may need to be developed for new crop types not already represented in the current version of the historical model. An example of the 2017 land use map is provided to illustrate the representation of land use for every year in the model (Figure 4).

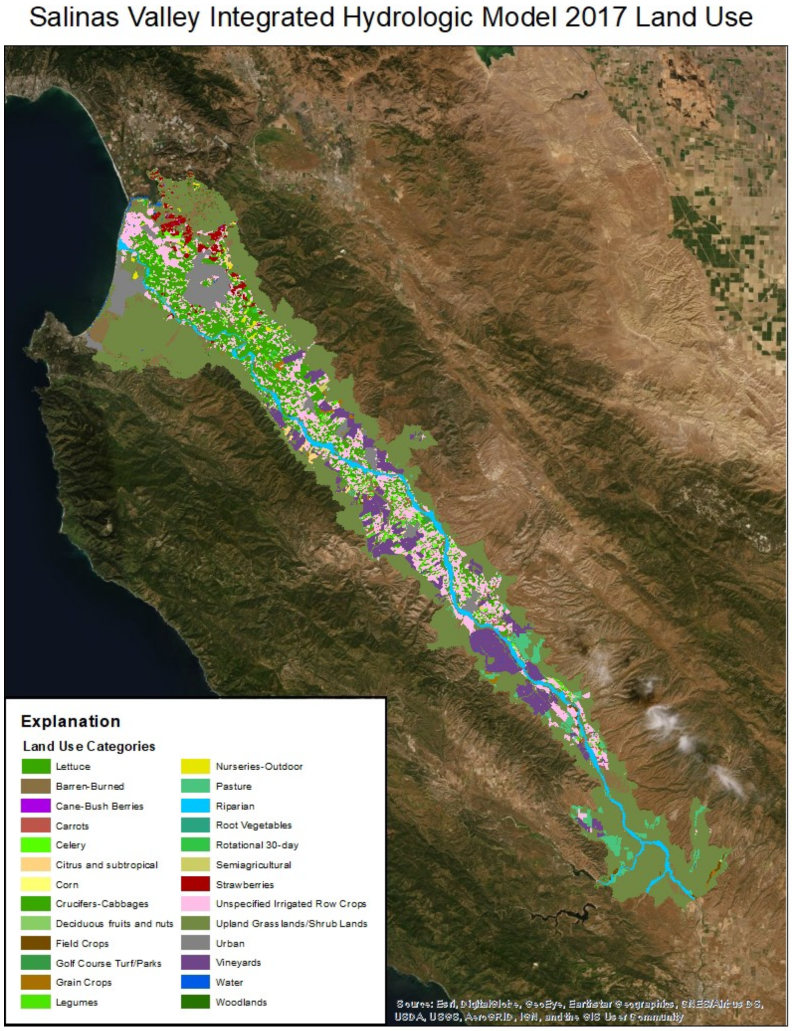

Figure 4: Salinas Valley Integrated Hydrologic Model (SVIHM) 2017 land use.

Model Review and Public Release

The model public release will consist of three elements: (1) a report about geologic and development and calibration of hydrologic models, (2) a data release with SVGM model input files and metadata, and (3) a data release with SVWM, SVIHM, and SVOM model input files and metadata in a public repository. The SVWM and SVIHM reports will document how the historical models were constructed. The SVOM report will include a description of the adaptations to the SVIHM to generate a baseline reservoir operations model, describe reservoir model implementation, and document implementation of rules. The report and data releases will be publicly available after completion of fundamental science review by the USGS. The USGS fundamental science review has multiple levels of scientific and technical review. These include technical, scientific, editorial, and regional review. This review ensures complete and accurate documentation of model development and results before data are potentially used for decision-making. The model is undergoing final calibration and has been updated through water year 2018. Final calibration is occurring simultaneously with report development.

The Salinas Valley models have been developed to address additional applications for ongoing regulatory and management efforts. A comprehensive 51-year climate, surface and groundwater, agricultural and reservoir operations model of the entire Salinas Valley is a substantial effort that warrants and benefits greatly from a sufficient technical review. This review provides a rigorous basis for further tool development and refinement and scenario testing. The technical review has been enhanced by use and further development of the Salinas Valley Suite in two regional projects, (1) the WaterSMART water supply vulnerability study cooperatively funded in partnership with the U.S. Bureau of Reclamation and (2) the Interlake Tunnel project. The WaterSMART Study includes forecast and analysis framework to evaluate conditions to 2100 for multiple possible climates, socio-economic growth scenarios, projects, and conservation strategies in the Salinas Valley and region. The Interlake Tunnel benefit analysis facilitated the operational model development which will benefit future project evaluations for years to come. These applications of the model allowed for more rigorous review of model input data, better implementation of important processes, and improved representation of land use.

Every effort is being made to publish the models within the estimated timeframe. However, it is important to note that the initial model scope was to address specific concerns about historical conditions for the Monterey County Basin Investigation. Since the start of project, the models have been refined with better representation wells and updated with four additional years of critical climate, land use, water supply, and reservoir storage, that represent drought recovery between 2014 and 2018. These data allow for (1) better representation of stakeholder conservation efforts that are essential for evaluation of water budgets and potential sustainability projects, (2) a longer duration for evaluation of operations, and (3) many updates to model input data sets to better represent the groundwater well network.

The Salinas Valley hydrologic model suite development has leveraged a unique opportunity to benefit multiple projects for stakeholders throughout the entire Salinas Valley. Although the technical review and model development has taken longer than anticipated, the value-added information and consistent analysis framework for these concurrent studies benefits both stakeholders and the models. As presented at the Model Workshop, the SVIHM is expected to be submitted for USGS Specialist Review in winter 2021-2022

Future model updates, developments, and applications

The SVWM and SVIHM will need annual updates to keep the models relevant for evaluating and reporting sustainability efforts for Sustainable Groundwater Management Act (SGMA) compliance or for use with other future projects. Updates to the SVIHM conceptual model, aquifer parameters, and input data facilitate timely SVOM updates, so that reservoir operations can continue to be refined to meet stakeholder needs. The SVWM and SVIHM will require periodic calibration to maintain model accuracy with potential changes in hydrology, climate, and land use. The model can also be improved with additional stakeholder support and refined to keep the model relevant to decision-making.

MCWRA and USGS continue to develop workflows and train staff to use model update tools. These self-updating model tools can convert MCWRA hydrologic data into model input. However, climate, land use, observation, extraction, diversion, and reservoir release datasets require some development. Data describing observed hydraulic heads, municipal and industrial groundwater extraction, wastewater reclamation, reported diversions, reservoir releases, and reported agricultural pumping are readily available in various MCWRA and Monterey County databases and require monthly aggregation and conversion to model units. These tools facilitate a model framework that can be readily updated with minimal lag time with support from the USGS.

PRISM climate data and climate station data are used to generate spatially distributed temperature, precipitation and potential evapotranspiration estimates using the BCM tools. There is a six-month lag time for some of these climate datasets. Climate data are used in the SVWM to develop ungaged watersheds inflows to the valley.

Land use will be updated in future updates of the SVIHM using available spatial datasets and the CalPUR method to attribute vague land use categories. As new spatial data become available, they can be prioritized in the composite land-use map and replace co-located data. The process for developing land-use input data will be to develop a composite map, enhance with CalPUR data, map onto model grid, and generate the input files. Additionally, new land use properties may need to be developed for new crop types not already represented in the current version of the historical model. As remote sensing technologies, such as satellite multi -spectral data analysis, are developed and refined alternate approaches to assigning time series crop water demand will be evaluated for future model updates.

The SVWM can be extended to look at nutrient and sediment loading and transport in the Salinas River watershed. This could be a powerful tool for soil conservation, nutrient evaluations, and water quality assessments. The SVWM can also be used to examine changes in runoff and recharge in response to land surface change. This can be a useful tool for initial assessments of potential surface storage sites, habitat restoration and flood flows.

The SVGM provides a basis for evaluating aquifer structure, evaluation of faults and other structures that may influence subsurface flow paths and facilitate interpretation of geophysics such as airborne electromagnetic (AEM) surveys.

The SVIHM can be extended to provide insights into several county initiatives: (1) assessment of Sea Water Intrusion (SWI) and contaminant transport, (2) evaluation of conceptual models of potential interactions between 180-ft and 400-ft aquifers (3) evaluation of optimal monitoring network expansion, (4) uncertainty estimates for important hydrologic predictions (SWI, GW-SW interactions, recharge).

The SVIHM could be extended to evaluate Sea Water Intrusion (SWI) more completely. Currently the model examines net volumes of landward flow from the ocean. In order of increasing effort, other options for SWI evaluation include particle tracking, the sharp water interface Modflow package (SWI2, Bakker and others 2013)), and coupled simulation of sea- and fresh water such as SEAWAT (Guo and Langevin, 2002; Langevin, 2001). The SVIHM geologic texture model, aquifer parameters, and model structure provide a backbone for any of these options for evaluating SWI.

SWI monitoring and analysis by the MCWRA has identified the occurrence of vertical migration of seawater from the overlying intruded Pressure 180-foot aquifer to the Pressure 400-foot aquifer (MCWRA, 2017). More information is needed to understand these interactions among aquifers and aquifer responses to stress. As monitoring and data collection efforts are refined and expanded, along with continued refinement of hydrostratigraphic information, the SVIHM can be used to evaluate new conceptual models of the aquifers and evaluate the aquifer’s response under various management scenarios.

Summary

A suite of geologic and hydrologic models has been developed to estimate water supply and availability in the Salinas Valley. These models will be documented and released to the public after completion of review and approval according to USGS fundamental science practices. After publication these models will continue to be updated to support future water management objectives.

Disclaimer

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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