# Appendix D

# Selected Modeling Tools and Quantitative Methodologies

## Abstract

Quantitative methods, including hydrologic modeling and geographic information system (GIS) analyses, are being used to identify opportunities and evaluate projects to achieve multiple benefits through storm water management. These benefits fall into five categories: enhanced water supply, improved water quality, flood protection, environmental protection / restoration, and community benefits. Table 1 lists these benefits and the primary analytical tools employed to evaluate projects to achieve them.

In general, an ArcGIS geodatabase with approximately 70 layers of storm water relevant information is used to identify (1) storm water sources, flows, and volumes; (2) network drainage points where storm water can be captured or diverted; (3) transport pathways and infrastructure; (4) landscape depressions where water has been or can be stored; (5) recharge areas; (6) habitat restoration areas; and other features that provide opportunities for storm water management. The volumes, flow rates and pollutant loads are then entered into a regional water balance model to calculate the cumulative system-wide effects of proposed or potential diversions and other management actions. The components of the analysis are described below, beginning with the georeferenced water balance model and GIS analyses that are the integrating component of the overall analysis.

**Table 1. Models, GIS and other Quantitative Analyses used to Evaluate Project Benefits.**

| Project Benefits | Tools and Data Sources | Data Outputs for Current Status | Target Conditions | Opportunity Analysis |
|---|---|---|---|---|
| **Water Quality Goal:** | | | | |
| Reduce Nitrates | SWAT Model | Loading in kg/yr | TMDL and MS4 Permit Limits | Identification of Sources and Pathways for Reduction |
| Reduce Pesticides | CCAMP Data Navigator and Report Card System | Concentrations in ug/L | TMDL and MS4 Permit Limits | Identification of Sources and Pathways for Reduction |
| Reduce Sediments | TELR Tool | Loading in kg/yr | TMDL and MS4 Permit Limits | Identification of Sources and Pathways for Reduction |
| Reduce Pathogens | GIS Analysis of Storm Drain Systems; CCAMP Data Navigator and Report Card System | Concentrations in mpn/100 ml | TMDL and MS4 Permit Limits | Identification of Sources and Pathways for Reduction |
| **Water Supply Goal:** | | | | |
| Recharge Groundwater | GIS Analysis and ESA Water Balance Model | Acre Feet per Year | GSP Goals and Extraction Rates | Identification of Areas for Diversion, Treatment and Recharge |
| Reuse Surface Water | GIS Analysis and ESA Water Balance Model | Acre Feet per Year | Current Demand | Identification of Areas for Diversion, Treatment and Recharge |
| **Flood Management Goal:** | | | | |
| Meet Winter Hydrograph Objectives | HEC/RAS Flood Model | Liters or Cubic Feet per Second | Peak Flows below Flood Stage | Identification of Areas for Diversion and Storage |
| Meet Summer Hydrograph Objectives | HEC/RAS Flood Model; Environmental Flow Analyses | Liters or Cubic Feet per Second | Low Flows above Environmental Flow Requirements and Beneficial Use Support Thresholds | Identification of Areas for Storage and Reuse |
| **Environmental Goal:** | | | | |
| Base flow | HEC/RAS Flood Model | Liters or Cubic Feet per Second | Low Flows above Environmental Flow Requirements | Identification of Areas for Storage and Reuse |
| Wetland condition | Watershed CRAM in Spatial Statistical Network Model | CRAM Scores | Reference Conditions | Identification of Areas for Restoration |
| Riparian and Other Habitat | State and National Wetlands Inventory | CRAM Scores | Reference Conditions | Identification of Areas for Restoration |
| **Community Goal:** | | | | |
| Bike Paths and Transportation | GIS Analysis | miles per capita | Centers for Disease Control 2016 Benchmarking Report | Identification of Suitable Restoration Area Borderlands |
| New Parkland and Open Space | GIS Analysis | acres per capita | National Recreation and Park Assoc. 2016 benchmarks: 9.5 acres per 1000 people | Identification of Restoration Areas |
| Educational and Training Opportunities | Project Specific | Students Served (#) | Project Specific | Identification of Restoration Tasks and Skills |
| Employment Opportunities | Project Specific | Jobs Created (#) | Project Specific | Project Specific |
| Property Value and Business Recruitment | GIS Analysis of Zoning Designations and Proximity to new Aquatic Features | Commercial occupancy rates (%); Rental Rates and Sale Prices ($) | Measureable Improvement | Hedonic Valuation Analyses |

Acronyms: SWAT= Sediment Water Assessment Tool, TMDL=Total Maximum Daily Load, MS4=municipal storm water permits, CCAMP=Central Coast Ambient Monitoring Program, TELR=Tool to Estimate Load Reduction, GIS=Geographic Information

System, ESA=project consultant, GSP-Groundwater Sustainability Plan, HEC/RAS= Hydrologic Engineering Center's River Analysis System, CRAM=California Rapid Assessment Method.

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# Section 1. Storm Water Hydrologic Modeling

ESA is developing modeling tools to enable quantitative assessment of project opportunities in the Greater Monterey County Integrated Regional Water Management planning region. The models are being developed in support of development of a new Storm Water Resources Plan (SWRP) for this region. The models were developed with a focus on the water supply and flood management goals of the SWRP. This document summarizes the methods and development of the model tools, the primary inputs, outputs, and assumptions for the models, and how these tools will be utilized to assess SWRP project opportunities. Two primary model tools have been developed to provide quantitative context for the SWRP projects.

1. **Water Balance Modeling** – A water balance model is under development for the SWRP. This model is a simplified rainfall-runoff and routing model which will capture the impact of changes in land use or routing and storage on typical daily, monthly, and annual flows in the planning area. This modeling will primarily support the water supply goals of the SWRP.

2. **Flood Modeling –** The flood modeling analysis combines multiple tools to enable assessment of extreme flow events and scenarios for reducing flooding associated with these events. The tools include a hydraulic model which is used to simulate water surface elevations and other hydraulic variables specifically relevant to flood conditions. This model will be combined with a conceptual lagoon model designed by ESA which will be used to evaluate management options at the Salinas River Lagoon to address flooding issues in the lower Salinas and Gabilan Creek watersheds. Additionally, a unit basin analysis will be conducted that will provide a generalized set of relationships between flood storage and peak flow reduction potential. These relationships can be used to conduct a rapid high-level assessment of flood reduction potential for a given storage facility size. These tools will primarily support the flood reduction goals of the SWRP.

These tools will be used to evaluate project scenarios and provide a set of outputs that can be used to evaluate the impact on water supply and flooding of potential projects. The following sections provide technical detail on the methods, inputs, and outputs for the water balance and flood modeling.

# 1 WATER BALANCE MODELING

The core tool developed for the water balance model is a 'parsimonious' hydrologic model representing rainfall, runoff, evapotranspiration, infiltration, groundwater, baseflow, and surface water flow after Limbrunner et al (2005). The model domain, sub-basins, streamlines, outflow nodes, and gages in the watershed are shown in Figure 1. The model is based on an adaptation of the U.S. Soil Conservation Service (now the National Resource Conservation Service) Curve Number (CN) method (USDA-SCS, 1983, 1986) and is described as parsimonious as it contains only three adjustable parameters—the CN itself as well as one groundwater and one surface water rate parameter as described below. This model makes many assumptions and is only appropriate for planning level studies such as the SWRP. More detailed project-level modeling is recommended for design and implementation of any project under the SWRP.

The model was developed using a combination of GIS, Matlab, and the USACE's HEC-HMS model to simulate daily flow in the planning region. The model input parameters were developed in GIS. The model contains a sub-basin component and a channel routing component. The sub-basin component of the water balance model was developed in Matlab. The channel routing component of the water balance model was handled in HEC-HMS. The details of the model development are provided in the following sections.

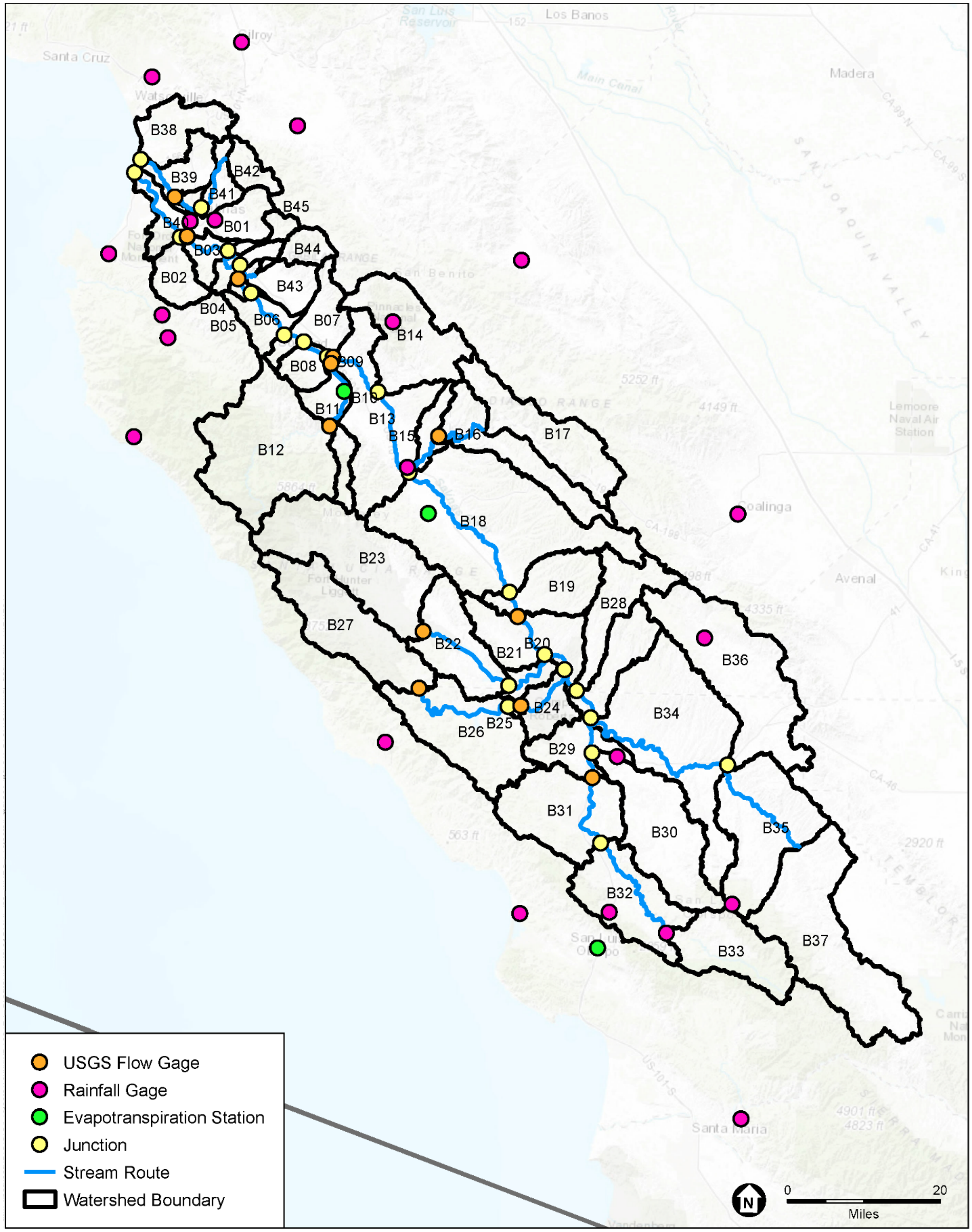



*Figure 1. Greater Monterey SWRP Water Balance Model Layout*

## 1.1 Model Methods

### 1.1.1 Sub-basin water balance

The sub-basin model simulates the processes of daily variations in evapotranspiration, soil moisture, groundwater saturation, groundwater outflow and stream flow. The following equations describe the computation methods used in the model.

The equations are calculated directly for individual landuse types where designated by the subscript 'L'. Direct runoff at a given timestep, $R_L(t)$, is related to the rainfall P(t), an initial abstraction value $Ia_L(t)$ representing all initial losses before runoff begins, and the watershed soil storage capacity $WS_L(t)$ which is related to curve number $CN_L(t)$. The curve number is a function of landuse and soils within each drainage area. The direct runoff is calculated using the following equations:

$$RL(t)=Pt-\ IaL(t)2Pt-IaLt+WSL(t)$$

$$IaLt=0.2WSL(t)$$

$$WSL(t)=1000CNL(t)-10$$

The curve number is a function of landuse, soil conditions, and antecedent rainfall. The curve number is calculated for average antecedent moisture conditions ($CN_{2,L}$) at each time step using relationships provided by Haith et al (1996) for dry and wet antecedent moisture conditions ($CN_{1,L}$ and $CN_{3,L}$). The curve number is related to the unsaturated zone soil storage $S_L(t)$ and the maximum allowable unsaturated soil storage $S_{max,L}$ as related in the following equations.

$$CN1,L=CN2,L2.334-0.01334*CN2,L$$

$$CN3,L=CN2,L0.4036-0.0059*CN2,L$$

$$CNL(t)=CN3,L-CN1,L*SL(t-1)Smax,L+CN1,L$$

$$Smax,L=1000CN1,L-10$$

Evapotranspiration $ET_L(t)$ is captured as a function of potential evapotranspiration $PET_L(t)$ reduced by the ratio of unsaturated soil zone storage to maximum unsaturated soil zone storage as shown in the equation below. This ratio mitigates the tendency for the subsurface to dry completely during extended periods without precipitation.

$$ETL(t)=SL(t-1)Smax,L*PETL(t)$$

Groundwater flow G(t) is a function of the infiltration $I_L(t)$ from the surface into the upper soil storage zone, percolation $Perc_L(t)$ from the upper zone to groundwater. The percolation is calculated using a soil surplus variable SS(t) defined as the prior day's soil storage plus the current day's infiltration. The soil $S_L(t)$ moisture is calculated using a continuity equation between the previous day's soil moisture plus infiltration for the current day, minus percolation and evapotranspiration for the current day. Groundwater flow is then calculated using a continuity equation between groundwater flow from the previous day plus percolation minus groundwater outflow (i.e. baseflow) $k_b$*G(t-1). The groundwater scalar $k_b$ is one of the calibration parameters.

$IL(t)=P(t)-RL(t)$ if $P(t) > R_L(t)$

$PercL(t)=SSL(t)-Smax,L$ if $SS_L > S_{max,L}$ and 0 otherwise

$$SL(t)=SLt-1+IL(t)-PercL(t)-ETL(t)$$

$$Gt=Gt-1+LALATPercL(t)-kbG(t-1)$$

Streamflow is calculated by routing direct runoff and baseflow (i.e. groundwater flow) through the stream network storage volume N(t) scaled by a calibration factor representing the inverse of the residence time in the stream network ($k_N$).

$$Qt=kNNt+LALATRL(t)+kbG(t-1)$$

$$Nt+1=Nt-Q(t)$$

A conceptual graphic representing the primary physical processes captured using this parsimonious water balance approach is shown in Figure 2. The input data for the water balance model is described in Section 1.2.

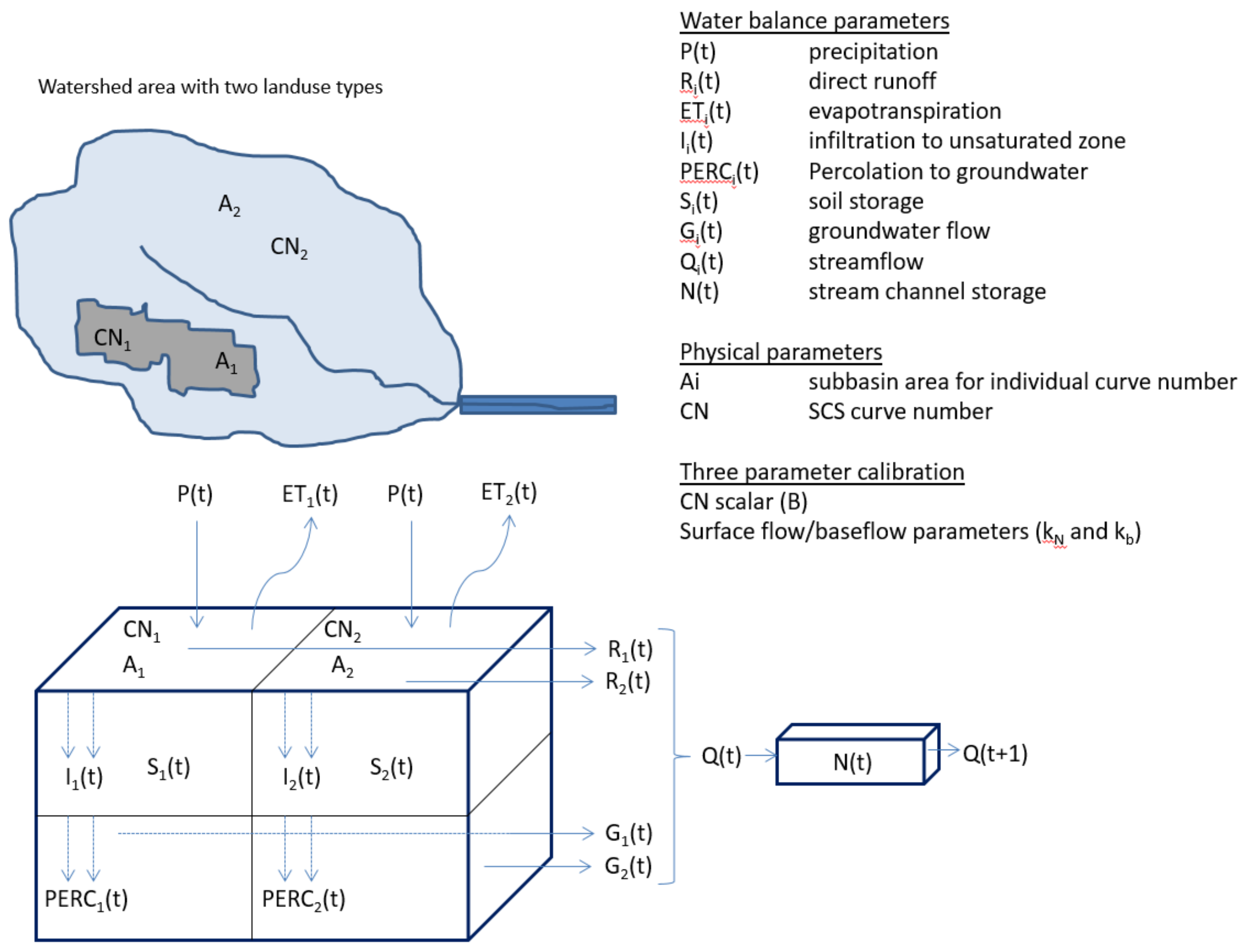



*Figure 2. Conceptual schematic of parsimonious water balance*

### 1.1.2 Routing model

The sub-basin water balance calculates the outflow from each sub-basin but does not capture the routing of that flow through individual stream channels. A separate model component was developed in HEC-HMS to simulate the routing in channel reaches between sub-basin outlet points. The Muskingum-Cunge routing method was selected to model the routing process. The model applies mass and energy continuity using channel properties including hydraulic roughness as described in the HEC-HMS technical reference manual (USACE, 2000). The input data for the routing model is described in Section 1.2.

## 1.2 Input data

### 1.2.1 Sub-basin water balance

The primary inputs to the sub-basin component of the water balance model are the sub-basin delineations, rainfall data, curve number data, evapotranspiration data, and runoff rate parameters.

#### 1.2.1.1 Sub-basin delineation

The sub-basins were developed using USGS HUC 10 basins (USDA/NRCS, 2017). ESA delineated additional basins at stream gage locations for calibration purposes. Sub-basin delineation for USGS streamflow gage locations was accomplished using the ArcHydro toolset in ESRI's ArcGIS version 10.2. The topographic dataset used to guide basin delineation was the USGS National Elevation Dataset (NED). The raster dataset downloaded for the NED has a 30-meter x 30-meter resolution or 1 arc second, is horizontally referenced to the North American Datum of 1983 (NAD83) with a UTM Zone 10N projection, and is vertically referenced to the North American Vertical Datum of 1988 (NAVD88). All units were converted to feet for this analysis using a conversion factor of 3.28 feet per meter.

The water balance model includes 45 sub-basins representing a drainage area of 4,463 square miles. Sub-basin delineations are shown in Figure 1. Sub-basin parameters are summarized in **2**.

**TABLE 2**
**WATER BALANCE MODEL SUB-BASIN INPUT DATA**

| Basin Index | Basin Name | Area (sq-mi) | Area Averaged Curve Number[1] | | |
|---|---|---|---|---|---|
| | | | $CN_1$ | $CN_2$ | $CN_3$ |
| B01 | Alisal Creek-Salinas River | 86.7 | 54 | 73 | 87 |
| B02 | El Toro Creek | 42.2 | 43 | 64 | 82 |
| B03 | USGS Gage 11152500 | 26.4 | 55 | 74 | 88 |
| B04 | 180600051507-Salinas River | 25.8 | 54 | 73 | 87 |
| B05 | USGS Gage 11152300 | 7.2 | 55 | 74 | 88 |
| B06 | Limekiln Creek-Salinas River | 41.5 | 54 | 73 | 87 |
| B07 | McCoy Creek-Salinas River | 61.9 | 49 | 69 | 85 |
| B08 | Lasher Canyon-Salinas River | 31.1 | 50 | 70 | 86 |
| B09 | Stonewall Creek-Salinas River | 0.7 | 65 | 81 | 92 |
| B10 | Arroyo Seco | 0.5 | 55 | 74 | 88 |
| B11 | USGS Gage 11152050 | 55.7 | 55 | 74 | 88 |
| B12 | USGS Gage 11152000 | 241.2 | 49 | 69 | 85 |
| B13 | USGS Gage 11151700 | 179 | 55 | 74 | 88 |
| B14 | Chalone Creek | 141.5 | 43 | 64 | 82 |
| B15 | San Lorenzo Creek | 27.6 | 54 | 73 | 87 |
| B16 | USGS Gage 11151300 | 102.4 | 50 | 70 | 86 |
| B17 | Lewis Creek | 130.7 | 51 | 71 | 86 |
| B18 | Pancho Rico Creek-Salinas River | 360.2 | 54 | 73 | 87 |
| B19 | Indian Valley-Salinas River | 87.5 | 51 | 71 | 86 |
| B20 | USGS Gage 11150500 | 173.7 | 51 | 71 | 86 |

| Basin Index | Basin Name | Area (sq-mi) | Area Averaged Curve Number[1] | | |
|---|---|---|---|---|---|
| | | | $CN_1$ | $CN_2$ | $CN_3$ |
| B21 | Kemp Canyon-San Antonio River | 21.5 | 51 | 71 | 86 |
| B22 | San Antonio River | 107.4 | 56 | 75 | 89 |
| B23 | USGS Gage 11149900 | 215.7 | 49 | 69 | 85 |
| B24 | 180600050611-Nacimiento River | 43.1 | 49 | 69 | 85 |
| B25 | USGS Gage 11149400 | 3.4 | 48 | 68 | 84 |
| B26 | Nacimiento River | 162.9 | 52 | 72 | 87 |
| B27 | USGS Gage 11148900 | 162.2 | 52 | 72 | 87 |
| B28 | Big Sandy Creek | 85.4 | 51 | 71 | 86 |
| B29 | Paso Robles Creek-Salinas River | 60.7 | 54 | 73 | 87 |
| B30 | Huerhuero Creek | 161.8 | 49 | 69 | 85 |
| B31 | USGS Gage 11147500 | 148.7 | 52 | 72 | 87 |
| B32 | Santa Margarita Creek-Salinas River | 128.4 | 51 | 71 | 86 |
| B33 | Santa Margarita Lake-Salinas River | 112.2 | 50 | 70 | 86 |
| B34 | Estrella River | 277.7 | 51 | 71 | 86 |
| B35 | Lower San Juan Creek | 178.8 | 48 | 68 | 84 |
| B36 | Cholame Creek | 237.2 | 51 | 71 | 86 |
| B37 | Upper San Juan Creek | 256.8 | 48 | 68 | 84 |
| B38 | Elkhorn Slough | 71.1 | 47 | 67 | 84 |
| B39 | Alisal Slough-Tembladero Slough | 47.8 | 58 | 76 | 89 |
| B40 | USGS Gage 11152650 | 7.8 | 81 | 91 | 97 |
| B41 | Natívdad Creek-Gabilan Creek | 28.7 | 56 | 75 | 89 |
| B42 | Mud Creek-Gabilan Creek | 28 | 40 | 61 | 80 |
| B43 | Johnson Creek | 46.8 | 62 | 79 | 91 |
| B44 | Chualar Creek | 28.3 | 40 | 61 | 80 |
| B45 | Quial Creek | 17.1 | 45 | 66 | 83 |

[1] Area averaged curve number provided for reference only. Water balance model operates on individual parcels within each sub-basin and the curve number is updated at each time step depending on antecedent moisture conditions.

#### 1.2.1.2 Rainfall Data

Observed rainfall data from rain gages in the vicinity of the watershed were used in the water balance model. Several gages were evaluated and ultimately a set of 24 gages were identified that provided continuous daily observations and were within or sufficiently nearby to be representative of storm conditions in the watershed. The gages and their data sources are summarized in 3. A map showing the gage locations is included in Figure 1**.**

**TABLE 3**
**WATER BALANCE MODEL RAINFALL GAGES**

| Name | Source | Start Date (mm/dd/yy) | End Date (mm/dd/yy) | Latitude | Longitude | Elevation (NAVD88 ft) |
|---|---|---|---|---|---|---|
| Big Sur Station CA US | NCDC | 12/31/1914 | 9/23/2017 | 36.2472 | -121.78 | 200.1 |
| Black Mountain | CDEC | 1/1/1987 | 9/30/2017 | 35.395 | -120.353 | 3625 |
| Carmel Valley CA US | NCDC | 12/31/1958 | 9/9/2017 | 36.4805 | -121.724 | 480 |
| Gilroy CA US | NCDC | 1/1/1942 | 9/24/2017 | 36.1356 | -120.361 | 669.9 |
| Hearst Castle CA US | NCDC | 2/28/1906 | 5/31/2017 | 37.003 | -121.561 | 193.9 |
| Hollister 2 CA US | NCDC | 11/30/1999 | 9/23/2017 | 35.6841 | -121.168 | 1525.9 |
| King City CA US | NCDC | 6/30/1948 | 6/21/2017 | 36.8483 | -121.421 | 274.9 |
| Monterey Nwsfo CA US | NCDC | 6/15/1902 | 8/30/2017 | 36.2069 | -121.138 | 319.9 |
| Morro Bay Fire Department CA US | NCDC | 6/30/1995 | 8/29/2017 | 36.5927 | -121.856 | 122 |
| New Cuyama Fire Station CA US | NCDC | 1/31/1959 | 8/30/2017 | 35.367 | -120.845 | 118.1 |
| Parkfield | NCDC | 12/31/1973 | 9/22/2017 | 34.9455 | -119.683 | 2160.1 |
| Paso Robles Municipal Airport CA US | CDEC | 1/1/1996 | 9/30/2017 | 35.613 | -118.277 | 3170 |
| Pinnacles National Monument CA US | NCDC | 1893-12-31 | 9/24/2017 | 35.6277 | -120.686 | 730 |
| Salinas Dam CA US | NCDC | 12/31/1936 | 9/15/2017 | 36.4819 | -121.182 | 1307.1 |
| Salinas Municipal Airport CA US | NCDC | 6/30/1948 | 8/30/2017 | 35.3372 | -120.504 | 1392.1 |
| Salinas Number 2 CA US | NCDC | 6/13/1930 | 9/24/2017 | 36.6636 | -121.608 | 74.1 |
| Salinas River At Paso Rovles | NCDC | 4/30/1958 | 9/23/2017 | 36.6594 | -121.666 | 44.9 |
| Salinas River Near Bradley | CDEC | 1/1/1987 | 9/30/2017 | 35.62858 | -120.684 | 700 |
| San Clemente Dam CA US | CDEC | 1/1/1987 | 9/30/2017 | 35.93024 | -120.869 | 443 |
| Santa Margarita Boost CA US | NCDC | 12/31/1939 | 5/30/2017 | 36.4375 | -121.709 | 600.1 |
| Santa Maria Public Airport CA US | NCDC | 11/30/1942 | 9/24/2017 | 35.3741 | -120.638 | 1148 |
| Twitchell Dam CA US | NCDC | 12/31/1947 | 9/24/2017 | 34.8994 | -120.449 | 242.1 |
| Watsonville Waterworks CA US | NCDC | 2/28/1962 | 9/10/2017 | 34.988 | -120.321 | 582 |

Inverse-distance-weighting was used to estimate rainfall data for gages that did not have complete records from 10/01/1995 to 10/01/2017. Distance weights were applied to these gages and two rainfall gages within closest proximity based on an inverse distance weighting (IDW) approach to generate rainfall data for these gages for the time period not covered. The closest 9 stations or those within a distance of 30 miles were given a weight based on the inverse distance between the gages.

The equation used to compute the weights is expressed as follows:

$$Wi=1di21n1dn2$$

Where, $W_i$, is the weight for gage i used to determine the gage with missing data

$d_i$ is the distance from gage i to the gage with missing data

$n$, is the number of gages, excluding the gage with missing data

**Spatial Rainfall Distribution**

Individual gages represent observed rainfall at discrete points around the watershed. This data must be spatially interpolated to represent rainfall over the full watershed area. ESA applied spatial weighting methods to extend the observed gage data and develop coverage over the entire Salinas basin for the storm events. Percent area coverage for each rainfall gage was tabulated for each sub-basin based on spatial weighting using Theissen polygons delineated around each gage.

Theissen polygons contain the area that is closest to each individual gage point relative to the location of each of the other gages. The ET GeoWizards toolbar in ArcGIS was used to develop the Theissen polygons. Each polygon essentially represents the area of influence for an individual gage. Theissen polygons were delineated for the 24 gages in GIS and intersected with the sub-basins. The weight assigned to each gage was calculated by the fraction of sub-basin area overlapping the Theissen polygon for a given gage. This computation is expressed in the equation below.

$$PSB=PG1*AG1ASB+PG2*AG2ASB+...+PGn*AGnASB$$

Where, $P_{SB}$, is the computed rainfall at a sub-basin (in)

$P_{Gn}$, is the observed rainfall for gage *n* (in)

$A_{Gn}$, is the coincident area of the sub-basin and the Theissen polygon for gage *n* (ac)

$A_{SB}$, is the area of the sub-basin (ac)

$n$, is the number of gages

### 1.2.1.3 Curve Number

Rainfall infiltration in each basin is characterized by loss factors assigned to overlapping land use types and hydrologic soil groups based on the Soil Conservation Service (SCS) Curve Number (CN) approach as outlined in the National Resource Conservation Service's (NRCS) Technical Release No. 55 (TR-55) (NRCS, 1986). Rather than calculating a composite CN for the entire watershed as a function of land use and hydrologic soil group, acreages of each curve number (rounded to the 1) for each sub-basin were tabulated for the parsimonious water balance model approach. ESA used high resolution geospatial datasets to calculate a CN for overlapping areas of land cover and soil type. A map of the curve number values is shown in Figure 3.

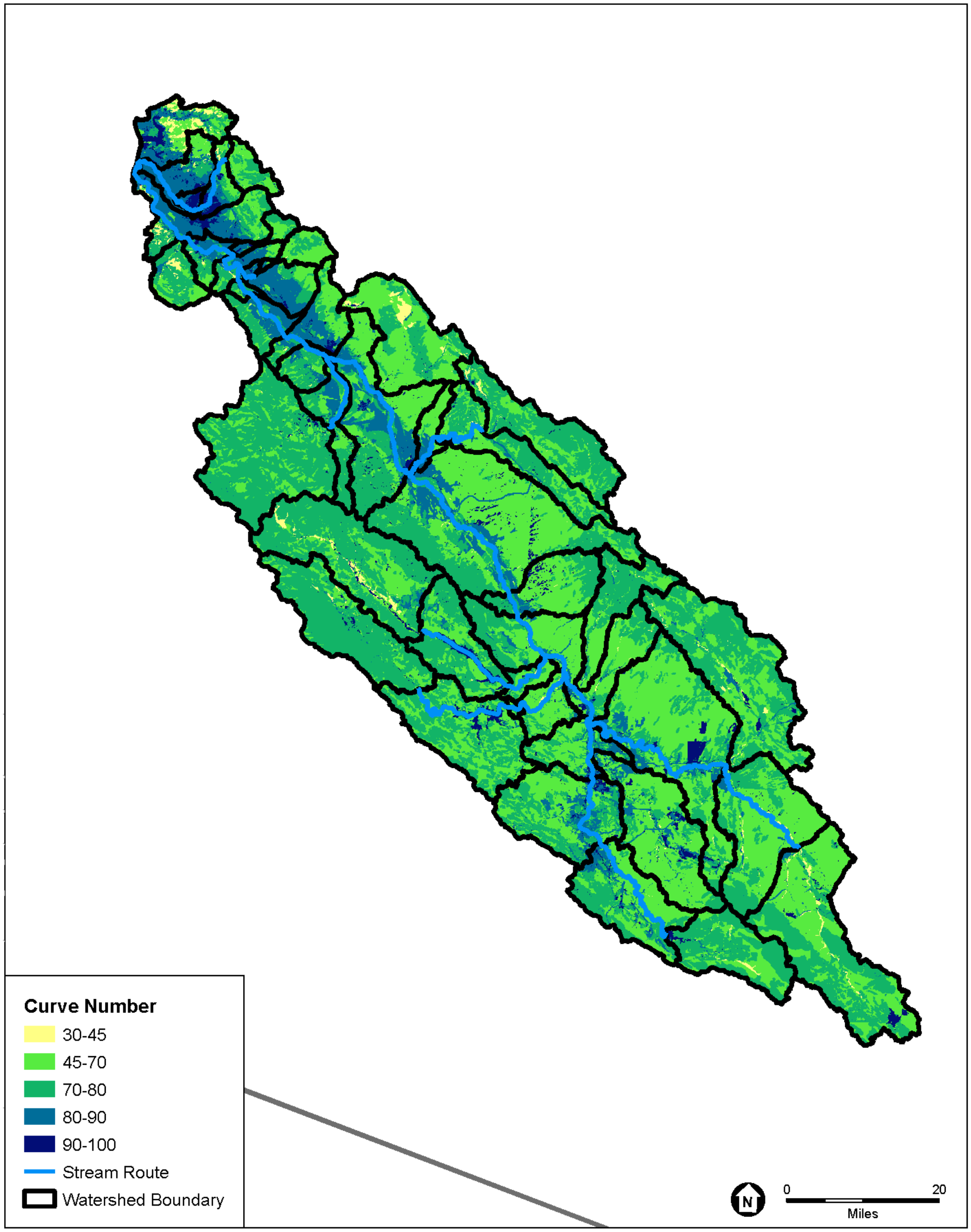



*Figure 3. SWRP Study Area curve number map*

Soil type was characterized using the NRCS Soil Survey Geographic (SSURGO) data for the Salinas watershed (NRCS, 2011). The CN method characterizes soil type by Hydrologic Soil Group (HSG) which represents the infiltration capacity of the soil. The HSG groups A, B, C, and D are organized in order of decreasing infiltration rates and increasing runoff potential.

Land cover type was characterized for the watershed using the National Land Cover Dataset (NLCD) generated for 2011 conditions by the Multi-Resolution Land Characteristics Consortium (MRLC, 2015). The NLCD data is a 30-meter resolution grid-based geospatial dataset and contains 20 land cover categories. The MRLC also provides percent impervious cover at the same resolution for the 2011 NLCD. Land use and percent impervious area were overlaid and a CN value of 98 following TR-55 methodology was applied to the impervious fraction of area. The land cover categories were compared between the NLCD and the TR-55 curve number tables, and Table 4 was generated for calculating curve numbers.

**TABLE 4**
**CURVE NUMBERS FOR AREAS COVERED BY NLCD**

| NLCD[1] Land Class[2] | Equivalent NRCS Class[3] | HSG[4] | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| Barren Land | Fallow - Bare Soil | 77 | 86 | 91 | 94 |
| Cultivated Crops | Row Crops – Straight, good condition | 67 | 78 | 85 | 89 |
| Deciduous Forest | Woods - Good | 30 | 55 | 70 | 77 |
| Developed, High Intensity | Urban – Commercial | 89 | 92 | 94 | 95 |
| Developed, Medium Intensity | Residential, 1/8 acre or less | 77 | 85 | 90 | 92 |
| Developed, Low Intensity | Residential, ½ acre lot | 54 | 70 | 80 | 85 |
| Developed, Open Space | Open Space, Good | 39 | 61 | 74 | 80 |
| Emergent Herbaceous Wetlands | Wetland[3] | 90 | | | |
| Evergreen Forest | Woods - Good | 30 | 55 | 70 | 77 |
| Hay/Pasture | Pasture, Grassland, Good | 39 | 61 | 74 | 80 |
| Herbaceous | Herbaceous, Good | 62 | 62 | 74 | 85 |
| Mixed Forest | Woods - Good | 30 | 55 | 70 | 77 |
| Open Water | Water[5] | 100 | | | |
| Shrub/Scrub | Desert Shrub, Fair | 55 | 72 | 81 | 86 |
| Woody Wetlands | Wetland[6] | 90 | | | |

[1] National Landcover dataset (NLCD)
[2] Multi-resolution Land Characteristics Consortium (MRLC) 2015
[3] National Resources Conservation Service (NRCS), 1986
[4] Hydrologic Soil Group
[5] NRCS does not have a class for water
[6] NRCS does not have a wetland class

#### 1.2.1.4 Evapotranspiration Data

Observed reference evapotranspiration (ETo) data from California Irrigation Management Information System (CIMIS) automated weather stations in the vicinity of the watershed were used (CIMIS, 2017). Several stations were evaluated and ultimately a set of 8 stations were identified that provided continuous daily observations and were within or sufficiently nearby to be representative of evapotranspiration conditions in the watershed. The stations and their data sources are summarized in Table 5.

**TABLE 5**
**WATER BALANCE MODEL CIMIS STATIONS**

| ID | Name | Start Date (dd/mm/yy) | End (dd/mm/yy) | Latitude | Longitude | Elevation (NAVD88 ft) |
|---|---|---|---|---|---|---|
| 19 | Castroville | 11/18/1982 | 9/30/2017 | 36.768167 | -121.773640 | 9 |
| 52 | San Luis Obispo | 4/2/1986 | 9/30/2017 | 35.305442 | -120.661780 | 330 |
| 88 | Cuyama | 5/20/1989 | 9/30/2017 | 34.942525 | -119.673800 | 2290 |
| 113 | King City-Oasis Rd. | 6/12/1993 | 9/30/2017 | 36.121083 | -121.084570 | 540 |
| 114 | Arroyo Seco | 6/18/1993 | 9/30/2017 | 36.347306 | -121.291350 | 235 |
| 116 | Salinas North | 6/18/1993 | 9/30/2017 | 36.716806 | -121.691890 | 61 |
| 160 | San Luis Obispo | 11/1/2000 | 9/30/2017 | 35.335261 | -120.735880 | 285 |
| 163 | Atascadero | 11/21/2000 | 9/30/2017 | 35.472556 | -120.648140 | 885 |

## Crop Factors

Reference evapotranspiration (ETo) data must be adjusted to estimate potential evapotranspiration (PET) using crop coefficients (Kc)—conversion factors that are used to estimate water use for a given crop or landscape (FAO, 1998). Crop coefficients have been developed for various agronomic crops, vegetable crops, and landscapes and vary depending on weather conditions and soil moisture content.

Crop evaporation was calculated using a modified version of the Penman equation.

$$ETc = Kc * ETo$$

Where, *ETc,* is the crop evapotranspiration (in)

*Kc,* is the crop coefficient (estimated from ration ET in crop field to ET in turf grass)

*ETo,* is the reference evapotranspiration (in)

Crop factors were determined for each NLCD land use code based on literature values. Crop factors were also determined based on seasonal variance. Seasonal variance in crop factors can be divided into four periods: initial (January-February), rapid (March-April), mid-season (May-October), and late growth (November-December) (Snyder, 2014). Literature values for different crop factors typically report a value for winter (initial growth) and summer (mid-season growth). Based on trends for field crops and vegetable crops for seasonal variance, we assigned the same numeric value of Kc for the initial and late growth periods, and the average between initial and mid-season Kc for the rapid growth period. Crop values for each NLCD land use code and season are reported in Table 6.

**TABLE 6**
**CROP FACTORS BY NLCD LANDUSE AND SEASON**

| NLCD | Land Use Description | Kc | | | | Source |
|---|---|---|---|---|---|---|
| | | Jan-Feb | Mar-Apr | May-Oct | Nov-Dec | |
| 11 | Open Water | 1.05 | 1.05 | 1.05 | 1.05 | FAO, 1998 |
| 21 | Developed, Open Space | 0.6 | 0.7 | 0.8 | 0.6 | FAO, 1998 |
| 22 | Developed, Low Intensity | 0.27 | 0.285 | 0.3 | 0.27 | UCCE & CDWR, 2000 |
| 23 | Developed, Medium Intensity | 0.18 | 0.19 | 0.2 | 0.18 | UCCE & CDWR, 2000 |
| 24 | Developed, High Intensity | 0.09 | 0.095 | 0.1 | 0.09 | UCCE & CDWR, 2000 |
| 31 | Barren Land | 0.12 | 0.195 | 0.27 | 0.12 | ITRC, 2003 |
| 41 | Deciduous Forest | 0.69 | 0.765 | 0.84 | 0.69 | ITRC, 2003 |
| 42 | Evergreen Forest | 1 | 1 | 1 | 1 | ASABE, 2017; FAO, 1998 |
| 43 | Mixed Forest | 0.72 | 0.81 | 0.9 | 0.72 | ASABE, 2017 |
| 52 | Shrub/Scrub | 0.45 | 0.475 | 0.5 | 0.45 | ASABE, 2017 |
| 71 | Herbaceous | 0.4 | 0.675 | 0.95 | 0.9 | ITRC; FAO, 1998 |
| 81 | Hay/Pasture | 0.4 | 0.675 | 0.95 | 0.85 | FAO, 1998 |
| 82 | Cultivated Crops | 0.54 | 0.59 | 0.64 | 0.54 | ITRC, 2003 |
| 90 | Woody Wetlands | 0.6 | 0.9 | 1.2 | 0.6 | FAO, 1998 |
| 95 | Emergent Herbaceous Wetlands | 1.05 | 1.075 | 1.1 | 1.1 | FAO, 1998 |

### Spatial Evapotranspiration Distribution

The distribution of evapotranspiration rates varies spatially. Evapotranspiration rates are measured at discrete points around the watershed. ESA applied spatial weighting methods to extend that observed data and develop coverage over the entire Salinas basin for the water balance model duration. Percent area coverage for each automated weather station was tabulated for each sub-basin based on spatial weighting using Theissen polygons delineated around each gage using the same method as for rainfall.

### 1.2.1.5 Runoff Rate Parameters

The parameter $k_b$ is a baseflow recession constant which governs the time release of water from the saturated groundwater layer in the water balance model. The inverse of this constant ($1/k_b$) represents the average residence time of water in the groundwater zone. The parameter $k_N$ represents the inverse of residence time in the stream network. This parameter serves as a simple surrogate for routing streamflow in the channels within a given basin. These two parameters will be adjusted for calibration. Routing between basin outlet points is handled via a separate routing model.

### 1.2.2 Routing Model

The sub-basin water balance calculates the outflow from each sub-basin but does not capture the routing of that flow through individual stream channels. A separate model component was developed in HEC-HMS to simulate the routing in channel reaches between sub-basin outlet points. Flow hydrographs for each sub-basin outlet node were routed using the Muskingum-Cunge routing method in HEC-HMS version 4.2. The method applies mass and energy continuity based on the channel properties of length, slope, channel cross section geometry (shape, width and side slope), and channel roughness.

Channel reaches were delineated using National Hydrography Dataset (USGS, 2017). Flow lines connecting basins were extracted and merged to form a stream routing network. Stream slopes were interpolated using a 30-meter digital elevation model (USGS, 2015) and channel cross-section geometry (width and average side slopes) were estimated using Google Earth version 7.3.0. Channel roughness was assigned based on Google Earth aerial imagery to estimate Manning's n (the coefficient describing channel bedform and vegetation roughness) for typical main channels as referenced in *Open-Channel Hydraulics* (Chow, 1959). A summary of the routing model parameters is included in Table 7.

**Table 7. Routing Model Parameters**

| Route Index | Stream Name | Length (ft) | Save (ft/ft) | Manning's n | Shape | Bottom Width (ft) | Side Slope (XH:1V) |
|---|---|---|---|---|---|---|---|
| R01 | Old Salinas River | 13994 | 0.003 | 0.025 | Trapezoidal | 15 | 1.5 |
| R02 | Tembladero Slough/Main Canal | 40951 | 0.004 | 0.035 | Trapezoidal | 45 | 1.0 |
| R03 | Tembladero Slough/Main Canal | 25386 | 0.006 | 0.045 | Trapezoidal | 10 | 2.5 |
| R04 | Gabilan Creek | 45719 | 0.014 | 0.05 | Trapezoidal | 10 | 3.0 |
| R05 | Salinas River | 65059 | 0.005 | 0.05 | Trapezoidal | 70 | 3.0 |
| R06 | Salinas River | 4777 | 0.008 | 0.06 | Trapezoidal | 65 | 1.0 |
| R07 | Salinas River | 35810 | 0.007 | 0.048 | Trapezoidal | 85 | 3.5 |
| R08 | Salinas River | 33178 | 0.014 | 0.05 | Trapezoidal | 110 | 5.5 |
| R09 | Chualar Creek | 17105 | 0.005 | 0.03 | Trapezoidal | 5 | 4.0 |
| R10 | Salinas River | 10195 | 0.008 | 0.05 | Trapezoidal | 60 | 5.5 |
| R11 | Salinas River | 14500 | 0.002 | 0.045 | Trapezoidal | 50 | 5.0 |
| R12 | Salinas River | 41944 | 0.004 | 0.045 | Trapezoidal | 50 | 4.0 |
| R13 | Salinas River | 16665 | 0.005 | 0.045 | Trapezoidal | 100 | 4.0 |
| R14 | Salinas River | 19299 | 0.005 | 0.045 | Trapezoidal | 115 | 3.0 |
| R15 | Arroyo Seco | 6023 | 0.003 | 0.04 | Trapezoidal | 230 | 3.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| R16 | Arroyo Seco | 55446 | 0.01 | 0.04 | Trapezoidal | 230 | 3.5 |
| R17 | Salinas River | 4389 | 0.001 | 0.045 | Trapezoidal | 115 | 4.5 |
| R18 | Salinas River | 47738 | 0.004 | 0.045 | Trapezoidal | 100 | 4.0 |
| R19 | Salinas River | 69440 | 0.003 | 0.045 | Trapezoidal | 80 | 3.5 |
| R20 | San Lorenzo Creek | 43946 | 0.015 | 0.04 | Trapezoidal | 40 | 6.0 |
| R21 | San Lorenzo Creek | 63834 | 0.029 | 0.048 | Trapezoidal | 15 | 3.0 |
| R22 | Salinas River | 132321 | 0.004 | 0.045 | Trapezoidal | 120 | 3.0 |
| R23 | Salinas River | 18817 | 0.005 | 0.048 | Trapezoidal | 140 | 3.0 |
| R24 | Salinas River | 36183 | 0.007 | 0.048 | Trapezoidal | 120 | 6.5 |
| R25 | San Antonio River | 46169 | 0.013 | 0.05 | Trapezoidal | 30 | 6.0 |
| R27 | Salinas River | 23149 | 0.008 | 0.05 | Trapezoidal | 120 | 4.5 |
| R28 | Nacimiento River | 54662 | 0.008 | 0.05 | Trapezoidal | 80 | 4.0 |
| R29 | Nacimiento River | 11090 | 0.046 | 0.05 | Trapezoidal | 50 | 4.0 |
| R31 | Salinas River | 18868 | 0.011 | 0.045 | Trapezoidal | 195 | 5.0 |
| R32 | Salinas River | 24825 | 0.009 | 0.045 | Trapezoidal | 215 | 6.5 |
| R33 | Estrella River | 150506 | 0.013 | 0.05 | Trapezoidal | 110 | 10.0 |
| R34 | San Juan Creek | 96523 | 0.007 | 0.04 | Trapezoidal | 215 | 6.0 |
| R35 | Salinas River | 27137 | 0.007 | 0.045 | Trapezoidal | 245 | 5.5 |
| R36 | Salinas River | 19393 | 0.01 | 0.045 | Trapezoidal | 165 | 5.0 |
| R37 | Salinas River | 63562 | 0.01 | 0.045 | Trapezoidal | 165 | 5.0 |
| R38 | Salinas River | 110202 | 0.025 | 0.06 | Trapezoidal | 130 | 5.0 |

# 2 FLOOD MODELING

The three primary components of the flood modeling include a unit sub-basin analysis, a HEC-RAS hydraulic model, and a quantitative conceptual lagoon model. The methods, assumptions, inputs and outputs for each of these components is described below.

## 2.1 Unit sub-basin analysis

Unit hydrographs were created using HEC-HMS version 4.2 software for range of parameters describing physical processes of rainfall and surface water runoff in the Gabilan watershed. Scenarios were chosen to be able to analyze identified projects and potential future projects.

### 2.1.1 Meteorological Inputs

The unit hydrographs are based on a partial-duration flood frequency storm at the centroid of the Gabilan watershed (Latitude: 36.7493°N Longitude: 121.6212°W) with a 5-minute intensity duration and 1-day storm duration. Intensity position was set to 50%. The partial-duration values in inches for the 2-year, 10-year, and 100-year annual recurrence intervals are included in Table 8.

**TABLE 8**
**PARTIAL-DEPTH DURATION (IN) FOR GABILAN WATERSHED**

| Duration | Depth (inches) | | |
|---|---|---|---|
| | **2-year** | **10-year** | **100-year** |
| 5-min | 0.139 | 0.202 | 0.333 |
| 15-min | 0.241 | 0.350 | 0.576 |
| 60-min | 0.459 | 0.668 | 1.100 |
| 2-hr | 0.687 | 0.991 | 1.590 |
| 3-hr | 0.863 | 1.240 | 1.980 |
| 6-hr | 1.190 | 1.730 | 2.740 |
| 12-hr | 1.580 | 2.320 | 3.690 |
| 24-hr | 2.110 | 3.140 | 5.000 |

### 2.1.2 Basin lag time

Lag times for sub-basins within the Gabilan watershed were calculated using the Snyder unit hydrograph method. Lag time represents the fraction of rainfall that is not realized as loss is referred to as “excess rainfall” and is converted to streamflow. The transformation method (also referred to as “convolution of excess rainfall to runoff at a location) converts a unit of excess rainfall to a flow rate. The Snyder unit hydrograph method is a common unit hydrograph method used in hydrologic modeling and is relied by several agencies in California (Alameda County, 2003). The Snyder unit hydrograph method is parameterized by two inputs: lag time and peaking coefficient.

The peak coefficient was set to 0.75 for all basins. The lag time is defined as the length of time between the midpoint of rainfall mass and peak flow of the resulting hydrograph. The lag time can be calculated from the following equation:

$$tL=1.56L*LcSo0.38$$

where: $t_L$, is lag time (hours)

$L$, is the length of the longest water course (miles)

$L_c$, is the length from the outlet to the watershed centroid (miles)

$S_o$, is the average watershed slope (feet/mile)

Longest watercourses and centroids were created for each basin using ArcHydro tools. Some watercourses were altered or created manually by assessing the terrain surface due to the nature of hand-delineated basins covering the urban drainage network. Average slopes were determined for each basin by creating a slope raster from the terrain using ArcGIS.

### 2.1.3 Peak Flow Reduction Curves

A range of parameters will be analyzed in order to provide a range of landuse and basin conditions. To represent the range in landuse, scenarios will be developed for a representative curve number of 60, 75, and 90. To represent a range of hydrograph lag times, scenarios will be developed for lag times of 1, 6, and 24 hours. Curves will be developed for the 2-, 10-, and 100-year events. For a given basin, landuse and lag time conditions can be estimated and the corresponding peak flow reduction can be interpolated from the chart for a given storage volume. The results have been generated for a 10,000-acre basin. Peak flow reduction scales linearly by basin area thus peak flow reduction should be multiplied by the ratio of the basin area to 10,000 acres.

Peak flow reduction curves will be generated to relate capture volume (basin detention size), flood frequency (annual recurrence intervals), and peak flow reduction (change in peak flow as a result of detention). An preliminary example set of curves for the 100-year event is shown in Figure 4. The full set of curves will be provided in excel format to enable distribution and use.

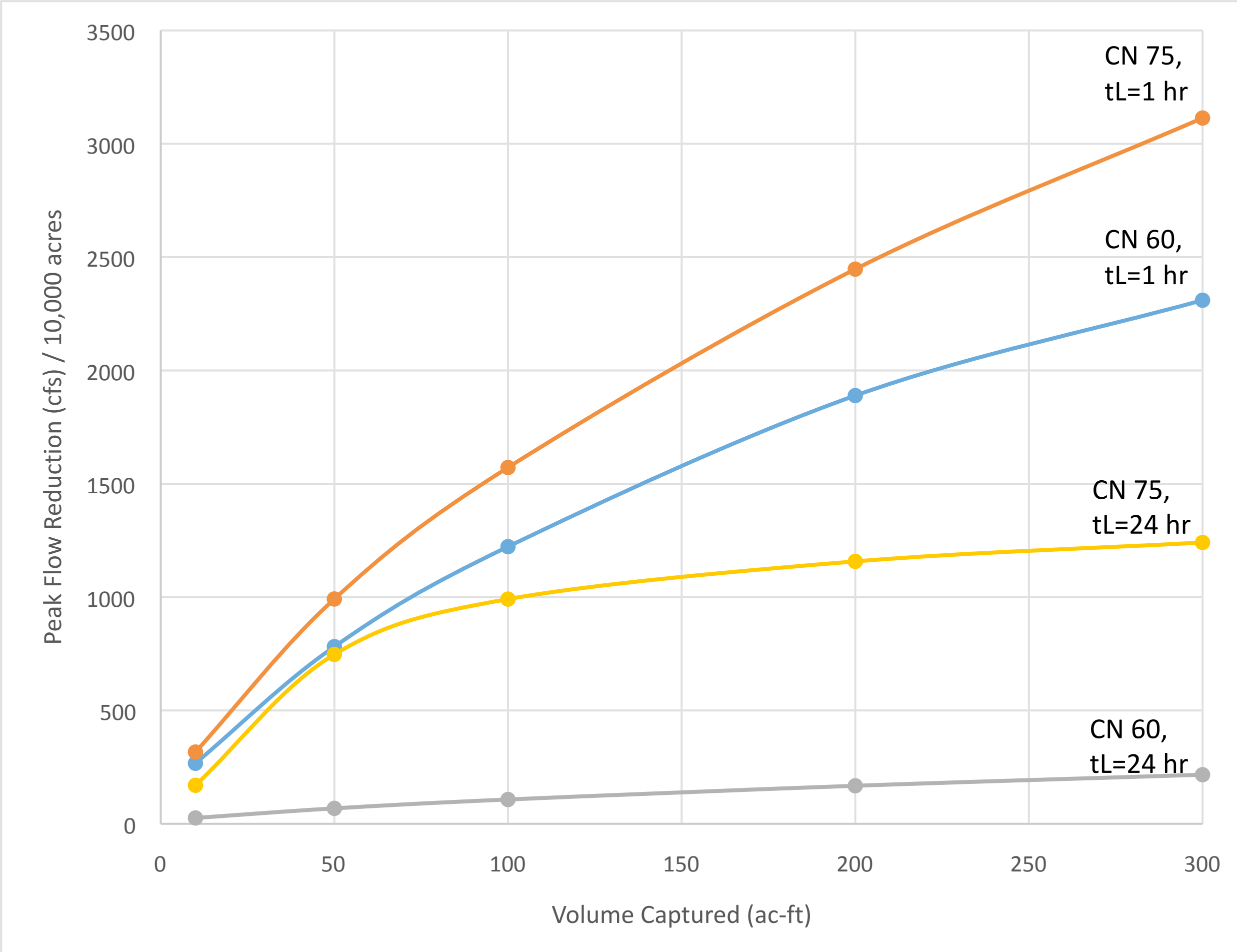



*Figure 4. Sample peak flow reduction curves for unit basin analysis*

## 2.2 HEC-RAS Hydraulic model

Several hydraulic models are available and can be applied to flood analysis for the SWRP. ESA will merge and edit the models as needed for the analysis. The primary models ESA will use are

1. **Prior ESA Model –** Unsteady HEC-RAS model developed by ESA for the sea level rise update to the Monterey Bay Local Coastal Program (ESA, 2016)

2. **FEMA Gabilan Creek Model –** Steady state HEC-2 model provided to ESA by FEMA.

3. **MCWRA Salinas River Model** – A 2D unsteady HEC-RAS model developed for the lower portion of the Salinas River.

These models will be linked depending on the flood scenario analyzed. Each of the models is described in the following sections.

### 2.2.1 Prior ESA model

The basis for this unsteady HEC-RAS hydraulic model was a model provided by the Monterey County Water Resources Agency (MCWRA) to ESA in 2014. The model is an updated version of the HEC-RAS model originally developed by Schaaf & Wheeler (1999) for flood analysis. The model has been periodically updated for flood mapping studies. However, the original channel data dates back to the original study. The existing conditions 100-year hydrology was also developed by Schaaf & Wheeler in 1999 using a HEC-1 hydrologic model for the Gabilan Creek watershed. This formed the basis for the existing conditions 100-year unsteady hydrograph boundary conditions used in the model. Updates to the model geometry required including positioning the model in real geospatial coordinates and updating overbank areas with LiDAR topography are described in the following section.

#### 2.2.1.1 Model Geometry Development

**Hydraulic Roughness –** The parameter representing the resistance to flow within a channel or floodplain due to vegetation, bedform, and bed material is known as the manning's roughness or 'n' value. The manning's n values were adopted from the existing model. The values are 0.025 for channel roughness and 0.065 for floodplain roughness.

**Georeferencing** – The original model provided by Monterey County required georeferencing to spatially orient the model input and output. The original mode was shifted to correctly orient the confluence of the Tembladero Slough and drainage canal from Merritt Lake (just upstream of Castroville). Tembladero Slough was digitized from Moss Landing up the Reclamation Ditch to the Hwy 101 crossing in Salinas using the HEC-GeoRAS toolbar in ArcGIS and then imported to the HEC-RAS model. Cross section spacing was then adjusted in HEC-RAS to align known bridge crossings with their spatial location. The model layout is shown in Figure 5.

*Figure 5. Reclamation Ditch hydraulic model layout*

**Update with LiDAR** – Because the overbank representation of the existing model was limited, it was necessary to update the overbank topography from new sources. This was accomplished by first extending the channel cross sections to include the full floodplain and then updating the cross section station-elevation data with topography from the 2009-2011 CA Coastal Conservancy Coastal Lidar Project: Hydro-flattened Bare Earth DEM that was downloaded from http://coast.noaa.gov/dataviewer/. This was only done for cross sections downstream of the railroad crossing west of Hwy 183, as the focus was primarily on flood behavior downstream. We determined that the elevations of the existing model were vertically referenced to an old vertical datum NGVD29. We thus converted the elevations to NAVD88 using the conversion factors listed in the FIS (+2.7 ft for Tembladero Slough, +2.77 ft for Reclamation Ditch). The model was also expanded into the Moro Cojo Slough and historic slough area between the Tembladero and Moro Cojo to represent alternate flood pathways that became apparent during the December 2014 flood.

**Incorporation of MLML data** – Hydraulic structure data was provided by Ross Clark, Charlie Endris, that was used to develop preliminary geometry for hydraulic structures located in the expanded portions of the model including:

1. Cabrillo Hwy crossing over Moro Cojo Slough
2. Moss Landing Rd tide gates at Moro Cojo

Other minor structure crossings in the model area were not accounted for due to lack of data. One improvement to the model would be to survey these crossings and add them into the model geometry to improve the representation of flow routing in the system.

#### 2.2.1.2 Model Hydrology Inputs

Future flows determined in the future $Q_{100}$ climate analysis were simulated by scaling the existing unsteady 100-year hydrographs that came with the HEC-RAS model provided by Monterey County. Base flow was maintained for the input hydrographs by only scaling the peak of each input hydrograph (flows > ~75% of the existing peak discharge). Within each hydrograph peak, a polynomial scaling function was used to produce smooth transitions between the existing rising and falling limbs and the future hydrograph peaks.

Inflow hydrographs were developed for Moro Cojo Slough and the unnamed canals/historic slough watershed. Area was determined for each watershed using USGS streamstats online tools. Then hydrographs were scaled from nearby subwatersheds analyzed by Schaaf and Wheeler that possessed similar attributes (drainage area, relief, and impervious percentage) using watershed area as the scaling factor. These were scaled for future conditions using the method described above.

The downstream boundary was driven by an unsteady tide as described in the extreme coastal tide level section for the Reclamation Ditch.

#### 2.2.1.3 Model Validation

The results of the updated hydraulic model run with the existing conditions 100-year hydrology and MHHW tailwater were compared to flooding extent and hydraulic flowpaths from a flood event that occurred in December 2014. The MLML provided a map of estimated extents and observed flow directions during this event. One key observation for this event was that flow backing up at the Moss Landing tide gates overtopped adjacent farm fields contributing additional water into Moro Cojo Slough which routes water to the harbor through the culverts under Moss Landing Road. The model reproduced this observed pattern for the 100-year flow as shown in Figure 6.

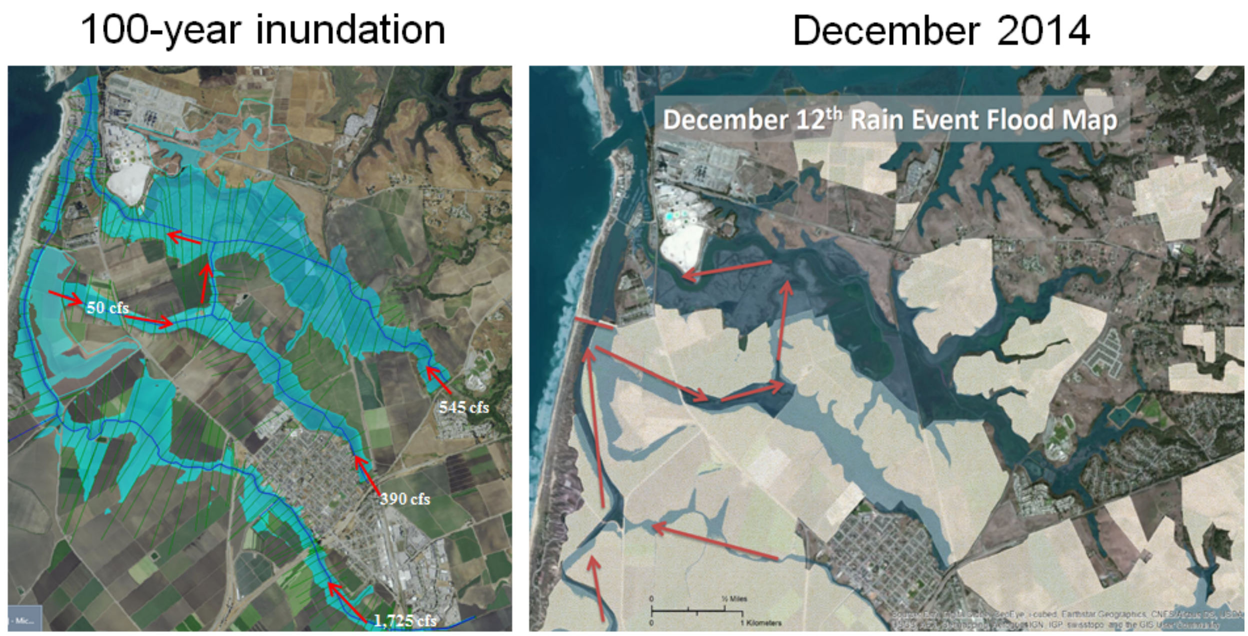



*Figure 6. Comparison of Modeled 100-year flowpaths and observed flowpaths during December 2014 flood*

#### 2.2.1.4 Model Limitations

Flood mapping was truncated for Tembladero Slough at the Cabrillo Hwy, Moro Cojo up to the Railroad, and the historic slough in between. From the Tembladero up to the City of Salinas, the cross sections are limited to in channel portions, and floodplains were not mapped for any of the model coverage upstream. Given the uncertainty regarding the location of cross-sections an improvement to the model would be collecting new channel cross-sections and channel bathymetry in the model domain. Additionally, replacing the overbank areas with 2D flow elements would improve the routing of flow once it escapes the channel and goes out of bank. Lastly, the main Salinas River channel is not represented in the model. There are known interactions with the Salinas River and the Reclamation Ditch system including breakout flows from upstream entering the Reclamation Ditch and a water control structure connection between the mouth of the Salinas River and the old Salinas River alignment. The model could be improved significantly by combining the model with a model of the Salinas River and replacing the overbank areas with 2D flow elements.

### 2.2.2 FEMA HEC-RAS Model for Gabilan Creek

ESA requested the existing HEC-RAS model for Gabilan Creek and was provided with files on October 23, 2017. The files provided are PDF scans of the input files for a HEC-2 model. This model is the precursor to HEC-RAS also developed by the USACE. The model extent for Gabilan Creek is shown in Figure 7. The HEC-2 files were manually digitized to extract cross-section geometry and roughness information.

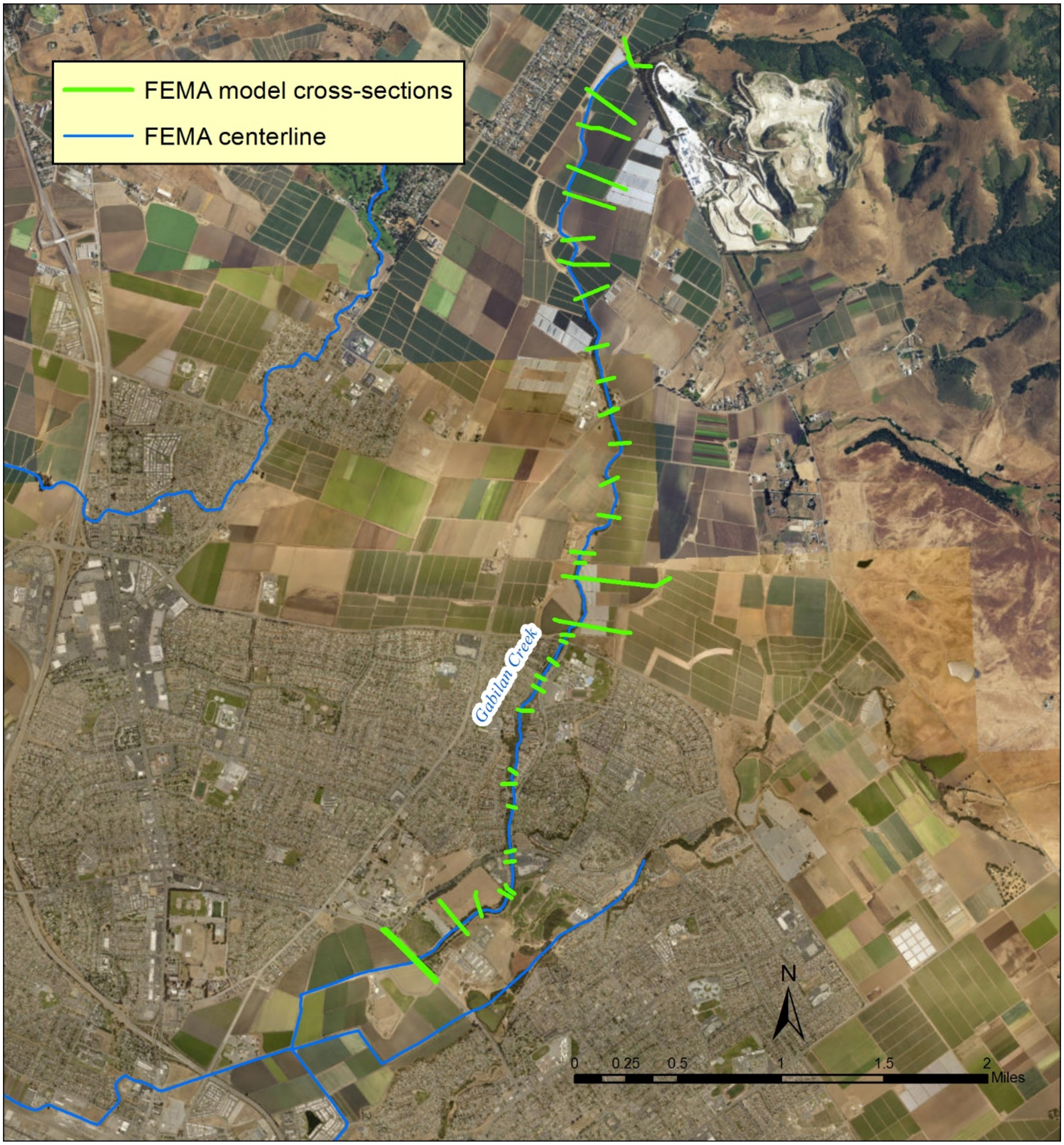



*Figure 7. Gabilan Creek FEMA model extent*

### 2.2.3 MCWRA Salinas River model

A two-dimensional HEC-RAS model was developed as part of the Salinas River Stream Maintenance Program (MCWRA, 2014). The model extends over 90 miles of the main river channel for the Salinas River. ESA will obtain this model and investigate the potential to combine flood scenarios on the Salinas River with the flood model for channels in the Gabilan Creek watershed.

## 2.3 Conceptual lagoon model

ESA will develop a lagoon quantified conceptual model (QCM) for the Salinas River lagoon, which will build on and supplement the hydrologic models developed for the upstream reaches above the lagoon. This approach is centered on a water budget for the lagoon, which is coupled with a sediment budget for the lagoon mouth (Figure 5). The model is based on two core concepts:

- All water flows entering and leaving the system should balance.
- The net erosion/sedimentation of the inlet channel results from a balance of erosive (fluvial and tidal) and constructive (wave) processes.

The model uses time series of nearshore waves and tides, watershed runoff, and evapotranspiration data as boundary conditions, and relies on topographic/bathymetric survey information to understand the stage vs storage relationship for the lagoon (Table 1). Using these boundary conditions, the model dynamically simulates time series of lagoon water levels, along with beach and lagoon mouth state (open or closed). With each time step, the net inflows or outflows to the system are estimated, along with the net sedimentation or erosion in the inlet bed. Mouth closure occurs in the model when sediment fills the inlet bed higher than lagoon water levels. After closure, the inlet bed is treated as the beach crest, and allowed to continue to grow vertically based on wave runup conditions. Breaching occurs in the model when the lagoon fills from accumulation of either watershed runoff or wave overwash, allowing water levels to eventually overtop the beach berm crest and erode a new mouth. For more information on how the model resolves different processes, refer to Behrens et al. (2015).

This approach is an adapted and refined version of earlier approaches for tidal conditions from Crissy Field Lagoon (Battalio et al. 2006) and for fluvial conditions from the Carmel River (Rich and Keller 2013), and has been applied and refined at sites throughout Northern, Central, and Southern California in the last five years. The model is trained by adjusting empirical coefficients that control the amount of sediment trapped in the mouth, beach berm growth, and frictional losses in the channel during outflow. Flow terms such as wave overwash and berm seepage are also adjusted to allow variations in lagoon water levels to match observations. Model accuracy is tested by comparing modeled lagoon water level time series against gaged observations, and by comparing the timing and length of mouth closure events to those of historical records.

# 3 MODEL OUTPUTS

## 3.1 Water Balance Model

The water balance model is run on a daily timestep over a fixed period of time. Currently the model is set to run over the period from October 1, 1995 to October 1, 2017. This period was selected to capture a sufficiently long period of time to conduct statistical analysis on the model output and was driven in part by gage availability. A summary of the direct outputs from the model and statistical variables that can be produced from the output is provided in Table 9.

**TABLE 9**
**WATER BALANCE MODEL OUTPUTS**

| Direct model output | Summary statistic variables | Example |
|---|---|---|
| Daily flow (cfs, ac-ft) | Average daily flow | Average daily flow (cfs) during dry season |
| | Flow exceedance percentiles | 50th percentile flow |
| Monthly flow (cfs, ac-ft) | Average monthly flow | Average monthly flow (ac-ft) during dry season |
| | Average flow for specific month | Average June flow in dry, wet, or average year |
| Annual flow(cfs, ac-ft) | Average annual flow | Average flow volume (ac-ft) in a given year |
| | Average annual flow by type of year | Average annual flow in dry, wet, or average year |

These variables can be analyzed for pre and post-project implementation to assess the impact of the project on downstream flows. Due to the simplified nature of the model, the most accurate data will be for monthly and annual flows.

## 3.2 Flood modeling

The flood modeling will provide information relating project impact to peak flow reduction and inundation extent reduction. The unit sub-basin analysis will provide graphical and tabular relationships between storage facility size and potential peak flow reduction as shown in Figure 4. This generalized information is meant to serve as a resource which can be rapidly queried to assess potential project benefit.

The hydraulic model output will consist of peak stage and flood extent associated with given flood events. An example of the output is the change in peak stage for pre and post-project conditions at a given point in the channel network for the 2-, 10-, and 100-year events.

The lagoon model output will consist of water levels and lagoon breach dynamics. The model will be used to evaluate options for reducing flood potential through lagoon management. An example of the output would be maximum water level during a 10-year event for pre and post-project conditions.

# 4 REFERENCES FOR WATER BALANCE AND FLOOD MODELING


Alameda County, 2016. Hydrology and Hydraulics Manual. Accessed at <http://www.acfloodcontrol.org/projects-and-programs/hydrology-hydraulics/hydrology-hydraulics-manual/>. Downloaded 1 October 2016.

ASABE, 2017. Determining Landscape Plant Water Demands. ASAE ANSI/ASABE S623.1. January. Accessed at https://elibrary.asabe.org/abstract.asp?aid=47623&t=2&redir=&redirType

CIMIS, 2017. California Irrigation Management Information System, California Department of Water Resources, CIMIS Station Reports. Accessed at <http://www.cimis.water.ca.gov/WSNReportCriteria.aspx>. Downloaded 20 November 2017.

Chow, V.T. 1959. *Open-channel hydraulics*, New York, McGraw-Hill, 680 p.

ESA, 2016. Monterey Bay Sea Level Rise. Climate Change Impacts to Combined Fluvial and Coastal Hazards. Prepared for Moss Landing Marine Labs with funding from the California Ocean Protection Council.

FAO, 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations Rome. Accessed at <http://www.fao.org/docrep/X0490E/x0490e00.htm#Contents>. Downloaded 11 July 2017.

ITRC, 2003. California Crop and Soil Evapotranspiration for Water Balances and Irrigation Scheduling/Design. Accessed at <http://itrc.org/reports/pdf/californiacrop.pdf> Downloaded 11 July 2017.

Limbrunner, J.F., R.M. Vogel, and S.C. Chapra, 2005a. A Parsimonious Watershed Model. In: Computer Models of Watershed Hydrology, 2nd ed., edited by V.P. Singh, CRC Press, Boca Raton, FL.

MCWRA, 2014. Salinas River Stream Maintenance Program. Revised Final EIR.

Snyder, R.L, 2014. Irrigation Scheduling Water Balance Method. UC Davis, Department of Land, Air and Water Resources Atmospheric Science. Accessed at <http://biomet.ucdavis.edu/irrigation_scheduling/bis/ISWBM.pdf> Downloaded 11 July 2017.

Snyder, R.L. and Schulbach, K.F., 1992. Central Coast Crop Coefficients for Field and Vegetable Crops. Drought Tips, No. 92-45. Accessed at <http://wwwcimis.water.ca.gov/Resources.aspx> Downloaded 11 July 2017.

UCCE & CDWR, 2000. A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California. The Landscape Coefficient Method and Water Use Classifications of Landscape Species III.

US Army Corps of Engineers, Hydrologic Engineering Center, Hydrologic Modeling System HEC-HMS, 2000. Technical Reference Manual, Davis, California

US Department of Agriculture, Soil Conservation Service, 1983. Computer Programs for Project Formulation - Hydrology, Technical Release 20, Washington D.C.

US Department of Agriculture, Soil Conservation Service, 1986. Urban Hydrology for Small Watersheds, Technical Release 55, Washington D.C.

USDA/NRCS - National Geospatial Center of Excellence, 2017. 10 Digit Watershed Boundary Dataset in HUC8. Accessed at <https://datagateway.nrcs.usda.gov/>. Downloaded 26 June 2017.

USGS, 2015. National Elevation Dataset. Accessed at <https://viewer.nationalmap.gov/> Downloaded 26 June 2017.

USGS, 2017. National Hydrography Dataset. Accessed at <https://viewer.nationalmap.gov/> Downloaded 26 June 2017.

# Section 2. GIS Analyses to Identify Storm Water Management Opportunities

The goal of this Storm Water Modeling and Geographic Information System (GIS) analysis is to highlight areas where certain types of storm water management efforts (treatment, capture, retention) could be designed to help achieve multiple Storm water environmental goals (Water Quality, Water Supply, Flood Management, Environmental, Community).

Opportunity areas can be identified where a set of storm water challenges and opportunities overlay. Our analysis uses both load and flow modeling and GIS interpretation to identify drainage areas where certain environmental goals have not been met and prioritize the design and construction of various management efforts based on secondary goals of the storm water program. A description of the GIS base map and layers used in this analysis is in Appendix 1.

## 2.1 Water Quality Treatment Systems

While treatment wetlands should be designed within areas that do not meet water quality objectives, including added design features that provide benefits for other goals should be evaluated.  Treatment wetlands provide Multi-parameter water quality benefits, flood attenuation, habitat enhancement, and community open space.  Base layers identifying opportunity areas for each of the secondary storm water goals can aid site selection and the integration of secondary design elements.

Wetland/Riparian treatment systems may be prioritized where blue line waters, overlay with:

- Historical wetland areas
- Large floodplain areas
- Drainages attributed to cause downstream flooding
- Drainages within or adjacent to residential communities
- Infiltration into groundwater is feasible
- Low productivity agriculture is present because of annual flooding or high ground water challenges.

For instance, including trails within treatment wetlands adjacent to DAC communities that have limited open space should be sought where partnerships with local parks departments are possible.  Within drainages that need flood attenuation or storm water capture, treatment systems can be designed to help reduce peak downstream flows.  Selecting wetland/riparian treatment systems over engineered treatment systems within drainage areas prioritized for habitat enhancement may be a priority.

#### Selection of engineered treatment systems (bioreactors, etc.)

It may be appropriate to select engineered treatment systems within areas with significant food safety concerns, no public access and where habitat enhancement is not a priority.  Agriculture drainage networks overlay with:

- limited floodplain areas
- Drainages attributed to cause downstream flooding

- Low productivity agriculture is present because of annual flooding or high ground water challenges.
- Areas noted as priority load reduction sub-watersheds
- Areas where farms are working collaboratively to address water quality challenges

**Urban LID and Water Quality treatment systems:**

Urban drainage areas or special development types (parking lots) overlay with:

- Drainages attributed to cause downstream flooding
- Drainages within or adjacent to residential communities
- Infiltration into groundwater is feasible
- Small areas available for detention/retention
- New development adjacent to blue lines where integrated BMPs are warranted.

For instance, including roof top and parking lot capture, reuse or infiltration for new development adjacent to urban creeks can help reduce flooding and urban water quality pollution loading.

## 2.2 Water Supply

Water supply enhancement projects can collect Winter Storm Water and summer agriculture runoff and either store that water for future use or collect, transport and reuse immediately. Projects that capture winter storm water for later reuse may be prioritized in areas with downstream flooding concerns or where summer flows do not support other environmental goals.

**Storm water Capture and reuse**

Blue line waters, overlay with:

- Large floodplain areas
- Drainages attributed to cause downstream flooding
- Areas noted as having limited water quality concerns
- Areas near collection and reuse infrastructure
- Infiltration into groundwater is feasible

## 2.3 Flood Attenuation and Capture projects

Flood attenuation projects can be designed to provide habitat and water quality benefits, capture and infiltration/reuse opportunities or strictly as short term flood management. Methods to prioritize the type of project for various drainage areas may include:

**Floodplain restoration projects**

Blue line waters, overlay with:

- Historical wetland areas
- Large floodplain areas
- Drainages attributed to cause downstream flooding
- Drainages within or adjacent to residential communities
- Infiltration into groundwater is feasible

- Low productivity agriculture because of annual flooding or high ground water challenges.
- Downstream summer flows are insufficient and a project could enhance summer surface flows to support environmental objectives.

**Flood water capture, retention and or reuse**

Blue line waters, overlay with:
- limited floodplain
- Drainages attributed to cause downstream flooding
- Agriculture with Highly productive summer crops that can accommodate winter flooding.
- Areas noted as having limited water quality concerns
- Areas near infiltration sites or collection and reuse infrastructure

## 2.4 Environmental Enhancement Projects

Environmental Enhancement Projects can be designed to achieve water quality, supply, flood and community goals. River and Wetland restoration projects can be selected for areas where they support other storm water objectives. Environmental projects can be designed primarily for habitat enhancement or can use habitat enhancement to achieve other goals.

**Wetland/Riparian Restoration**

Blue line waters, overlay with:
- Large floodplain areas
- Historical Wetland areas
- Drainages attributed to cause downstream flooding
- Area is adjacent to communities with limited parks and open space
- Wetland areas adjacent to communities with low environmental condition
- Low productivity agriculture because of annual flooding or high ground water challenges.
- Range lands with low riparian width or condition

**Treatment Wetlands**

Blue line waters, overlay with:
- Large floodplain areas
- Historical Wetland areas
- Drainages attributed to cause downstream flooding
- Areas noted as priority load reduction sub-watersheds
- Areas where farms are working collaboratively to address water quality challenges
- Low productivity agriculture because of annual flooding or high ground water challenges.
- Agriculture that can accommodate winter flooding.
- Areas near infiltration sites or collection and reuse infrastructure

## 2.5 Community Enhancement Projects

Community Enhancement Projects can be designed to benefit water quality, supply, flood and environmental goals. Storm water projects can be selected for areas where they support community goals.

**Flood Plain Open space**

Blue line waters, overlay with:

- Drainages within or adjacent to residential communities
- Large floodplain areas
- Historical Wetland areas
- Drainages attributed to cause downstream flooding
- Flood prone areas
- Areas lacking community open space
- Areas identified as needing walking and bike paths
- Areas that link community destinations
- Areas where linear land acquisition adjacent to waterways is feasible.
- Areas where ball fields and other recreation is a priority

# Section 3. Quantitative Analysis of Nitrate Loading

### Water Quality Model: Soil and Water Assessment Tool (SWAT)

## 1. Model set-up

Objectives of the nutrient transport model:

a. Collect and evaluate the best data available for the Central Coast watersheds, including elevation, soils, land-use, fertilizer application, tile drain discharge, stream flow, crop management, etc. Using available data, model the fate and transport of nutrients through the Moro Cojo, Gabilan/Tembladero, and Elkhorn watersheds. Identify data gaps and collect necessary samples in the field to calibrate and verify model.

b. Evaluate proposed projects and management strategies of nutrient runoff using treatment wetlands, riparian buffers, and resevoirs and identify the most effective size and locations for treatment based on model outputs.

c. Inform agencies of modeled project results in the planning area that improve water quality suitable for human and environmental uses.

***Soil and Water Assessment Tool***

The Soil and Water Assessment Tool (SWAT) is a continuous daily time step model that is physically based (Arnold et al., 1998). It requires specific information about weather, soils, elevation, land use, management practices, and vegetation to predict the impact of land management practices on water, sediment, and chemical yields. The model delineates the watershed into sub-basins based on elevation that can be further designated into hydrologic response units (HRUs). The HRUs are unique units based on land use, soil, and slope. Equations used in the model for runoff, evapotranspiration, nutrient uptake, etc. are explained in Neitsch et al., (2005). The Soil and Water Assessment Tool (SWAT) was developed by the USDA Agricultural Research Service and Texas A&M scientists to model the quality and quantity of surface and groundwater and predict the environmental impact of land use, land management practices, and climate change. The objective of the model is to provide the ability to predict the effect of management decisions on water, sediment, nutrient and pesticide yields. Model components include weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, reservoir storage, crop growth, irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. The current SWAT modeling tool is an ongoing effort of 30 years of modeling efforts.

Land use, elevation, and soils data are the primary input variables to the SWAT model for watershed delineation. The SWAT model delineated the stream flow path similar to the National Hydrography Data (NHDPlus) Version2 and it was not required to “burn in” a stream data set, however, ditches and tile drains are poorly represented. Other important model inputs include: daily precipitation and weather (temperature, solar radiation, relative humidity, wind, etc), point discharge data (annual, monthly, or daily), reservoir outflow, potential ET, and stream water quality.

Once the watershed is delineated into sub-basins and/or HRUs (hydrologic response units) additional data can be modified on a sub-basin level including: main channel parameters, groundwater parameters, monthly water use (agriculture and urban), management parameters (crop cover, urban, irrigation, tile drain, operations (till, fertilizer application, etc.), septic input, sub-basin operations (filter strips, terracing, grassed waterways, etc), nutrient cycling (concentration of N in rainfall, denitrification, N uptake, NO3 percolation, N fixation, organic N concentration, half-life of N in groundwater, etc.), erosion, sub-basin drainage. These input parameters have default values in the model that can be modified if there are known values within a watershed or sub-basin. See Table 10 for data sources.

**Table 10. Table of data sources for SWAT model.**

| | | | |
|---|---|---|---|
| | time to drain soil | 24 hrs | model suggestio |
| | time to reach from drain | 48 hrs | model suggestio |
| **Fertilizer Application** | | | |
| | Type of fertilizer | elemental N and P | data on fertilizer |
| | Amout of fertilizer | 180 lbs N, 50 lbs P /Ac (201 kg N, 56 kg P/ha) | Scenario1:USDA; |
| | | variable depending on crop type | Scenario2:MC Cc |
| | time of application | based on heat units (soon after planting) | |
| **Irrigation** | | | |
| | Source | deep aquifer/mrwpca recycled water | |
| | timing | by heat units (as opposed to date) | |
| | irrigation amount (depth) | 13mm | MC County |
| | irrigation salt | variable | MC County |
| | irrigation efficiency | 0.85 | Dept. of Food an |
| | irrigation surface runoff ratio | 0.75 (0-1.0) | default/unknowi |
| **Crop rotations** | **number** | **3** | **max for model** |
| | | | |
| **Weather** | | | |
| | precipitation | 2001-2016 | http://www.cimi<br>http://cdmo.bar |
| | wind speed | 2001-2016 | "" |
| | humidity | 2001-2016 | "" |
| | temperature | 2001-2016 | "" |
| | solar radiation | 2001-2016 | http://www.cimi |
| **GIS files** | | | |
| | Land Use | | 2011 NLCD |
| | Elevation | 3m | USGS DEM data |
| | Soils | | SSURGO |
| **Observed Data for Calibration** | | | |
| | daily Flow | 2001-2016 | https://waterdat<br>Reclamation Ditc |
| | monthly [$NO_3$] | 2001-2016 | http://cdmo.bar |
| | crop yields | | http://www.co.r<br>h/agricultural-co<br>economic-contri |

Based on nitrogen application data from Monterey County the most common crops in these watersheds and surrounding areas for 2015 include artichokes, Broccoli, celery, lettuce; however, this only includes data from Tiers 2 and 3 to provide an idea of the amount of nitrogen and irrigation applied for each crop type. This real data can be used to estimate farming schedule and practices based on local crop type and practices (N application and irrigation). Crop rotations and schedules vary depending on organic vs. conventional and are constantly changing. Therefore, crop rotations were created based on the most common crop types in the area and applied it to the model. For simplicity, total irrigation and total N application was divided equally by the crop length in weeks so weekly application occurred in the model. This is something that can be modified since application may be applied more frequently at the beginning stages of crop growth.

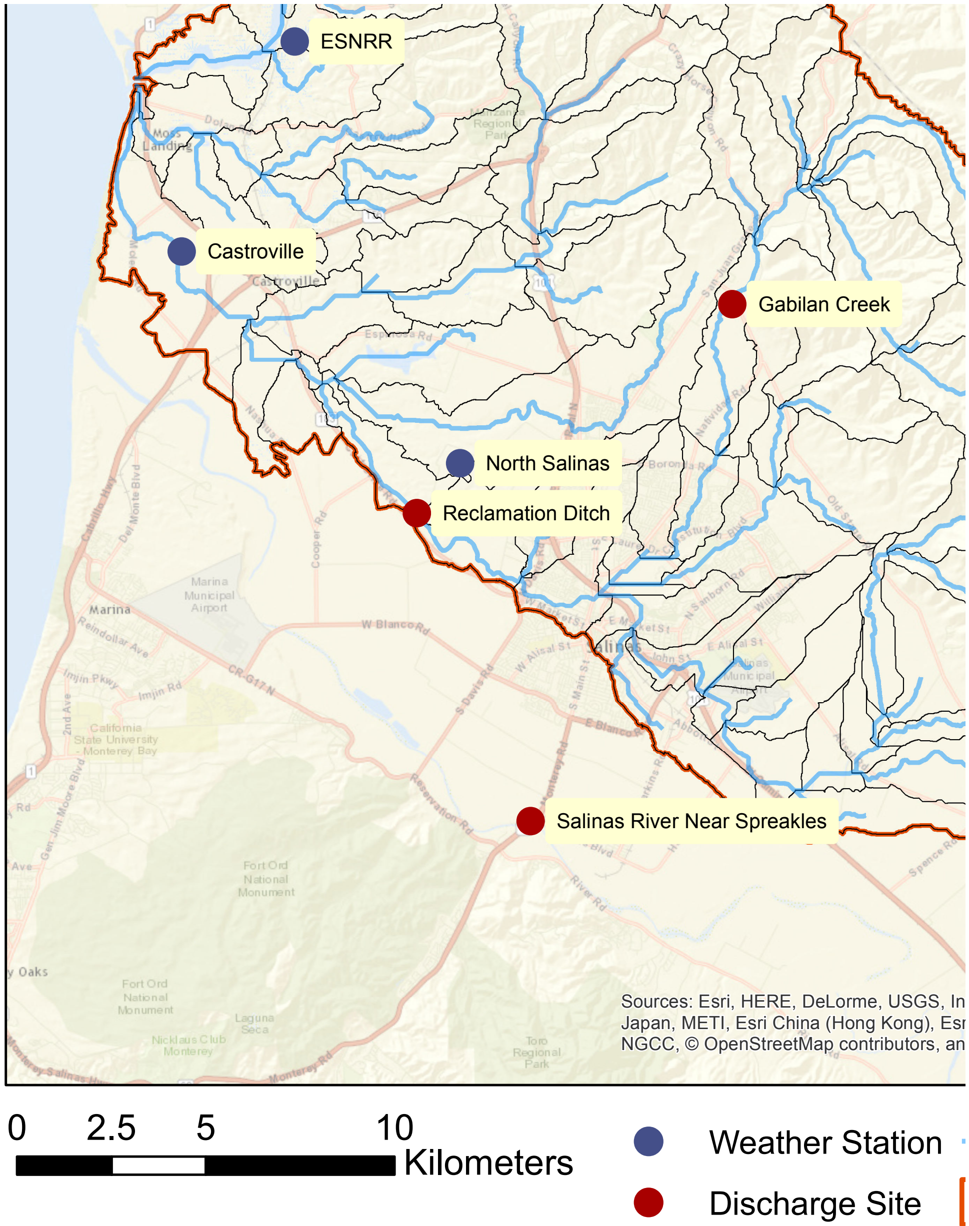
Four farming schedules/rotations were created and estimated weekly irrigation and N application based on crop type. The rotations include 1) Broccoli-lettuce, 2) Artichokes-lettuce 3) Strawberries – lettuce and 4) Celery – lettuce- spinach. These schedules were applied to specific sub-basins based on the general crop type listed on the ranch map. The ranch map data from Monterey County reports crop type for each ranch so I can identify the most common crop type in each sub-basin. For irrigation source, I used an outside source (purple pipe recycled water) for majority of the sub-basins. Tile drains are still applied to 100% of the agriculture land until data can be updated. We are testing the impact of tile drains on flow in the watersheds.

The SCS curve (runoff curve) was adjusted based on soil type (Hydrologic group B (moderate infiltration rates) and in good condition). This SCS curve applied may also have a large impact on the loading results. The next steps will be to investigate different scenarios (different SCS curve, irrigation water source, tile drains, etc). Another option is to set irrigation to trigger based on heat stress of the plant. These scenarios will be investigated and the model will be calibrated before wetland, riparian buffers, and reservoir project scenarios are modeled.

## 2. Application to SWRP water quality analysis

First, the model must delineate the watershed (flowlines and sub-basins) based on elevation (Figure 8). The watershed flowlines and boundary match well to the NHD Plus version 2 delineation (National Hydrography Dataset). After watershed delineation, the HRU analysis must be completed using land use data (National Land Cover Data 2011), soils, and slope with a threshold applied of 15%. Precipitation and temperature data for 35 years was uploaded from the CIMIS stations.

**Figure 8. Watershed flowlines and sub-basins based on elevation.**




***Current Model Status***

Currently the model is in the calibration stage which has been a great deal of work due to the highly managed watersheds. We continue to collect and update the model with the best available data. Irrigation practices and application in the model are being investigated in more detail. The SWAT code has been modified to express the excess irrigation water from outside sources is incorporated into flow. If this is successful irrigation parameters with crop yield values can be calibrated. The Monterey county farm report and areas of the ARGG HRU were used to estimate crop yields for different crops for the years 2000-2016.

***Moving Forward with Model Scenarios***

***Model Scenario 1. Treatment wetlands****:* In summary future model iterations will focus on quantifying nutrient loads based on the type of landuse converted to wetlands, the size of wetlands (total hectares) in each sub-basin, and the general location based on idealized project locations from GIS analysis. We expect the lower watershed to be the most critical location for wetlands since nutrients are elevated downstream and low elevation is present. It is beneficial to use current knowledge and consult with the GIS expert to eliminate sites that are not an option for wetlands due to slope, landuse, etc. Data has been collected and the best available modeling approach using SWAT has been investigated for this project. Multiple iterations for implementing treatment wetlands have been conducted in SWAT for this project and results of nitrate reduction will be presented in kg/d or kg/yr nitrate.

The implementation of constructed wetlands will be introduced in the model as another scenario once the model is calibrated. The size and neighborhood approach to nutrient mitigation using wetlands will be investigated. The efficiency of a wetland is influenced by the ratio of wetland size to the contributing drainage area, which impacts the retention time in the wetland. Since retention time plays a crucial role in wetland performance at reducing nutrients, the success is variable because water input to the wetland from agriculture fields fluctuates. Therefore, retention times in wetlands are variable and unpredictable, yet critical components. One study in Maryland showed that wetlands were successful at removing significant nitrate during a dry year, but during a wet year with 83% greater inflow the wetland retention time decreased to less than 1 day and was inefficient at removing nutrients (Whigham et al. 1999). Although, even ratios of 1:100 can be effective (>50%) at removing nitrogen during certain times of year (Woltemade, 2000).

In addition to wetland size, case studies have also demonstrated that location of constructed or restored wetlands is an important factor in nutrient management. For example, a wetland placed at the ends of lateral drainage capturing only 4% of watershed runoff, resulted in only 4% of watershed nitrate removal whereas a wetland capturing 70% of runoff resulted in 45% of nitrate removal (Crumpton 1995, 1997). Another critical point to consider in the management of nutrients using constructed wetlands, may be the ratio of groundwater vs surface runoff discharging the watershed. Interesting studies have suggested that watersheds discharging a greater percentage of groundwater tends to discharge more nitrates (Jordan et al. 1997). Unfortunately, watershed scale restoration efforts to test idealistic locations are limited, and therefore, modeling must be used to gain insight to the fate and transport of nonpoint source pollutants and establishing wetland restoration sites (Woltemade 2000).

***Model Scenario 2. Riparian Buffers/filter strips:*** Model iterations will include results of nutrient loading in kg/d or kg/yr of nitrate following suggested locations of riparian buffers/filter strips. The best available modeling approach for riparian fencing using SWAT has been investigated for this project and multiple preliminary iterations including size and locations have been completed.

***Model Scenario 3: Stormwater Resevoirs.*** Model iterations would involve placement of stormwater catchment resevoirs in designated project locations. Resevoirs may potentially provide a nutrient “sink” in the watershed in the model that remove nutrients from the system. Information and data on nutrient removal in stormwater resevoirs will be investigated and the impact of resevoirs on nitrate concentrations will be reported in kg/d or kg/yr.

Furthermore, a combination of these storm water management projects will be modeled to identify the necessary actions to attain nitrogen reduction for these designated Central Coast watersheds. It is likely that not one action will be sufficient at reducing nutrients to appropriate levels. Data is currently being collected to simulate these scenarios in the model. The results of the simulations will provide nitrate loading data for each sub-basin on a monthly and annual basis before and after the implementation of storm water projects. After the model is appropriately calibrated, the results can be utilized for management of storm water management practices to maximize nutrient reduction in watersheds and meet regulatory standards.

# Section 4. Analysis of Environmental Benefits:

# Spatial Statistical Network Modelling of Habitat Condition

The techniques described here are used to spatially analyze wetland and riparian habitat condition in order to identify opportunities to use storm water to protect, enhance or restore habitat that provides environmental benefits as well as aesthetic and recreational benefits for under-served communities.

From 2006 to 2017, approximately 49 riparian sites were evaluated within the Gabilan watershed using the California Rapid Assessment Method (CRAM). The sites were given an "index score" based on a number of factors visible at the sampling site, including landscape context, hydrology, physical structure, and biotic structure. In an attempt to extrapolate the results to other non-sampled reaches of the watershed, we employed a suite of GIS tools and models developed by a collaboration of researchers at NOAA and the Commonwealth Scientific and Industrial Organisation (CSIRO) in Australia. The ArcGIS Spatial Tools for the Analysis of River Systems (STARS) was used to generate a landscape network of stream reaches, observed sample sites, and predictive sites. Hydrologic distances were calculated among all stream segments and an additive function was used to calculate cumulative land-use covariates (e.g. total amount of agricultural land or urban land upstream of a sample site or stream reach). The STARS toolset was then used to export the topological, spatial, and attribute information in a format that was accessed and analyzed in R statistical software.

Using R, we used a spatial statistical network model (SSN), developed by Ver Hoef et al. (2016), to assess autocorrelation of sites in upstream ("tail-up"), downstream ("tail-down"), and overland ("Euclidean") directions. The SSN model operates on the principle that samples close together tend to be similar and therefore the condition of un-sampled sites nearby may be estimated. The locations of un-sampled sites, referred to as "predicted" sites, were chosen using the midpoint and endpoints of each stream segment. The SSN package was used to create generalized linear models for predicted CRAM scores using five different functions for tail-up and tail-down components, and four functions for Euclidean components. Refer to Ver Hoef and Peterson (2010) for details on the different functions. The performance of each of the functions was then analyzed using the InfoCritCompare function in the SSN package and the function with the lowest Aikake Information Criterion (AIC) value was selected as the best autocorrelation model to use. The final output included 425 predicted CRAM sites with a mean index score of 49, compare with a mean of 51 for the observed CRAM sites (Figure 9). Additionally, the results include an assessment of standard error (SE) for each of the predicted sites. Not surprisingly lower SE values are clustered near the observed CRAM sites while higher values are in the upper reaches of the watershed where no CRAM sites exist.

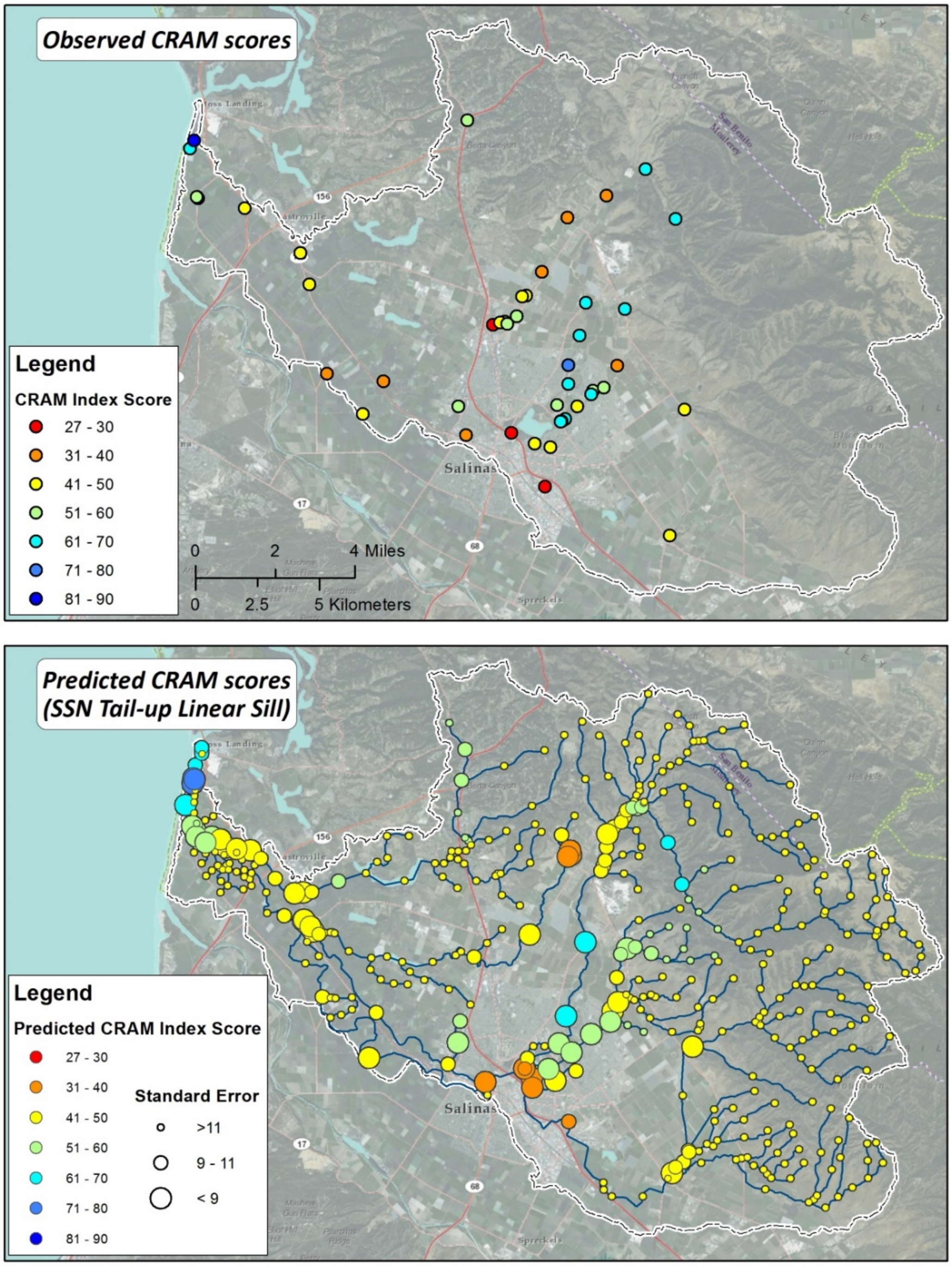
We are currently using the SSN package to predict conditions at CRAM sites based on one or more land-use covariates, such as agriculture, grazing, urban, and forested land. If a strong correlation exists between one or more of these stressors and the CRAM index score, then these may be better at predicting the condition of un-sampled sites than a strictly spatial statistical network.

**Literature Cited**

Ver Hoef, J.M., and E.E. Peterson. 2010. A moving average approach for spatial statistical models (with discussion). Journal of the American Statistical Association 105: 6-18.

Ver Hoef, J.M., E.E. Peterson, and D. Theobald. 2016. Spatial statistical models that use flow and stream distance. Environmental and Ecological Statistics 13: 449-464.

**Figure 9.** Observed and predicted CRAM scores in the Gabilan watershed.



# Section 5. Storm Water Tool to Estimate Load Reductions

The Storm Water Tool to Estimate Load Reductions (swTELR) is an urban pollutant loading model with a supporting data management and visualization system accessible at www.swtelr.com. TELR and the supporting rapid assessment methods (2N RAM) tools were designed by 2nd Nature LLC to track and account for the cause and effect linkage between urban land management and the resulting receiving water quality benefits. The outputs are estimates of pollutant loads discharged from the urban landscape to the receiving waters, which are directly influenced by the quantified outcomes of urban storm water improvement actions.

The Central Coast Regional Water Quality Control Board has encouraged municipalities to use the swTELR to address MS4 permit reporting requirements. The Monterey County Resource Management Agency has contributed staff time and funding to this SWRP development project to allow the use of swTELR in the quantitative analysis of storm water management opportunities and the evaluation implementation projects.

The figures below illustrate the user interface graphics related to urban catchment delineation and load estimation. Detailed descriptions of the tools and user guidance are available in the following documents:

2NDNATURE LLC 2016. Stormwater Tool to Estimate Load Reduction (TELR) Draft Final Technical Document v1. August 2016.

2NDNATURE LLC 2016. Best Management Practices Rapid Assessment Methodology (BMP RAM) Technical Document v 3.1. November 2016.

**Figure 10.** TELR user interface showing delineated urban catchments.

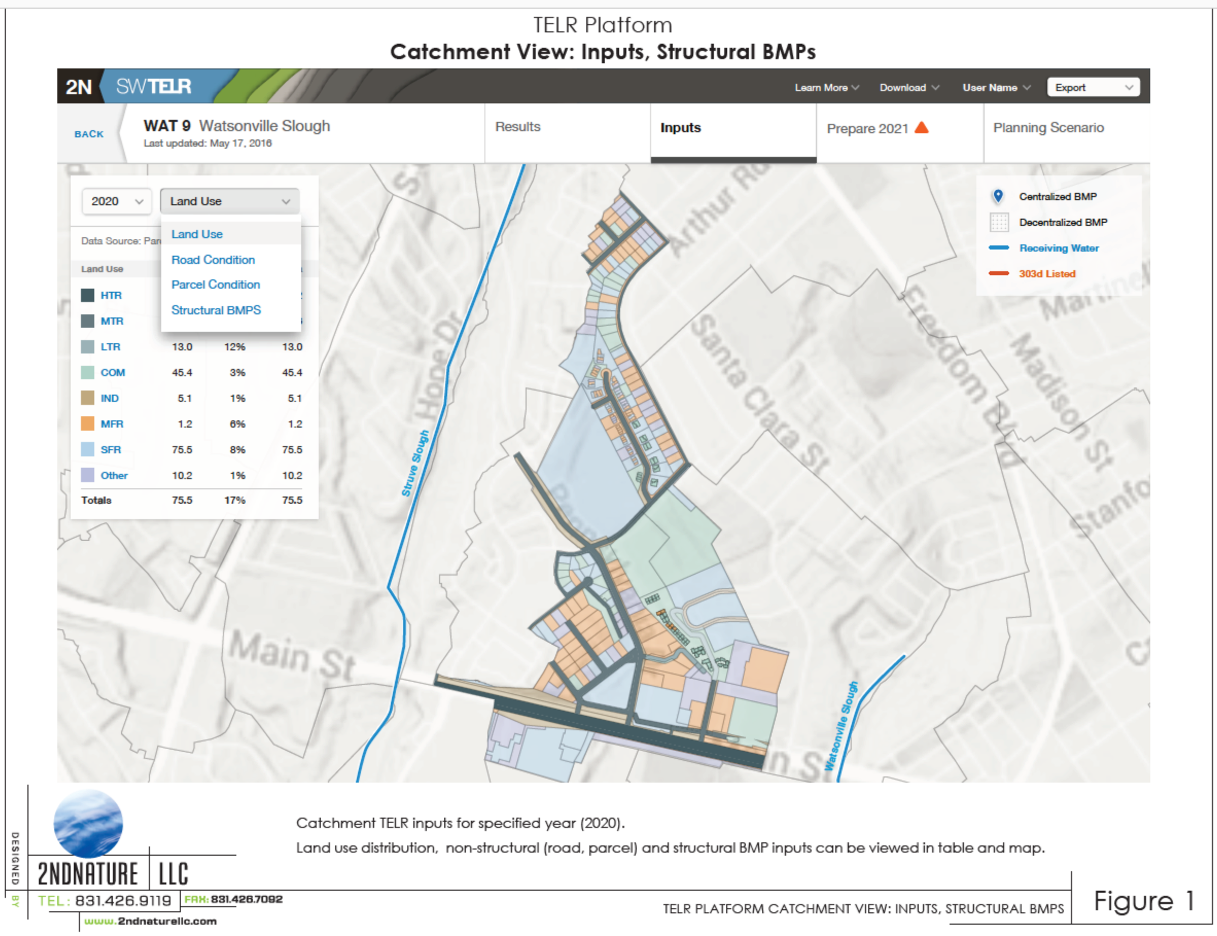


**Figure 11.** TELR user interface showing urban runoff estimates for delineated catchments.