Salinas River Watershed Area
Salt Modeling

Prepared for

California Central Coast Regional Water Quality Control Board
US Environmental Protection Agency, Region IX

Prepared by

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1 Introduction

Tetra Tech supported EPA Region 9 and the Central Coast Regional Water Quality Control Board (CCRWQCB) for an assessment of salt impairments and development of a salt mass balance in the Lower Salinas River and Reclamation Canal watersheds. This effort can inform development of salt-related TMDLs by the CCRWQCB and a salt and nutrient management plan for the Salinas Valley aquifers. Three reaches have reported 2010 303(d) listings for salt-related impairments in these watersheds including impairments due to chloride, sodium, electrical conductivity, and total dissolved solids – Lower Salinas River, Santa Rita Creek, and Alisal Creek. This report provides data analysis and a literature review (Sections 1 through 5), development of a water and salt mass balance tool (Sections 6 through 8), and salt source assessment (Section 9). The results of the analysis provide a strong foundation for assessing salt sources and understanding salt mass balance in the study area, but can be improved with refined representation of cropland locations, rotations, and irrigation practices. Recommendations are provided in Section 10.

1.1 Watershed Description

1.1.1 Project Area

The Salinas River watershed area in California covers 4,410 square miles in Monterey and San Luis Obispo Counties, with smaller portions in San Benito County. The entire Salinas River region contains the Estrella River Watershed (HUC8 18060005), the Salinas River Watershed (HUC8 18060004), and the Reclamation Canal Watershed (HUC8 18060011). For the purposes of this study, the northernmost part of the Reclamation Canal Watershed called the Elkhorn Slough will be excluded from analysis because it is not impaired for salts and drains directly into Monterey Bay. The entire region of the 3 HUC8s listed above with Elkhorn Slough omitted will be referred to as the “Salinas River Watershed area” in this document (Figure 1). The Lower Salinas River begins downstream of the town of Gonzales, corresponding to the upstream extent of salt-related impairments. In this document, the portion of the Salinas River Watershed area beginning with the Lower Salinas River is called the “Lower Salinas River Watershed area,” and it also includes the Reclamation Canal Watershed. It covers approximately 296 square miles.

Elevations in the watershed range from 5,847 feet within the Santa Lucia Mountains (Junipero Serra Peak, located within Los Padres National Forest) down to sea level, as the Salinas River passes through the Salinas River National Wildlife Refuge into Monterey Bay (Figure 2). The average elevation throughout the watershed is 443 feet above sea level. Other than the low slope areas of the Salinas River valley bottom there are many areas with steeper slopes. The average slope across the watershed is ~25 percent, with steeper slopes found along the Santa Lucia Mountain range within Los Padres National Forest.

The largest urban area in the Salinas River Watershed area is the City of Salinas, which is located in the lower portion of the watershed. The population of the City of Salinas in 2010 was 150,441, while the six other smaller cities in the area (Atascadero, Soledad, Greenfield, King City, Paso Robles, Prunedale) have populations under 30,000 each (US Census Bureau, 2010).

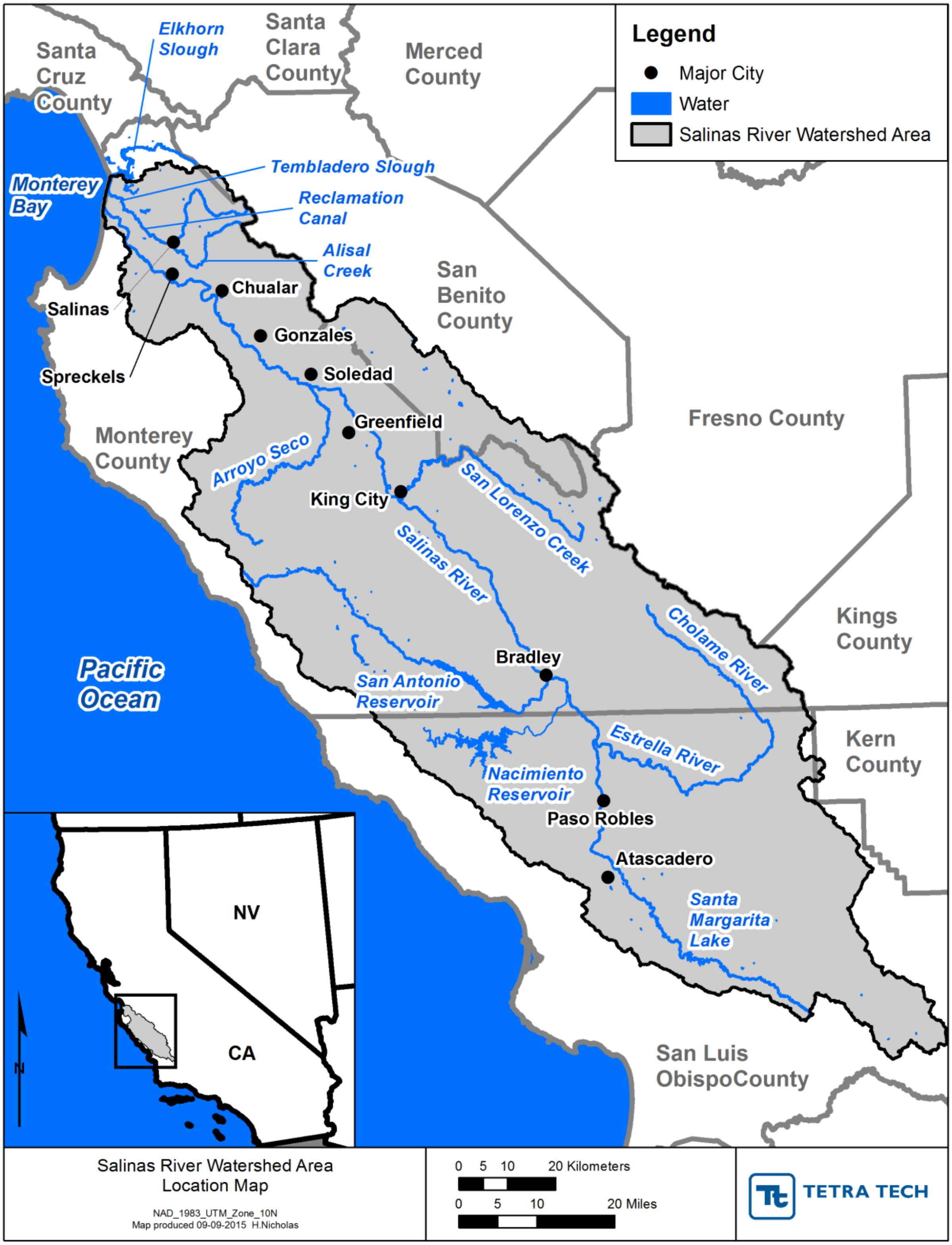


Figure 1. Salinas River Watershed area location map

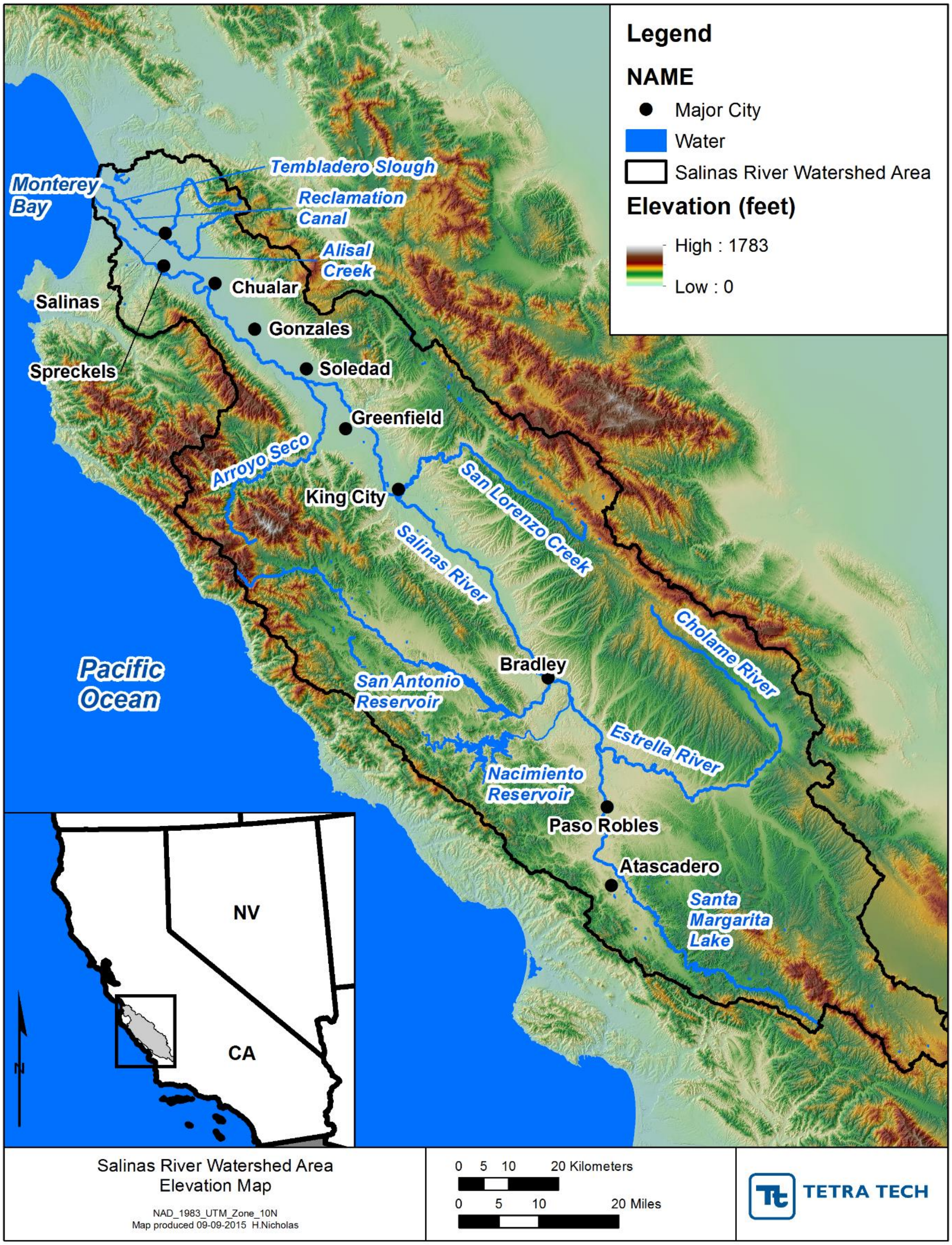


Figure 2. Salinas River Watershed area elevation map

1.1.2 Hydrology

1.1.2.1 Surface Water

Originating in the south near Santa Margarita in San Luis Obispo County, the Salinas River flows to the northwest along US Highway 101 approximately 120 miles to the Pacific Ocean at Monterey Bay, with the mouth of the Salinas River occurring north of the City of Marina (Figure 1). Mean annual discharge of the Salinas River ranges from 309,000 AFY at Spreckels, CA to 343,000 AFY at Bradley, CA (Kennedy/Jenks Consultants, 2004). The majority of the flow occurs during the months of November through March.

The Estrella River joins the Salinas River approximately 3.5 miles south of the border with Monterey County. Major reservoirs are located along the Nacimiento River and the San Antonio River, and these rivers flow into the Salinas River downstream of the county border. The Nacimiento River watershed encompasses approximately 330 square miles, and the San Antonio River watershed covers approximately 328 square miles. During the spring and summer months, the Nacimiento and San Antonio reservoirs are operated by Monterey County Water Resources Agency (MCWRA) to maintain required fish bypass flows at the Salinas River Diversion Facility, while maximizing recharge to the groundwater basin via the Salinas River bed (MCWRA, 2006).

Approximately 15 miles downstream of the county border, the river starts to flow through agricultural lands with smaller pockets of developed areas. San Lorenzo Creek flows into the Salinas River from the east at King City, and Arroyo Seco joins the river about 20 miles downstream of King City from the south-southwest. The flows from Arroyo Seco are known to be a major source of aquifer recharge before joining the Salinas River and have been estimated to be between 40,000 and 60,000 AFY (MCWRA, 2001). Many smaller creeks flow into the agricultural valley from the surrounding hills and mountains. Some of these creeks are ditched in the lower portions of the watershed. Several creeks flow into the Lower Salinas River, including Limekiln Creek from the west, Chualar Creek and Quail Creek from the east, and El Toro Creek from the west, before the river becomes the Salinas Lagoon and discharges into Monterey Bay.

Another important waterbody in the Basin is the Reclamation Ditch or Canal, which drains approximately 157 square miles, including the cities Salinas, Castroville, and parts of the Prunedale area. In 1911, the watershed was reclaimed from swampland to improve transportation and reduce pestilence in the City of Salinas. The Reclamation Canal ran from south of the City of Salinas, through the City to the northwest where it connected with other watersheds. Since that time, the Reclamation Canal has been partially infilled within the City limits and the water system has been transformed into a drainage system for agricultural and urban irrigation water, agricultural tile drains and agricultural and urban stormwater and floodwaters. The Reclamation Canal watershed includes the watersheds of Tembladero Slough, Merritt Lake, Santa Rita Creek, Espinosa Lake, Gabilan Creek, Natividad Creek, Alisal Slough and Alisal Creek. The drainage areas also includes numerous dry lakes, which provide detention and flood control during the wet winter months. Even with the existing detention capacities of the dry lakes in the area, the area is characterized by relatively frequent flooding (CCoWs, 2006).

1.1.2.2 Groundwater

The vast majority of water supplies in the Salinas Basin are sourced from local groundwater. Other sources of water used for agricultural production include surface water diverted from Arroyo Seco, municipal waste water processed for the Monterey County Water Recycling Project, and the Salinas Valley Water Project surface water diversions from Salinas River. Current conservation efforts have led to municipal wastewater recycling, used primarily to supplement local groundwater for agricultural irrigation in the northern portion of the basin, but in general, communities, industry, and agriculture in the basin are dependent on quality groundwater.

The Salinas Valley Groundwater Basin underlies the Salinas Valley formed by the Salinas River and its tributaries. The Basin is the major source of fresh water and thus is a critical regional resource. Historical and current rates of groundwater withdrawals have been identified as the major contributor to declining water quality, due to falling groundwater levels causing saltwater intrusion from the Bay. In addition to the identified problem of saltwater intrusion, salts can accumulate and concentrate in the soil as a result of irrigation practices and ultimately migrate to aquifers through percolation. Salts can be transported to surface waters through both surface and subsurface flow pathways.

The Salinas Valley region is underlain by four hydrologically-linked subareas: the Pressure Area, East Side Area, Forebay and Arroyo Seco Area, and the Upper Valley Area (Figure 3). Although the underlying geologies of each area are similar, each is defined by unique attributes that determines its function and contribution as a water bearing unit in the Valley. The four areas are also defined by general land use patterns that determine the extent and use of groundwater withdrawals that support the communities they serve. The elongated, intermontane valley extends about 80 miles northwest, ranging in width from 3 miles at the Salinas and Santa Lucia Ranges to approximately 14 miles at its termination point opening onto Monterey Bay (Figure 3). The valley encompasses approximately 561 square miles and is bound on the west by the Sierra De Salinas and Santa Lucia Range, on the east by the Gabilan and Diablo Ranges, on the northeast by the San Andreas Fault, and by a series of aligned and interconnected faults on the southwest. The altitude of the valley floor increases from zero to about 400 feet above sea level as it extends north to south from Monterey Bay to Bradley (MCWRA, 2006).

Before the construction of the Nacimiento Dam in 1957 and the San Antonio Dam ten years later, aquifer recharge in the Valley was completely unmanaged and dependent on precipitation, streamflow, and applied irrigation. With the construction of the reservoirs, the MCWRA has actively been managing the dam outflows to two tributaries (Nacimiento and San Antonio Rivers) of the Salinas River, providing a combination of flood control and groundwater recharge to the Valley aquifers (MCWRA, 2006). Operation of the Nacimiento and San Antonio Reservoirs has the primary function of regulating the release of water to maintain Salinas River streamflow during dry conditions. This provides a degree of regularity to the timing and magnitude of aquifer recharge by maximizing groundwater recharge from the streambed and lessening the reliance on recharge from variable precipitation totals.

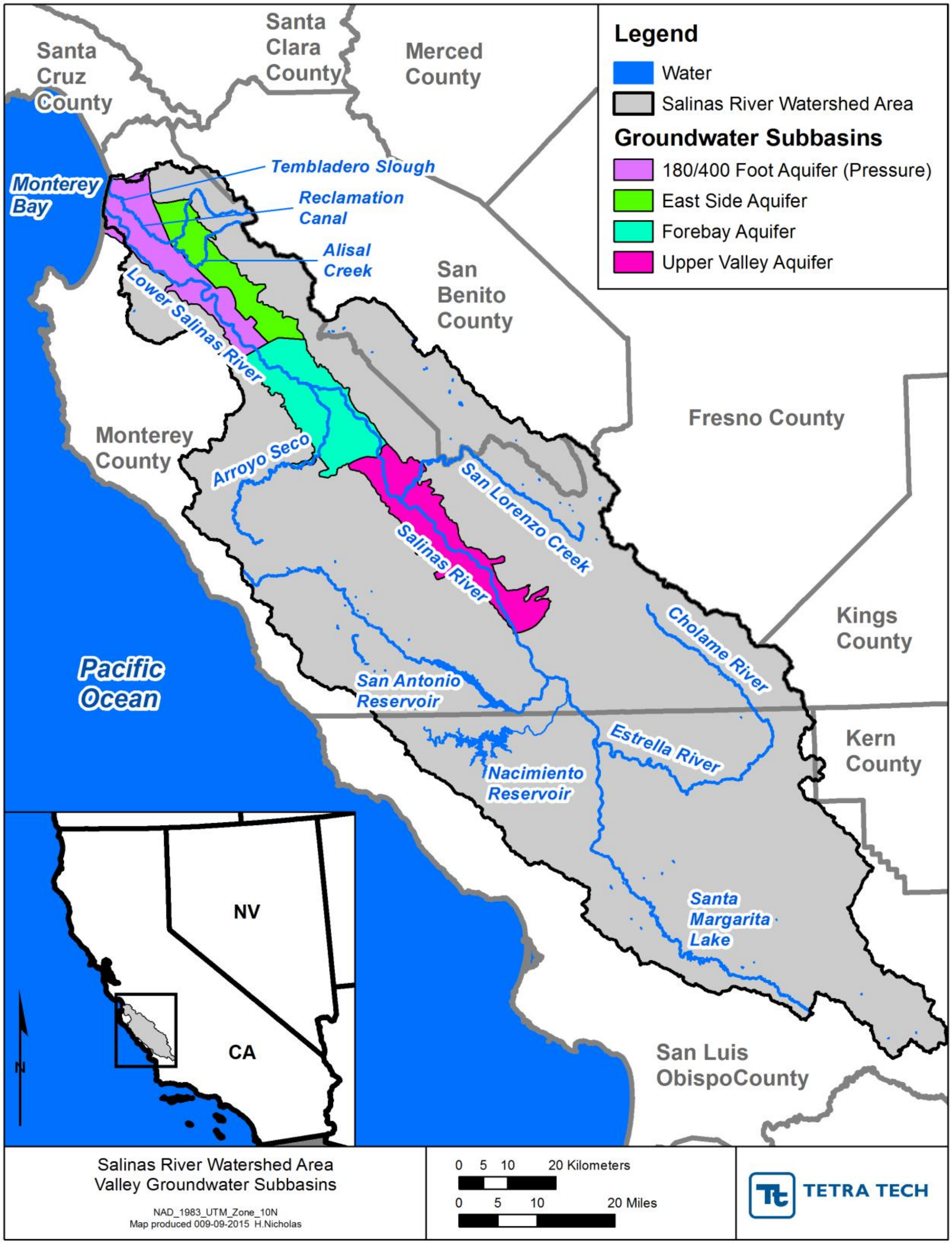


Figure 3. Groundwater areas in the Salinas Valley region

1.1.3 Climate

The climate summary presented here provides general background information about conditions in the Salinas River Watershed area. General trends and gradients are discussed but not explored in detail; the intention is to describe climate for context, and introduce the data sources used subsequently in the development of the water and salt balance tool. While this summary focuses on average conditions, the water and salt balance tool, discussed later in the report, accounts for spatial gradients and specific monthly values for given years reflecting spatial and temporal variability.

The Salinas River Watershed area has a semi-arid Mediterranean climate with warm, dry summers and cool, moist winters. Long term (1981–2010) average temperatures at Monterey and Paso Robles are 56 and 59 degrees Fahrenheit, respectively (National Climatic Data Center, 2015). Precipitation generally increases with altitude and decreases from north to south (Kulongoski and Belitz, 2007), with average annual precipitation of 21 inches at Monterey and 15 inches at Paso Robles (National Climatic Data Center, 2015). A presentation of climate data extracted from several data sources follows.

Long-term monitoring data has been interpolated over the United States by Oregon State University under the PRISM Climate Group in a way that accounts for elevation impacts. The data sets used for precipitation and temperature shown below (called "30-year Normals") were produced by interpolating monitoring data observed over the years 1981 to 2010 into a gridded data set (http://prism.oregonstate.edu; data set published July 10, 2012).

Estimated potential evapotranspiration (PET) data produced by Trabucco and Zomer (2009) were obtained from the Consortium for Spatial Information (CGIAR-CSI, http://www.cgiar-csi.org/), which is an initiative of the CGIAR. CGIAR links the international science, research and development communities, with CGIAR scientists, national and international partners, and others working to apply and advance geospatial science for sustainable development, conservation, and poverty alleviation in developing countries.

The National Climatic Data Center (NCDC) manages the largest climate data archive in the world and provides services and data to the public, business, industry, government, and researchers (http://www.ncdc.noaa.gov/). One of NCDC's data products is the Global Summary of the Day (GSOD), which provides daily meteorological data from over 9,000 stations worldwide. Daily precipitation and temperature data were obtained for several stations located in the Salinas River Watershed and are summarized below.

The California Irrigation Management Information System (CIMIS) manages a network of nearly 150 meteorological monitoring stations in California (http://www.cimis.water.ca.gov/). The effort is focused on providing data beneficial to irrigators to assist with efficient water use. CIMIS estimates potential evapotranspiration (PET) for a reference crop (well-watered grass) using a modified version of the Penman-Monteith equation, and provides hourly and daily values. PET data were obtained from CIMIS for several stations located in the Salinas River Watershed and are summarized below.

1.1.3.1 Precipitation and PET

As is found in most of the central coast of California there is a predominantly wet winter and dry summer (Table 1, Figure 4). The fact that the annual PET total exceeds the annual precipitation total is important to note, as it is an indicator of the potential need for imported water (from outside the watershed, or subsurface stores) to produce agricultural commodities such as row crops. Annual average precipitation ranges from a low of 5.6 inches in the inland to a high of 59.5 in the higher elevation areas in the western part of the watershed (Figure 5). Monthly average precipitation at the NCDC GSOD stations (Table 2) shows the same pattern of high winter totals and low summer totals as indicated by Table 1, but with variations in magnitude. PET ranges from about 37 inches to 63 inches annually; the pattern for ET is somewhat different than for precipitation, with lower PET next to the coast and higher values moving inland (Figure 6). Table 3 provides average monthly PET at the CIMIS stations; PET is considerably higher in the summer than the winter as seen in Table 1.

Table 1. Monthly average precipitation and evapotranspiration statistics for 30-year normals in the Salinas River Watershed area

Time Period	Average Monthly Precipitation[1] (inches)	Average Monthly Potential Evapotranspiration[2] (inches)
January	3.83	1.83
February	3.69	2.36
March	3.12	4.04
April	1.16	1.96
May	0.41	5.62
June	0.07	7.32
July	0.02	8.04
August	0.04	7.19
September	0.25	6.24
October	0.95	4.72
November	1.68	3.52
December	3.02	2.37
Annual Average (inches/year)	18.45	55.20

[1] Obtained from PRISM

[2] Obtained from CGIAR

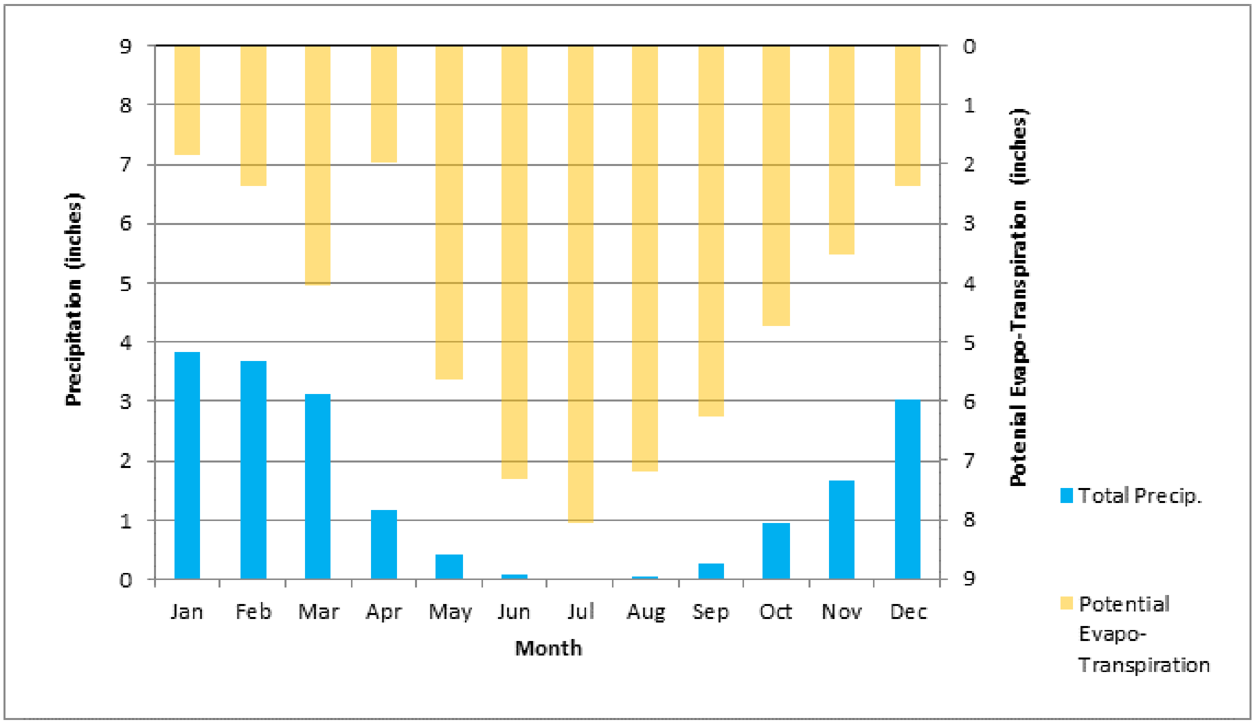


Figure 4. Monthly average precipitation and evapotranspiration based on 30-year normals for the Salinas River Watershed area (PRISM and CGIAR)

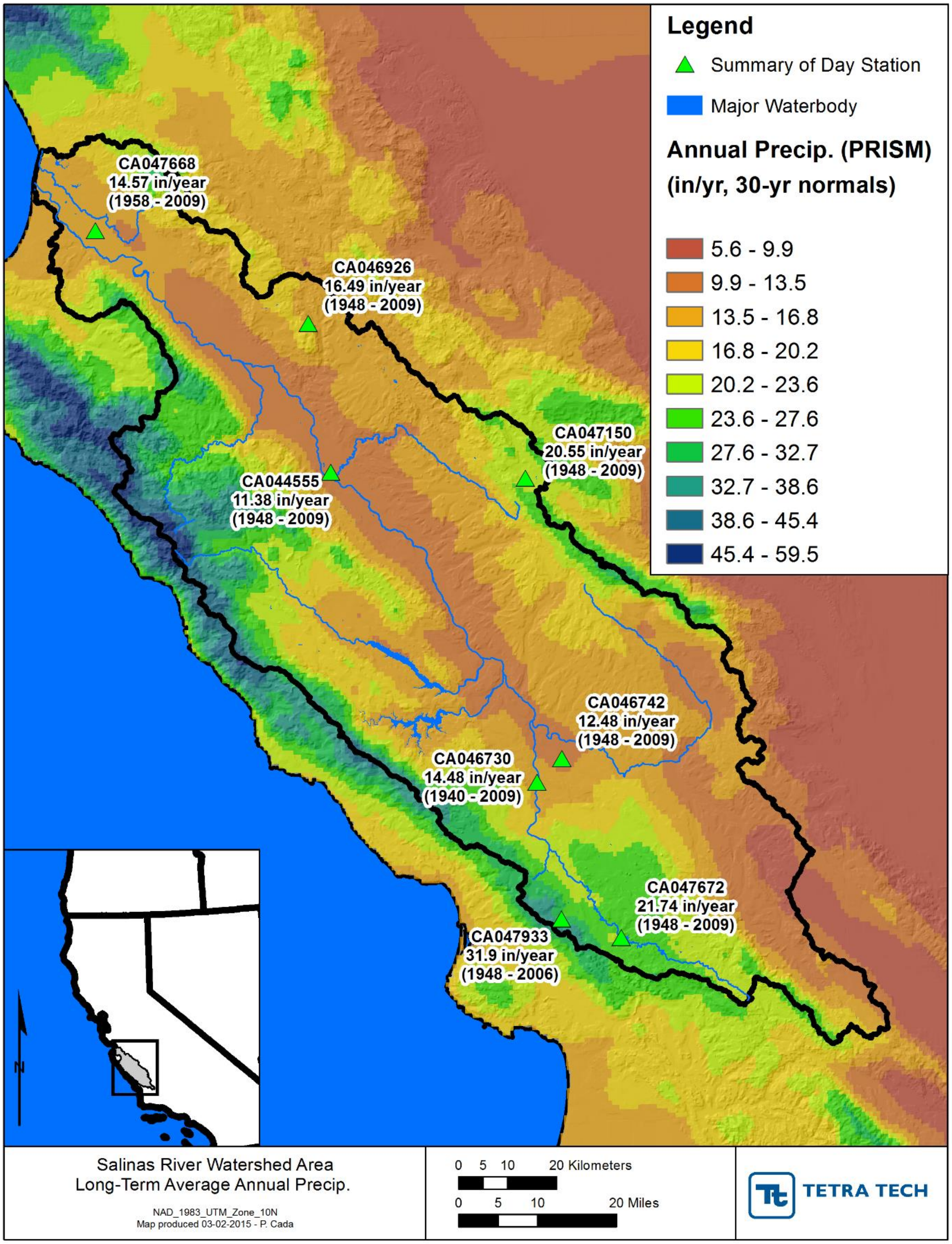


Figure 5. Long-term average annual precipitation for the Salinas River Watershed area (data sources: NCDC GSOD stations and PRISM 30-year Normals)

Table 2. Monthly average precipitation statistics for select NCDC GSOD stations in the Salinas River Watershed area

Time Period	CA044555 KING CITY	CA046730 PASO ROBLES	CA046742 PASO ROBLES MUNI AP	CA046926 PINNACLES NM	CA047150 PRIEST VALLEY	CA047668 SALINAS #2	CA047672 SALINAS DAM	CA047933 SANTA MARGARITA BOOST
January	2.34	3.10	2.74	3.27	4.30	2.92	4.72	6.97
February	2.28	2.94	2.49	3.09	3.86	2.73	4.39	6.21
March	1.91	2.35	2.13	2.87	3.38	2.36	3.55	5.11
April	0.82	1.06	0.89	1.27	1.57	1.08	1.75	2.40
May	0.26	0.28	0.25	0.43	0.54	0.31	0.41	0.62
June	0.04	0.02	0.02	0.07	0.07	0.09	0.04	0.08
July	0.01	0.03	0.02	0.04	0.05	0.03	0.02	0.03
August	0.03	0.04	0.04	0.05	0.05	0.06	0.04	0.05
September	0.18	0.19	0.22	0.22	0.30	0.23	0.26	0.36
October	0.50	0.60	0.51	0.77	0.91	0.65	0.84	1.32
November	1.12	1.39	1.19	1.70	2.10	1.74	2.16	3.52
December	1.90	2.47	1.97	2.72	3.41	2.38	3.56	5.22
Annual Average	11.38	14.48	12.48	16.49	20.55	14.57	21.74	31.90

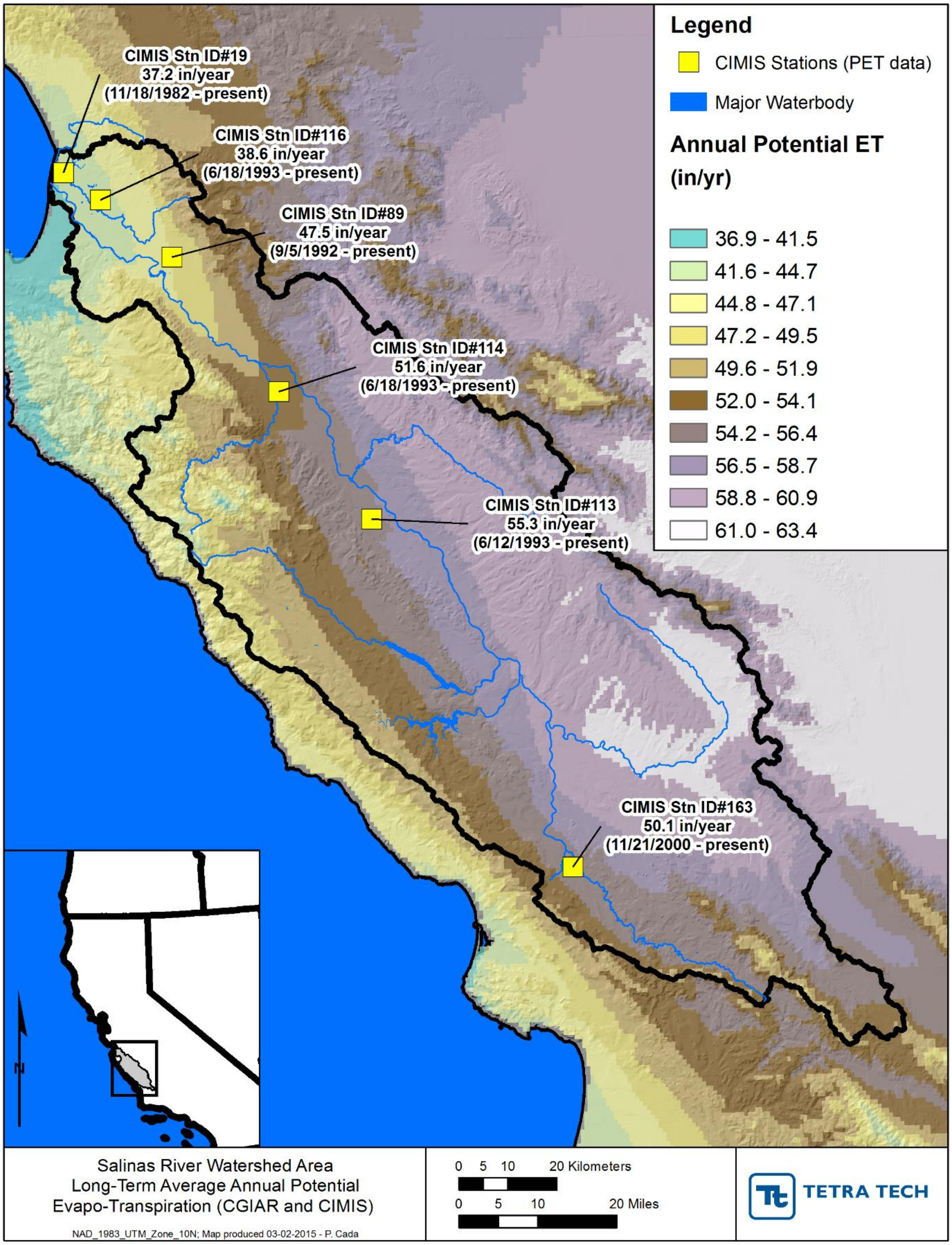


Figure 6. Long-term average annual evapotranspiration for the Salinas River Watershed area (data sources: CIMIS stations and CGIAR)

Table 3. Monthly average potential evapotranspiration statistics for select CIMIS stations in the Salinas River Watershed area

Time Period	Stn ID #19 Castroville	Stn ID #89 Salinas South	Stn ID #113 King City-Oasis Rd.	Stn ID #114 Arroyo Seco	Stn ID #116 Salinas North	Stn ID #163 Atascadero
January	1.6	1.63	1.82	1.79	1.56	1.73
February	1.96	2.04	2.34	2.3	1.9	2.23
March	3.12	3.55	4.02	3.96	3.1	3.68
April	4.2	4.75	5.37	5.26	4.09	4.74
May	4.77	5.54	6.96	6.57	4.71	6.15
June	4.82	6.43	7.54	6.75	4.94	6.56
July	4.05	6.31	7.54	6.84	4.46	6.63
August	3.61	5.75	6.77	6.15	4.19	6.39
September	3.15	4.58	5.27	4.73	3.53	4.98
October	2.65	3.47	3.86	3.56	2.84	3.48
November	1.81	2.01	2.15	2.09	1.82	2.01
December	1.47	1.45	1.63	1.58	1.46	1.48
Annual Average	37.21	47.51	55.27	51.58	38.6	50.06

1.1.3.2 Temperature

Minimum, average, and maximum monthly 30-year normals were analyzed for the watershed. On average, temperatures tend to be mild throughout the year (Table 4, Figure 7, and Figure 8). Table 5 provides monthly averages for the NCDC GSOD stations; there is much less variation in temperature among stations than is seen for precipitation and PET.

Table 4. PRISM monthly average temperature statistics for 30-year normals in the Salinas River Watershed area

Time Period	Average Daily Minimum Temp. (degrees F)	Average Daily Temp. (degrees F)	Average Daily Maximum Temp. (degrees F)
January	35.6	47.9	60.1
February	37.4	49.6	61.7
March	39.2	52.2	65.1

Time Period	Average Daily Minimum Temp. (degrees F)	Average Daily Temp. (degrees F)	Average Daily Maximum Temp. (degrees F)
April	40.3	55.2	70.1
May	44.9	61.2	77.6
June	49.5	67.0	84.6
July	54.2	72.1	90.3
August	53.7	71.9	90.3
September	51.0	68.7	86.7
October	45.8	62.1	78.4
November	38.8	52.9	66.8
December	35.0	47.3	59.5
Annual Average	**43.8**	**59.0**	**74.3**

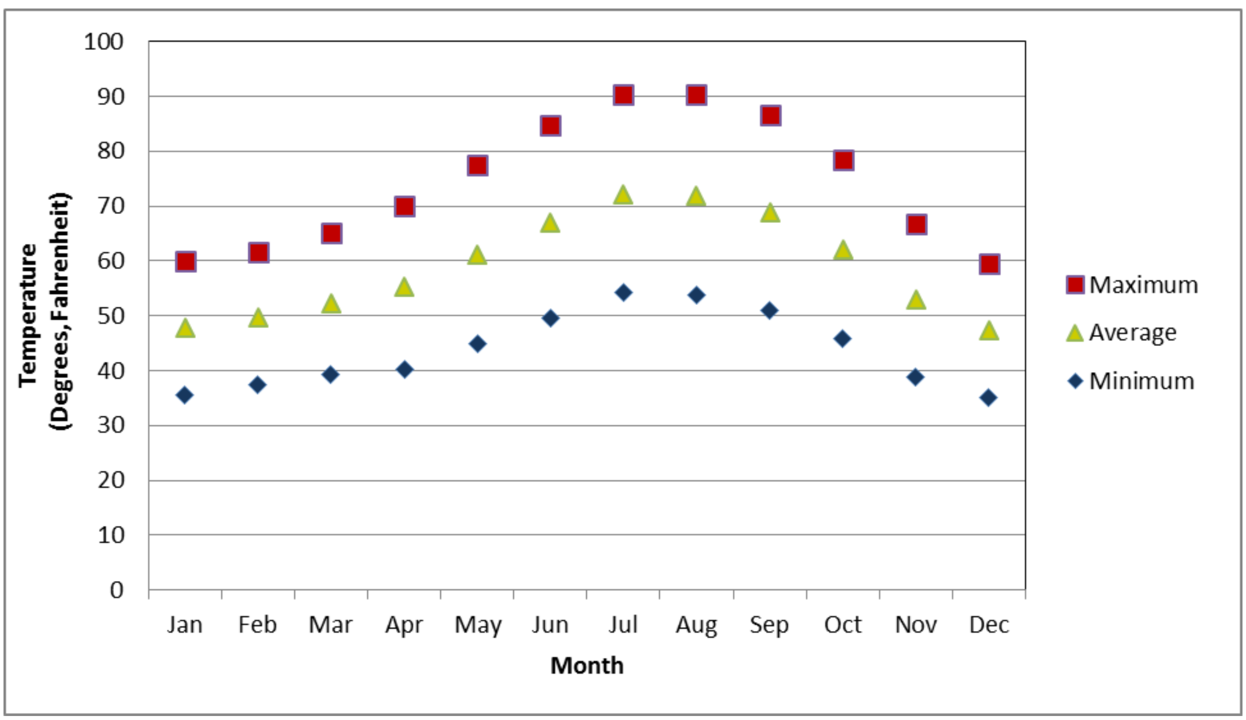


Figure 7. PRISM temperature statistics for the Salinas River Watershed area

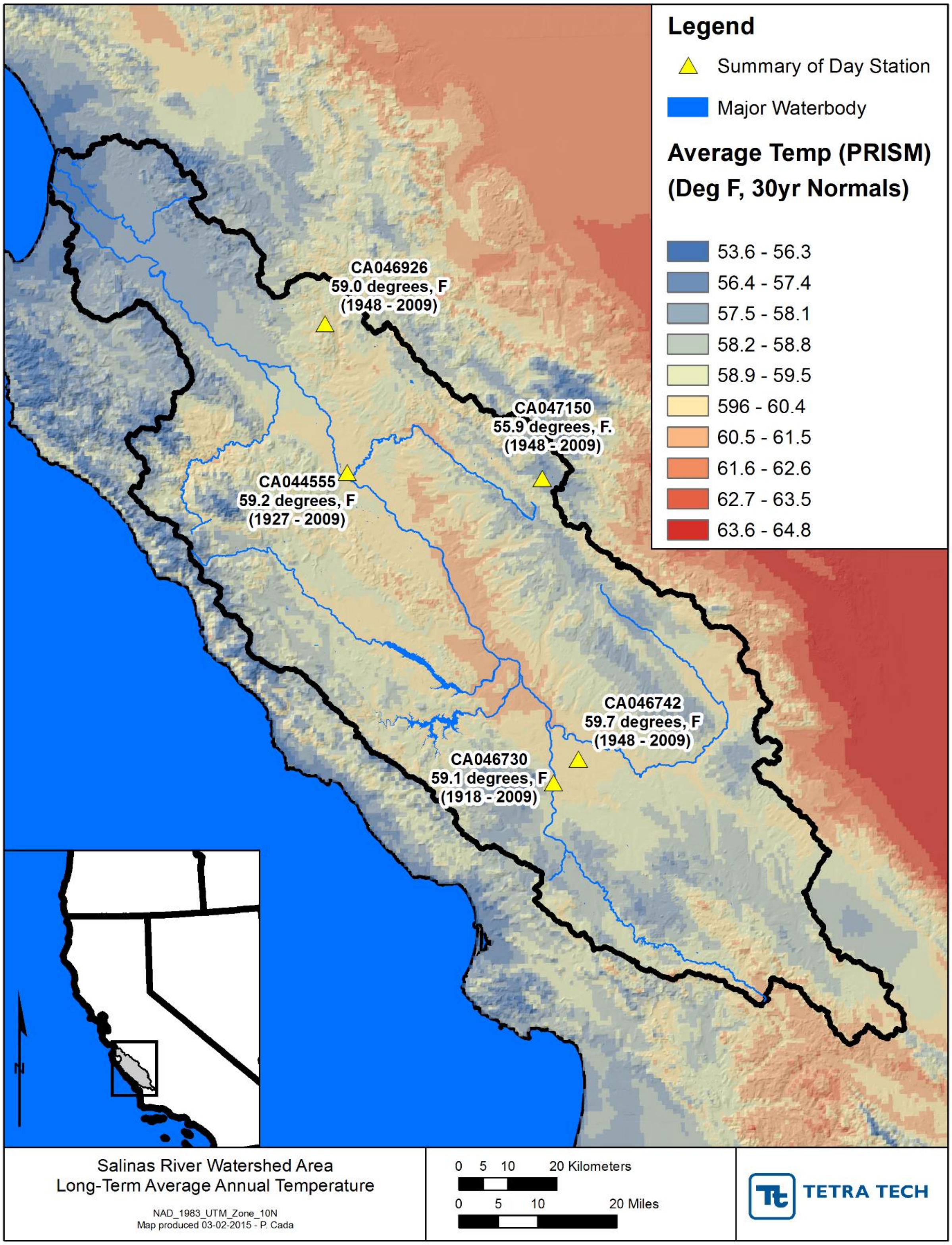


Figure 8. Long-term average annual temperature for the Salinas River Watershed area (data sources: NCDC GSOD stations and PRISM 30-year normals)

Table 5. Monthly average temperature statistics for select NCDC GSOD stations in the Salinas River Watershed area

Time Period	CA044555 KING CITY	CA046730 PASO ROBLES	CA046742 PASO ROBLES MUNI AP	CA046926 PINNACLES NM	CA047150 PRIEST VALLEY
January	48.9	46.4	46.8	47.0	42.6
February	51.8	49.8	50.0	49.3	45.1
March	54.4	53.0	52.7	51.4	47.5
April	57.8	56.9	56.7	55.3	51.6
May	61.9	62.4	62.9	61.1	58.5
June	65.9	67.7	68.9	67.2	65.7
July	68.4	72.6	73.8	72.7	72.2
August	68.1	71.9	73.3	72.1	71.1
September	67.3	68.3	69.7	69.1	66.5
October	62.3	61.2	62.0	61.9	57.9
November	54.5	52.3	52.8	53.3	48.4
December	49.3	46.3	46.6	47.4	43.1
Annual Average	59.2	59.1	59.7	59.0	55.9

1.1.4 Land Use/Land Cover

Land cover in the watershed area varies greatly by location. The Salinas Valley is composed primarily of cropland, and is known as "America's Salad Bowl" due to the prominence of vegetables and greens grown in the region. Numerous vineyards are also present. The Salinas Valley is surrounded by grassland and shrubland in the rolling to steep hills, with forests on the steep slopes of the surrounding ranges. Land use/land cover data representing general conditions in 2011 were obtained from the National Land Cover Dataset (NLCD[1]; Jin et al., 2013), and are shown in Table 6 and Figure 9. NLCD is based on interpretation of satellite imagery, and is subject to some degree of uncertainty, but is useful for characterizing overall land use/land cover in the Salinas River Watershed Area. It is important to note that NLCD does not distinguish between crop types, and there may be some classification error between cropland and pasture/hay uses. Interpretation of specific crop areas is better performed using a local data source. A more detailed analysis of agricultural land use in the Salinas Valley is presented in Section

[1] http://www.mrlc.gov/nlcd2011.php

7.2.1, which is based on GIS crop reporting data provided by the Monterey County Agricultural Commissioner's Office.

Table 6. Land use and land cover for the Salinas River Watershed area

Land Use/Land Cover	Estrella HUC8		Salinas HUC8		Reclamation HUC8 w/o Elkhorn		Total Area	
	Area (mi^2)	Percent Area	Area (mi^2)	Percent Area	Area (mi^2)	Percent Area	Area (mi^2)	Percent Area
Water	0.2	0.0%	19.7	0.6%	0.3	0.3%	20.3	0.5%
Open Developed	31.4	3.3%	172.7	5.2%	19.5	14.9%	223.7	5.1%
Low Density Developed	0.4	0.0%	24.8	0.7%	7.9	6.0%	33.1	0.7%
Med Density Developed	0.1	0.0%	16.5	0.5%	10.2	7.8%	26.9	0.6%
High Density Developed	0.0	0.0%	2.3	0.1%	2.1	1.6%	4.4	0.1%
Barren	36.8	3.9%	65.9	2.0%	0.4	0.3%	103.0	2.3%
Deciduous Forest	0.0	0.0%	0.3	0.0%	0.0	0.0%	0.3	0.0%
Evergreen Forest	0.5	0.1%	212.1	6.4%	16.8	12.8%	229.6	5.2%
Mixed Forest	23.7	2.5%	357.5	10.7%	0.8	0.6%	382.1	8.6%
Shrub/Scrub	247.2	26.0%	1027.5	30.8%	12.6	9.6%	1287.3	29.1%
Herbaceous	559.4	58.8%	1034.6	31.0%	23.1	17.6%	1616.8	36.6%
Hay/Pasture	13.9	1.5%	49.5	1.5%	1.5	1.1%	64.9	1.5%
Cultivated Crops	35.5	3.7%	309.8	9.3%	33.5	25.6%	378.8	8.6%
Woody Wetlands	0.6	0.1%	26.7	0.8%	1.0	0.8%	28.3	0.6%
Emergent Herbaceous Wetlands	1.4	0.2%	17.4	0.5%	1.4	1.1%	20.2	0.5%
TOTAL	951.2	100.0%	3337.3	100.0%	131.1	100.0%	4419.6	100.0%

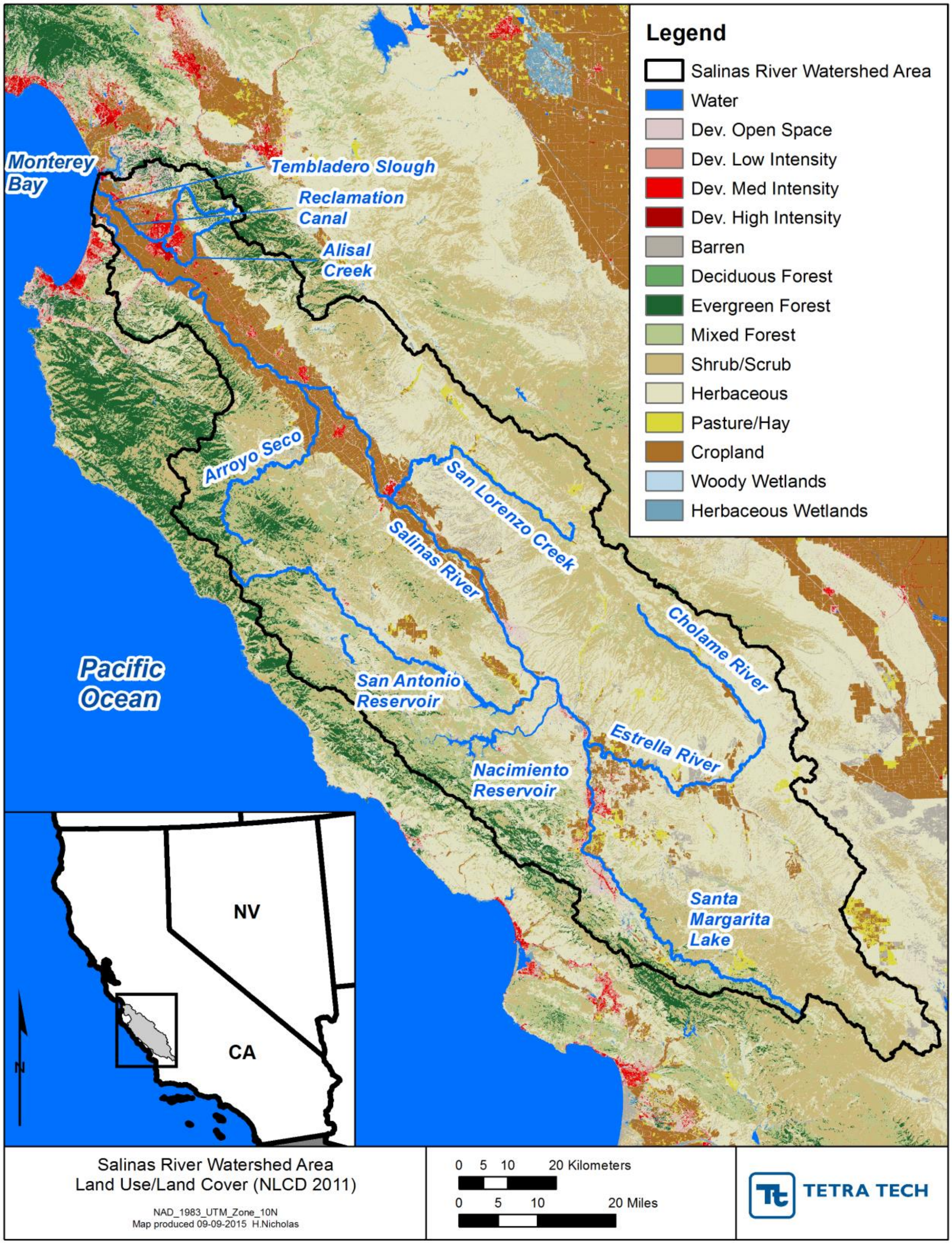


Figure 9. Land use/land cover map for the Salinas River Watershed area

1.1.5 Soils

Soils characteristics of the Salinas River watershed are a major factor determining whether incident rainfall is converted to surface runoff or infiltrated into subsurface soil layers. Runoff has the potential to carry pollutants, including salts and nitrates that have built up on and in soils, to surface water. Infiltrated water can carry those same pollutants into subsurface zones and ultimately groundwater. Natural soil salinity can also accumulate and be transported into lower soil zones and aquifers as rainfall and applied irrigation water percolate through soil layers.

To better characterize the soil characteristics critical to understanding current impairment in the watershed, soils data were extracted from the Soil Survey Geographic (SSURGO) databases produced USDA NRCS and revised throughout 2013 and 2014. All data were analyzed for the entire soil profile for each SSURGO map unit's dominant component using USDA's Soil Data Viewer tool within ArcGIS v10.1 (Service Pack 1). More information about the Soil Data Viewer tool can be accessed at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053614. Soil attributes of interest to this study include:

- Hydrologic soil group
- Soil hydrologic conductivity
- Soil background salinity

Each of these is discussed in the sections that follow.

1.1.5.1 Hydrologic Soil Group

Hydrologic soil group (HSG) assignments are developed using estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, thoroughly wet, and receive precipitation from long-duration storms. Soils are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). These groups are defined as such:

- **Group A -** Soils having a high infiltration rate (low runoff potential) when thoroughly wet, usually consisting of deep, well drained to excessively drained sands/gravelly sands. These soils have a high rate of water transmission.
- **Group B -** Soils having a moderate infiltration rate when thoroughly wet usually consisting of moderately deep/deep, moderately well drained/well drained soils with moderately fine/moderately coarse texture. These soils often have a moderate rate of water transmission.
- **Group C -** Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
- **Group D -** Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

When soils are assigned to a dual hydrologic group (A/D, B/D, or C/D) the first letter is for drained areas and the second is for undrained areas. Only soils that in their natural condition are classified as group D are assigned to dual classes.

About 76 percent of soils are classified as C, C/D or D soils with only 21 percent classified as A or B soils, and the remainder as "other" classification (Table 7, Figure 11)

Table 7. Hydrologic soil groups for the Salinas River Watershed area

Hydrologic Soil Group	Percent of Watershed (%)
Other	4.2
A	5.6
B	15.5
C	44.7
C/D	0.1
D	29.9

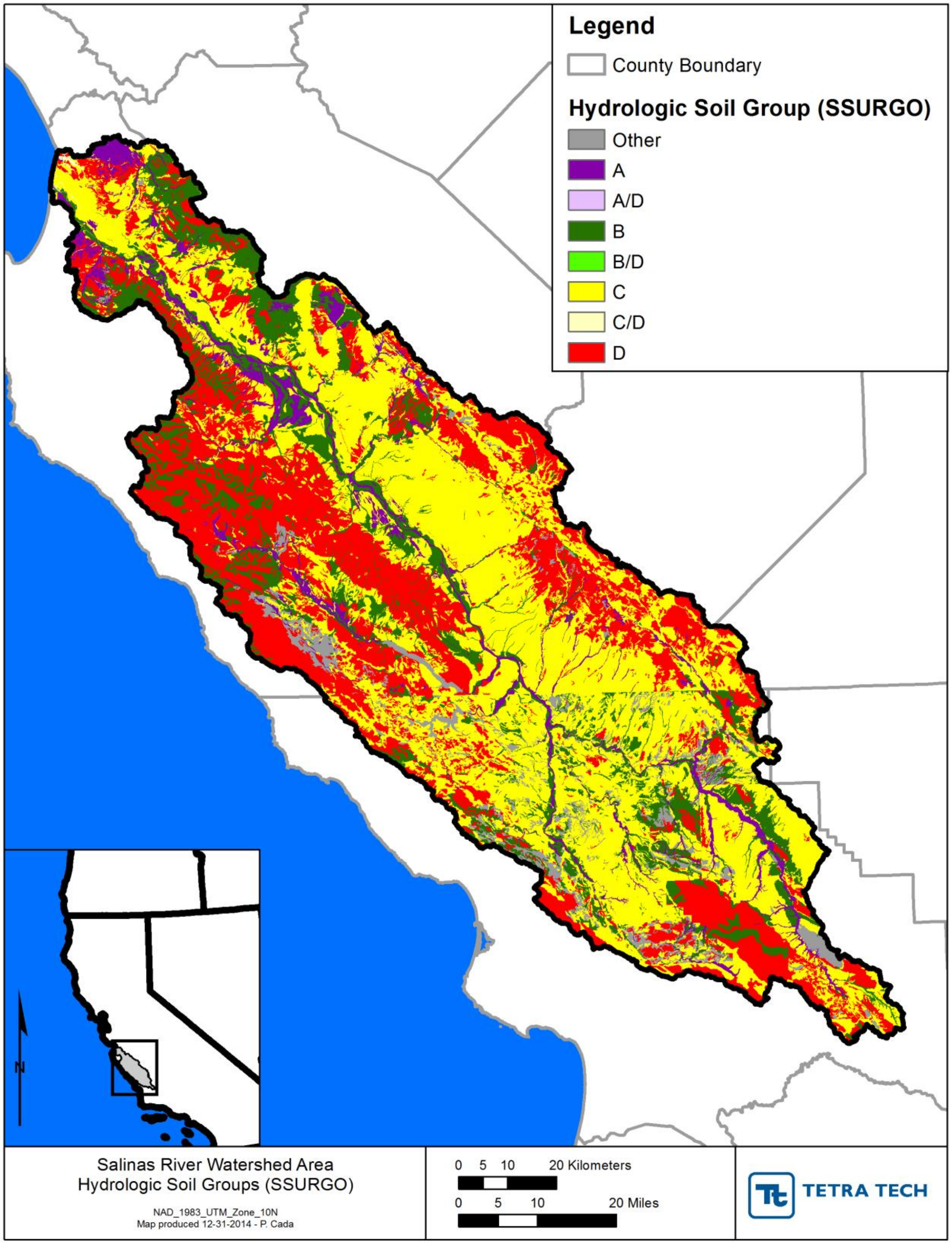


Figure 10. Hydrologic soil groups for the Salinas River Watershed area (SSURGO)

1.1.5.2 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (K_{sat}) is a measure of the ease with which pores in saturated soils transmit water. Estimates are expressed in terms of micrometers per second (um/s) and are based on soil characteristics observed in the field, particularly structure, porosity, and texture. The "representative" value indicates the expected value of this attribute for the component and was used in the analysis of the Salinas River watershed. The numeric Ksat values have been grouped according to standard Ksat class limits (Table 8)

In conjunction with HSG classifications, the K_{sat} classification outputs can serve to identify areas that may be more suitable (or not) for a particular activity. Most of the watershed has a Moderately High or High rate of water transmission within the soil profile when soils are saturated (Figure 11).

Table 8. Saturated hydraulic conductivity (Ksat) classes for soils in the Salinas River Watershed area

Standard Ksat Classes	Range of Ksat values (um/sec)	Percent of Watershed (%)
Very Low	0.00 - 0.01	5.5
Low	0.01 - 0.1	-
Moderately Low	0.1 - 1.0	6.2
Moderately High	1 - 10	55.7
High	10 - 100	31.3
Very High	100 - 705	1.2

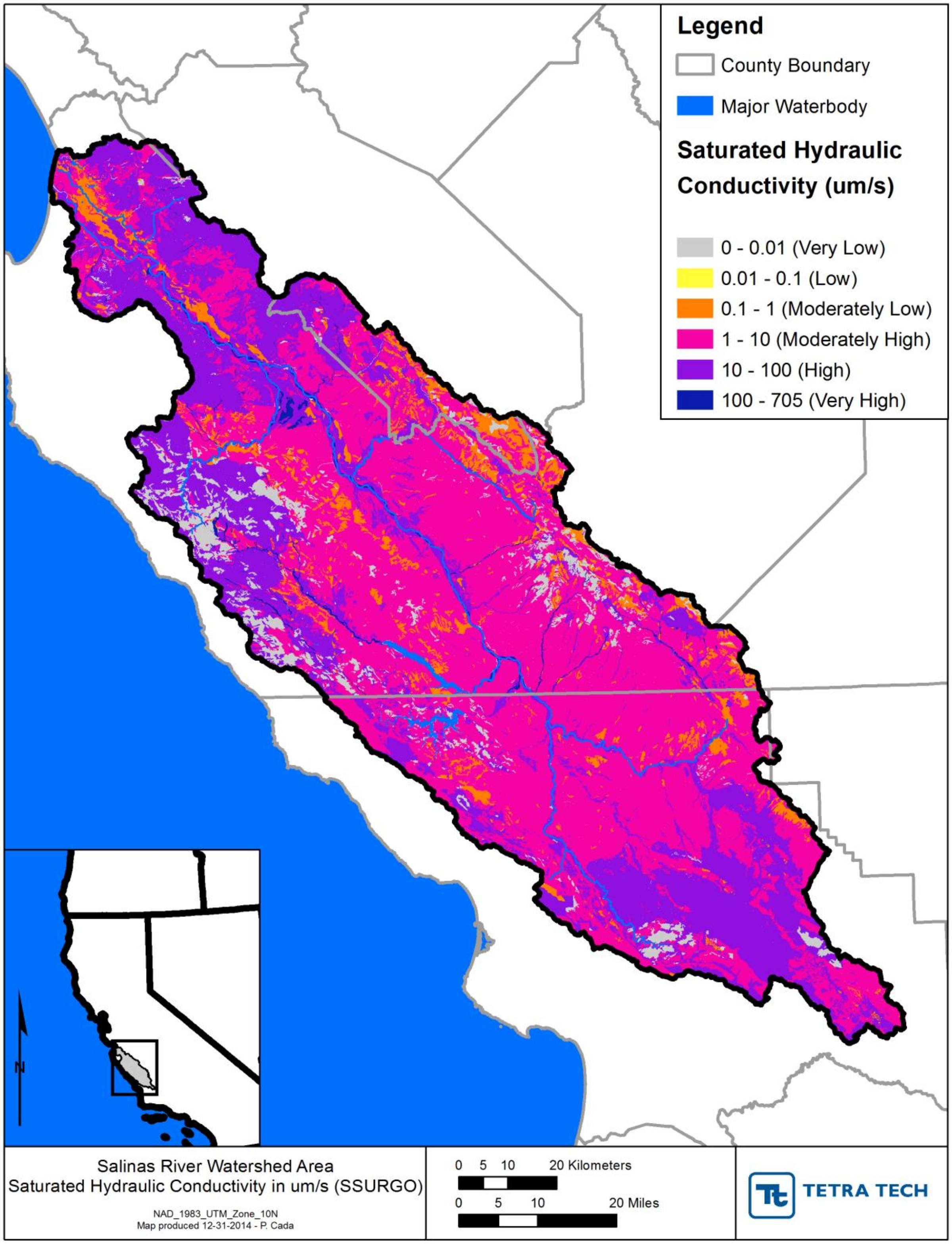


Figure 11. Saturated hydraulic conductivity (Ksat) for soils in the Salinas River Watershed Area (SSURGO)

1.1.5.3 Electrical Conductivity

Electrical conductivity (EC) is the electrolytic conductivity measured from an extract of saturated soil paste, expressed as deciSiemens per meter (dS/m) or microSiemens per meter (µS/m) at 25 °C, and is one way to estimate the concentration of water-soluble salts in the soil profile of interest. EC is a measure of ionic strength, not salt mass, but is often used to indicate saline soils. High concentrations of salts interfere with the absorption of water by plants because the osmotic pressure in the soil solution is nearly as high as or higher than that in the plant cells. Soils with EC values less than 1 dS/m are considered non-saline and tend not to impact most crop production and soil microbial processes. When EC is between 2 – 4 dS/m, the soil is categorized as slightly saline, while EC greater than 4 dS/m signifies a saline soil. Soils that have a high proportion of sodium ions relative to total ions are called sodic soils, and tend to have poor structure and drainage due to the effect of sodium on clay particles. Differences in ion content can influence the relative proportion of sodium, chloride, and total salt exported from the soils (Davis et al, 2012).

EC data are provided from the SSURGO dataset, and is derived by testing a soil saturated paste extracted from the field. These soils tests were conducted during original soil surveys and should be considered representative of the native soil concentration of water-soluble salts (i.e., background levels). The "representative" value provided in the soil surveys indicates the expected value of this attribute for the component and was used in the analysis of the Salinas River watershed. As can be seen from Table 9 and Figure 12 the majority of the watershed is near or at an EC of 1 dS/.

Table 9. Electrical conductivity of soils in the Salinas River Watershed area (SSURGO)

Electrical Conductivity (dS/m)	Percent of Watershed (%)
0	24.5
0.01 - 0.20	0.6
0.21 - 0.50	0.6
0.51 - 0.75	0.8
0.76 - 1.00	70.9
1.01 - 1.50	0.0
1.51 - 2.00	1.1
2.01 - 3.00	0.3
3.01 - 6.00	0.9
6.01 - 12	0.3

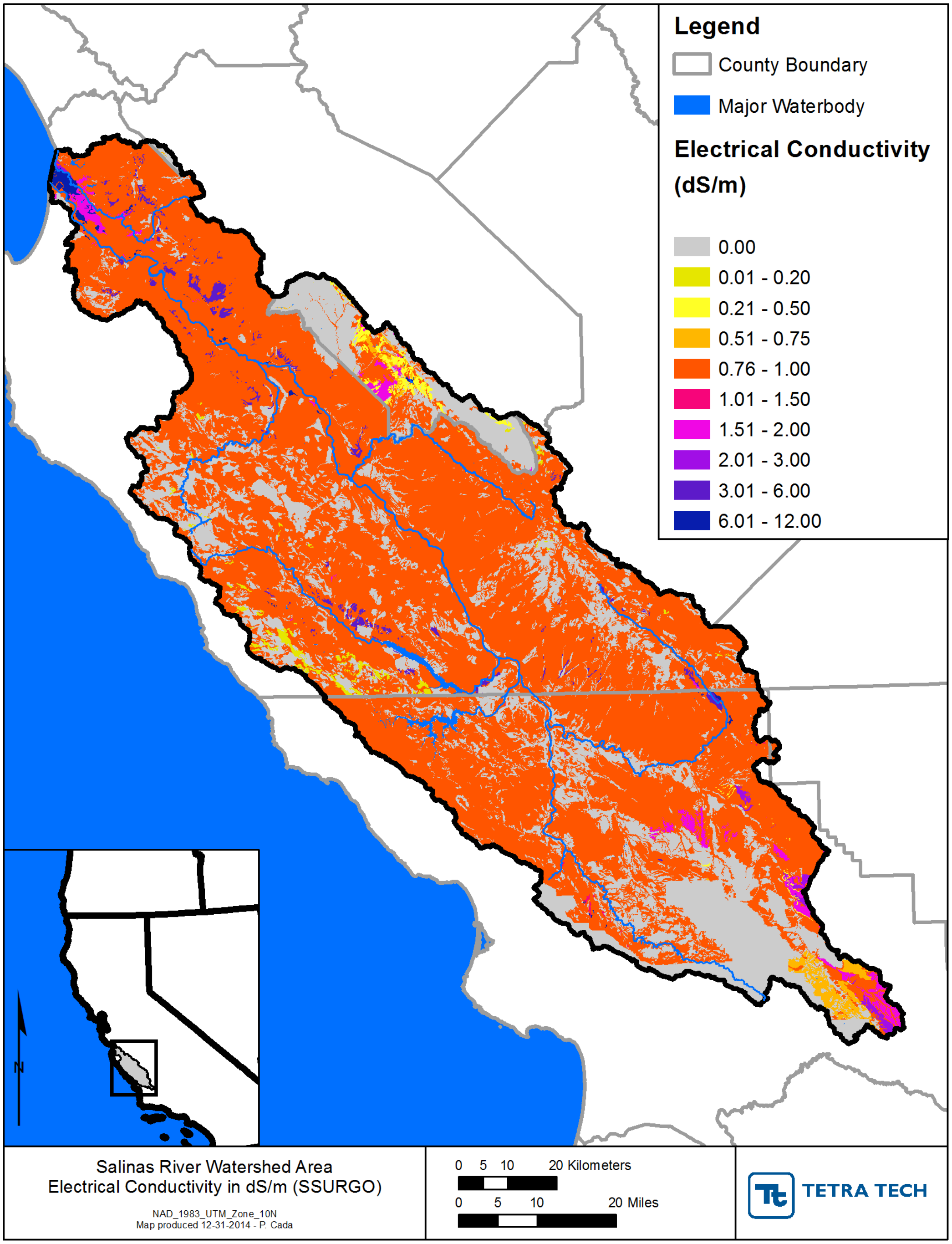


Figure 12. Background electrical conductivity of soils in the Salinas River Watershed area (SSURGO)

1.1.6 Geology

The Salinas River Watershed area is characterized by a complex geology (Figure 13). The entire area is underlain by granitic basement rock with marine deposits making up the deepest sediments. Overlaying these layers are a mix of non-marine sands and clays deposited as the rivers and streams of the watershed moved and shifted along their historic courses. Prevailing winds also played a major role in the determining current soil and geologic conditions and many areas show a varied mixing and layering of fine sediments. Soils that characterize the areas are generally highly permeable with high hydraulic conductivity. Land use in the Valley includes significant areas of agriculture and the native soils are generally suitable for crop production with very little background salinity. The one exception is for areas that are directly adjacent to the Bay that show high natural salt concentrations.

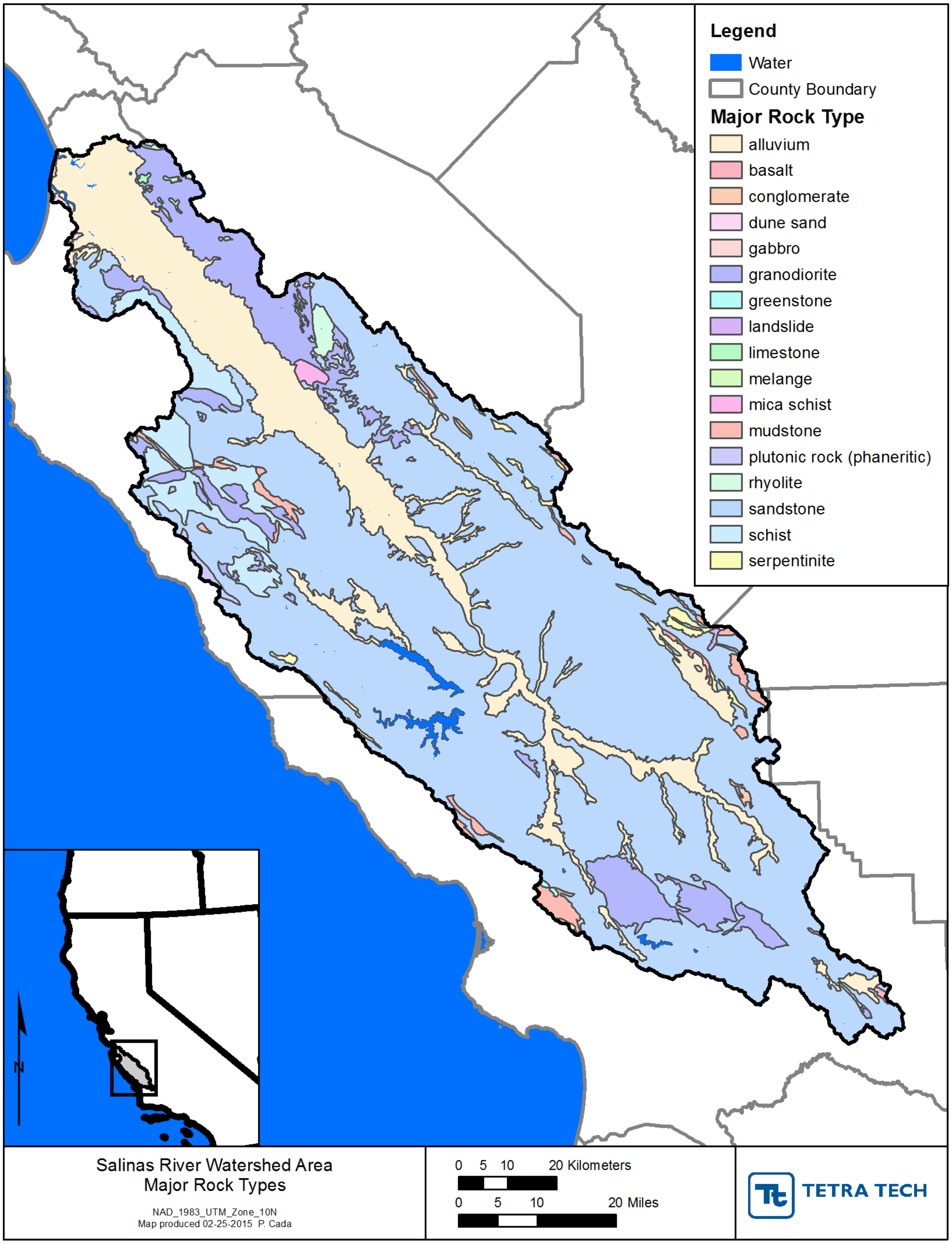
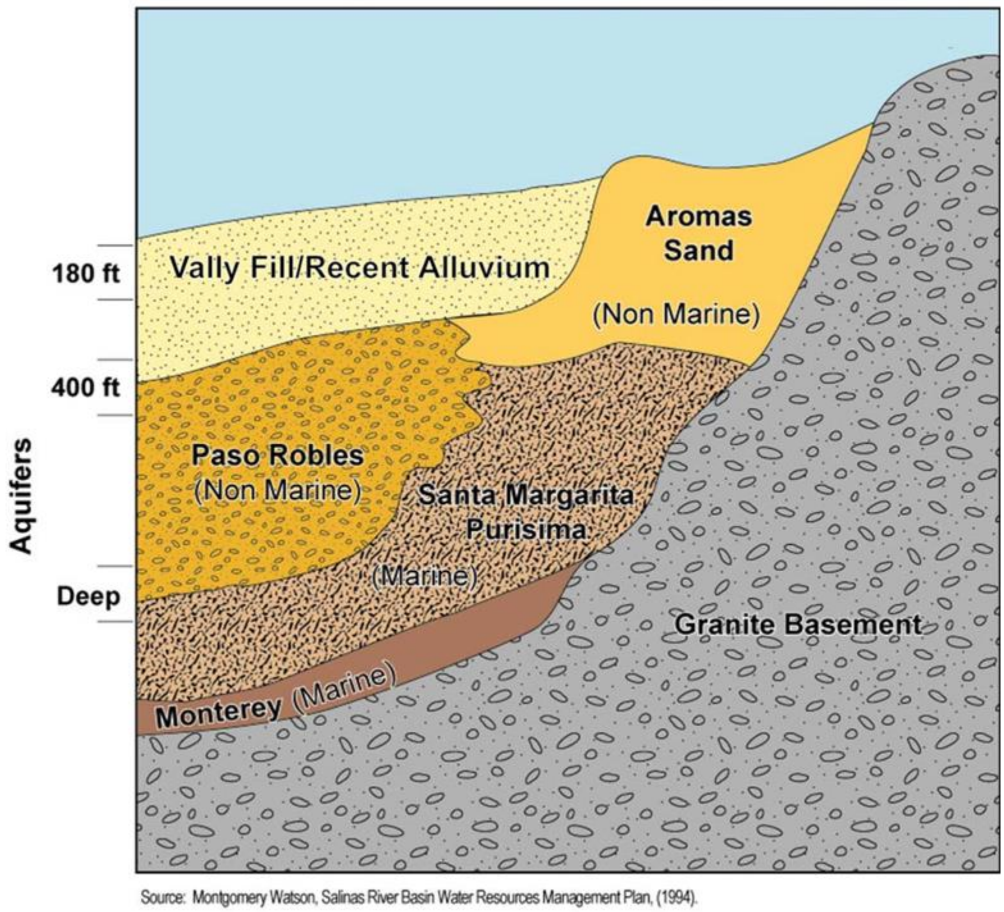


Figure 13. Major rock types within the Salinas River Watershed area (USGS)

1.1.6.1 Major Geologic Formations

A summary of the geology of the study area is presented here; more information is available from many of the reports discussed in Section 4. There are six major geologic formations that make up the subsurface profile of the Salinas River Watershed area. Granitic basement rock underlies the entire area, which is overlain by the marine Monterey, Santa Margarita, and Purisima formations. Marine formations retain the native salinity acquired from the depositional environment in which they were created. The non-marine Paso Robles generally defines the next deepest geologic layer, which is uncomfortably overlain by Aromas Sand, meaning that it is not completely covered. Together with the Aromas Sand formation, Valley Fill/Recent Alluvium make up the surface geology of the watershed, along with granitic outcrops that form the local mountain ranges. Figure 14 provides a conceptual illustration of the basin's geological stratigraphy, showing the depth and general orientation of each major formation (MCWRA, 2006).



Source: Montgomery Watson, Salinas River Basin Water Resources Management Plan, (1994).

Figure 14. Geologic profile of the Salinas River Watershed area (MCWRA, 2006)

Groundwater resources in the watershed are generally sourced from the shallower (less than 400 feet deep), unconsolidated formations. The oldest of these formations are dated to the post-Miocene era and consist of the poorly consolidated marine sandstone, siltstone, and claystone beds that characterize the Purisima Formation. Groundwater sourced from the Purisima formation tend to be from upper, well flushed layers, however, so this native salinity is not thought to be a factor in current surface water impairments. The Purisima formation overlies the Monterey Shale, both of which pinch-out against the granitic ridge and become thicker and deeper moving northwest towards Monterey Bay. The top of the Purisima Formation exists at elevations of approximately -600 feet inland to greater than -800 feet near the coast (Johnson, 1983). Because the Purisima Formation is not exposed at the ground surface anywhere within the study area, recharge is controlleds by infiltration through the overlying Aromas Sand (Fugro West Inc., 1995).

Moving towards the surface, the younger Pleistocene age Aromas Sand partially overlies the Purisima Formation and is exposed in various locations throughout the Salinas River Watershed area. Similar to the Purisima Formation, the Aromas thickens coastward (Fugro West Inc., 1995).

The origin of a geologic formation is a major factor in the occurrence of natural background salinity. Igneous geologic formations are characterized by low salinity, while high levels of dissolved solids often occur in areas underlain by ancient marine sediments. In the Salinas River Watershed area three major geologic formations are marine in origin: the Monterey, Santa Margarita, and Purisima formations. Currently, only the upper layers of the Purisima formation are a source of groundwater. As time passes, salts are removed from the sedimentary rocks by wind and water erosion, thus the remaining salinity in these upper layers is quite low. If they were not, current and historical groundwater extractions would not have continued because the quality of the water would make it unsuitable for irrigation and other uses.

Natural background soil salinity can be increased by irrigation. In the Salinas Valley with its arid/semi-arid climate evaporation exceeds precipitation, which can lead to salts concentrating in soil layers. Both irrigation water and precipitation contain traces of salts. Over time, if soils are not properly flushed, the evaporation of water can leave salts in the soil. These salts may be carried in irrigation return flow or in overland flow during rainfall events to surface waters or ultimately percolate to active aquifers.

Each of the major geologic formations is discussed in more detail in the following sub-sections in order of age, which generally corresponds to depth.

1.1.6.1.1 Granite Basement and Monterey Formation

The basement rocks consist of Mesozoic “Salinian Block” granite. This basement rock can be observed near Prunedale, CA where it is exposed along a ridge on the western side of the Vergeles fault. The basement rock formation has been determined to dip at approximately 8 degrees towards the Monterey Bay, based on contoured well log data. Overlying the basement rock is the Monterey Formation, a Miocene-aged marine shale and mudstone generally composing the base of water-bearing sediments in the northern Salinas Valley area (MCWRA 2006).

The yield of wells completed in weathered granite are a function of saturated thickness and the permeability of the weathered granite, and are usually significantly higher than wells completed in fresh granite. The yield of wells completed in the fresh granite are typically low and completely dependent on the number of fractures intersected by the well bore and the degree of connectivity of the fractures to each other and a source of recharge (Fugro West Inc.,1995).

1.1.6.1.2 Santa Margarita and Purisima Formations

The Santa Margarita Formation is composed of friable arkosic sandstone. It underlies the Purisima formation and may also directly underlie the Paso Robles formation in areas where the Purisima formation is absent. The Purisima Formation is comprised of poorly consolidated marine, sandstone, siltstone, and claystone beds (MCWRA, 2006).

In general, attempts to develop water supplies from this formation have resulted in limited well yields and marginal water quality due to elevated sodium adsorption ratios. The differences in the success of wells in the Purisima between areas is due to local differences in the geology and hydrogeology. Finer-grained Purisima reduces well yield, while in areas where the formation is not exposed the potential for flushing the formation of saline connate fluids results in poor water quality (Fugro West Inc., 1995).

1.1.6.1.3 Paso Robles Formation

The Paso Robles Formation is a late Pliocene to early Pleistocene age continental sequence consisting of clay and sand sequences generally present below about 60 feet mean sea level (MSL). It is exposed in the southeast hills of the watershed and near Laguna Seca, but is buried by alluvium within the Salinas Valley. This formation is commonly exposed at lower elevations in the central and southern portions of former Fort Ord in drainages where the overlying Aromas Sand has been removed by stream erosion. Roadcut exposures of the Paso Robles Formation typically display lenticular beds of sand, gravel, silt, and clay (Harding ESE, 2001).

The Paso Robles Formation comprises the most important aquifers in the central and southern portions of the Salinas Valley. Based on available well logs, Thorup (1976) concluded there are three members of the Paso Robles Formation:

1. The "A" member is referred to as the 400-Foot Aquifer and is about 200-feet thick
2. The "B" member contains the Deep Aquifer (previously called the 900-Foot Aquifer) and varies in depth about from 600 to 1,200 feet below the ground surface (bgs).
3. The "C" member is an unnamed section of water-bearing sediments about 200 feet thick.

1.1.6.1.4 Aromas Sand

The Pleistocene-age Aromas Sand overlies the Paso Robles Formation and consists mainly of cross-bedded sand with some clayey layers. The sands are composed of fine- to coarse-grained, friable quartz and feldspar. Cross-bedding and a uniform grain size exposed in an abandoned borrow area on former Fort Ord indicate eolian deposition. Outcrops of the Aromas become isolated and scattered toward the west of Fort Ord and ultimately becomes buried beneath older dune sand in the city of Seaside. According to Muir (1982), the Aromas Sand may range up to 300 feet thick. This formation is a distinct red or brownish color, and typically thickens towards the coast (MCWRA, 2006).

Well yields are relatively high and are a function of the local saturated thickness and lithology. Groundwater in the Aromas Sands occurs generally under unconfined to semi-confined conditions, with the degree of confinement increasing with depth (Fugro West Inc., 1995).

1.1.6.1.5 Valley Fill Deposits

The Aromas Sands is locally overlain by Valley Fill, a unit composed of alternating interconnected, complex beds of fine-grained and coarser-grained estuarine and fluvial deposits. The Valley Fill ranges from approximately 25 feet to 100 feet thick. This Pleistocene-age unit is considered to include two distinct depositional sequences: 1) an estuarine clay that forms the Salinas Valley Aquitard (SVA), which underlies older dune sand and 2) a sand and gravel fluvial sequence beneath the SVA. Together, these two formations comprise the important Pressure aquifer that serves population centers near the northwestern portion of the Basin (Harding ESE, 2001).

The SVA is limited to the northern portion of the Salinas Valley. The maximum thickness of the SVA is approximately 100 feet and it extends beneath the Salinas Valley from Monterey Bay south to the city of Chualar, CA. Moving perpendicular across the valley, the SVA extends from Highway 1 to an irregular boundary with the East Side Area. The SVA pinches out just east of Highway 1 in the city of Marina/Fort Ord area and ends to the south beneath former Fort Ord against an erosional contact with the Aromas Sand and Paso Robles Formation (Harding ESE, 2001).

The fluvial sand and gravel sequence that comingles with the SVA extends west beyond the pinch-out of the SVA near Marina and former Fort Ord. Outcrops of this formation have been documented on the Monterey Bay floor in previous studies (Greene, 1970, 1977, 1990; Simpson, 1946). Within the valley, these sediments also extend somewhat beyond the southern limits of the SVA near Chualar. These deposits range from approximately 100 to 300 feet thick (Harding ESE, 2001).

1.1.6.1.6 Recent Alluvium

Overlying the Valley Fill is approximately 10 to 75 feet of Recent Alluvium deposited by the Salinas River. The Recent Alluvium is present in the more established drainages and typically has low to moderate permeability. The Recent Alluvium also includes perched groundwater zones that have not generally been affected by seawater intrusion, but have, in some cases, been impacted by percolation irrigation water from agriculture (MCWRA, 2006).

1.1.6.2 Hydrogeologic Subareas

The characterization of the Salinas Valley groundwater system provide important information to diagnose and address water quality issues in the watershed. Understanding the linkages and characteristics of these subareas is critical to the goal of understanding water and salt movement throughout the system, and accurately representing the sources and pathways of salts.

The subsurface hydrology of the Salinas Valley Groundwater Basin is generally characterized by groundwater flow that moves down the valley from the headwaters of the Salinas River to San Ardo and, ultimately, Monterey Bay (Figure 15). Between San Ardo and Monterey Bay the average hydraulic gradient has been measured at 0.001 ft/ft, similar to the gradient of the Salinas River (Ferriz, 2001). Local pumping depression cones have significantly modified the piezometric surface in certain areas, however, causing local variability in flow direction as areas of higher groundwater elevation move in to fill withdrawals. This phenomenon is most pronounced near the city of Salinas where a groundwater trough has shifted the hydrologic gradient away from the Bay, northeast towards the East Side subarea (Brown and Caldwell, 2015). In general, specific capacity values (used to describe the productivity of wells in a formation) for wells in the Basin are smallest in the northern end and tend to increase to the south (MCWRA, 2006).

Recharge in the lower basin portion of the Salinas Valley is largely by infiltration along the channel of the Salinas River (~30% of total recharge) and its tributaries (~20% of total recharge). The second major source of recharge is irrigation return water (~40%). The remaining recharge is from infiltration and percolation of precipitation over the valley floor, subsurface inflow, and seawater intrusion (MCWRA, 2006). The sections that follow investigate the characteristics of the aquifer in more depth.

In general the active groundwater in the Salinas Valley Basin is considered to be water resources located in the top 800 feet of the underlying aquifer. It is the source of all groundwater withdrawals that serve the beneficial uses of agricultural and municipal water use in the Valley.

As discussed previously in Section 1.1.2.2, the Salinas Valley Groundwater Basin generally has been separated into four hydrologically-linked subareas: the Pressure Area, East Side Area, combined Forebay and Arroyo Seco Areas, and the Upper Valley Area. The Basin subareas are shown in Figure 15 along with the general groundwater flow directions between them based on Brown and Caldwell (2015). However, there is local variability in flow direction depending location, season, and aquifer depth.

The Salinas Valley Groundwater Basin is functionally one unit in that all subareas are hydrologically connected. Although there are no barriers to the horizontal flow between subareas, groundwater flow in certain parts of the aquifer does slow due to differences in the subsurface stratigraphy. Examples include flow from the Pressure Area to the East Side Area and flow from the Forebay Area to the Pressure Area. The "boundaries" between areas have been identified as zones of transition between different depositional environments in past millennia (MCWRA, 2006). Figure 16 presents a profile of the Basin showing the general connectivity of all areas and Table 10 presents some basic characteristics of each of the hydrologic subareas. Each of the units is described in further detail below.

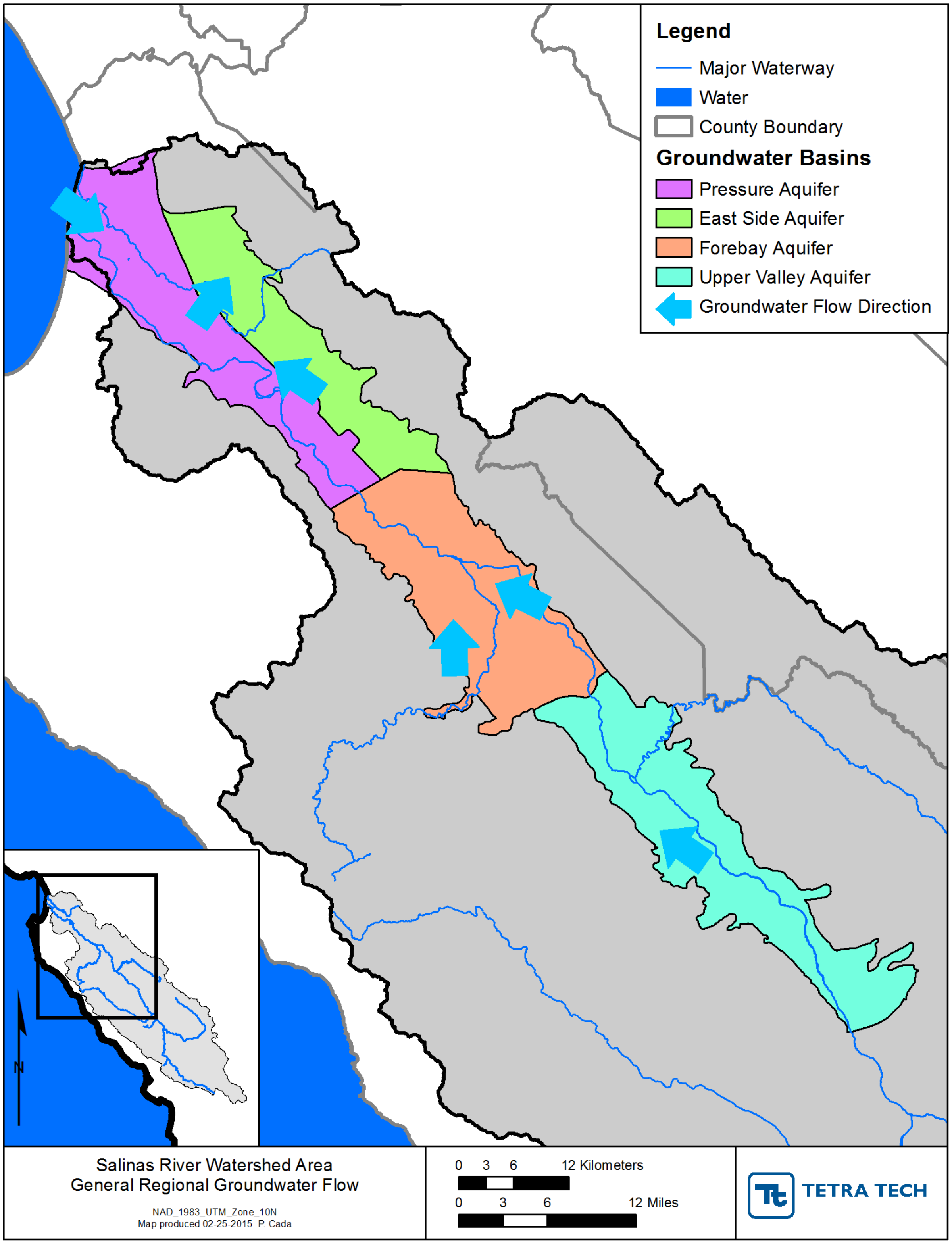


Figure 15. Regional groundwater flow direction in the Salinas Valley (based on information from Brown and Caldwell, 2015)

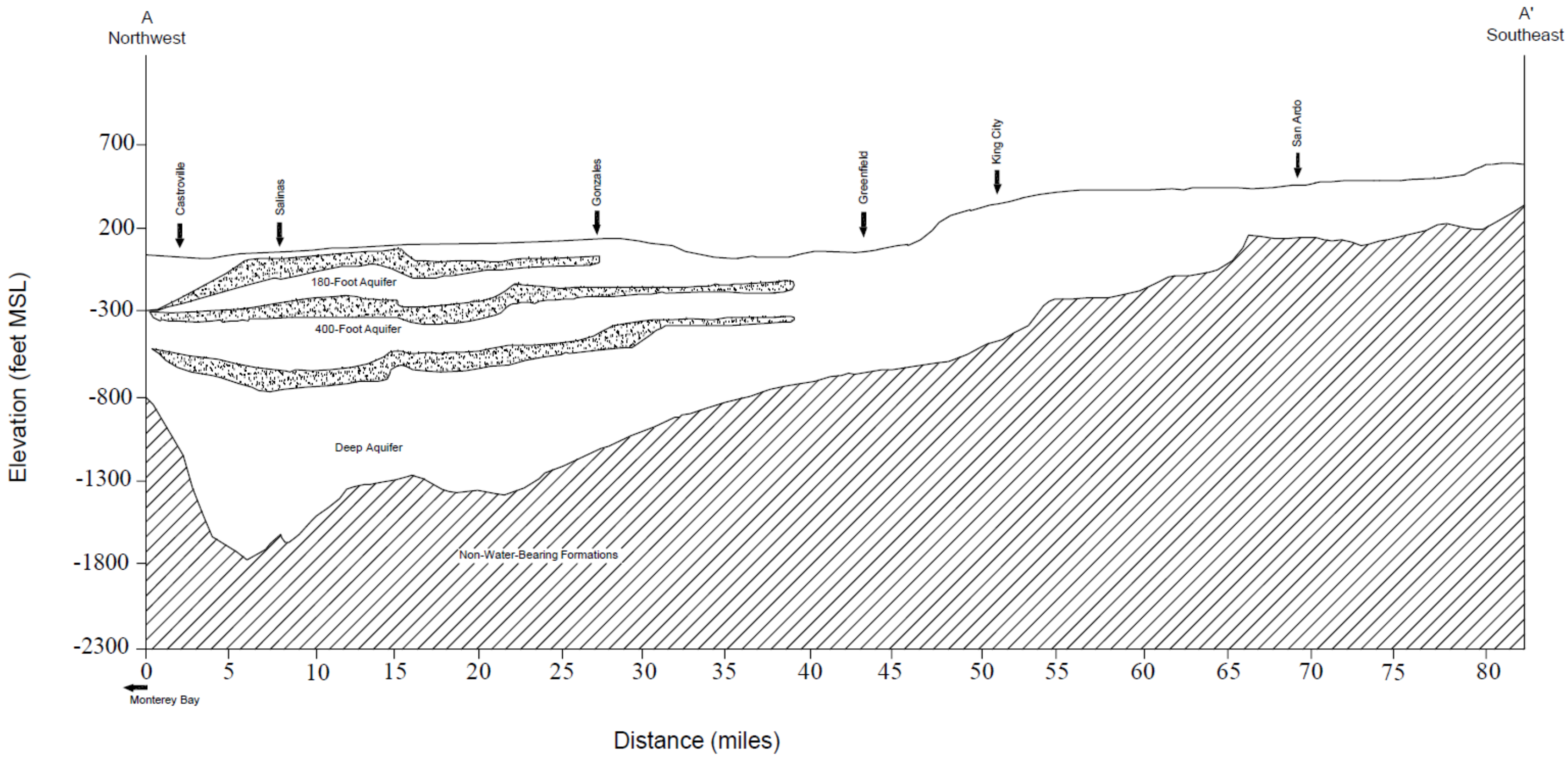


Figure 16. Lengthwise cross section of the Salinas Valley Groundwater Basin (Source: MCWRA, 2006)

Table 10. Characteristics of the Salinas Valley aquifer subareas

Aquifer	Depth Below MSL (ft)	Thickness (ft)	Specific Capacity (gal/min/ft)	Correlated Geologic Formation
Pressure 180	100	50–200	60	Aromas Sands, Paso Robles, Valley Fill
Pressure 400	300–350	200	60*	Aromas Sands, Paso Robles
East Side	NA	NA	26	Aromas Sands, Paso Robles
Forebay	NA	NA	100	Aromas Sands, Paso Robles
Arroyo Seco	NA	NA	100	Aromas Sands, Paso Robles
Upper Valley	NA	NA	NA	NA
Deep Aquifer	NA	NA	NA	Paso Robles

* Assumed to be approximately equal to values in the Pressure 180-ft aquifer

1.1.6.2.1 Pressure Area

The Pressure Area is located in the northern part of the Salinas Valley, west of the East Side Aquifer. This subarea consists of three separate confined aquifers due to the presence of the SVA, which hydrological separates the area vertically as shown in Figure 17. The pressure area is sometimes referred to by the names of these aquifers: the Pressure 180-Foot Aquifer, the Pressure 400-Foot Aquifer, and the Deep Aquifer (also referred to as the 900-Foot Aquifer) (MCWRA, 2006).

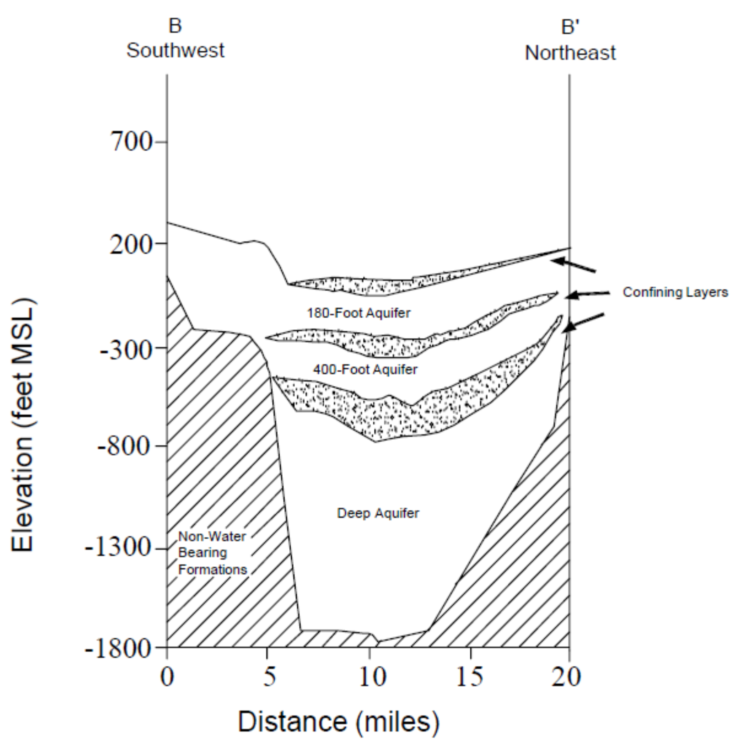


Figure 17. Cross section of the Pressure Area aquifer looking southwest (Source: MCWRA 2006)

SVA

Shallow groundwater in the Pressure Area is typically found perched on top or located within the SVA overlying and confining the Pressure 180-Foot Aquifer. It is not a source of water for agricultural or municipal purposes, however (Kennedy/Jenks Consultants, 2004). Its major relevance is that inadequate well seals sometimes allow the relatively very poor water quality of the perched zone to directly enter the deeper aquifers (Harding ESE 2001). There is also some evidence of contribution from the SVA directly to the Salinas River in the Marina area.

The SVA has been identified by Kennedy/Jenks Consultants (2004) as scattered, thin, laterally discontinuous yellow sandy clay layers typically less than 100 feet thick in the area west of Salinas, thinning to approximately 25 feet near Salinas (CA DWR, 1973) and pinching out east of Salinas. The formation typically extends vertically from the ground surface to approximately 100–150 feet below mean sea level (MSL). The SVA extends laterally from Monterey Bay south to Chualar and from Fort Ord east to an irregular contact at the Pressure Area/East Side Area boundary. Two potential gaps in the SVA identified by Kennedy/Jenks Consultants (2004) may create locally unconfined or semi-confined conditions in the Pressure 180-Foot Aquifer.

180-Foot Aquifer

The 180-Foot Aquifer name was derived from its approximate depth beneath the valley floor. It is the shallowest major aquifer within the Pressure subarea. It was also one of the earliest targets of groundwater withdrawals for agricultural use in the Basin. There is a bit of uncertainty as to which geologic formations the Pressure 180-Foot Aquifer correlates to, but it is agreed that it spans more than one stratigraphic unit. CA DWR (1970, 1973) correlates the aquifer to lower valley terrace deposits and upper Aromas Sands, whereas Leedshill-Herkenhoff, Inc. (1984) correlates the aquifer with the Paso Robles Formation. CA DWR (1973) and Harding ESE (2001) assign the aquifer to Valley Fill and Greene (1970) places it in the upper Aromas Sands Formations (MCWRA, 2006).

The depth and thickness of the Pressure 180-Foot Aquifer is variable, but generally the top is encountered at about 100 feet below MSL, increasing in depth slightly from southeast near Salinas to the northwest near the ocean. Individual sand bodies are typically 100–150 feet thick, although they range in thickness from less than 50 feet to greater than 200 feet where the Pressure 180- Foot Aquifer and the Pressure 400-Foot Aquifer appear to be in contact (Kennedy/Jenks Consultants, 2004; CA DWR, 1970 and 1973; MCWRA, 2006). Recharge to the Pressure 180-Foot Aquifer occurs where SVA pinches out in the Forebay Area and where it is exposed on the floor of the Monterey Bay (Todd, 1989; MCWRA, 2006). Specific capacities of wells in this aquifer are reported to be on the order of 60 gal/min/ft (MCWRA, 2006).

Although the 180-Foot Aquifer is usually described as a single aquifer within the Salinas Valley, it has been divided into upper and lower units beneath former Fort Ord. The upper portion of the fluvial valley fill deposits beneath former Fort Ord is typically comprised of sand; this unit is called the Upper 180-Foot Aquifer and is about 20–60 feet thick. The Upper 180-Foot Aquifer is separated from the lower gravelly portion of the valley fill deposits by about 20 feet of silty or clayey beds. The gravelly portion is called the Lower 180-Foot Aquifer and is up to 120 feet thick. A seasonal hydraulic head difference of several feet (about 20 feet near the active Fort Ord drinking water supply wells) has been observed between these two members of the 180-Foot Aquifer (Harding ESE, 2001).

The Upper 180-Foot Aquifer has a distinctly different seasonal response to pumping in the Salinas Valley than does the Lower 180-Foot Aquifer. This reflects the degree to which there is hydraulic communication to the aquifers within the valley. Although groundwater elevations rise and fall seasonally as monitored in the 180-Foot and 400-Foot Aquifers, the groundwater flow directions in the Upper 180-Foot Aquifer differ from the Lower (Harding ESE, 2001).

Quarterly monitoring data indicate an **eastward** gradient in the Lower 180-Foot Aquifer that steepens during the irrigation season but does not change direction significantly. In contrast, groundwater flow direction at the same location in the Upper 180-Foot Aquifer indicate a **southeast** groundwater flow. The difference in flow directions suggests the Upper 180-Foot Aquifer is not in direct hydraulic communication with the 180-Foot Aquifer beneath the Salinas Valley. If it was, groundwater should flow east or northeast directly towards the Valley. Instead, it appears that the Upper 180-Foot Aquifer is forced to drain through a pinch-out in the Intermediate 180-Foot Aquitard located between the Main Garrison and East Garrison of Fort Ord. There it flows into the Lower 180-Foot Aquifer, then continuing east towards the Salinas Valley (Harding ESE, 2001).

400-Foot Aquifer

The SVA underlying the Pressure 180-Foot Aquifer is referred to as the 180/400-Foot Aquitard, which separates the Pressure 180-Foot Aquifer and Pressure 400-Foot Aquifer. The aquitard is, generally, 50–100 feet thick,although it can be as much as 250 feet thick (Kennedy/Jenks Consultants, 2004; MCWRA, 2006). MCFCWCD (1960) describes two "holes" in the aquitard, one under the Salinas River near Blanco and the other under the old Salinas River bed near the coast. The Pressure 180-Foot Aquifer and Pressure 400-Foot Aquifer also appear to be interconnected in places between Salinas and Chualar and south of Chualar (MCFCWCD, 1960; MCWRA, 2006).

The Pressure 400-Foot Aquifer underlies the 180/400-Foot Aquitard and is an areally extensive layer of coarse- and fine-grained sand and gravel. The top of the aquifer is typically 300–350 feet below MSL (Kennedy/Jenks Consultants, 2004), however, the depth of the top and thickness of the aquifer shows large variability increasing from southeast to the northwest (Thorup 1976). CA DWR (1970, 1973) indicates that near Salinas the aquifer consists of a single thick permeable bed approximately 200 feet thick which, tends northwest towards Castroville. CA DWR (1970, 1973) and Greene (1970) suggest that the upper portion of the Pressure 400-Foot aquifer correlates to the Aromas Sands and the lower portion correlates to the Paso Robles Formation. Thorup (1976) correlates this aquifer with the Paso Robles Formation (MCWRA, 2006). Similar to the 180-Foot Aquifer, the SVA prevents direct recharge from rainfall to the 400-Foot Aquifer, but the 180/400 Aquitard displaces recharge to the 400-Foot Aquifer further south, possibly to the Arroyo Seco area (Harding ESE, 2001).

Monterey Bay Interface

Both the 180-Foot and 400-Foot Aquifers outcrop along the canyon walls of Monterey Bay where they interface with seawater. Groundwater withdrawal from the Salinas Valley, primarily for agricultural irrigation, has steadily resulted in seawater intrusion in the 180-Foot Aquifer and the 400-Foot Aquifer proportional to the use of each aquifer. Seawater has currently intruded (as defined by chloride concentrations exceeding 500 mg/L) about 6 miles in the 180-Foot Aquifer and about 3 miles in the 400-Foot Aquifer along the Salinas Valley floor (Harding ESE, 2001). Beneath the Marina and former Fort Ord area, seawater has intruded about 2 miles in the 180-Foot Aquifer and about 3 miles in the 400-Foot Aquifer, although the extent of the intrusion in the 400-Foot Aquifer is unclear (Harding ESE, 2001).

1.1.6.2.2 East Side Area

The East Side Area is located in the northeast portion of the Salinas Valley from approximately Santa Rita to Gonzales, east of the Pressure Area. This area is generally bounded by the foothills of the Gabilan Range on the northeast and State Highway 101 on the southwest (Kennedy/Jenks Consultants, 2004). Hydrogeologically, this area is characterized by a series of connected alluvial fans that are built up by small streams draining the Gabilan Range (Kennedy/Jenks Consultants, 2004). CA DWR originally defined this area in 1946 as the area bounded by the Pressure Area on the west and the Forebay Area on the south, containing unconfined groundwater that is typically recharged by streams draining the Gabilan Range and directly from precipitation during wet years (MCWRA, 2006).

The East Side Area generally consists of a poorly bedded sequence of gravel, sand, silt, and sandy and gravelly clay (MCFCWCD, 1960). The sands and gravel beds of the East Side area are generally thinner and less continuous than in the Pressure Area and typically do not correlate well between wells due to the complex depositional and erosional conditions associated with alluvial fans. The principal blue clay beds that are found in the Pressure Area are rare in the East Side Area. Studies in the area suggest that the blue clay onlaps and pinches out onto alluvial fan facies in the East Side Area (Kennedy/Jenks Consultants, 2004; MCWRA, 2006).

Lacking confining clay layers, confined aquifer conditions are not observed in the East Side Area. The sediments that make up the East Side Area can be time-stratigraphically correlated to equivalent zones in the Pressure Area, however (Kennedy/Jenks Consultants, 2004). The designation of these stratigraphic zones has been used to analyze the lateral connectivity between the aquifers of the Pressure and East Side Areas. As reported by Simpson in 1946, the aquifers in this area are generally unconfined with some localized areas of slight pressure due to local confinement. Specific capacities of wells in the East Side Area are reported to be on the order of 26 gal/min/ft (MCWRA, 2006).

1.1.6.2.3 Forebay and Arroyo Seco Area

The Forebay Area is located in the center of the Salinas Valley and extends from the town of Gonzales in the north to approximately three miles south of Greenfield. The Forebay Area is bounded by the Pressure and East Side Areas on the northwest, the Arroyo Seco Area on the southwest, and the Upper Valley Area on the southeast. The non-water bearing rocks that define its boundaries include Quaternary terrace deposits native to the subarea or Monterey Shale of the Santa Lucia Range to the west, and Quaternary terrace deposits or alluvium with granitic rocks of the Gabilan Range to the east.

The primary water-bearing units in the Forebay Area are the same as those found in the Pressure and East Side Areas. Groundwater in this area is unconfined and occurs in lenses of sand and gravel that are interbedded with larger units of finer grained material (CA DWR, 2004). The Deep or 900- Foot Aquifer found in the Pressure and East Side Areas is also present in the Forebay Area. This deeper aquifer consists of alternating layers of sand-gravel mixtures and clays rather than a distinct aquifer and aquitard (Montgomery Watson, 1994). Specific capacities for wells in the Forebay Area have been reported to be on the order of 100 gal/min/ft (MCWRA, 2006).

The Forebay Area is also the primary zone for recharge of the Pressure and East Side Areas of the Salinas Valley Groundwater Basin. This occurs where the SVA pinches out at the southern end of the Pressure and East Side Areas and the northern end of the Forebay Area. Sources of recharge include percolation from the Salinas River (and its tributaries) and groundwater outflow from the Upper Valley Area and the Arroyo Seco Area (Simpson, 1946; MCWRA, 2006).

The Arroyo Seco Area is located southwest of the Forebay Area and extends from the confluence of the Arroyo Seco and the Salinas River south to approximately three miles south of Greenfield, where its southern boundary meets that of the Forebay Area. This area is generally thought of as an extension of the Forebay Area, with the major distinction of being recharged primarily by the Arroyo Seco from which its name is derived. Soils in the Arroyo Seco Area are characterized by coarse texture, 85% of which are deep, uniform, and highly permeable. The Arroyo Seco streambed is also characterized by permeable sediments, described by CA DWR as a broad gravel wash (MCWRA, 2006).

1.1.6.2.4 Deep Aquifer

The term Deep Aquifer is typically used to describe aquifers that exist at depths greater than 800-feet that are thought to be present throughout the entire Salinas Valley Groundwater Basin; however, it is currently undefined both geologically and areally. Some studies have broken the deep aquifer into subareas of its own according to depth, including the 800-Foot Aquifer, 900-Foot Aquifer, 1,000-Foot Aquifer, and the 1,500-Foot Aquifers (Harding ESE, 2001). Various studies have correlated the Deep Aquifer with the

Paso Robles Formation, but in some locations it is considered to be Purisima Formation, while some recent evidence suggests that it may extend into the Santa Margarita Formation (MCWRA, 1995).

Due the greater depth and higher cost of installation, most production wells (municipal or agricultural) have not penetrated the Deep Aquifer. Those that have are generally limited to the Pressure subarea where wells have been installed progressively deeper to avoid saline contaminated water. Generally, water from this aquifer contains higher natural concentrations of salt and has high sodium adsorption ratios (SAR). For this reason, growers in the Salinas Valley have found the Deep Aquifer to be less desirable as a source of irrigation water (Harding ESE, 2001).

Seawater intrusion has not been detected in Deep Aquifer wells, but there is no evidence indicating that the Deep Aquifer is not connected to the ocean. Due to lack of evidence to the contrary it is currently assumed that the Deep Aquifer in the Pressure Area, like the 180-foot and 400-foot aquifers above it, is connected to the ocean and vulnerable to seawater intrusion. Water levels in Deep Aquifer wells have fallen approximately 60 feet since the late 1970s and are now substantially below sea level. Total extraction over this period of time has averaged less than 5,000 acre-feet per year (MCWRA, 1995).

1.1.6.3 Aquifer and Salinas River Interactions

Analysis of limited groundwater elevation data near the Salinas River and review of published water levels from the aquifers beneath the Salinas Valley indicate that the Salinas River is not gaining water from the Pressure 180-Foot Aquifer (Harding Lawson Associates, 1994). This is due to the river stage elevations being above sea level, while the groundwater elevations in the 180-Foot Aquifer are commonly below sea level. Thus, the potential is for flow from the river to percolate to the 180-Foot Aquifer through potential gaps in the SVA, though this is thought to be minimal. The Salinas River loses water to aquifers within the Upper Valley and Forebay subareas, as well, but becomes a gaining stream roughly north of Chualar where the SVA is present. This indicates that the River must be gaining water from the shallow aquifer of the SVA (MCWRA, 1996). Recharge from the Salinas River to any aquifers except the shallow perched aquifer within the Pressure subarea is probably minor due to the presence of the SVA. Eastward flowing groundwater from the former Fort Ord area is also thought to discharge, at least partially, to the Salinas River (Harding ESE, 2001).

2 Impairments and Listings

2.1.1.1 Clean Water Act Section 303(d) List

Section 303(d) of the federal Clean Water Act requires every state to evaluate its waterbodies and maintain a list of waters that are considered "impaired" either because the water exceeds water quality standards, or does not achieve its designated use. For each waterbody on the CCRWQCB's 303(d) impaired waters list, the agency must develop a total maximum daily load (TMDL) that contains an analysis of pollutant sources and a linkage to instream impairments.

2.1.1.2 Beneficial Uses

Waterbodies may be listed as impaired if they are not meeting their designated beneficial uses. Beneficial uses for all waterways in the Salinas River Watershed Area are described in Appendix A based on the Central Coast Basin Plan's "identified uses of inland surface waters" (CCRWQCB, 2011). Beneficial uses range from municipal and domestic water supply, agricultural supply, groundwater recharge, water contact and non-contact recreation, aquatic habitat, and more.

2.1.1.3 Water Quality Objectives and Guidelines

The impairments in this watershed are tied to the agricultural supply beneficial use. The Water Quality Control Plan for the Central Coast Basin (2011) contains guidelines for interpretation of quality of water for irrigation (Table 11); these guidelines serve as 303(d) listing criteria for waters with a beneficial use of Agricultural Supply (AGR). Three guidelines for salt-related constituents in water are provided – electrical conductivity, chloride mass, and sodium mass. Total dissolved solids is not listed directly as a guideline, but a conversion factor from conductivity is given in the Plan. Salinity (as measured in parts per thousand, or ppt) is not discussed at all, but is listed here for reference. In Section 5 (Data Analysis), surface water quality monitoring data are compared to the thresholds in Table 11.

Table 11. Guidelines for interpretation of quality of water for irrigation (Central Coast Basin Plan, 2011)

Chemical of Parameter	Threshold
303(d) Listing Guideline	
Chloride (Cl)	106 mg/L
Sodium (Na)	69 mg/L
Electrical Conductivity (COND)[1]	3,000 µS/cm
Guidelines Calculated from Conductivity	
Total Dissolved Solids (TDS)[2]	1,920 mg/L
Salinity (Sal)[3]	1.92 ppt

[1] Listing is for 3.0 mmho/cm which is equivalent to 3000 µS/cm.

[2] TDS is calculated as the COND guideline (in mmho/cm) multiplied by 640, as specified in the Plan.

[3] Salinity in ppt is approximately equal to TDS in mg/L multiplied by 0.001.

The Plan also contains water quality objectives for specific surface waters and groundwaters (Table 12) for total dissolved solids, chloride mass, and sodium mass. The objectives provide a baseline for evaluating water quality management, and may also be used as listing criteria. However, the Plan states that the Regional Board can use judgment to balance uses with water quality objectives. In addition the objectives are interpreted as annual means and are applied to gross areas of water bodies[2]. For purposes of subsequent comparative analyses in Section 5, the TDS guideline has been converted to electrical conductivity and salinity.

Table 12. Water quality objectives (annual means) related to salts for Salinas River Watershed area (Central Coast Basin Plan, 2011)

Sub-Area	Constituents Specified in Plan			Calculated from TDS	
	TDS (mg/L)	Chloride (mg/L)	Sodium (mg/L)	Electrical Conductivity (uS/cm)[1]	Salinity (ppt)[2]
Surface Water Quality Objectives					
Salinas River—above Bradley	250	20	20	391	0.25
Salinas River—above Spreckels	600	80	70	938	0.60
Gabilan Tributary	300	50	50	469	0.30
Diablo Tributary	1,200	80	150	1,875	1.20
Nacimiento River	200	20	20	313	0.20
San Antonio River	250	20	20	391	0.25
Groundwater Quality Objectives					
Upper Valley	600	150	70	938	0.60
Upper Forebay	800	100	100	1,250	0.80
Lower Forebay	1,500	250	150	2,344	1.50
180-foot Aquifer	1,500	250	250	2,344	1.50
400-ft Aquifer	400	50	50	625	0.40

[1] Electrical conductivity in µS/cm is calculated as TDS objective divided by 0.640.

[2] Salinity in ppt is approximately equal to TDS in mg/L divided by 1,000.

2.1.1.4 Impairments

Seven reaches are assessed on the 2010 303(d) list as having salt-related impairments in the Salinas River Watershed area (Table 13 and Figure 18), including impairments due to chloride, sodium, electrical

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[2] The Plan states erroneously in the narrative that the objectives are median values; the footnote to the objective table is correct and notes that the values are annual means.

conductivity, and total dissolved solids (EPA, 2010). This report addresses salt-related impairments in the Lower Salinas River Watershed area, which includes the Lower Salinas River, Santa Rita Creek, and Alisal Creek.

Following publication of the 2010 303(d) list, it was discovered that Santa Rita Creek's beneficial uses may have been improperly assessed when the listing was developed. There are two Santa Rita Creeks in the Salinas River watershed: the one tributary to the Reclamation Canal (which is the subject of the 303(d) listing for sodium), and another in the upper Salinas watershed in San Luis Obispo County. The reach in San Luis Obispo County has a beneficial use of AGR, whereas the reach tributary to the Reclamation Canal does not. The Agricultural Supply guidelines were mistakenly applied to Santa Rita Creek in the Reclamation Canal HUC8. Documentation of the listing is included here for completeness, but for the purposes of this report Santa Rita Creek is assumed to be un-impaired for sodium or any other salt-related analyte.

In addition to salt-related impairment, thirty seven waterbodies are on the 303(d) impairment list for these three HUCs. Listed waterbodies range from rivers and streams to lakes, reservoirs, estuaries, bays, and harbors. Categories of impairment across the watershed are: nutrients (chlorophyll-a, low dissolved oxygen, nitrate, unionized ammonia, and generic "nutrients"), metals/metalloids (boron, nickel, copper, mercury, and generic "metals"), pesticides (chlorpyrifos, diazinon, chlordane, DDD, toxaphene, dieldrin, and generic "pesticides"), sediment (sedimentation/siltation and turbidity), toxicity (sediment and unknown toxicities), pathogens (enterococcus, E. coli, fecal coliform, total coliform, and generic "pathogens"), other organics (PCBs, and "priority organics"), as well as miscellaneous listings (pH and water temperature). Impairments related to nutrients (phosphorus and nitrogen species) were addressed in a recent nutrient TMDL, and those specific nutrient-related impairments are provided in Appendix B.

Table 13. Salt-related impairments for Salinas River Watershed area from the 2010 303(d) list

Waterbody	HUC Location	List of Salt-Related Impairments
Lower Salinas River Watershed Area Impairments		
Lower Salinas River	Lower Salinas	Chloride, Sodium, Electrical Conductivity, Total Dissolved Solids
Santa Rita Creek [1]	Reclamation Canal	Sodium
Alisal Creek	Lower Salinas	Sodium
Upper Salinas River and Estrella River HUC 8 Impairments		
Upper Salinas River	Upper Salinas	Chloride, Sodium
San Lorenzo Creek	Upper Salinas	Chloride, Sodium, Electrical Conductivity
Cholame Creek	Estrella	Chloride, Sodium, Electrical Conductivity
Estrella River	Estrella	Chloride, Sodium

[1] Santa Rita Creek is included in this table since it is technically on the 2010 303(d) list. However, its beneficial uses may have been improperly assessed so it is not considered impaired for the purposes of this report.

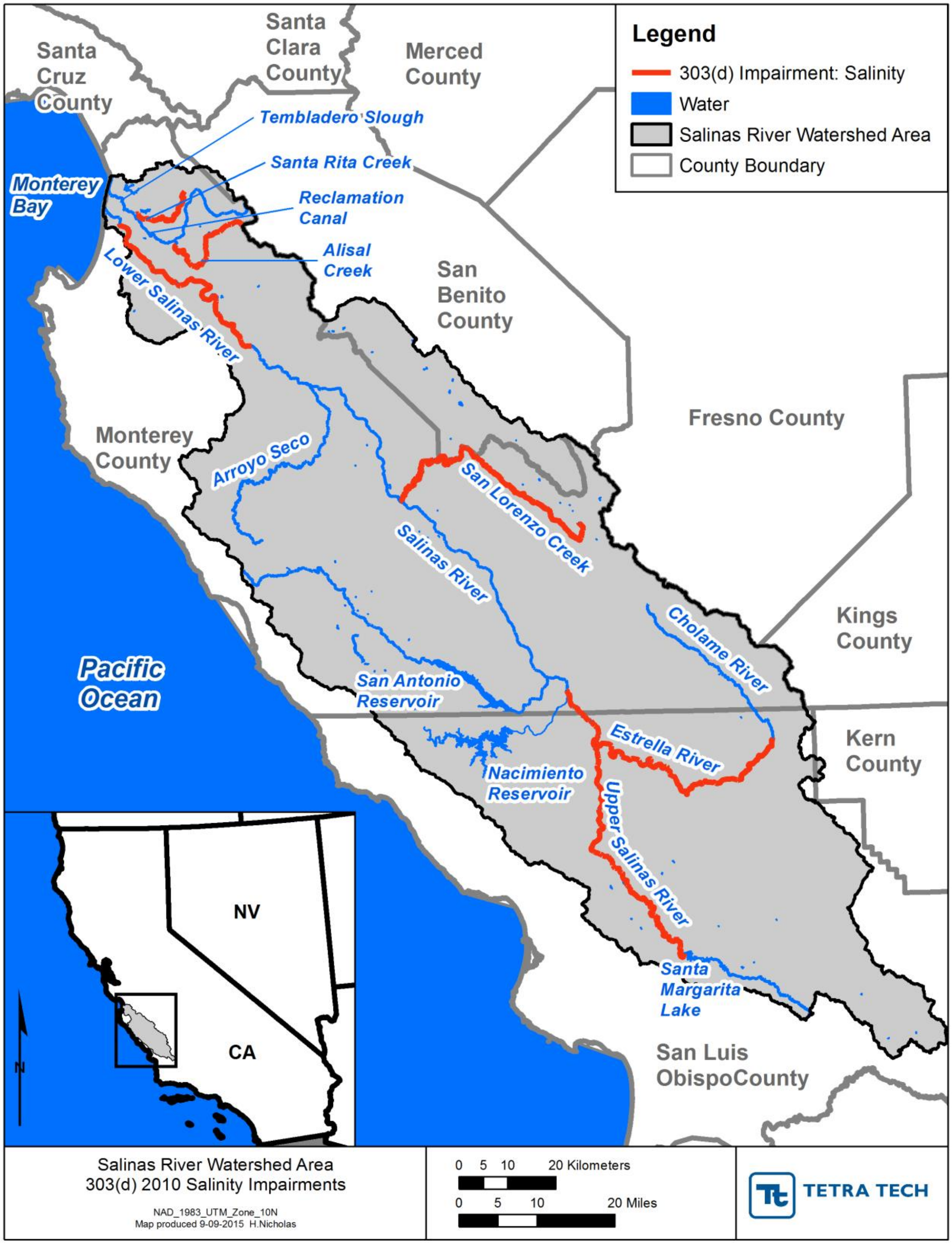

Figure 18. Reaches with 2010 303(d) salt-related impairments within the Salinas River Watershed area

3 Data Inventory

A significant volume of monitoring data has been collected by the State, other agencies, and stakeholders within the Salinas River Watershed area. Data compiled for this technical memo include surface and groundwater monitoring data of water flows and storage, as well as water quality sampling. Data sources range from existing agricultural monitoring and reporting programs, the Groundwater Ambient Monitoring and Assessment (GAMA) program, the Central Coast Ambient Monitoring Program (CCAMP), the US Geological Survey (USGS), the Central Coast Water Quality Preservation (CCWQP) Cooperative Monitoring Program (CMP), etc. This section details an inventory of key data sources, as well as hydrology and water quality sampling data for both surface water and groundwater across the Salinas River Watershed area.

3.1 Key Data Sources

There are many different agencies that conduct surface and groundwater monitoring across the Salinas River Watershed area. The types of data compiled from each agency and program, as well as a summary of the sampling program are described in Table 14.

Table 14. Sources and descriptions of surface and groundwater monitoring data for the Salinas Watershed area

Agency	Program	Hydrology Data		Water Quality Data		Description
		SW	GW	SW	GW	
United States Geological Survey (USGS)		X		X	X	Federal agency providing water quality and quantity data nationwide for the purposes of better understanding all water resources.
Central Coast Water Quality Preservation (CCWQP)	Central Coast Ambient Monitoring Program (CCAMP)			X		Regional water quality monitoring and assessment program to provide scientific information to the Regional Board staff and public for the purpose of protecting, restoring, and enhancing waters of central California.
Central Coast Water Quality Preservation (CCWQP)	Cooperative Monitoring Program (CMP)			X		Non-profit corporation founded by farmers to monitor water quality on behalf of irrigated agriculture in compliance with Central Coast Regional Water Board's Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands.
Monterey Bay National Marine Sanctuary (MBNMS)	Snapshot Day			X		Volunteer program conducts water quality sampling across the Marine Sanctuary to increase information and public awareness about water quality issues in the watershed. Sampling includes basic water quality, nutrients, and bacteria.
Elkhorn Slough National Estuarine Research Reserve (ESNERR)				X		One of 28 National Estuarine Research Reserves nationwide, established as a field laboratory for scientific research and estuarine education. Administered by the National Oceanic and Atmospheric Administration and managed by California Department of Fish and Wildlife. Water

Agency	Program	Hydrology Data		Water Quality Data		Description
		SW	GW	SW	GW	
						quality sampling extends outside of Elkhorn Slough to entire lagoon area.
California State University Monterey Bay (CSUMB)	Central Coast Watershed Studies (CCoWs)			X		This study team conducts watershed and ecosystem research and education in support of sustainable ecosystem management in the Central Coast region. Studies range from storm water monitoring, wildlife ecology, land use/ land cover assessment, and snowpack modeling.
University of California at Davis, Marine Pollution Studies Laboratory at Granite Canyon				X		Granite Canyon laboratory conducts applied toxicology research in watersheds, estuaries, and coastal waters.
State Water Resources Control Board (SWRCB)	Surface Water Ambient Monitoring Program (SWAMP)			X		This program is tasked with assessing water quality in all of California's surface waters. Monitoring is conducted directly and through collaborative partnerships, and it provides data to support water resource management.
	Groundwater Ambient Monitoring and Assessment Program (GAMA)				X	GAMA is California's comprehensive groundwater quality monitoring program. GAMA tests groundwater sources for naturally occurring and anthropogenic chemicals, and compiles test rests with existing groundwater quality data from several agencies in the GeoTracker system.
California Department of Water Resources (CA DWR)				X		CA DWR collects and analyzes groundwater data, investigates and reports groundwater conditions, and encourages integrated water management.
Monterey County Water Resources Agency (MCWRA)		X	X			MCWRA's mission statement is to manage, protect, and enhance the quantity and quality of water and provide specific flood control services for Monterey County. MCWRA conducts water quality sampling; however, the data are not publically available.
Central Coast Regional Water Quality Control Board	Irrigated Lands Regulatory Program (ILRP)				X	The ILRP was initiated in 2003 to prevent agricultural runoff from impairing surface waters. All commercial irrigated lands are required to obtain regulatory coverage through this program.
Central Coast Regional Water Quality Control Board	Groundwater Assessment and Protection (GAP)				X	The GAP program is a new and integral component of the CCAMP regionally scaled water quality monitoring and assessment program. Sometimes referred to as CCAMP-GAP.

3.2 HYDROLOGY

Collected data related to hydrology include stream flow gaging, reservoir release data, and groundwater storage and extraction data.

3.2.1 Surface Water

Information on surface water flow includes data from the USGS and the MCWRA (Figure 19). There are a total of 25 USGS stations across the watershed area with historical data. Thirteen of USGS stations provide recent flow data, and are summarized in Table 15 with the MCWRA flow monitoring data. The full inventory of all USGS gages and periods of record across the watershed can be found in Appendix D.

The Monterey Regional Water Pollution Control Agency (MRWPCA) also records flow and water quality data associated with recycled water usage in the Lower Salinas Valley. These data have been formally requested, but have not been received at the writing of this memo.

Table 15. Flow data for surface waters in the Salinas River Watershed Area

Station ID	Location Name	Reach or Region	Agency	Data Type	Period of Record
11152000	Arroyo Seco near Soledad CA	Arroyo Seco	USGS	Daily flow	1901-present
11152050	Arroyo Seco below Reliz Creek near Soledad CA	Arroyo Seco, close to confluence	USGS	Daily flow	1994-present
11152600	Gabilan Creek near Salinas CA	Gabilan	USGS	Daily flow	1970-present
11152500	Salinas River near Spreckels CA	Lower Salinas, downstream	USGS	Daily flow	1929-present
11152300	Salinas River near Chualar Canyon	Lower Salinas, upstream	USGS	Daily flow	1977-present
11148900	Nacimiento River below Sapaque Creek near Bryson CA	Nacimiento, above Reservoir	USGS	Daily flow	1971-present
11149400	Nacimiento River below Nacimiento Dam near Bradley CA	Nacimiento, below Reservoir	USGS	Daily flow	1957-present
11152650	Reclamation Ditch near Salinas CA	Reclamation	USGS	Daily flow	1970-present
11151700	Salinas River at Soledad CA	Salinas, above Arroyo Seco confluence	USGS	Daily flow	1968-present
11150500	Salinas River near Bradley CA	Salinas, top of Salinas Valley	USGS	Daily flow	1948-present
11149900	San Antonio River near Lockwood CA	San Antonio, above Reservoir	USGS	Daily flow	1965-present

Station ID	Location Name	Reach or Region	Agency	Data Type	Period of Record
11151300	San Lorenzo Creek below Bitterwater Creek near King City CA	San Lorenzo	USGS	Daily flow	1958-present
11147500	Salinas River above Paso Robles CA	Upper Salinas, above Estrella confluence	USGS	Daily flow	1939-present
Nacimiento	Nacimiento Reservoir gage	Below Nacimiento Reservoir	MCWRA	Daily reservoir releases	1958-present
San Antonio	San Antonio Reservoir gage	Below San Antonio Reservoir	MCWRA	Daily reservoir releases	1966-present
aBlanco	Water pump from Blanco Drain area to the Salinas River (water flows naturally throughout the year, but for several months it is supplemented by pumping)	Blanco Drain to the Salinas River	MCWRA	Daily pumping	2010-2013

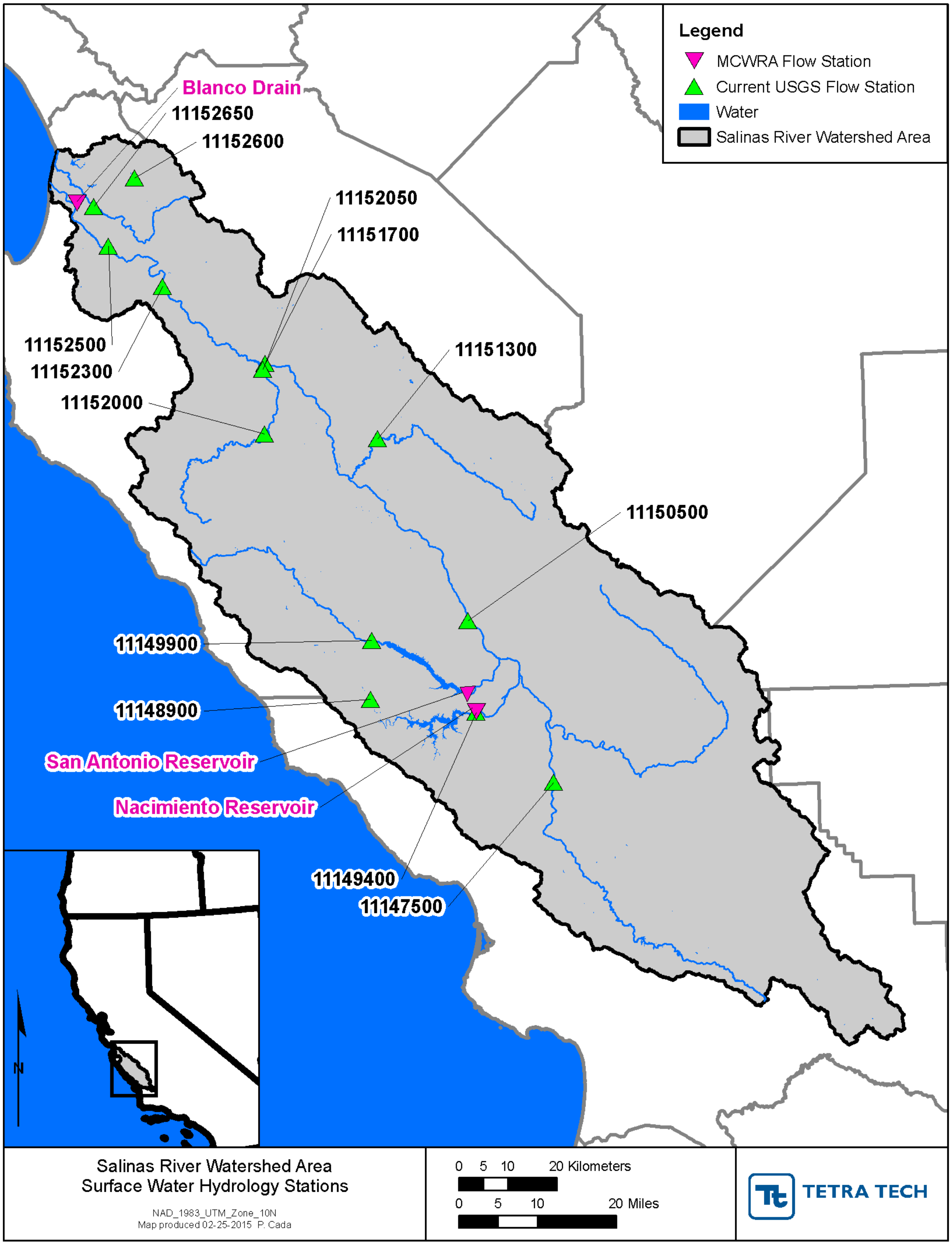

Figure 19. Surface water flow discharge gage locations

3.2.2 Groundwater

The quantity and flux of groundwater in the aquifers of the watershed was characterized by using a combination of available data from MCWRA. The MCWRA has been collecting data across the Salinas Valley for decades, and summaries of the groundwater data (from water table elevation, to groundwater extraction, to physical characteristics of the aquifers) were made available by MCWRA through their website as well as through direct contact with the agency. The summary of available data used to quantify groundwater hydrology is summarized in Table 16.

Table 16. Pumping/recharge data for groundwater in the Salinas River Watershed Area.

Agency	Dataset	Data Description	Period of Record
MCWRA	Groundwater withdrawals	Groundwater extraction totals, organized by end-use from over 300 monitoring wells.	1995-2013
MCWRA	Groundwater levels	Historical groundwater levels for aquifer subareas	1945-1999
MCWRA	Aquifer subarea physical characteristics	Formation depths, thicknesses, and specific capacity for each aquifer subarea	N/A
MCWRA	Major tributary outflows	Average annual outflow for Nacimiento Reservoir, San Antonio Reservoir, and the Arroyo Seco tributary	Unknown[1]

[1] From MCWRA's Monterey County Groundwater Management Plan. Period of record unclear.

3.3 WATER QUALITY

Water quality sampling data for groundwater and surface water across the watershed area were compiled into a master database for analysis.

3.3.1 Surface Water Quality

Water quality sampling data for surface waters across the watershed used in this report come from a total of 9 different agencies. The data sources, which were described in Table 14 are listed below.

1. United States Geological Survey (USGS)
2. CCRWQCB: Central Coast Ambient Monitoring Program (CCAMP)
3. Central Coast Water Quality Preservation (CCWQP): Cooperative Monitoring Program (CMP)
4. Monterey Bay National Marine Sanctuary (MBNMS): Snapshot Day
5. Elkhorn Slough National Estuarine Research Reserve (ESNERR)
6. California State University Monterey Bay (CSUMB): Central Coast Watershed Studies (CCoWs)
7. University of California at Davis, Marine Pollution Studies Laboratory at Granite Canyon (Granite)
8. State Water Resources Control Board (SWRCB): Surface Water Ambient Monitoring Program (SWAMP)

9. California Department of Water Resources (CA DWR)

Table 17 provides an inventory of available water quality data from each sampling agency and program from the Reclamation Canal, Salinas River, and Estrella River HUCs. The full suite of data inventory for salt-related analytes by station is included in Appendix C. A map of all water quality sampling stations with salt data for the nine agencies can be seen in Figure 20. There is a high density of sampling in the Lower Salinas River Watershed area, so Figure 21 provides a closer view of that area.

Table 17. Summary table of water quality sampling data for surface waters in the Salinas River Watershed area

Agency	Program	Count of Stations	Total Count of Samples at all Stations[1]					Period of Record
			CL	COND	NA	SAL	TDS	
CA DWR		2	0	6	0	0	0	1999-2005
CCRWQCB	CCAMP	32	1,104	865	1,008	897	1,105	1999-2012
CCWQP	CMP	26	0	1,061	0	1,067	1,088	2005-2011
CSUMB	CCoWs	65	0	967	0	0	0	2000-2003
ESNERR		11	0	1,685	0	2,200	0	1989-2014
MBNMS	SnapShotDay	40	0	282	0	0	0	2000-2008
SWRCB	SWAMP	20	11	0	3	0	12	2003-2013
UC Davis	Granite Canyon	4	0	44	0	42	0	2008-2009
USGS		1	199	245	198	0	195	1967-2013

1. CL – chloride; COND – conductivity; NA – sodium; SAL – salinity; TDS – total dissolved solids

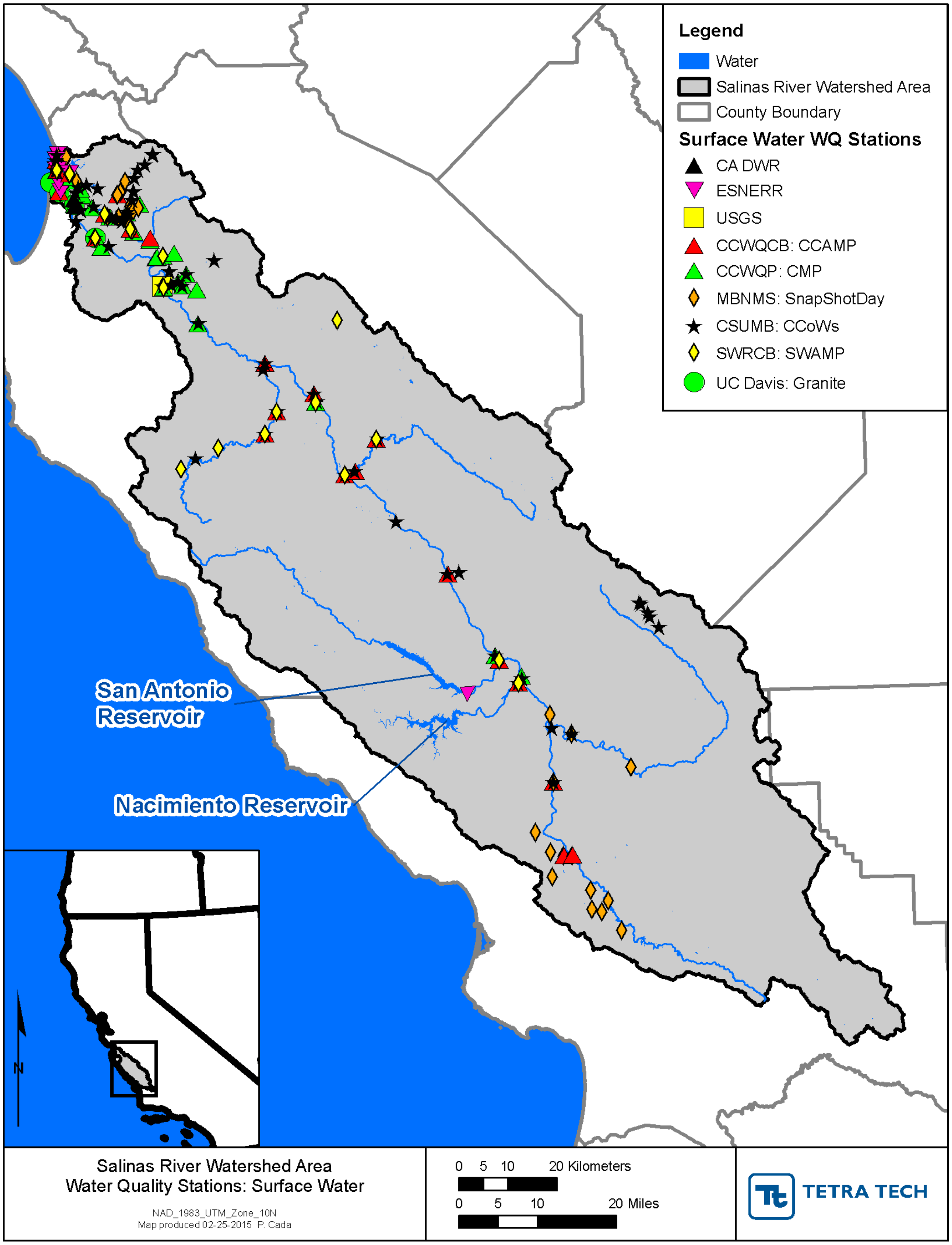

Figure 20. Surface water sampling sites with salt-related water quality data for the Salinas River Watershed area

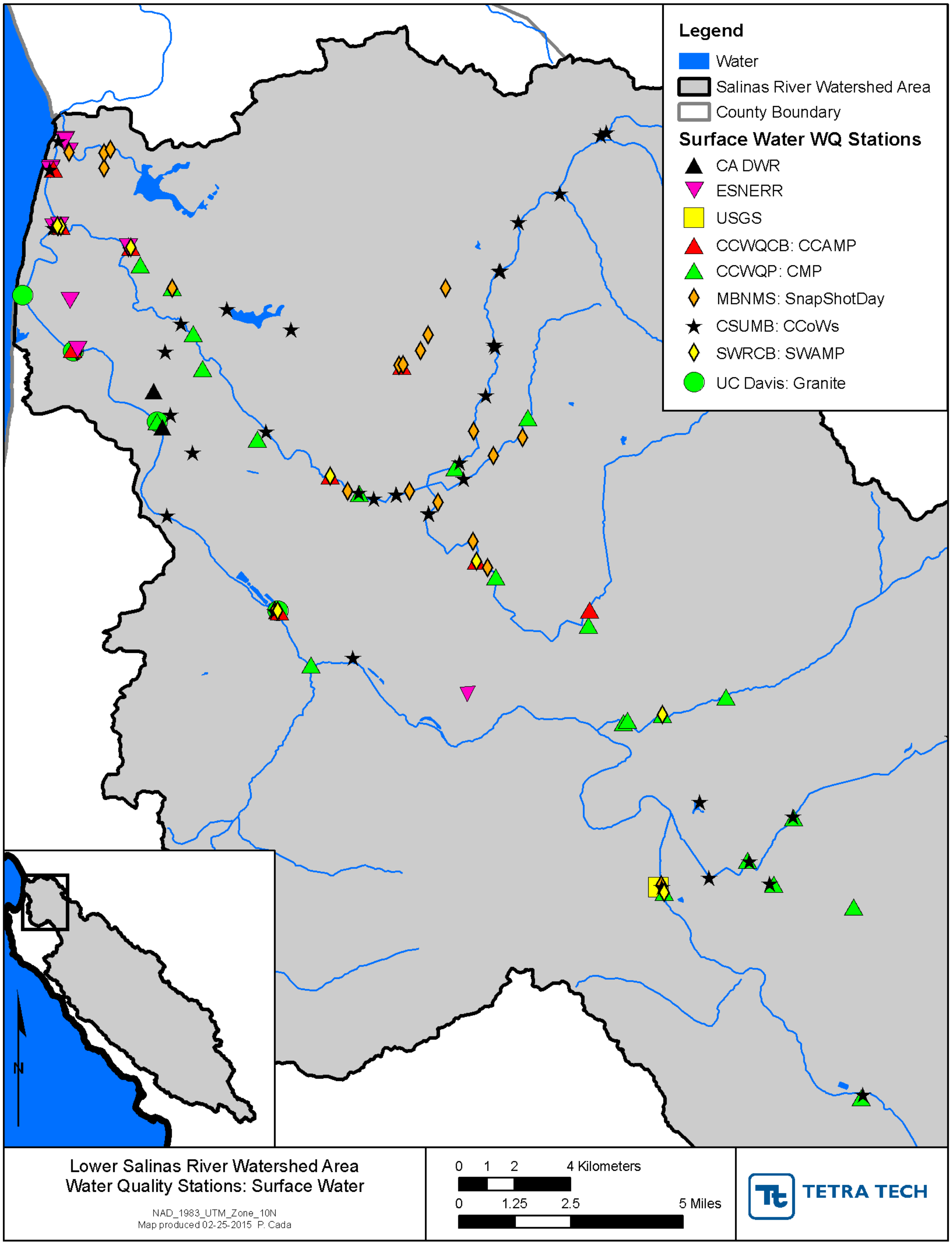

Figure 21. Surface water sampling sites with salt-related water quality data for the Lower Salinas River Watershed area

3.3.2 Groundwater Quality

Water quality data are available from groundwater monitoring wells across the Salinas River Watershed area. The organizations identified for analysis for groundwater sampling are USGS (data available through National Water Information System or NWIS), GAMA (data available through GeoTracker), MCWRA (data not publically available), Groundwater Assessment and Protection (GAP), and the Irrigated Lands Regulatory Program (ILRP). Note that while GAMA was established in 2000, the GeoTracker website includes data from multiple sources, including monitoring conducted prior to 2000. The summary table below details the number of wells present in each groundwater subbasin, and the total count of samples associated with those wells, as well as their period of record (Table 18 and Figure 22). The Pressure aquifer (also known as the 180/400 Foot Aquifer) is divided into coastal and non-coastal samples, based on whether the well is located within the region of recorded seawater intrusion along the coast or further inland. For the purpose of this report and the nature of the impairments, groundwater wells will be analyzed further based on their location in each groundwater aquifer.

Table 18. Water quality data from groundwater wells in the Salinas River Watershed area

Agency	Groundwater Aquifer	Count of Wells	Total Count of Samples at all Stations				Period of Record
			CL	NA	COND	TDS	
GeoTracker GAMA	East Side	359	760	406	695	513	1971-2014
	Forebay	159	204	198	290	290	1971-2014
	Other	1,133	2,838	2,331	1,790	2,961	1971-2014
	Pressure	502	606	452	683	532	1971-2014
	Upper Valley	130	183	218	170	462	1971-2014
	Pressure: coastal	136	301	115	301	124	2005-2011
USGS	East Side	14	9	9	24	9	2005-2012
	Forebay	9	4	4	13	4	2005-2008
	Other	8	3	3	10	3	2005-2008
	Pressure	11	6	6	20	6	2005-2008
	Upper Valley	10	5	5	18	5	2005-2008
	Pressure: coastal	3	1	1	5	1	2005-2008
GAP	East Side	10	11	11	11	0	2012-2013
	Forebay	10	10	10	10	0	2012-2013
	Other	28	27	27	27	0	2012-2013
	Pressure	14	14	14	14	0	2012-2013
	Upper Valley	6	6	6	6	0	2013

Agency	Groundwater Aquifer	Count of Wells	Total Count of Samples at all Stations				Period of Record
			CL	NA	COND	TDS	
	Pressure: coastal	4	4	4	4	0	2012-2013
ILRP	East Side	93	128	128	160	88	2012-2014
	Forebay	208	321	321	386	289	2010-2014
	Other	604	796	797	835	790	2012-2014
	Pressure	151	252	252	299	150	2012-2014
	Upper Valley	66	95	95	120	94	2012-2014
	Pressure: coastal	37	46	46	53	19	2012-2014

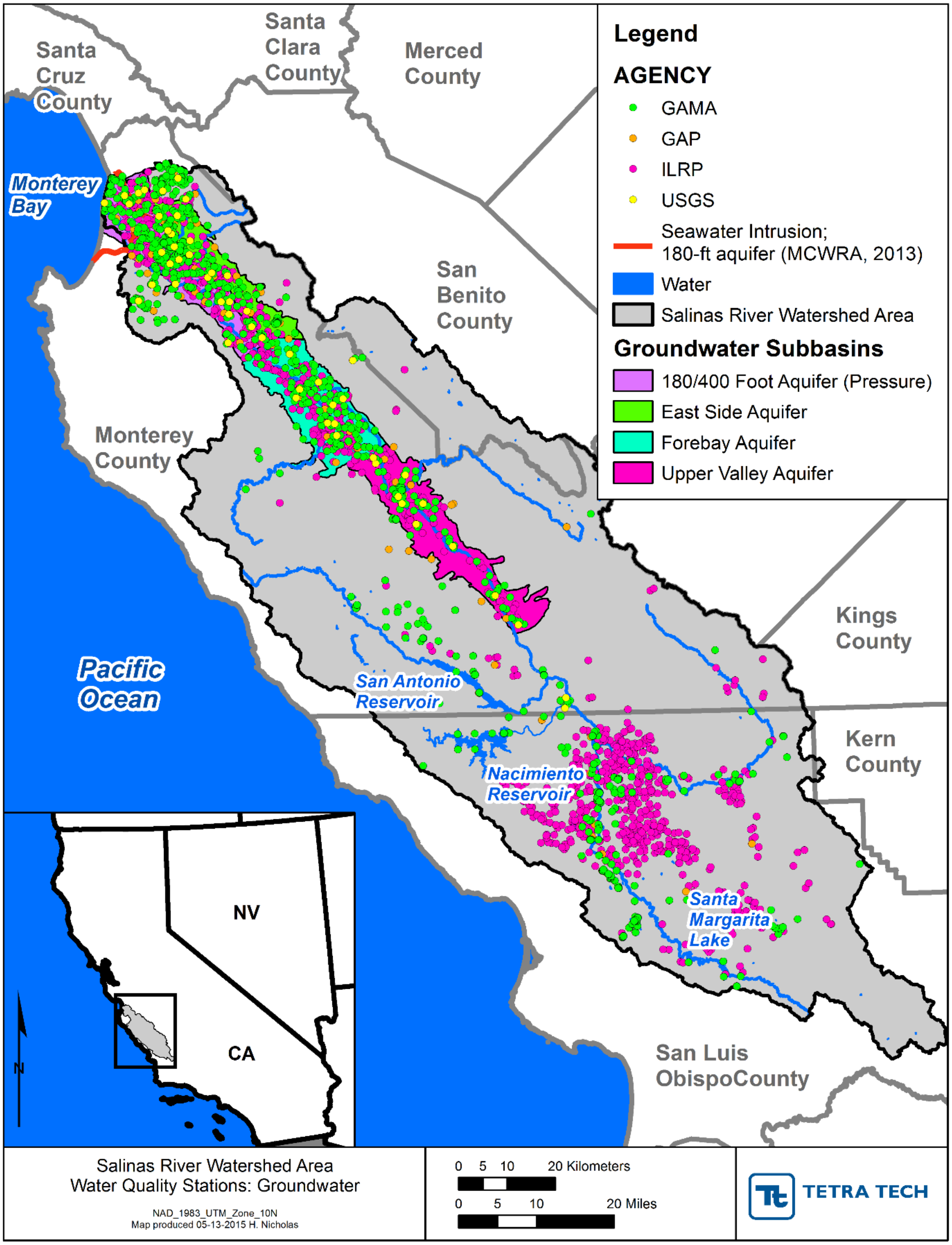

Figure 22. Locations of groundwater sampling wells with salt-related water quality data

3.4 OTHER DATA

There are six storm drain outfalls associated with the City of Salinas MS4 permit. These storm drains are monitored by the CCAMP program and stations are: 309AXX, 309SDR, 309U07, 309U19, 309U32, 309U53. The only available water quality data at the writing of this memo were from 309AXX which is an outfall to the Reclamation Canal, and 309SDR which is an outfall to the Lower Salinas River. These stations will not be considered direct instream data, but rather will be treated as point sources from the City of Salinas.

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4 Reports/Studies Inventory

Previous studies and reports relevant to the region and the analysis were reviewed to support development of information in this report and subsequent tasks. Brief summaries are provided for each reference.

4.1 Report Summaries

Simpson, R.T. 1946. Bulletin No. 52-B. Salinas Basin Investigation Summary Report. State of California, Department of Public Works, Division of Water Resources. Monterey County, Salinas, California.

Bulletin 52b provided an investigation into the water resources of Salinas Valley at a time when seawater intrusion into the aquifer was becoming a concern. The study included a detailed accounting of historic and present-day agricultural practices in the basin, including the development and implementation of modern irrigation, a summary of inflows and outflows to the groundwater basin, and the loss of fresh groundwater resources due to salt water intrusion, which at that time, had left about 1,000 acres of land without potable groundwater in the 180-Foot Aquifer.

Engineering-Science. 1987. Monterey Wastewater Reclamation Study for Agriculture, Final Report. Prepared for Monterey Regional Water Pollution Control Agency.

The safety and feasibility of the use of reclaimed wastewater for agricultural irrigation in the lower Salinas Valley was studied through field-scale experiments over five years. Wastewater effluent treated with two different levels of tertiary treatment, in addition to well water that served as the control, were applied to crops. The major findings were the following: there were no viruses found on the crop samples; levels of naturally occurring bacteria were the same on the effluent-irrigated crops compared to the control crops; naturally occurring viruses were not found in the reclaimed water; both levels of tertiary treatment removed substantial amounts of virus that was experimentally added to the wastewater; and metals did not accumulate in the soils or plant tissues.

Increased total dissolved solids and nitrate concentrations were found in the shallow groundwater in all treatment types, suggesting that the effects were a result of irrigation in general and not due to the use of the reclaimed wastewater per se. Soil salinity was greater in the effluent-irrigated soils than in the well water-irrigated control soils, especially deeper soils. Chloride, calcium, magnesium, and sodium concentrations were higher in the effluent-irrigated soils, with more pronounced differences in the plots that received more irrigation. Salinities were, however, in the appropriate range for agricultural irrigation water.

Yates, E.B. 1988. Simulated Effects of Ground-Water Management Alternatives for the Salinas Valley, California. USGS Water Resources Investigation Report 87-4066.

This report provides background information on the geology, hydrology, inflows, outflows, and water usage within the basin. A two-dimensional digital simulation of the groundwater basin was created and calibrated for both steady-state and transient simulations based on measured data from 1970-1981. Major groundwater inflows were identified as Salinas River and tributaries recharge, as well as irrigation water percolation, whereas major outflows were identified as localized evapotranspiration and agricultural/municipal pumpage. The calibrated model was used to investigate multiple different water resource management alternatives which call for basin-wide or localized increases or decreases in pumpage. Simulations indicated that the rate of seawater intrusion is most sensitive to pumpage near the coast.

Staal Gardner & Dunne Inc. 1994. Hydrogeologic Investigation: Arroyo Seco Cone. Prepared for MCWRA. Project No. 93-71-1480. Monterey, California.

The purpose of this investigation was to explore the feasibility of diverting water from Arroyo Seco to spreading basins for groundwater recharge. The hydrogeology of the Arroyo Seco Cone (i.e., alluvial fan) area in the Salinas Valley was characterized, the availability of surface flows from Arroyo Seco were assessed, and estimates of potential annual recharge through spreading basins estimated. The authors concluded that the success of spreading operations would be limited by a number of factors: high surface flows tend to occur over short time periods, limiting the opportunity for infiltration; aquifer storage is limited by naturally high groundwater levels, especially during high flow events; while infiltration rates and aquifer transmissivity are high, the aquifer would not be able to redistribute diverted water fast enough to support widespread recharge. Groundwater quality was found to be excellent in the vicinity of the Arroyo Seco due to local recharge, with average conductivity of 350 umhos/cm. However, quality worsened with increased distance from the Arroyo Seco, with conductivity values reaching 3,500 umhos/cm. The report concludes that the high values are due to agricultural return flow. The report also provides a summary of several characteristics of the hydrogeology of the Arroyo Seco Cone area, including hydrostratigraphy, aquifer water levels, available storage, transmissivity, annual recharge, and water balance and fate of flows in the Arroyo Seco.

FUGRO WEST, INC. 1995. North Monterey County Hydrogeologic Study, Volume I: Water Resources. Prepared for MCWRA. Project No. 94-71-0160. Monterey, California.

- 1996. North Monterey County Hydrogeologic Study, Volume II: Critical Issues Report and Interim Management Plan. Prepared for MCWRA and North County Inter-Agency Committee. Project No. 94-61-0162. Monterey, California.

MCWRA developed an investigation to better understand the hydrogeologic setting in the North Monterey County (North County) area. This roughly 54,000-acre area overlaps the northern Salinas and southern Pajaros groundwater basins. It is bounded by the Pajaro River to the north, the San Benito-Monterey County line on the east, Blackie Road on the south, and the Elkhorn Slough and Monterey Bay on the west. The reports quantify the various components of water supply and demand, focus on the institutional and planning limitations, and suggest possible responses to these limitations.

The report identifies significant water supply and water quality problems including falling water levels, seawater intrusion and nitrate ion contamination, and confirms that groundwater resources have been in a state of chronic overdraft since the 1950's. Annual groundwater extractions were found to exceed average annual recharge by more than 100 percent. At build-out (under current land use plans), water demand could increase to 300 percent of sustainable yield. Supplemental water supplies for the area have been recommended since the 1950's. However, imported supply is likely not available with the possible exception of a proposed Pajaro Valley Water Management Agency water importation project and Salinas River Basin Management Project.

Salinas Valley Groundwater Basin Hydrology Conference. 1995. Hydrogeology and Water Supply of Salinas Valley. Prepared for MCWRA.

MCWRA convened a panel of scientists and engineers familiar with the Salinas Valley groundwater basin to define the basic physical characteristics of the basin including surface and groundwater flows, major hydrogeological characteristics, and water resources problems. Conclusions made by the panel identified that seawater intrusion occurs near the coast primarily due to extraction of fresh groundwater in the northern part of the Salinas Valley exceeding recharge, groundwater levels continue to decline in the East Side Area, and nitrate has contaminated groundwater to varying concentrations throughout the Valley with the highest levels of contamination in the East Side, Forebay, and Upper Valley Areas. The accumulation of salts was also identified as a long-range problem because of the lack of subsurface outflow from the basin.

MCWRA. 1997. Water Resources Data Report: Water Year 1994-1995. Salinas, California.

The primary purpose of this report was to provide a summary of water resources data collected in the Salinas Valley during water year 1995. The data included precipitation, evapotranspiration, stream flow, reservoir storage and operations for Nacimiento and San Antonio Reservoirs, groundwater hydrology and levels, and groundwater quality including seawater intrusion and nitrates. Surface water quality was not discussed in the report. A number of longer term analyses and trends using historic data were also presented. Some of the findings relevant to characterizing the hydrology, hydrogeology, and groundwater quality are presented below:

- The Salinas Valley has three distinct regions of climate and water demand based on long term monitoring from the California Irrigation Management Information System (CIMIS). Peak summertime reference evapotranspiration values range from 0.15 in/day next to the coast to 0.25 in/day in the interior region.
- Mean annual precipitation ranges from 10 in/yr in the interior of the Valley to over 70 in/yr in the Santa Lucia Mountains. Topography exerts a strong influence on rainfall.
- Long-term trends in rainfall show distinct wet and dry periods lasting several years. A major drought occurred from 1984 through 1991; however, rainfall increased following 1991 and water year 1995 was considered a wet year.
- The report included summaries of streambed absorption based on analyses of USGS flow data and annual surveys conducted by MCWRA. An estimation of streambed evapotranspiration in the Salinas River was also provided.
- Long term trends in groundwater levels were presented. Between 1945 and 1995, levels were fairly stable in the Forebay and Upper Valley Areas, while declines were noted in the Pressure and East Side Areas.
- In general, groundwater quality for irrigation use was considered good to excellent in most locations. However, high mineral and salt content were found in some areas associated with irrigation return flow, seawater intrusion, and naturally occurring highly alkaline soils in the vicinity of the East Side hills.

Montgomery Watson. 1997. Salinas Valley Integrated Groundwater and Surface Model Update, Final Report. Prepared for Monterey County Water Resources Agency.

The Salinas Valley Integrated Groundwater and Surface Model was developed to evaluate the hydrologic and water supply operational issues in the Salinas River Basin. Model capabilities include simulation of groundwater flow, surface waters (Salinas River and its primary tributaries from Nacimiento and San Antonio Reservoirs to the Monterey Bay), interaction between surface and groundwater, streamflow operation of Nacimiento and San Antonio Reservoirs, rate and extent of seawater intrusion, crop water use requirements, and direct runoff and deep infiltration from precipitation and irrigation waters. This model update includes updated land use and irrigated crop areas, revision of "in-between crop" assumptions, revision of the land cover type of the Salinas River riparian corridor, and revision of the distribution of hydraulic conductivity. The model updates improved its simulation capabilities and the model can be used to evaluate alternative management options for the Salinas River Basin Management Plan.

Watson, F., L. Pierce, M. Mulitsch, W. Newman, A. Rocha, M. Fain, J. Nelson. 1999. Water Resources and Land Use Change in the Salinas Valley. The Watershed Institute, California State University Monterey Bay, Rep. No. WI-1999-01.

This report supplies a basic characterization of the Salinas watershed as ecologically complex (five key ecosystem types), and economically valuable (huge volume of agricultural land in the Salinas Valley). Half of the Salinas watershed is considered natural lands, and almost the entire other half of the watershed is managed agriculture. Agriculture accounts for 92.5% of all groundwater extractions, and croplands continue to expand. Under future predictions of changing land use in the watershed, this report details the impacts on hydrology and ecology on both spatial and temporal scales. Computer models Biome-BGC, Macaque, and a hybrid model of the two were used to simulate future conditions in the watershed.

CCRQWCB. 2000. Salinas River Watershed Characterization Report 1999. Central Coast Ambient Monitoring Program. Prepared by Karen Worcester, Dave Paradies, Mary Adams, and Daniel Berman.

This report focuses on the CCAMP monitoring conducted to characterize and study the Salinas River and its tributaries. CCAMP monitoring locations were described in detail, and their monitoring frequencies and activities summarized. Monitoring involved conventional water quality, benthic macroinvertebrate sampling, sediment chemistry, and tissue bioaccumulation. Data were used to characterize stretches of water as being impaired for analytes to varying levels based on exceedance criteria. Box and whisker plots present stations with relative concentrations of each constituent of interest, including chloride and sodium. The main source of salt impairments was considered to be agriculture in this watershed Salinity impairments in the lower watershed were identified as being caused by seawater intrusion, while impairments in the upper watershed were attributed to natural sources, particularly surface waters of eastern tributaries.

Harding ESE. 2001. Hydrogeologic Investigation of the Salinas Valley Basin in the Vicinity of Fort Ord and Marina Salinas Valley, California. Prepared for MCWRA. Project No. 51750 007. Novato, California.

MCWRA commissioned a study of the geologic and hydrogeologic conditions in the Pressure aquifer subarea of the Salinas Valley groundwater basin. The study examined the aquifers underlying the City of Marina and former Fort Ord, including the perched zone or A-aquifer, the Pressure 180-Foot Aquifer, the Pressure 400-Foot Aquifer, the Deep Aquifer, and aquifers within the Purisima and Santa Margarita Formations. Hydrostratigraphic continuity throughout the study area was a focus of the report with respect to the potential for seawater intrusion and it was determined that groundwater withdrawal from the Salinas Valley has steadily resulted in seawater intrusion in the 180-Foot Aquifer and the 400-Foot Aquifer, proportional to water withdrawals. Seawater has currently intruded about 6 miles in the 180-Foot Aquifer and about 3 miles in the 400-Foot Aquifer along the Salinas Valley floor. Beneath the Marina and former Fort Ord area, seawater has intruded about 2 miles in the 180-Foot Aquifer and about 3 miles in the 400-Foot Aquifer.

Casagrande, J., F. Watson, T. Anderson, and W. Newman. 2002. Hydrology and Water Quality of the Carmel and Salinas Lagoons, Monterey Bay, California.

This report presents a study of the water quality of the Salinas and Carmel Lagoons and how it impacts survival of central coast steelhead trout before and after breaching events. The study aim was to inform policy development related to the impact of manual breaching on steelhead trout runs. The introduction includes a description of the hydrology of the Salinas Lagoon.

Nine sites along the Salinas Lagoon were monitored from August 2001 through July 2002 for temperature, salinity, dissolved oxygen, depth, and bed sediment size. Lagoon bathymetry was mapped. Dry season (August) conditions in the Salinas Lagoon are characterized by high diurnal fluctuations in surface temperature and oxygen, indicating high rates of photosynthesis and respiration. A longitudinal gradient of cooler surface temperatures and lower dissolved oxygen concentrations was observed as one moves towards the bay. The deep waters under the bridges at Highway 1 were highly saline and anoxic. Pre-breach conditions in October were slightly cooler overall, but with continued high diurnal fluctuations in surface temperature and oxygen and a strong mixing regime. The diurnal fluctuations in oxygen were highest inland and more moderate near the ocean, and the salinity was close to freshwater conditions, with high salinity persisting under Highway 1. Post-breach conditions in December included higher salinity in the lagoon waters. Surface oxygen was moderately high and decreased to moderately low concentrations at 1.5 meter depths. Surface inland waters were warmer, had higher oxygen concentrations, and were less saline than surface waters near the ocean.

Hanson, R. 2003. Geohydrologic Framework of Recharge and Seawater Intrusion in the Pajaro Valley, Santa Cruz and Monterey Counties, California. US Geological Survey. Water-Resources Investigations Report 03-4096. Prepared in cooperation with Pajaro Valley Water Management Agency. Sacramento, California.

This report discusses the hydrogeology of the Pajaro Valley and Pajaro River watershed, which are located adjacent to the Salinas River watershed to the north. The focus is on recharge processes and seawater intrusion into the various aquifers in the coastal subregion of the Pajaro Valley. Nearly all of the water demand is satisfied via groundwater pumping, with 84 percent used for agriculture and 16 percent used for municipal and industrial purposes. The aquifers are comprised of extensive coarse-grained deposits mixed with fine-grained deposits that tend to restrict lateral and downward movement of groundwater. An upper aquifer system is made up of alluvial deposits and upper Aromas Sand of Pleistocene age, generally located at a depth of 100 to 200 feet below sea level near the coast. A lower aquifer system is composed of lower Aromas Sand and Purisima Formation of Miocene to Pliocene age, generally located at a depth of 300 to 600 feet below sea level near the coast. The upper aquifer is affected by seawater intrusion due to groundwater pumpage in excess of recharge, while the lower aquifer contains old seawater and/or dissolved minerals. The two main sources of recharge in the study area are deep percolation of precipitation and infiltration through the bed of the Pajaro River. Data suggest that only the upper aquifer system is recharged, while the water in the lower aquifer system is in part a nonrenewable resource.

McMillian, A. 2003. Salinas Valley Water Table Elevations: A Visualization Using GIS. Capstone Project, California State University, Monterey Bay. The Watershed Institute, Seaside, CA.

The impacts of management alternatives on water table elevations in the Salinas Valley were evaluated using the Salinas Valley Integrated Groundwater and Surface Model. Simulated water table elevations for the time period 1949–1994 were visualized with animated maps. Review of the water table elevations over time along with precipitation data suggested that the operation of the Nacimiento and San Antonio reservoirs helped maintain water table elevations, and that lower water table elevations are related to an increase in groundwater withdrawals for agricultural and municipal purposes.

Kennedy/Jenks Consultants. 2004. Hydrostratigraphic Analysis of the Northern Salinas Valley. Prepared for MCWRA. K/J Project No. 035901.00. San Francisco, California.

MCWRA commissioned a study that included a 3-D conceptual model of the lithostratigraphic makeup of groundwater bearing zones of the Pressure 180-Foot and Pressure 400-Foot aquifers and the implications on seawater intrusion pathways. The distributions of interbedded clays and coarse-grained sediments suggested a lower permeability and slower groundwater flows in the East Side Subarea. The analysis also confirmed areas of absence and thinning of the aquitard that separates the Pressure 180- and Pressure 400-Foot aquifers in the Pressure Subarea. Seawater is intruding into the groundwater zones from the submarine outcrops of and directly into the Pressure 180- and Pressure 400-Foot aquifers. Mixing and vertical migration of seawater are highly possible in several areas between the coast and the City of Salinas due to the identified aquitard discontinuities.

Casagrande, J. and Watson, F. 2006. Reclamation Ditch Watershed Assessment and Management Plan: Part A - Watershed Assessment. Monterey County Water Resources Agency and the Watershed Institute, California State University Monterey Bay.

From 2003-2005, the Central Coast Watershed Studies team of the Watershed Institute at California State University Monterey Bay completed an assessment and management strategy for MCWRA. The assessment investigated five elements that drive the function and use of reclamation drainage in the watershed: historical conditions, hydrology and channel conditions, water quality, biological assessment, and a botanical assessment. Water quality concerns exist at several sites with respect to nitrate, phosphate, dissolved oxygen, water temperature, fecal coliform indicators, suspended sediment, and insecticides. There are fifteen 303(d) listings for water quality impairment within five water bodies in the watershed. The management strategy covered five elements: existing plans, public process, watershed management goals, management actions, and management strategies. Management goals listed for the watershed relate to water quality, flood control, parklands, determining fish passage and steelhead presence/absence, special status species protection, mosquito abatement, food safety and agricultural pest control, harbor sedimentation, sustainable water supply, and economic viability.

MCWRA. 2006. Monterey County Groundwater Management Plan. Monterey County Water Resources Agency, RMC Water and Environment, Luhdorff & Scalmanini Consulting Engineers.

MCWRA prepared a groundwater management plan for the purpose of managing its groundwater resources identifying three objectives: developing integrated water supplies to meet existing and projected water demand, determining a sustainable groundwater yield, and preserving groundwater quality for beneficial use. The plan provides a comprehensive overview of the Salinas Valley Groundwater Basin and recommends a management framework for its groundwater resources, focusing on the Seaside and Paso Robles subareas. Identified threats to groundwater quality include seawater intrusion resulting from overdraft in the Pressure aquifer subarea, and locally elevated nitrate contamination due to existing agricultural practices, animal confinement facilities, sewage treatment plants, septic tank systems, and municipal and industrial runoff.

CCRWQCB. 2011b. Water Quality Control Plan for the Central Coastal Basin. State water Resources Control Board, California Environmental Protection Agency.

This report, frequently referenced as the "Basin Plan", was created to show how surface and groundwater quality should be managed in order to "provide the highest water quality reasonably possible." The report specifies beneficial uses for all major inland waters and provides water quality criteria for all pollutants relative to beneficial use. The Basin Plan details an implementation plan for water quality issues, with information about the control of National Pollutant Discharge Elimination System dischargers, water discharge requirements, as well as nonpoint sources. The Salinas River hydrologic unit includes a list of major dischargers, one of which is located within the Lower Salinas Valley (an MRWPCA facility which provides reclaimed water to the Castroville Irrigation Project). The Basin Plan also includes regulatory information for waste management, stormwater management, control actions, and provides summaries associated with all completed regional TMDLs.

CCRWQCB. 2013. Total Maximum Daily Loads for Nitrogen Compounds and Orthophosphate for the Lower Salinas River and Reclamation Canal Basin, and the Moro Cojo Slough Subwatershed, Monterey County, California. San Luis Obispo, California.

The completed Nutrient TMDL for the Lower Salinas River and Reclamation Canal Basin addresses the elevated levels of nitrogen compounds and orthophosphate in multiple streams. Impaired reaches were analyzed for nitrate, orthophosphate, chlorophyll-a, and unionized ammonia throughout the Salinas/Reclamation area. The report covers water quality monitoring trends, numeric target assessment, source analysis, and load allocation, as well as implementation measures needed to address these stream impairments. Agriculture within the Salinas Valley is understood to be the primary source for increased nutrient levels in the watershed. Load allocations were assigned based on source identification, requiring reductions in existing loads by cropland landowners and operators, as well as MS4 stormwater entities.

Kulongoski, Justin, and Kenneth Belitz. 2007 (revised 2011). Ground-Water Quality Data in the Monterey Bay and Salinas Valley Basins, California, 2005—Results from the California GAMA Program. US. Geological Survey Data Series 258.

This report presents results from the GAMA program in the Monterey Bay and Salinas Valley GAMA unit and describes the status of groundwater quality. The hydrogeologic setting of the study unit is described. Ninety-one public supply wells were sampled to provide a statistical representation of groundwater quality. Three wells located along a groundwater flow path were monitored to evaluate lateral changes in water chemistry, and three wells located at different depths were monitored to evaluate changes with depth. The parameters monitored were volatile organic compounds, pesticides, pesticide degradates, nutrients, major and minor ions, trace elements, radioactivity, microbial indicators, and noble gases. Six of the 270 monitored constituents were detected at concentrations that exceeded health-based regulatory thresholds, and six constituents exceeded aesthetic thresholds. The median total dissolved solids (TDS) concentration was 467 mg/L, with four of the 34 samples above the secondary maximum contaminant level (SMCL) of 1,000 mg/L. Exceedances of the SMCL were also observed for sulfate, iron, manganese, molybdenum, and chromium.

Tetra Tech. 2013. Santa Maria Watershed TMDL—Salt Modeling Report. Central Coast Regional Water Quality Control Board, EPA Region 9.

This salt modeling report was used to develop the Santa Maria Watershed TMDL for salts. The pollutants addressed in this model and report are based on the 303(d) listings for electrical conductivity, sodium, chloride, and boron. Surface waters were impaired for salt due to their beneficial use for agriculture since elevated levels of these constituents can inhibit plant growth and crop yield, as well as cause damage and toxicity. The report provides a watershed characterization and outlines regional hydrogeology, which were then used to develop a conceptual model for water and salt movement through the system. Salt loading in the Santa Maria watershed was simulated using SaltMod and HSPF models. For the model, climactic parameters were developed (seasonal rainfall and potential evapotranspiration), the subsurface zone was characterized (thicknesses and soil properties), and the aquifer itself was characterized (depth to water table, groundwater basins, inflows and outflows). Agriculture played a large role in the water and salt balance for the system, so detailed information about irrigation, crop types and rotations, and tile drainage were taken into consideration. The resulting model was calibrated for both hydrology and water quality, and a source analysis was also conducted.

Brown and Caldwell. 2015. State of the Salinas River Groundwater Basin. Prepared for the Monterey County Water Resources Agency by Brown and Caldwell Consulting Engineers, Walnut Creek, CA.

Brown and Caldwell conducted an examination of the status of the Salinas Valley Groundwater Basin for MCWRA. A major focus of the report is the impact of prolonged drought on groundwater head elevations, groundwater storage, and seawater intrusion into the Pressure Area. A water balance is provided for inflows and outflows for each of the aquifer areas. A storage change analysis was also conducted spanning 1944 to 2013. They concluded that storage change was most sensitive to cumulative precipitation surplus. During 1959 to 2013 (corresponding to when the Naciemento and San Antonio Reservoirs have been operating), there has been a net loss of 6,000 ac-ft/yr of storage from the Salinas Valley Groundwater Basin. An analysis of seawater intrusion is also provided. When combined with seawater intrusion, the Basin is considered to be out of hydrologic balance by 17,000 to 24,000 ac-ft annually. However, the total volume of groundwater in the Basin is estimated to be over 16 million ac-ft. Technical options were discussed for addressing seawater intrusion which focused on shifting areas of heavy groundwater pumping out of the Pressure and East Side Areas.

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5 Data Analysis

Water quality and quantity data across the Salinas River Watershed area have been evaluated further in this section. Data were summarized using with summary statistics by station. Key hydrological and water quality stations were identified throughout the watershed in order to assess spatial and temporal trends. Finally, this section also provides an analysis of the 303(d)-listed impairments for the Lower Salinas area including Alisal Creek (sodium) and the Lower Salinas River (sodium, chloride, electrical conductivity, and total dissolved solids).

5.1 Summary of Hydrology and Water Quality Data

5.1.1 Hydrology: Surface Water

The USGS flow stations across the watershed as well as the reservoir release data and Blanco Drain pumping data have been summarized below. Average monthly flows since 1990 were calculated for each station (except as noted in table footnotes) and are presented in Table 19.

Table 19. Average monthly flows (cfs) for surface water stations in the watershed

Waterbody	Gage	Average Monthly Flow (cfs)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Salinas	11147500	319	386	349	121	29	5.2	0.17	0.023	0.020	2.1	2.2	67
Nacimiento	11148900	497	601	405	136	39	13	1.9	0.15	0.016	15	18	198
Nacimiento	11149400	219	527	183	148	173	262	335	336	249	155	200	100
San Antonio	11149900	269	335	262	110	39	15	3.3	0.37	Dry	4.3	4.1	81
Salinas	11150500	699	1128	802	352	293	392	472	479	335	205	285	194
San Lorenzo	11151300	37	53	51	14	7.0	2.3	1.1	0.64	0.70	1.3	2.3	12
Salinas	11151700	658	1186	872	346	146	157	180	164	118	73	123	130
Arroyo Seco	11152000	421	488	415	210	89	41	16	6.3	4.6	21	31	157
Arroyo Seco	11152050[1]	374	413	348	151	22	2.6	Dry	Dry	0.00	10	5.5	92
Salinas	11152300	840	1365	1068	414	119	64	65	50	41	27	43	122
Salinas	11152500	738	1380	1009	410	98	24	18	10	6.4	6.4	14	89
Gabilan	11152600	9.0	18	11	6.8	1.9	1.0	0.49	0.21	0.11	0.09	0.37	3.2
Reclamation	11152650[2]	20	21	25	14	4.0	3.0	2.9	2.7	2.1	4.4	5.4	18
Blanco Drain	Blanco[3]	No Data	No Data	No Data	4.7	5.8	5.8	4.5	4.1	3.6	2.1	1.3	No Data

Waterbody	Gage	Average Monthly Flow (cfs)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nacimiento	Nacimiento	236	576	182	136	167	265	339	340	251	164	212	108
San Antonio	San Antonio	48	111	29	45	82	127	132	130	74	44	62	23

[1]Period of record begins in 1994; [2]Period of record begins in 2002; [3]Period of record is 2010-2013.

5.1.1.1 Key Hydrology Stations

In order to explore the temporal and spatial trends of surface water flow in the Salinas River Watershed area, several surface water hydrology stations were selected for further analysis (Figure 23). One station was selected along the Reclamation Canal (USGS 11152650), which is hydrologically disconnected from the Salinas Watershed. Three stations were selected along the Salinas River mainstem (USGS 11152300, 11152500, 11150500), including one near the reservoirs to reflect the variable flow patterns due to water resource management conducted by MCWRA.

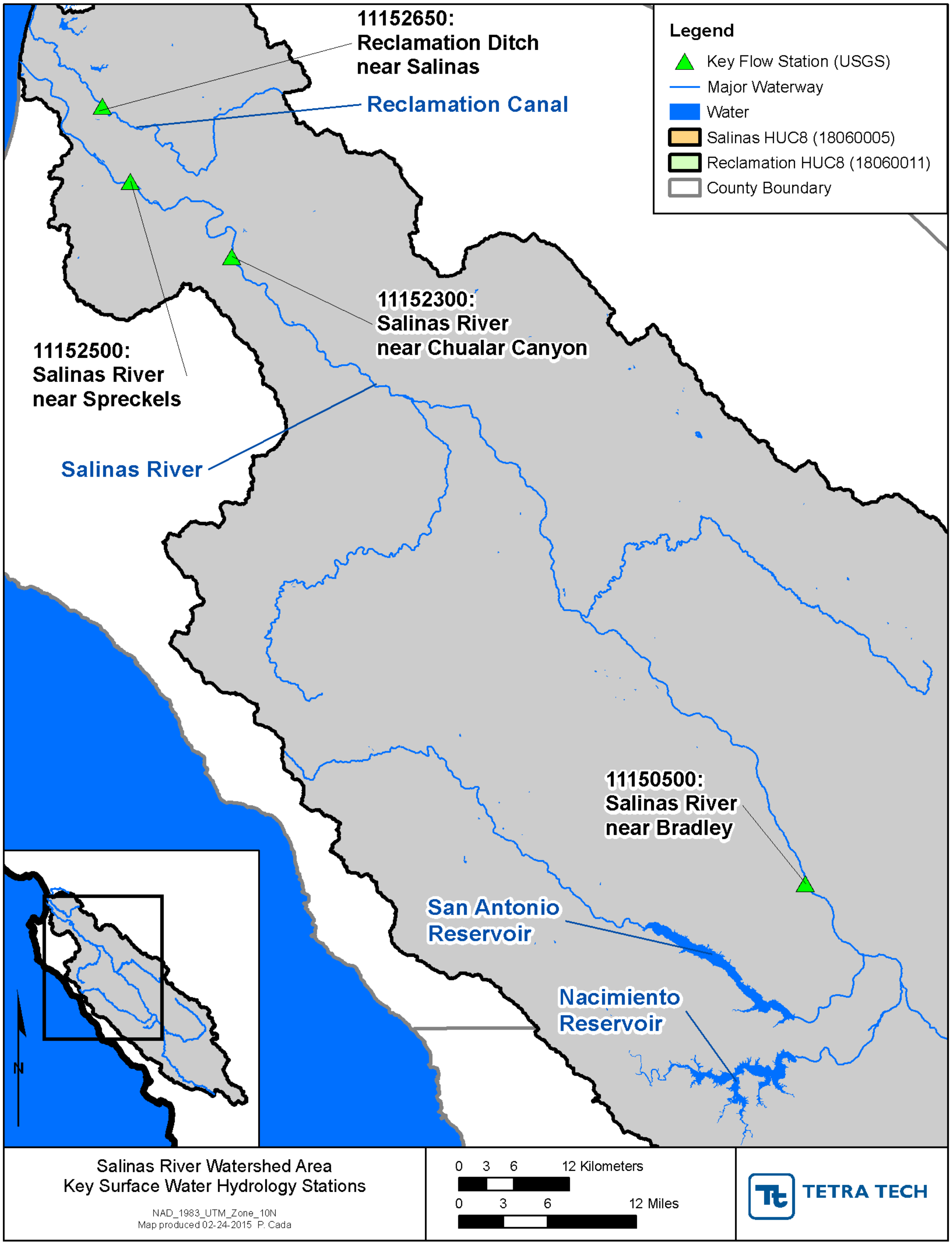

Figure 23. Locations of key surface water hydrology gages

Average monthly stream discharge at all three Salinas River mainstem gages from 1990-2014 is seen in Figure 24. The moderating impact of reservoir operations can be seen in the monthly average flow at Salinas River near Bradley. In order to manage the low volumes of natural water recharge in the system, surface water is stored in the San Antonio and Nacimiento Reservoirs. These reservoirs release water into tributaries to the Salinas River strategically throughout the year to allow the water to infiltrate through the riverbed and recharge the groundwater aquifers seasonally. Flows seen at Salinas River near Bradley show a different flow pattern than the downstream Salinas River gages, where flows are higher January through April and very low for the rest of the year. The decrease in flow between Bradley and Chualar/Spreckels is due to evapotranspiration from riparian vegetation and infiltration into the aquifer that occurs along the Salinas River.

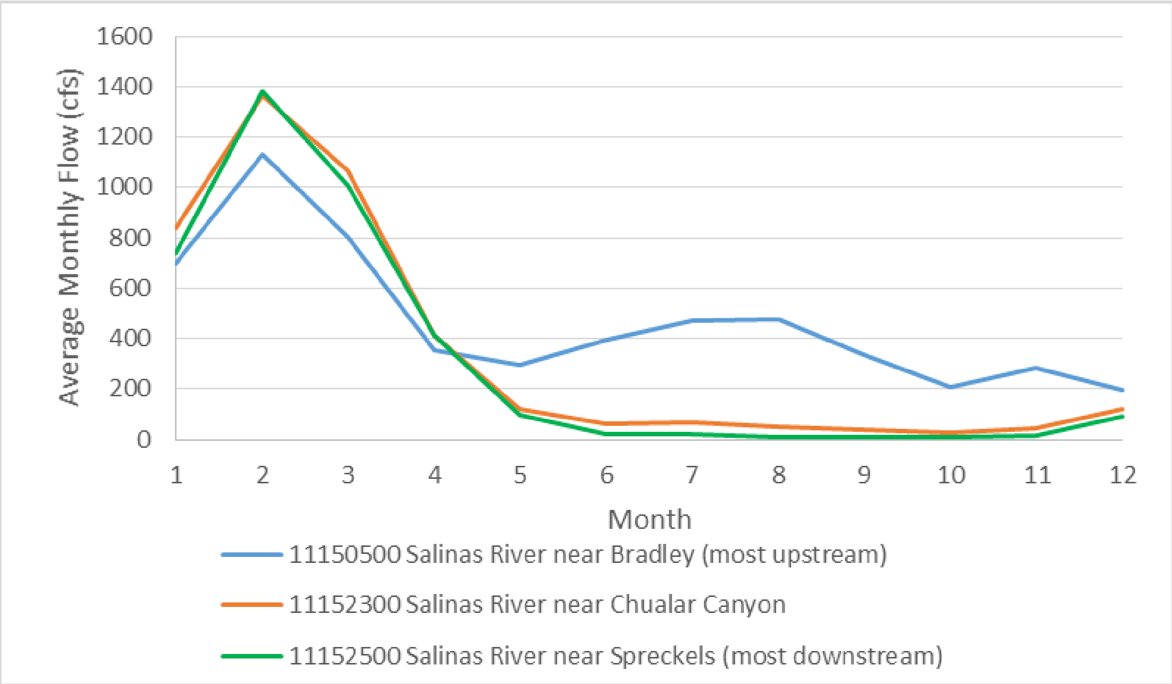

Figure 24. Average monthly flows at three major USGS gages along the Salinas River mainstem, 1990-2014

Average monthly discharge at USGS gage 11152650 on the Reclamation Canal reveals seasonal fluxes as well, reflecting responses to inputs of seasonal winter precipitation (Figure 25). The pattern is similar to that seen at the Salinas River stations farther from the reservoirs, but the difference in magnitude between winter and summer is considerably less, and flows begin increasing in October.

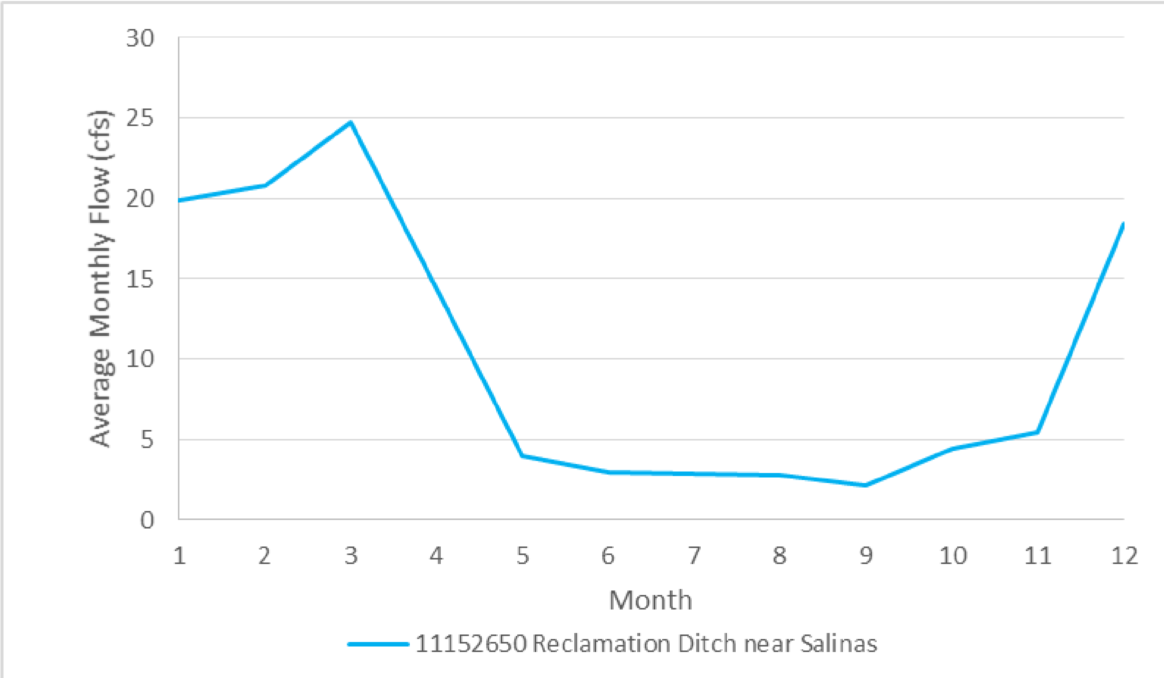

Figure 25. Average monthly flows for the USGS gage on the Reclamation Canal, 1990-2014

5.1.2 Hydrology: Groundwater

Groundwater is the source for almost all agricultural and municipal water demands in the Salinas Valley with agricultural accounting for approximately 90% of all withdrawals. Groundwater use in the Salinas Valley peaked in the early 1970’s, and has been generally declining since. Projections of groundwater use within the Salinas Valley show a continuing decline due primarily to changes in crop patterns, continued improvements in irrigation efficiency, and some conversion of agricultural lands to urban land uses.

The impacts of groundwater use are not distributed uniformly throughout the Salinas Valley. The impacts of groundwater extraction occur mostly within the local area of the extraction. The impacts diminish rapidly with distance from the extraction, and the impacts tend to be very small at large distances from the extraction (MCWRA, 2006). Water use in any given year is a function of land use, water use efficiencies, as well as hydrologic and meteorological conditions.

5.1.2.1 Groundwater Levels

Groundwater levels in the Salinas Valley basin have been measured regularly by MCWRA in monitoring and production wells. Historical groundwater elevations reflect localized drawdown and depressed groundwater levels during the summer irrigation season followed by recovery of groundwater elevations in the winter. Figure 26 shows changes in average groundwater levels as measured in selected wells in the Pressure, East Side, Forebay and Upper Valley Areas over the period of record (MCWRA, 2006).

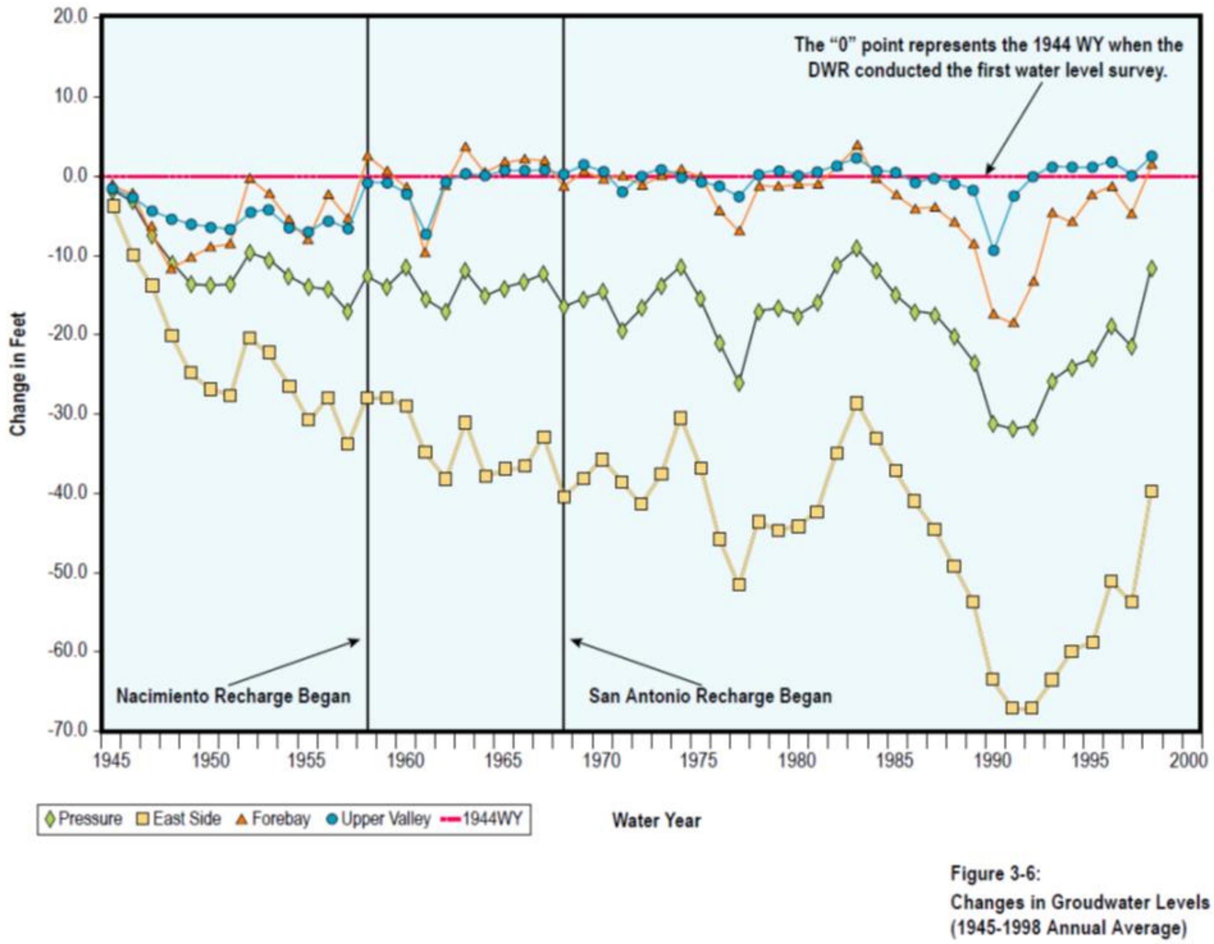

Figure 26. Groundwater levels over time in the Salinas Valley Basin (Source: MCWRA, 2006)

As shown in Figure 26, groundwater levels in the Upper Valley, Forebay, and Pressure areas have been relatively stable, while the East side area has shown a general, somewhat dramatic decline. The stability in groundwater depth in the Upper Valley and Forebay areas is generally attributable to the managed releases from the Nacimiento and San Antonio Reservoirs. Water levels in the Pressure Area have appeared to be relatively stable, as well, but that stability is thought to only be partially attributable to steady recharge from the Forebay Area.

The Pressure Area abuts the ocean, which provides a constant head boundary. As the Pressure Area has been overdrawn, seawater has intruded into the aquifer replacing freshwater providing relatively stable water levels, but degrading water quality. Groundwater elevations in both the Pressure 180-Foot Aquifer and Pressure 400-Foot Aquifer have been below sea level groundwater elevations for many years, and the differences between the elevations in these two aquifers have been fairly consistent creating a situation that promotes seawater intrusion (MCWRA, 2006). The sections below describe water use trends in each of the aquifer subareas and groundwater elevation observations, where available, from monitoring conducted by MCWRA (Harding ESE, 2001) in 1997 through 1999.

5.1.2.1.1 Pressure Area

Based on investigations by Montgomery Watson and Raines, Melton & Carella, Inc (1998) and MCWRA, in areas north of Salinas, 90% of groundwater pumping occurs from the Pressure 400-Foot Aquifer with 5% of pumping occurring from the Deep Aquifer and smaller amounts from the Pressure 180-Foot

Aquifer. In areas south of Salinas, 60% of pumping is from the Pressure 400-Foot Aquifer, while 40% of pumping is from the Pressure 180-Foot Aquifer. Use of the Pressure 400-Foot Aquifer is most limited in the vicinity of Chualar to Gonzales (MCWRA, 2001; MCWRA, 2006). Data from dedicated monitoring and agricultural production wells in the Salinas Valley Basin clearly indicate a seasonal trend in groundwater elevations, with lows occurring in the summer and fall. The trend is very similar between the Lower 180-Foot and Pressure 180-Foot Aquifers (Harding ESE, 2001).

The confined Lower 180-Foot Aquifer is equivalent to the 180-Foot Aquifer in the Salinas Valley and has historically been the major water producer beneath the former Fort Ord and city of Marina. Seasonal groundwater elevation fluctuations increase to the east across former Fort Ord and are highest within the Salinas Valley. Maximum fluctuations reach about 30 feet but are relatively stable approaching Monterey Bay, likely due to the subsurface interface with seawater. Although the Upper 180-Foot Aquifer beneath former Fort Ord lies within the Salinas Valley groundwater basin, it is not in direct hydraulic communication with the 180-Foot Aquifer beneath the Salinas Valley floor. This has been determined to be the case even though lithologic data indicate only a thin hydraulic barrier (the Intermediate 180-Foot Aquitard) between the two (Harding ESE, 2001).

During summer months when demand for water is highest, groundwater elevations beneath former Fort Ord closest to the Salinas Valley typically drop 15 to 20 feet in the Lower 180-Foot Aquifer, whereas they may only drop 5 feet in the Upper 180-Foot Aquifer at the same location(Harding ESE 2001). Groundwater elevations in the Upper 180-Foot Aquifer range from slightly above mean sea level (MSL) to about 16 feet below MSL. Groundwater in the Lower 180-Foot Aquifer range from 5 feet below MSL near Monterey Bay to about 35 feet below MSL beneath the Salinas Valley and remain below sea level throughout the study area throughout the year. Groundwater in the Lower 180-foot Aquifer flows at a rate ranging from 0.0007–0.0016 ft/ft. These gradients are steeper than gradients measured along the valley, which are typically 0.0006 ft/ft (Harding ESE, 2001).

Groundwater elevations in the 400-Foot Aquifer in 1997 and 1999 range from about 10 feet below MSL to as much as 60 feet below MSL slightly north of the study area (north of McFadden Road). Hydraulic distinction between the Lower 180-Foot Aquifer and the 400-Foot Aquifer beneath the eastern portion of former Fort Ord is evidenced by about five feet of head difference. This is comparable to the five to ten feet of head difference between these two aquifers beneath the Salinas Valley. As in the 180-Foot Aquifer, groundwater elevations were below MSL throughout the study area at these times. Groundwater gradients in the 400-Foot Aquifer range from 0.0011 to 0.0016 ft/ft (Harding ESE 2001).

A groundwater depression surrounds Fort Ord supply wells 29 and 30 and groundwater elevations are locally as low as 30 feet below MSL. Although the lowest groundwater elevations are measured north of McFadden Road (60 to 50 feet below MSL), another low elevation area (40 to 30 feet below MSL) was located south of Blanco Road within the valley in 1999 and 1997, respectively. The consistent landward gradient in both the 180-Foot and the 400-Foot Aquifers and the persistent sub-sea level elevations are both important preconditions necessary for seawater intrusion (Harding ESE, 2001).

5.1.2.1.2 East Side Area

Most of the groundwater extractions (~40%) occurring from the East Side Area are from the East Side Shallow Zone, with remaining extractions from the intermediate East Side Deep Zone—both zone depths are defined as in the Pressure Area. The East Side Area appears to have been one the natural sources of recharge to the adjacent Pressure Area, however, historical groundwater level declines in the East Side Area have caused an apparent reversal of groundwater gradient from the Pressure Area to the East Side Area. Groundwater recharge in East Side Area is through percolation from small streams that flow from the Gabilan Range and, to a lesser degree, from precipitation recharge (Simpson, 1946; Kennedy/Jenks Consultants, 2004; MCWRA, 2006).

5.1.2.1.3 Forebay and Arroyo Seco Area

The majority of the pumping occurring in the Forebay Area is from the shallow aquifer zone of the Forebay Area, however, deeper wells are believed to be pumping from a deeper Forebay aquifer zone. Although the Deep Aquifer, as defined in the Pressure and East Side Areas, is presumed to extend into the Forebay Area, fewer wells are known to be pumping from this aquifer in the Forebay Area. Pumping occurring in the Arroyo Seco Area is from the single unconfined aquifer.

Recharge in this area is from the alluvial fan of the Arroyo Seco and its major tributary Reliz Creek, other small tributaries in the area, the Nacimiento and San Antonio Rivers and Reservoirs, as well as the Salinas River. It is estimated that about half of applied irrigation water also acts as recharge (Montgomery Watson, 1998). Recharge from direct precipitation is minor and probably occurs only in wet years. Subsurface flow from the Upper Valley subarea and subsurface flow from the east and west subarea boundaries account for the remainder of the recharge. The depth to the base of fresh water in the subarea ranges from about 200 feet at the eastern valley margin to 2,200 feet at the western margin (Durbin et al, 1978) with a sharp rise from about 2,000 to 1,000 feet at the southern subarea margin (CA DWR, 2004; MCWRA, 2006).

5.1.2.1.4 Upper Valley Area

Most wells in the Upper Valley Area are relatively shallow and lie along the course of the Salinas River. Groundwater recharge in the Upper Valley Area is primarily from percolation through channel deposits of the Salinas River and tributary drainages (Simpson, 1946). A lesser volume of recharge results from the percolation of precipitation along the valley margins and from applied irrigation water (Leedshill-Herkenhoff, Inc, 1985). Subsurface flow from precipitation recharged through the Pancho Rico Formation east of the subarea and minimal subsurface flows from drainages along the Salinas River account for the remainder of the recharge (CA DWR, 2004; MCWRA, 2006).

5.1.2.2 Land Use Influence on Groundwater

Major land uses in the Salinas Valley include agriculture, rangeland, forest, and urban development (Figure 9). In general, the forests are located on steep slopes of the surrounding ranges, the rangelands are in the rolling to steep hills, and the agriculture and urban development are located in the valley floor adjacent to Salinas River (MCWRA, 2006).

Land use influence on water withdrawals is predictably dictated by prevailing uses and requirements due to seasonal variation in rainfall patterns. Demand is highest in the summer months for both developed and agricultural areas, where urban demands are related to landscaping requirements, whereas agricultural demands are high due to the growing season for most crops.

Irrigation practices in the Salinas River Valley Basin are largely determined by available groundwater resources and are thus influenced by the aquifer subareas where the withdrawals are made. Groundwater withdrawn from the Pressure Area has primarily supplied drinking water wells, as opposed to agricultural wells as in the Salinas Valley.

5.1.2.2.1 Urban Irrigation

The highest densities of urban development (residential, commercial and industrial) are clustered in the northern part of the valley, in the vicinity of Monterey Bay. Urban acreages have also experienced substantial growth, most of which has occurred in Marina, Castroville, Salinas, Gonzales, Greenfield, Soledad, and King City (MCWRA, 2006). Urban water use has been increasing as a result. These increases in urban water use, particularly on non-irrigated lands in the northern portion of the Salinas Valley, will place additional pressure on groundwater pumping.

5.1.2.2.2 Municipal Water Supplies

Most of the residential development in the study area is served by various sized water distribution systems that derive their supply from groundwater. A water system is defined as a distribution system that serves more than one parcel. In Monterey County, water systems are categorized by the number of connections. Systems with greater than 200 connections are considered "large water systems" and are under the jurisdiction of the California Department of Health Services (Fugro West Inc., 1995).

Drinking water for city of Marina residents is supplied by the Marina Coast Water District (MCWD) which owns and operates three large capacity production wells and several smaller capacity wells with minimal contribution to the system. MCWD is in the process of acquiring the water supply system on former Fort Ord (including the three active production wells), which currently provides drinking water to residents on the former base. Note that the City of Marina replaced its 180-Foot Aquifer production wells with 400-Foot and Deep Aquifer wells in the 1980's when water quality was degraded by seawater intrusion (Harding ESE, 2001).

5.1.2.2.3 Agriculture Irrigation

Agriculture is the largest user of water in the Salinas Valley. Since the late 1940’s, irrigated acreage within the valley has increased substantially until leveling off in the 1980’s. Figure 27 shows the total irrigated acres by crop type for 1949–1994 (MCWRA, 2006). It is important to note that significant advances in irrigation efficiency have been made in recent years. In 1993, drip irrigation was used on 25,080 of 173,610 acres in Monterey County, while in 2013, it was used on 124,285 of 182,150 acres in Monterey County. Growers have also incorporated other best management practices, such as water flowmeters, sprinkler improvements, micro irrigation systems, leakage reduction, and reduced sprinkler spacing in recent years, on a significant amount of acreage in Monterey County.

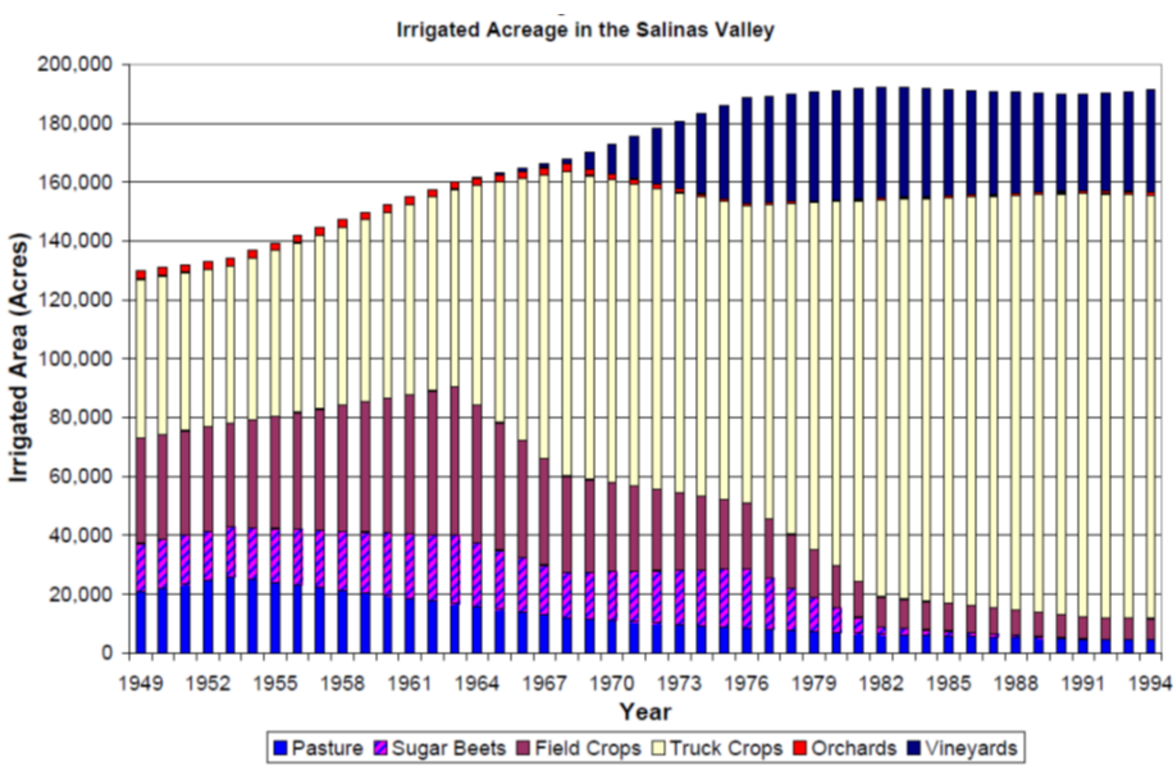

Figure 27. Acres of irrigated land in the Salinas Valley (from MCWRA, 2006).

The Salinas River watershed includes both single crop and rotational agriculture. Crop rotation refers to the practice of sequencing different crops on the same plot of land within a single growing season or over multiple growing seasons. Crop scheduling and rotation schedules, including time periods when fields are left fallow are critical to the timing of irrigation water application. Scheduling and rotation for the major crops of the study area include:

- Grapes: permanent crop grown year round, but irrigated only in the spring–fall.
- Rotational vegetables: grown and irrigated year round. The main varieties of rotational vegetables (lettuce, celery, broccoli, cauliflower, and spinach) have similar water requirements and evapotranspiration characteristics. Fallow periods in between plantings are assumed to be negligible.
- Strawberries: a biennial crop grown and irrigated year round, except for approximately a month in the fall when the soil is readied for next year's crop.

Groundwater levels in the Salinas Valley basin have been measured regularly by MCWRA in monitoring and production wells. Most wells measured by MCWRA in the study area are agricultural production wells that are pumped regularly from about April through September each year to irrigate farm land. Water level measurements taken in the fall are typically at their lowest elevations, but quickly rebound as indicated by subsequent measurements in winter. Most measured water levels at former Fort Ord are from monitoring wells and are not pumped except to collect groundwater samples (Harding ESE, 2001).

Estimated historical groundwater use (as determined via groundwater use reporting, anecdotal records and groundwater modeling) is summarized in the Draft Environmental Impact Report/Environmental Impact Statement for the Salinas Valley Water Project (Harding ESE, 2001) and shown in Figure 28. A general decline in agricultural groundwater use since 1970 can be seen, as well as the relatively steady increase in pumping for urban uses (MCWRA, 2006).

Data compiled by the MCWRA for the years 1995–2013 have been summarized by beneficial use (urban vs. agriculture) and by aquifer subarea in Figure 29 and Figure 30, respectively. Figure 29 shows that the basic trend of agricultural irrigation far outweighing urban irrigation is unchanged. A small increase in urban groundwater withdrawals is also apparent in 2002, although volumes seem to drop again in 2010. Withdrawals by aquifer sub area, show that the most groundwater is withdrawn in the Forebay and Upper Valley Areas with the Forebay being utilized more for all years except 1995–1999. The next most heavily used aquifer is the Pressure subarea, which has consistently greater withdrawals than the East Side subarea for the period of record.

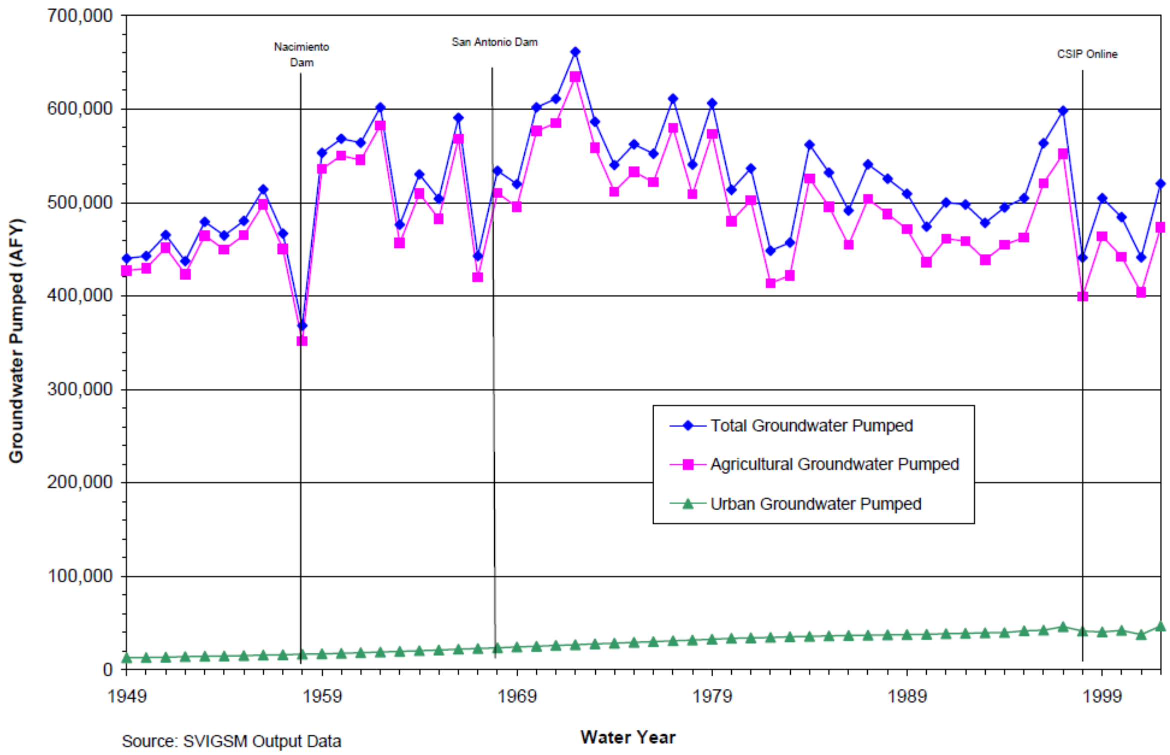

Figure 28. Estimated groundwater pumping in the Salinas Valley, 1949–2003 (from Harding ESE, 2001)

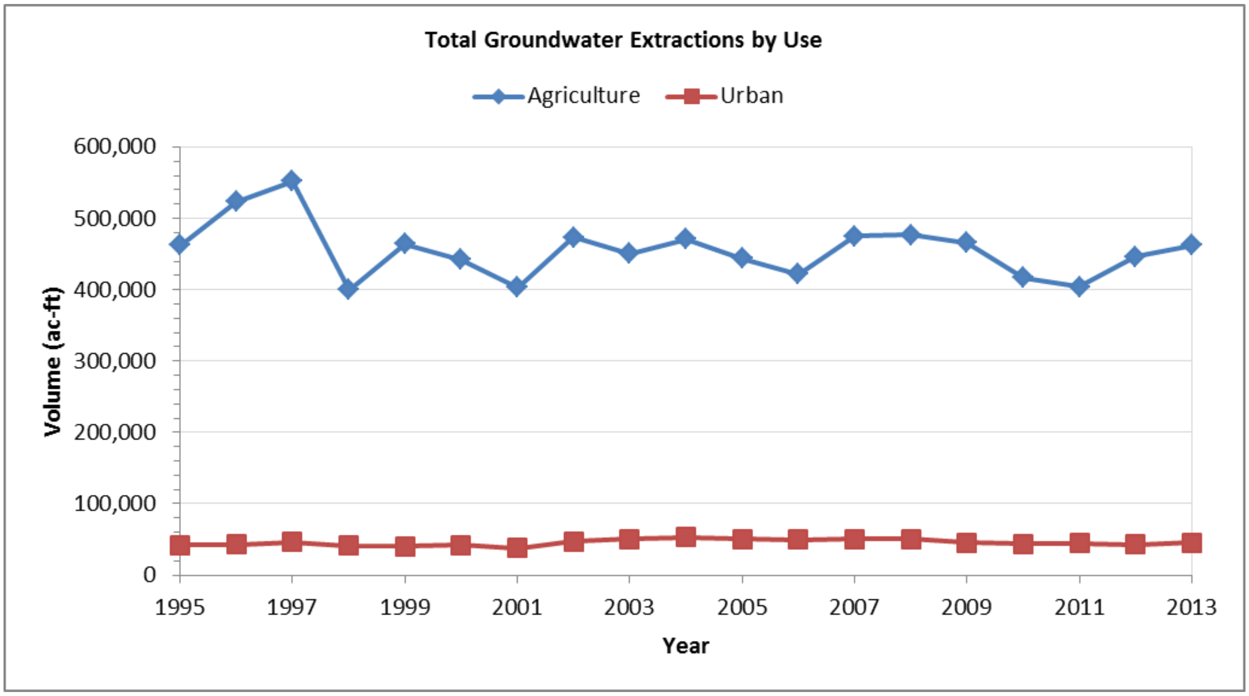

Figure 29. Estimated groundwater pumping in the Salinas Valley, 1995–2013

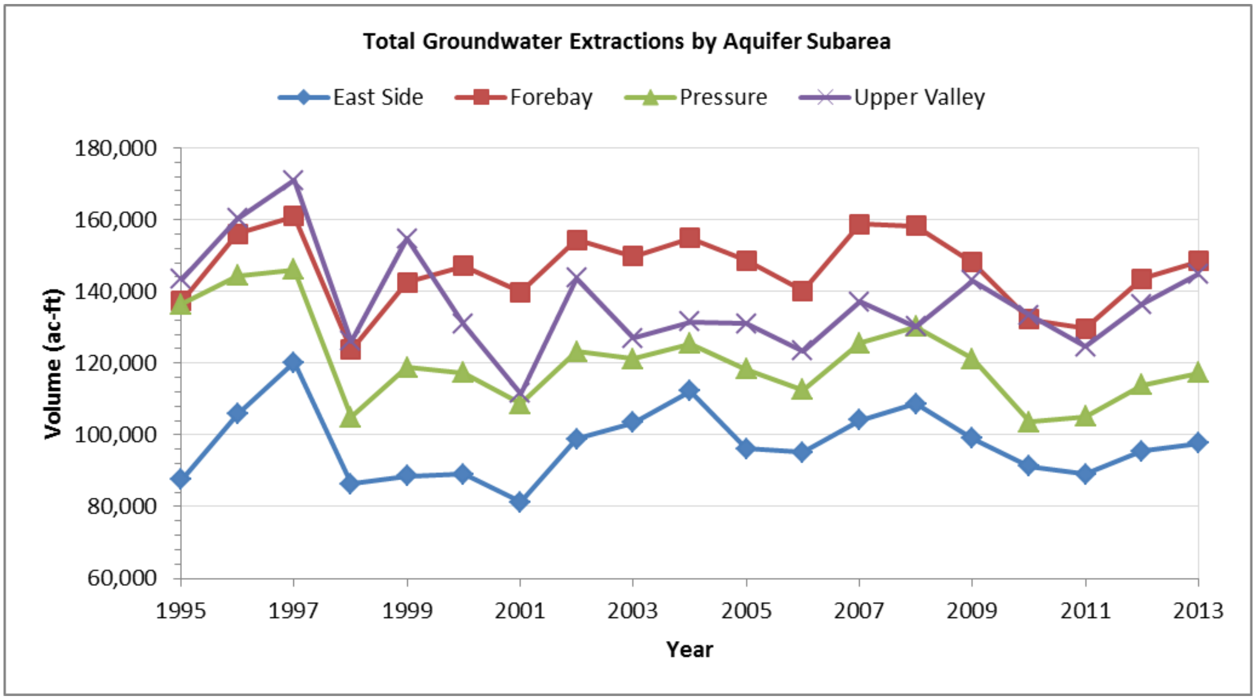

Figure 30. Estimated groundwater pumping in the Salinas Valley by aquifer subarea, 1995–2013

5.1.3 Water Quality: Surface Water

Summary statistics were tabulated for all salt-related analytes at all sampling stations across the watershed from all nine monitoring agencies. Statistics are shown in Table 20 for locations with 100 or more observations to provide an indication of the ranges of values. An examination of the median values for each analyte shows a great deal of variation from station to station. For example, the median conductivity ranges across two orders of magnitude from 474 µS/cm to 45,500 µS/cm. Similar observations apply to other analytes, although the range is closer to one order of magnitude in some cases. The full suite of summary statistics for each station and each constituent are provided in Appendix D. Many stations were monitored for a subset of the five parameters, and in many cases there were relatively few samples taken.

Note that in processing water quality data for surface water, the following steps were taken:

1. Samples recorded as “field replicates” were retained as individual samples.
2. Samples recorded as “lab replicates” were averaged.
3. Samples with results recorded as zero without other flags were removed.
4. Samples marked as non-detects were assigned the method detection limit).
5. Some samples were flagged as “did not quantify”, but had values recorded. The flag was ignored and the values were included in the final dataset.
6. Samples that had QA codes that merited removal from the database were removed (i.e. “Analyte found in blank. Sample contamination indicated.”).

Table 20. Summary statistics organized by analyte for stations with more than 100 samples

Waterbody	Station ID	Agency	Summary Statistics				
			Count	Min	Max	Mean	Median
Chloride (mg/L)							
Salinas	11152300	USGS	199	3.1	144.0	26.8	20
Old Salinas	309OLD	CCRWQCB	128	79	17,000	2,382	1,580
Salinas	309DAV	CCRWQCB	123	5.7	1,070	83.0	52
Tembladero	309TDW	CCRWQCB	116	42	9,600	1,020	530
Conductivity (µS/cm)							
Salinas	11152300	USGS	245	158	1,490	541.3	474
Moro Cojo	306MORMLN	ESNERR	206	830	88,590	38,866	43,245
Moro Cojo	306MORMLS	ESNERR	206	118.7	82,660	35,825	44,577
Old Salinas	309OSRPRS	ESNERR	204	110	50,000	11,680	7,559
Moro Cojo	306MOREH1	ESNERR	199	1326	83,670	37,487	45,500
Old Salinas	309OSRMDW	ESNERR	197	20	60,720	9,200	6,360.0
Old Salinas	309OSRPRN	ESNERR	196	20	62,130	23,293	21,168
Salinas	309SLRBRG	ESNERR	194	24.7	53,000	5,683	2,400
Tembladero	309TEMPRS	ESNERR	194	12.7	3,929	1,842	2,059
Old Salinas	309OLD	CCRWQCB	126	568.2	46,194	8,758	5,984
Tembladero	309TDW	CCRWQCB	125	404	15,190	3,721	2,827
Salinas	309DAV	CCRWQCB	120	92.4	2,346	1,012	797.6
Reclamation	REC-JON	CSUMB	106	124	1,865	830.2	765
Sodium (mg/L)							
Salinas	11152300	USGS	198	5.5	143	33.3	25.5

Waterbody	Station ID	Agency	Summary Statistics				
			Count	Min	Max	Mean	Median
Old Salinas	309OLD	CCRWQCB	124	39	8,600	1,316	888
Salinas	309DAV	CCRWQCB	114	7.5	1,500	88.9	54.5
Tembladero	309TDW	CCRWQCB	114	41	5,900	613.8	360
Salinity (ppt)							
Old Salinas	309OSRPRS	ESNERR	273	0.05	32.8	7.3	5.0
Moro Cojo	306MOREH1	ESNERR	270	0.12	50.0	24.8	30.0
Old Salinas	309OSRPRN	ESNERR	266	0.01	33.9	16.0	15.2
Salinas	309SLRBRG	ESNERR	263	0.01	35.0	3.8	1.5
Moro Cojo	306MORMLN	ESNERR	260	0.35	62.6	25.1	28.0
Moro Cojo	306MORMLS	ESNERR	258	0.057	48.0	23.3	29.4
Old Salinas	309OSRMDW	ESNERR	241	0.01	41.3	6.1	4.3
Tembladero	309TEMPRS	ESNERR	212	0.0033	5.0	1.0	1.1
Old Salinas	309OLD	CCRWQCB	125	0.29	30.0	5.1	3.4
Tembladero	309TDW	CCRWQCB	124	0.2	8.8	2.1	1.5
Salinas	309DAV	CCRWQCB	121	0.03	2.8	0.6	0.4
Salinas Lagoon	309SLRLAG	ESNERR	102	0.04	45.6	9.0	6.0
Total Dissolved Solids (mg/L)							
Salinas	11152300	USGS	195	116.0	807	347.6	298
Old Salinas	309OLD	CCRWQCB	133	193	59,000	5,671	3,600
Salinas	309DAV	CCRWQCB	126	75.3	14,200	842.6	550
Tembladero	309TDW	CCRWQCB	122	306	18,000	2,727	1,900

5.1.3.1 Spatial Distribution of Medians

Maps of median concentrations are used to explore the spatial distribution of analyte concentrations across the Salinas River Watershed area (Figure 31, Figure 33, Figure 35, Figure 37, and Figure 39). Due to the large number of stations in the Lower Salinas River area, zoomed versions of those maps are also provided (Figure 32, Figure 34, Figure 36, Figure 38, and Figure 40). The symbols for median concentrations were assigned based on the water quality guidelines for each analyte discussed in Section 2.1.1.3. For example, the graded symbols for median conductivity were grouped from zero to one-half of the water quality guideline (1,500 µS/cm for this map), one-half the water quality guideline to the water quality guideline (3,000 µS/cm for this map), and concentrations greater than the water quality guideline. Symbols are sized based on median concentrations only, and have no relation to the number of samples taken.

In the middle and upper portions of the Salinas River watershed, median values tend to be lower than those found in the Lower Salinas River Area. One exception is San Lorenzo Creek, where median concentrations are in the medium or high categories for all five analytes. As shown in Table 13, San Lorenzo Creek is impaired for chloride, sodium, and conductivity. In the rest of the middle and upper watershed, TDS and salinity (Figure 33 and Figure 39, respectively) have uniformly low median values, while conductivity, sodium, and chloride have a handful of medium values (Figure 31, Figure 35, and Figure 37).

In the Lower Salinas River Area, high median values tend to be located near the coast for all five analytes, although not all values are high by the coast (notably for TDS, Figure 34, and some high values are found farther into the watershed (see sodium in Figure 36 and chloride in Figure 38). The reason for the elevated medians adjacent to the coast needs further investigation in the Source Analysis phase of the project. Casagrande and Watson (2006) indicate brackish slough is located parallel to the coast, while freshwater slough with salinity generally lower than 1.5 ppt extends nearly ten miles inland. This is consistent with the median values shown in Figure 40. For all the analytes, median values in the Lower Salinas River area away from the coast are typically low, but there is a greater proportion of medium and high values scattered throughout the area than is observed in the middle and upper portions of the Salinas River watershed.

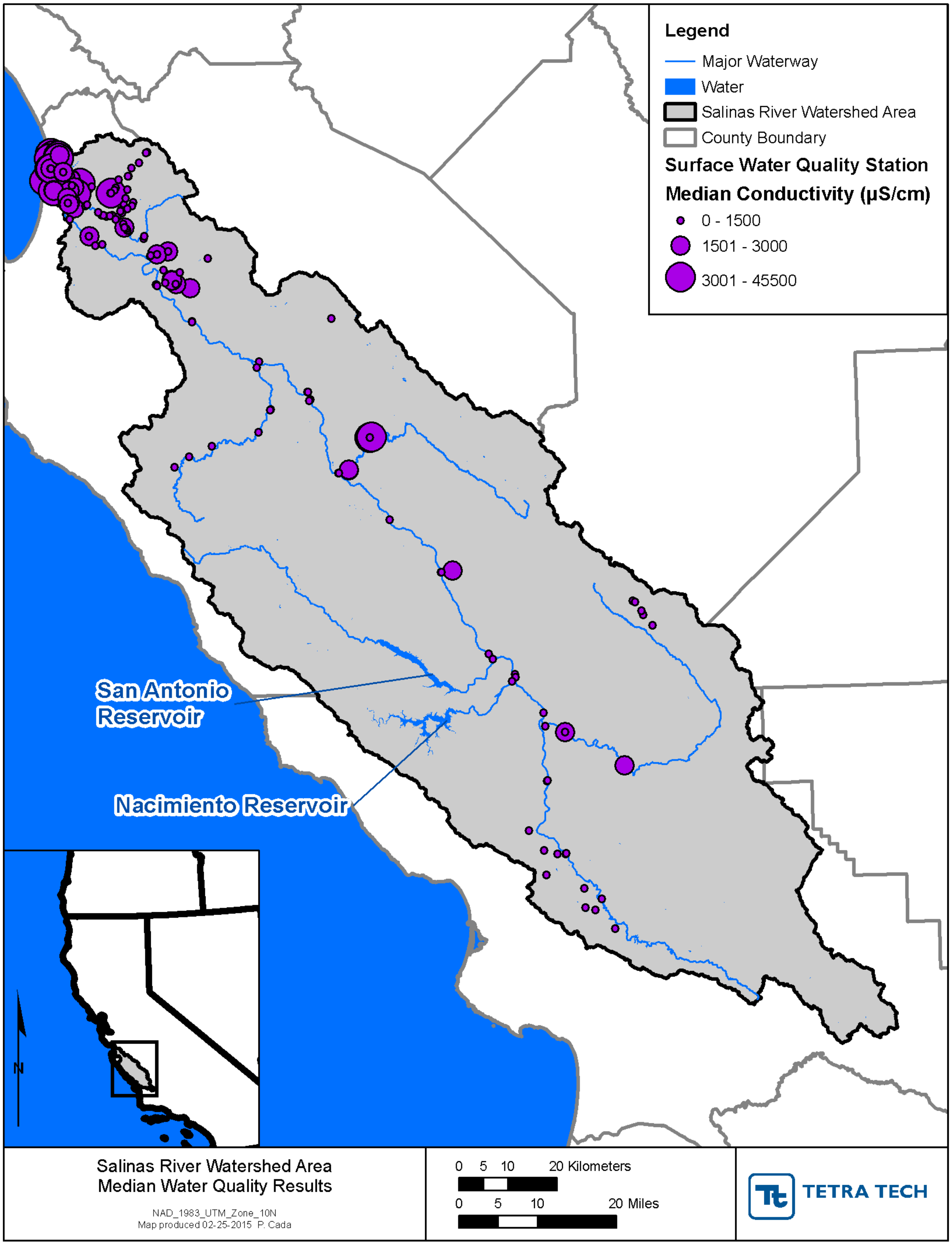

Figure 31. Median conductivity results for the entire Salinas River Watershed area

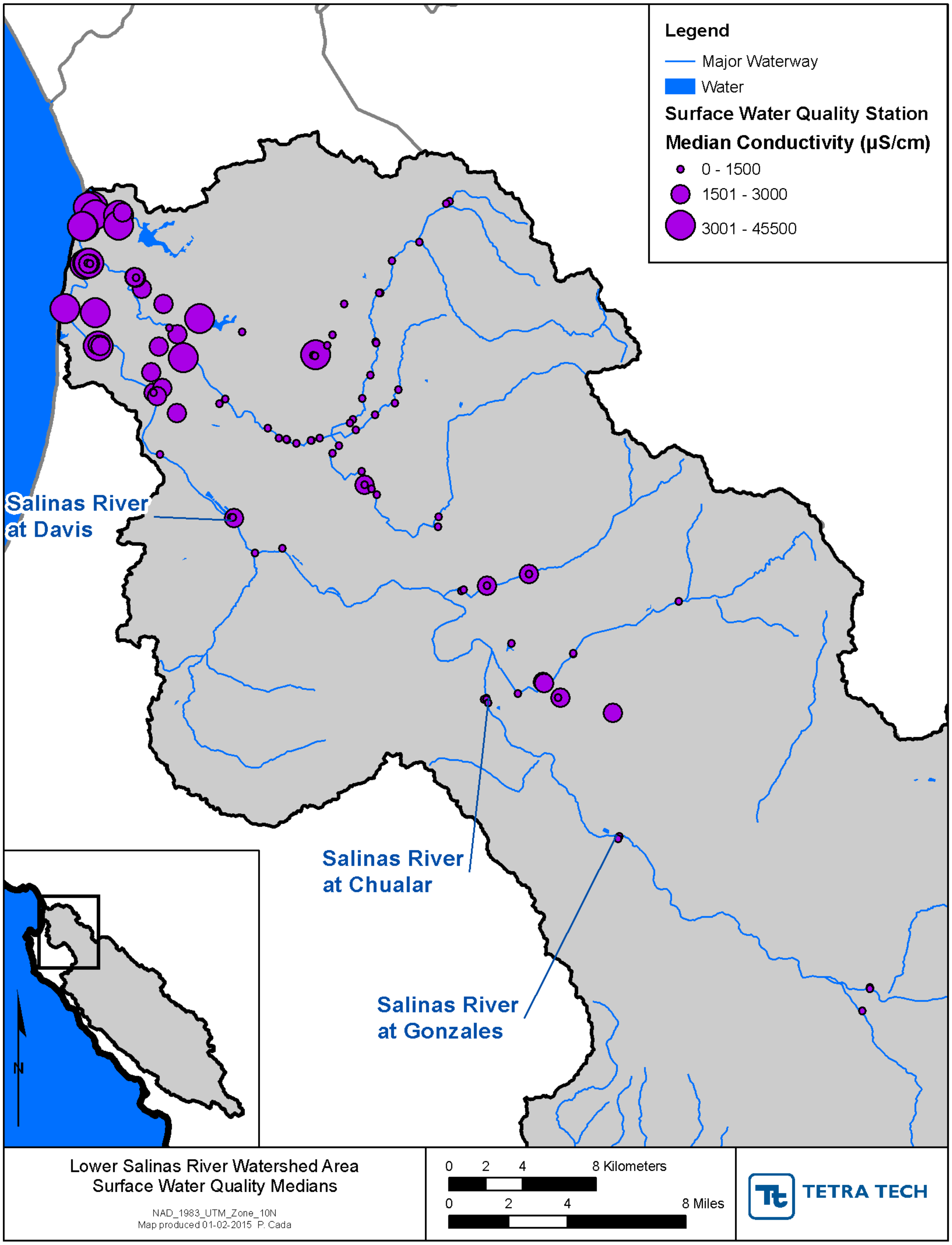

Figure 32. Median conductivity results for the Lower Salinas River Watershed area

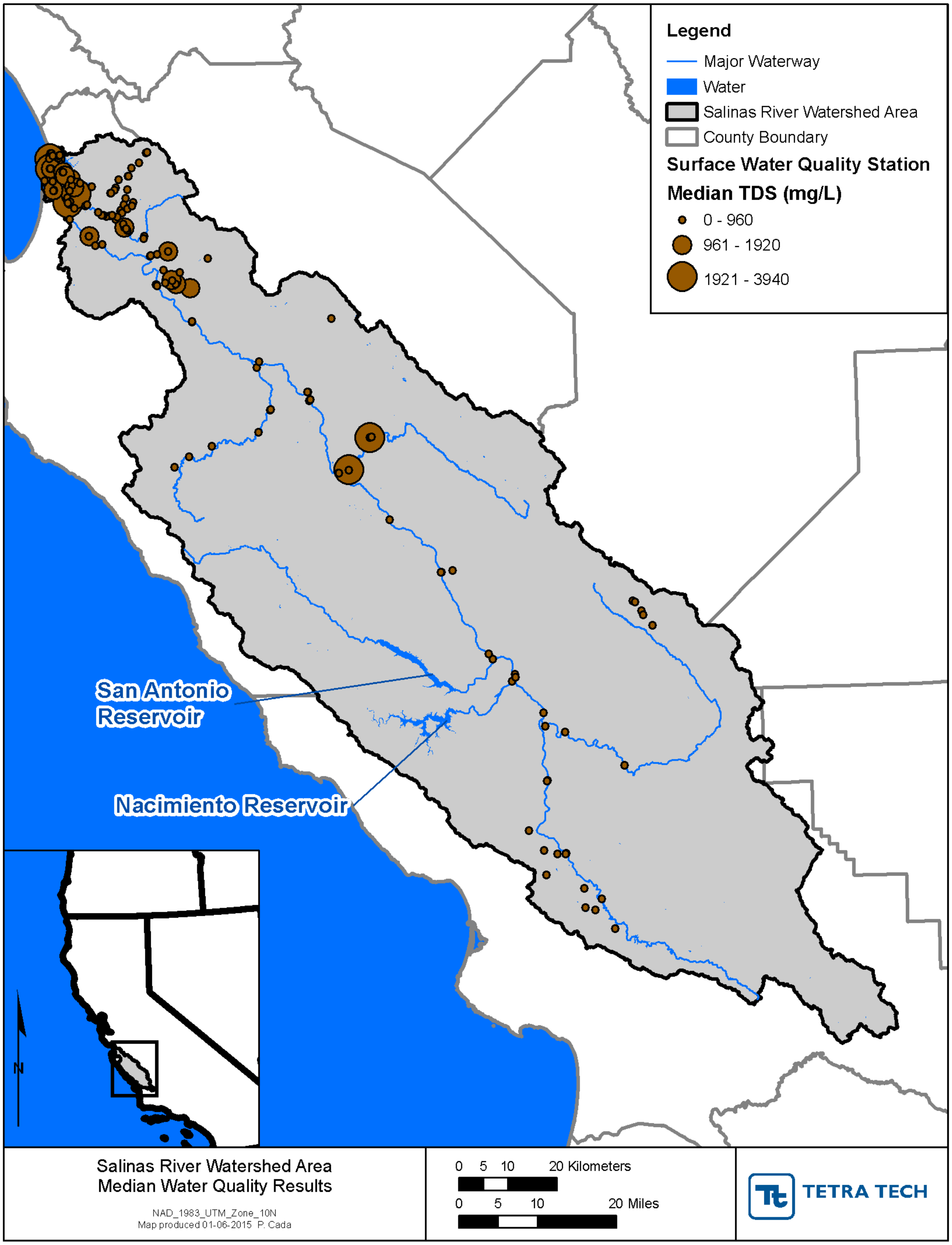

Figure 33. Median TDS results for the entire Salinas River Watershed area

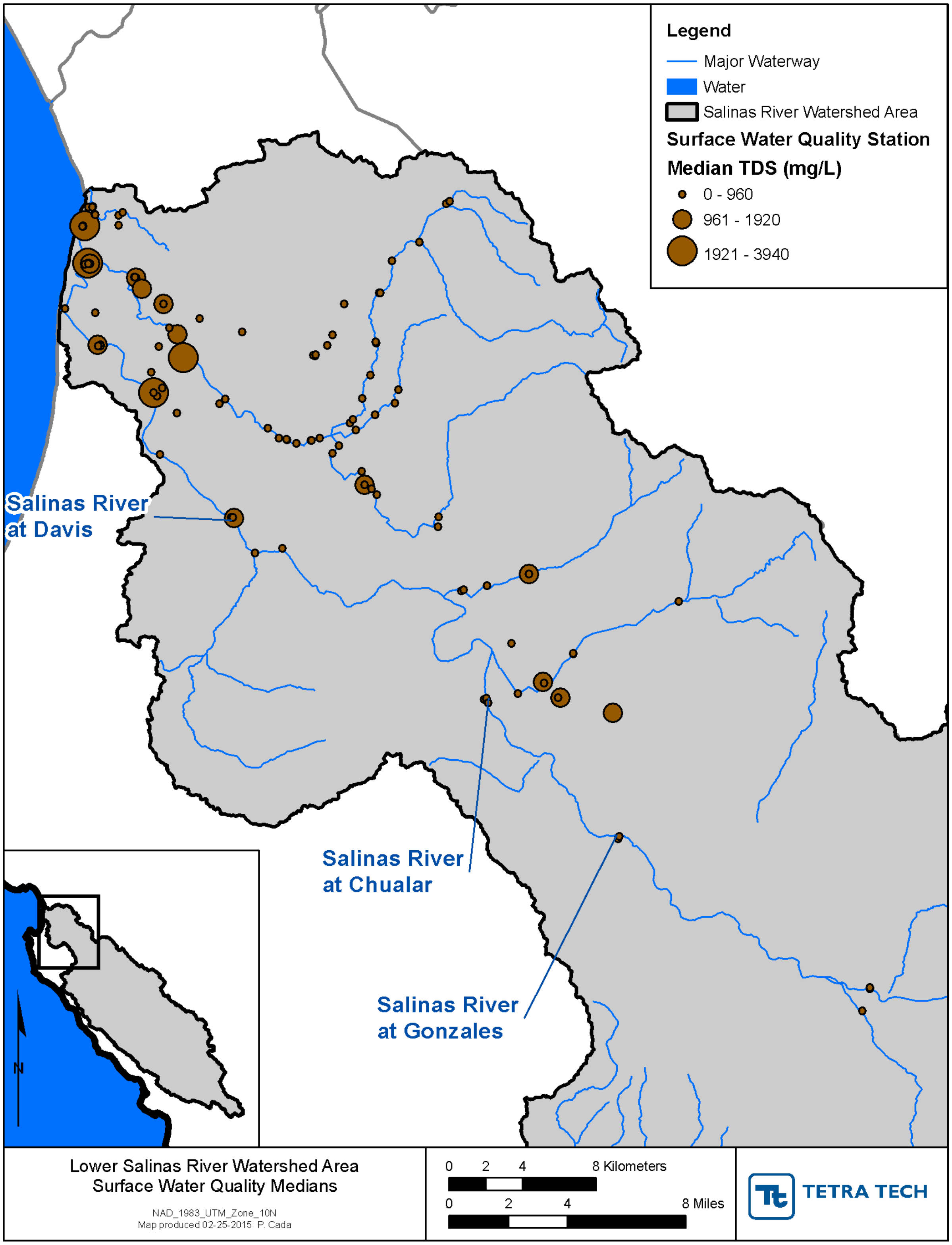

Figure 34. Median TDS results for the Lower Salinas River Watershed area

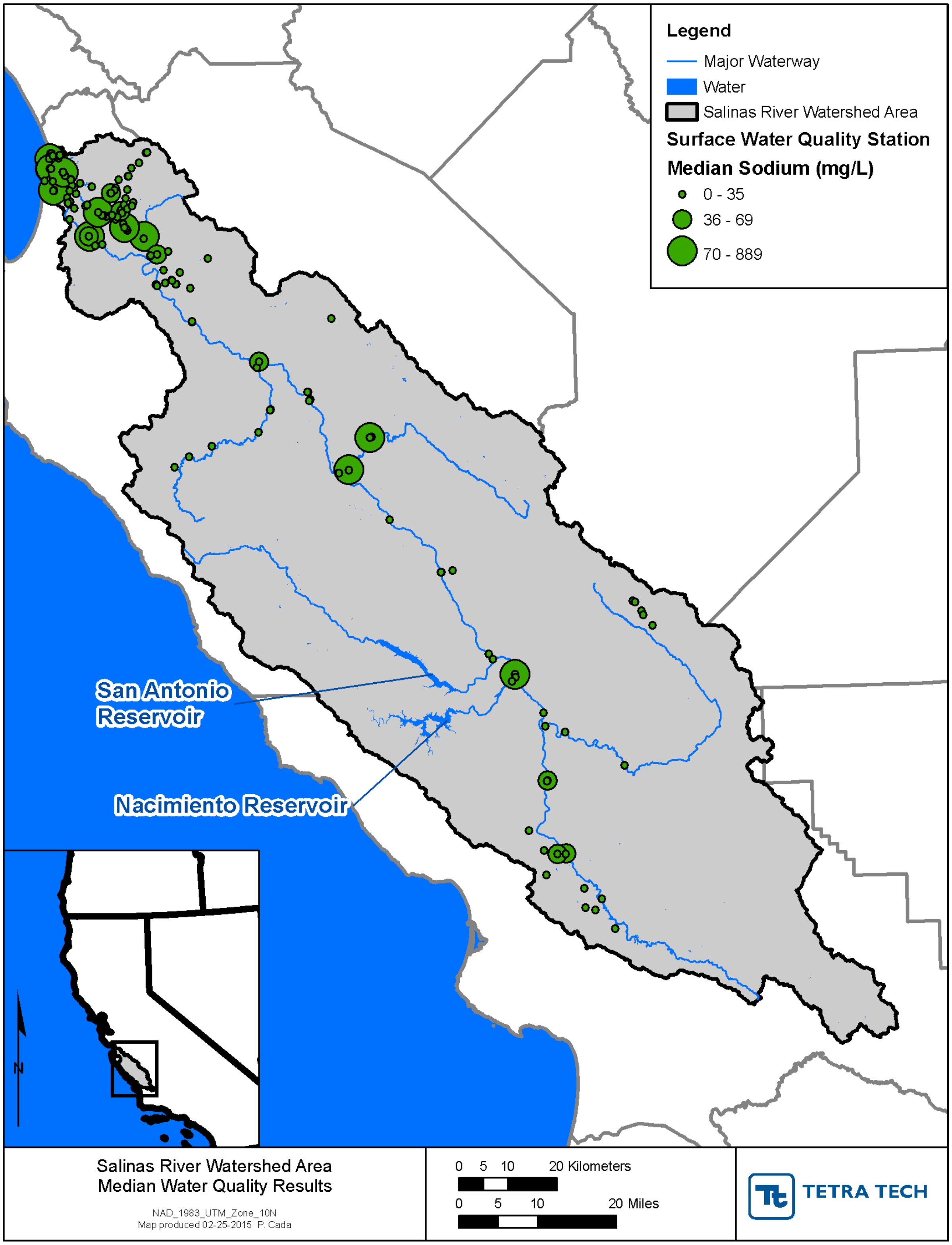

Figure 35. Median sodium results for the entire Salinas River Watershed area

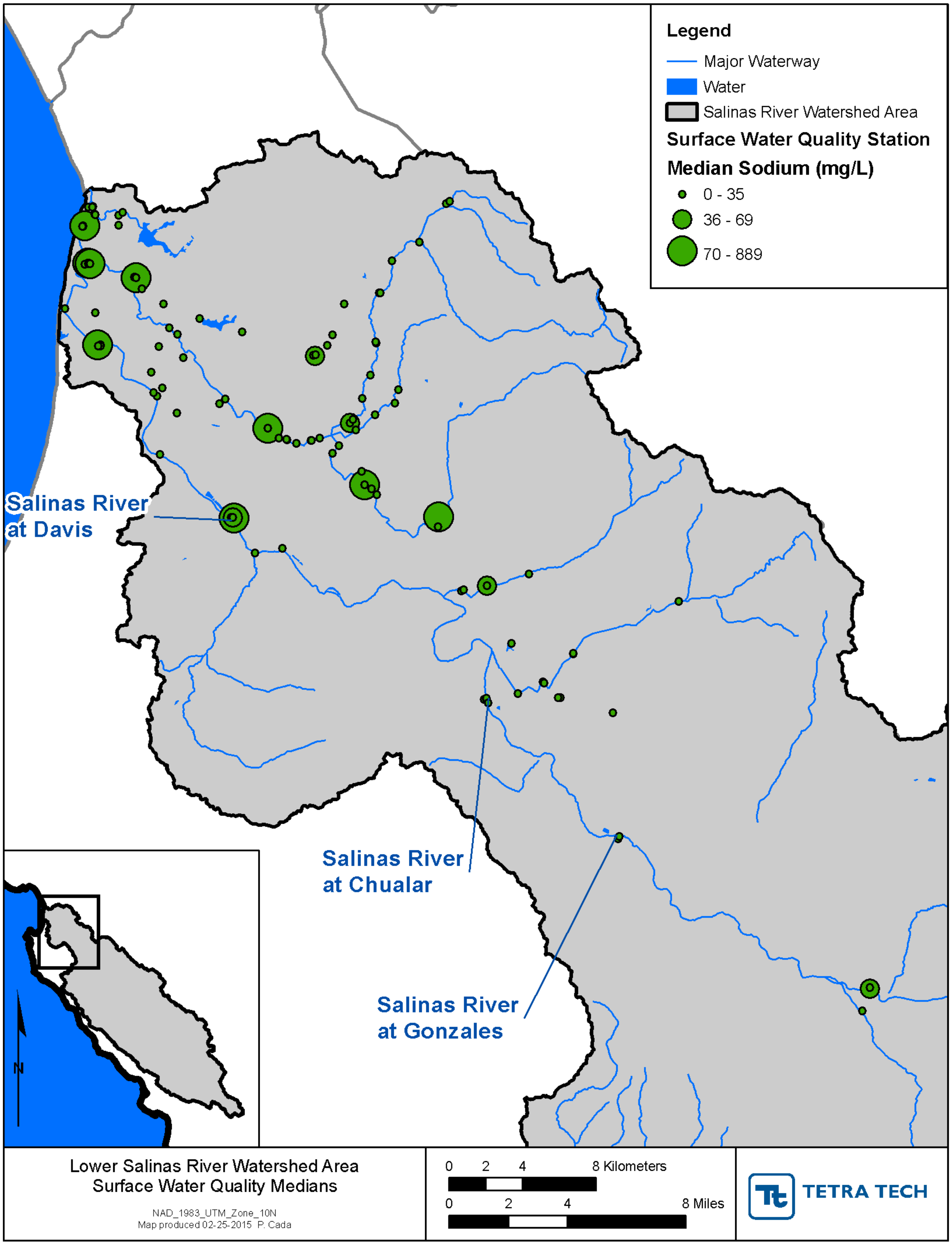

Figure 36. Median sodium results for the Lower Salinas River Watershed area

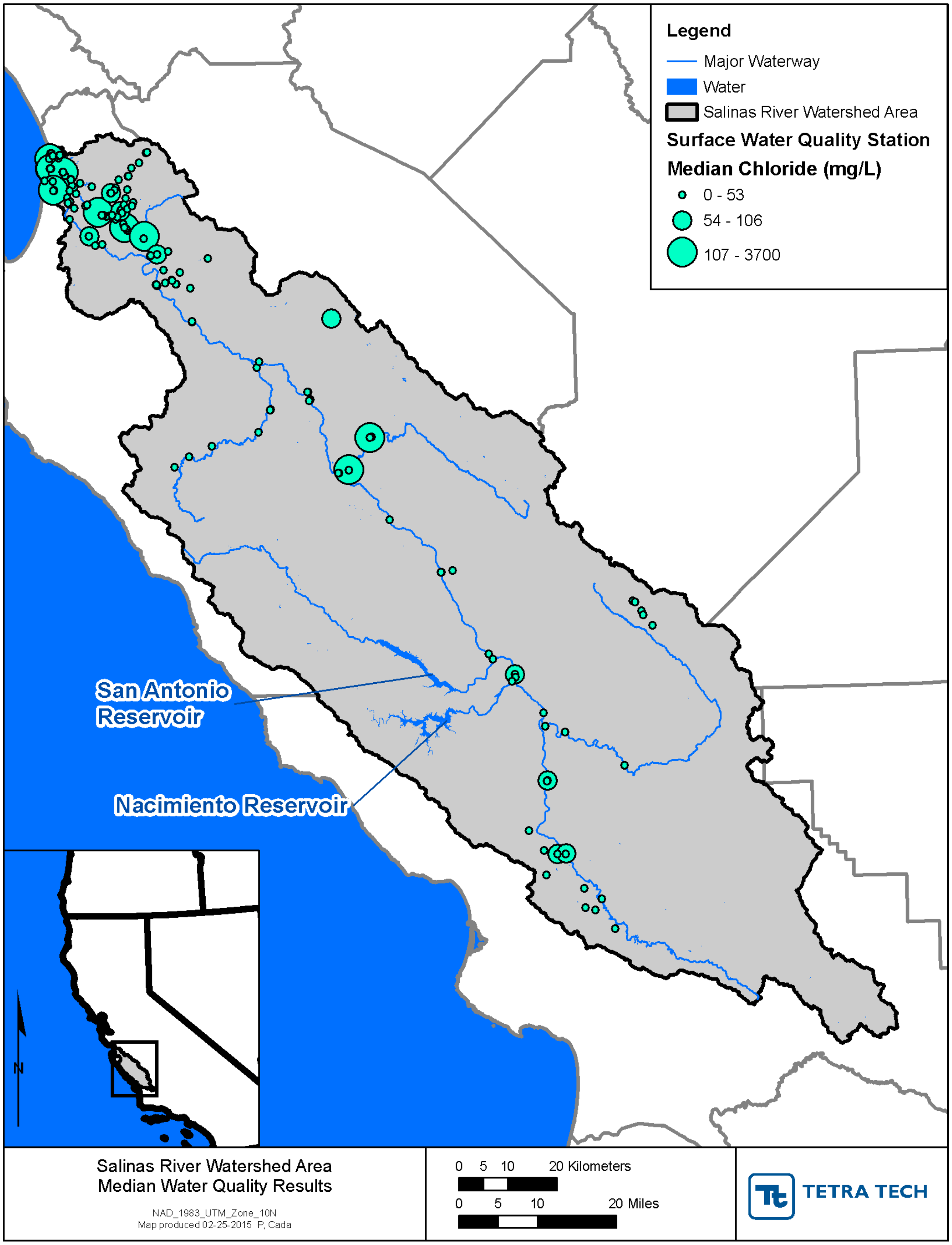

Figure 37. Median chloride results for the entire Salinas River Watershed area

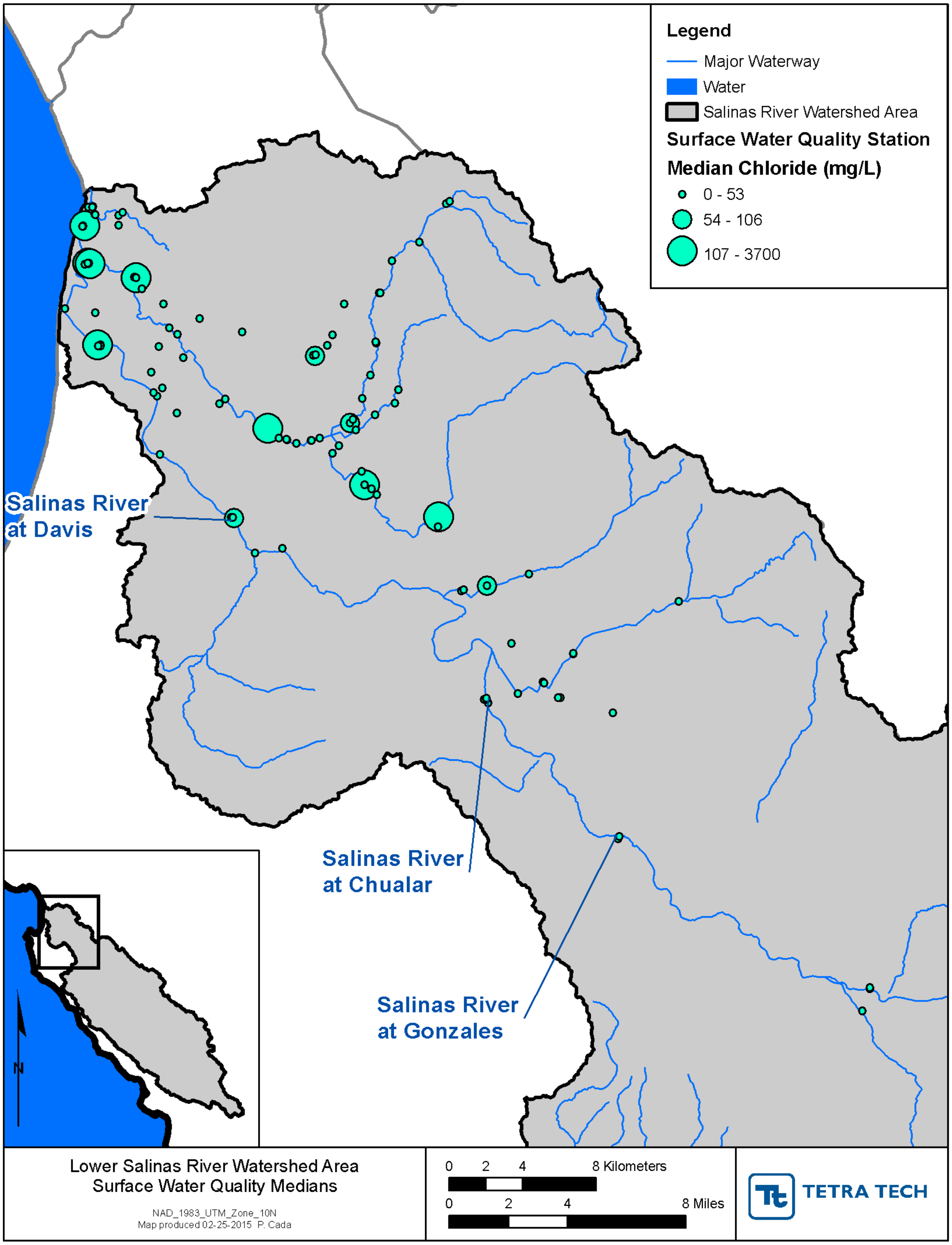

Figure 38. Median chloride results for the Lower Salinas River Watershed area

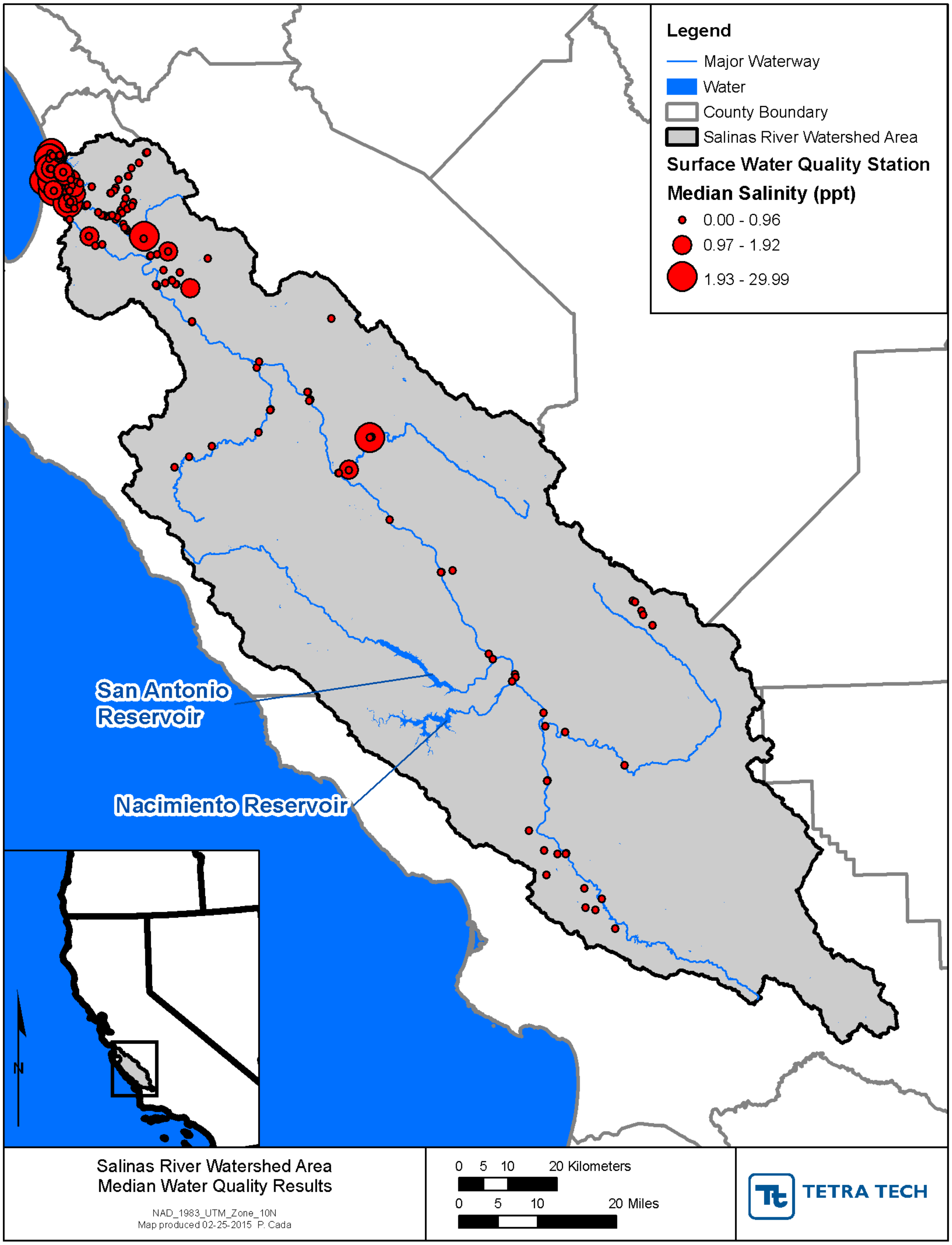

Figure 39. Median salinity results for the entire Salinas River Watershed area

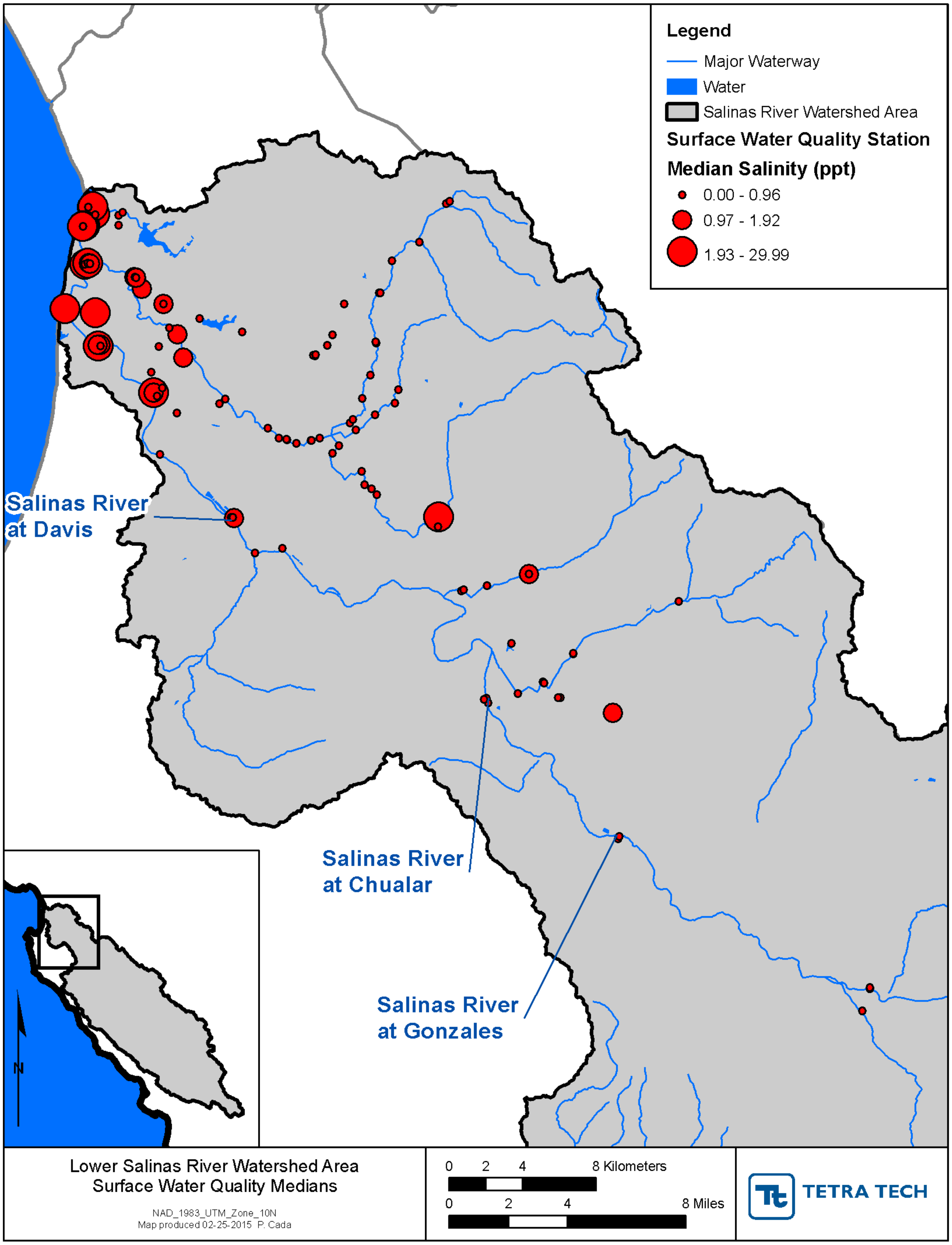

Figure 40. Median salinity results for the Lower Salinas River Watershed area

5.1.3.2 Key Water Quality Stations

To assess changes in water quality over time, three locations were chosen for a more focused examination of trends. Each location has multiple sampling stations across agencies. The locations chosen and the sampling station IDs for co-located monitoring are included in Table 21 and depicted in Figure 41. These three locations were chosen for in-depth analysis because they fall along the reach of the Lower Salinas River which is listed for salt-impairment. The Salinas at Gonzales location falls at the upstream end of the impairment, the Salinas at Davis location falls near the downstream end of the impairment, and the Salinas at Chualar location falls reasonably between the two. These locations were also selected because due to station colocation, they have a large volume of sample counts compared to other stations along the Lower Salinas.

Table 21. Station co-locations along the Lower Salinas River

Station Colocations							
Location	**CCAMP ID**	**CMP ID**	**SWAMP ID**	**GRANITE ID**	**CCoWs ID**	**MBNMS ID**	**USGS ID**
Lower Salinas River							
Salinas River at Gonzales River Road Bridge		309SAG			SAL-GON		
Salinas River at Davis Road	309DAV		309DAV	309DAV	SAL-DAV	309-SALIN-32	
Salinas River at Chualar Bridge on River Road	309SAC	309SAC	309SAC		SAL-CHU	309-SALIN-33	11152300

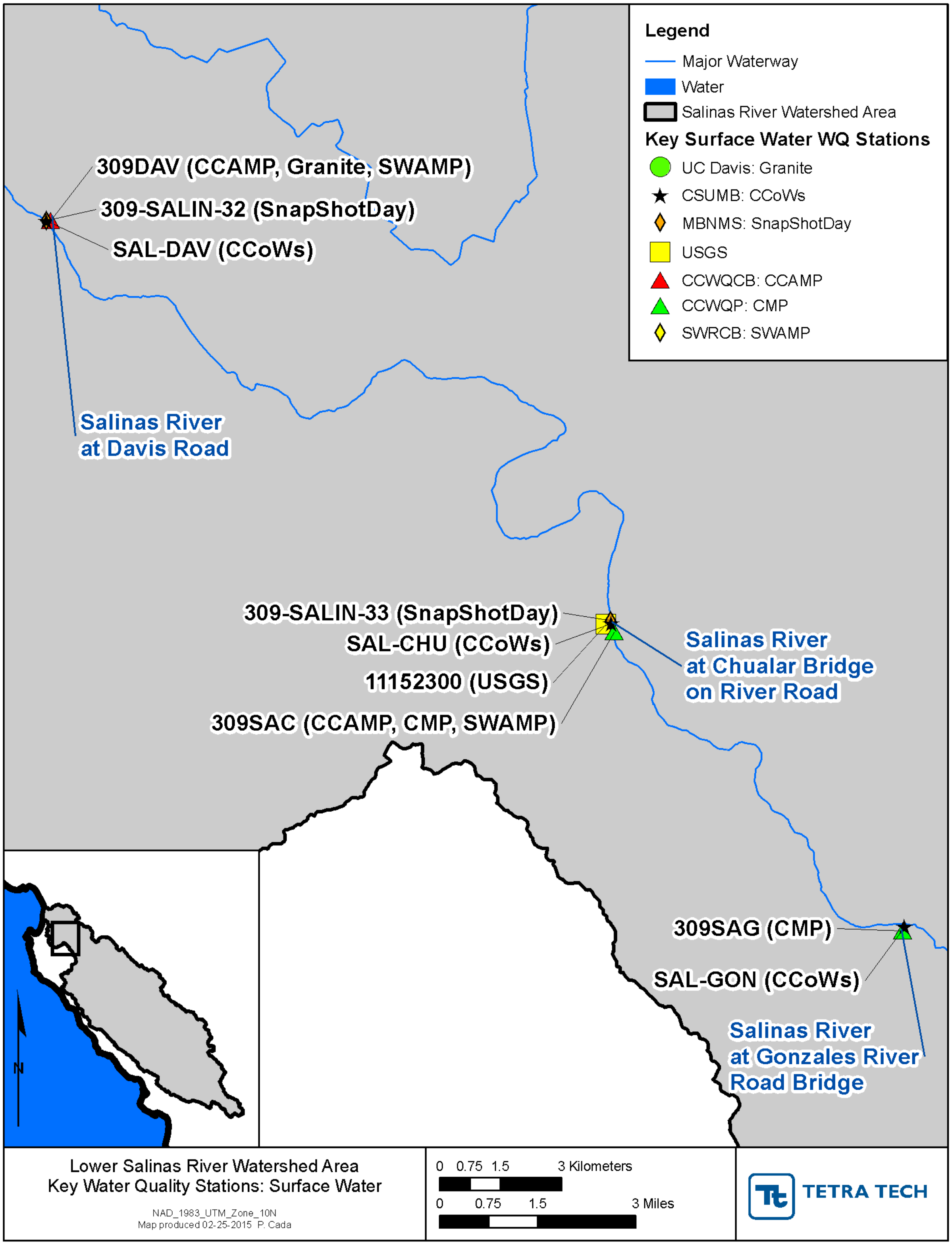

Figure 41. Locations of key water quality stations for surface water in the Lower Salinas River area

To visualize data among the key locations along the Lower Salinas River, box and whisker plots were constructed for the combined station data at each location, by analyte (conductivity, Figure 42; TDS, Figure 43; sodium, Figure 44; chloride, Figure 45; and salinity, Figure 46). For each location, the lower band of the gray box represents the first quartile, the middle band is the second quartile (median), and the upper band is the third quartile of the dataset. The whisker underneath the box captures the minimum, and the whisker above the box captures the maximum at that individual station. Stations are displayed from upstream on the right to downstream on the left. The applicable water quality guidelines and water quality objectives (as discussed in Section 2.1.1.3) are shown in each figure.

For each of the analytes, the median value and overall distribution is higher at Salinas River at Davis Road than for the two upstream locations. This is consistent with the findings in Section 5.1.3.1, where higher median values were found close to the Pacific coast. When a parameter is measured at both of the upstream locations (Figure 42, Figure 43, and Figure 46), the medians and overall distributions are remarkably similar. The only exception is for salinity, where an outlier is apparent at the Chualer Bridge location. Another observation is that the interquartile range (between the first quartile and the third quartile, representing 50 percent of the data) is quite narrow for most parameters at most stations. This indicates that the majority of the data tend to be clustered around the median.

For conductivity (Figure 42), all of the values are lower than the guideline (3,000 µS/cm). However, a handful of observations at Gonzales River Road Bridge and Chualar Bridge are higher than the objective (937.5 µS/cm). The TDS guideline (1,920 mg/L) is exceeded by some observations at Davis Road (Figure 43), but is not exceeded at Gonzales River Road Bridge or Chualar Bridge. However, both of those locations have some values higher than the objective (600 mg/L). For sodium (Figure 44), the guideline and objective are nearly identical (69 mg/L and 70 mg/L, respectively), and Chualar Bridge has values higher than the guideline and objective, whereas Davis Road has numerous observations higher than the guideline. The same applies to chloride (Figure 45), although the guideline and objective are farther apart at 106 mg/L and 80 mg/L respectively, and there are relatively fewer exceedances of the guideline at Davis Road. For salinity (Figure 46), the guideline of 1.92 ppt and objective of 0.6 ppt are exceeded at Chualar Bridge, and the guideline is exceeded at Davis Road.

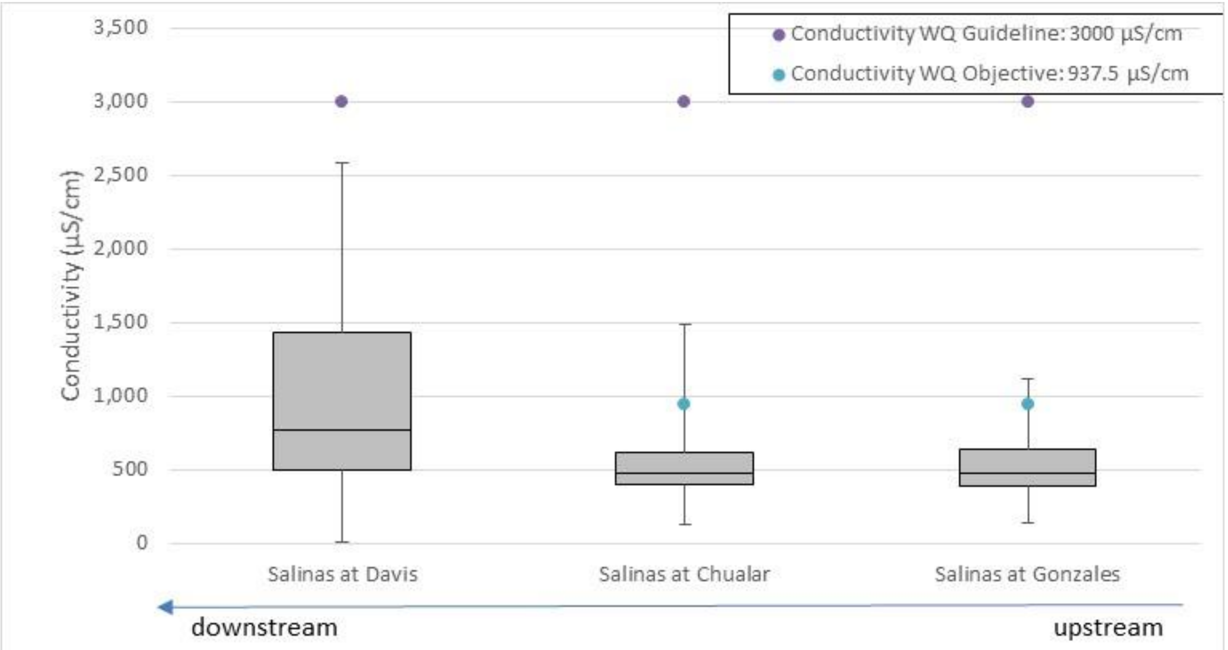

Figure 42. Box-and-whisker plot: conductivity results for key locations along the Lower Salinas River

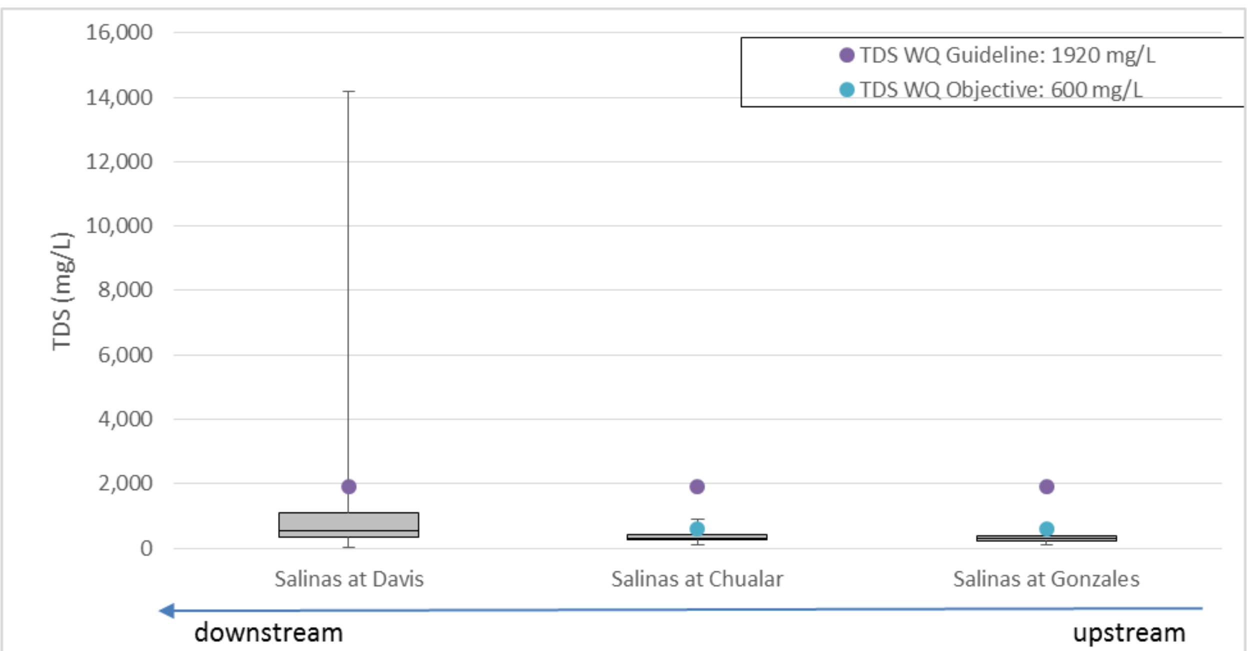

Figure 43. Box-and-whisker plot: TDS results for key locations along the Lower Salinas River

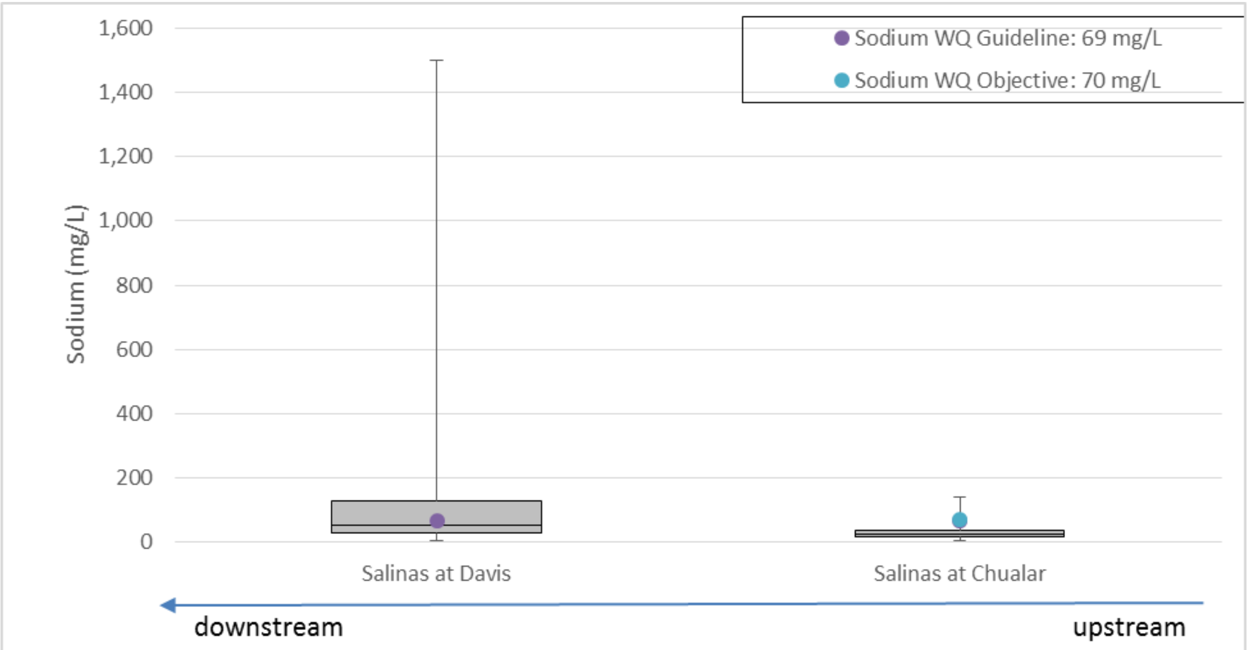

Figure 44. Box-and-whisker plot: sodium results for key locations along the Lower Salinas River

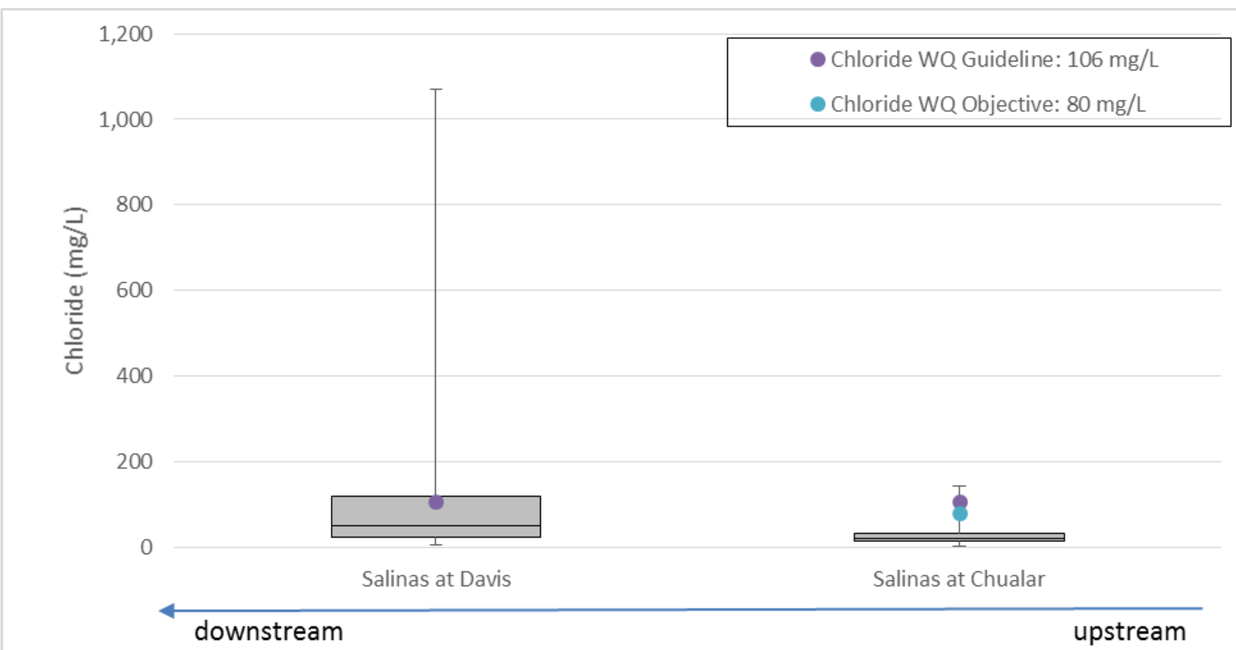

Figure 45. Box-and-whisker plot: chloride results for key locations along the Lower Salinas River

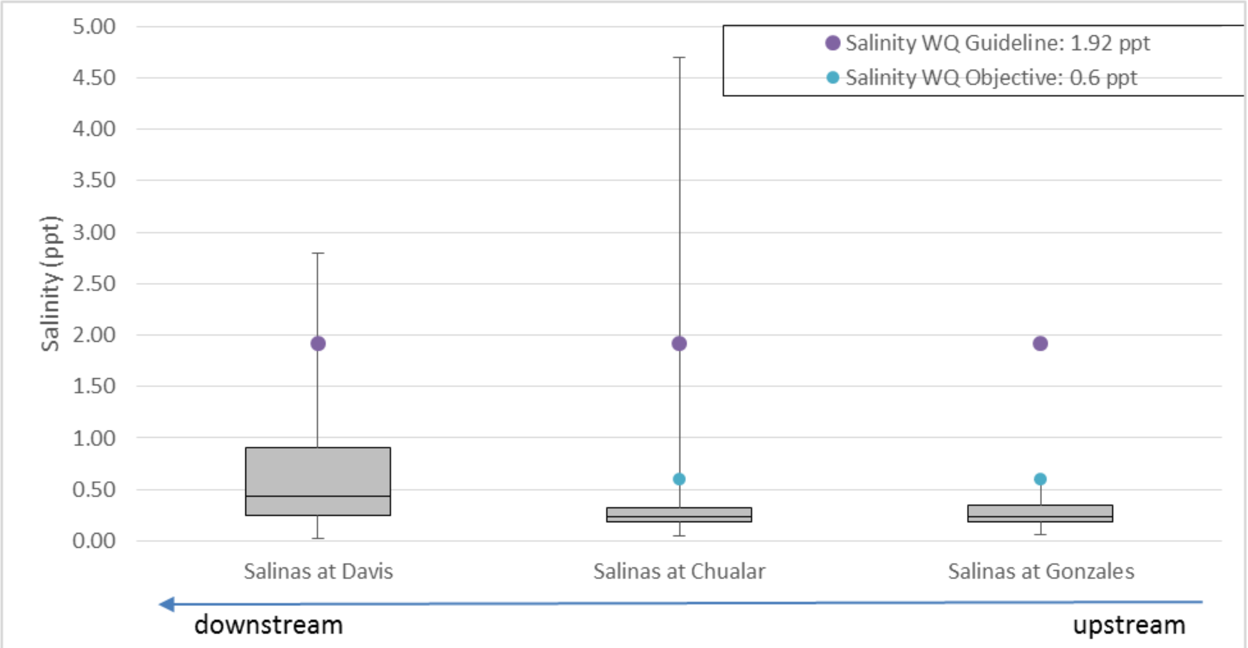

Figure 46. Box-and-whisker plot: salinity results for key locations along the Lower Salinas River

Time series plots at Salinas River at Chualar Bridge for each of the analytes are shown in Figure 47, Figure 48, Figure 49, Figure 50, and Figure 51 (note that some outliers were omitted from the plots since the intention is to visualize the overall trend of the data). This station includes data from USGS, which began monitoring at this station in 1967. However, data were only taken for one year, then monitoring was suspended. Monitoring resumed again in 1977; due to the large temporal gap and relatively few values available from the early time period, the 1967-1968 data are omitted from the time series plots. A visual observation of the time series suggests a possible weak decreasing trend for some of the parameters monitored by USGS during the first half of the monitored period, but cannot be confirmed without statistical tests for trend. During the more recent time period when monitoring data overlap from multiple agencies, there does not appear to be any visual trend.

Plots are shown for all analytes for an additional station – Salinas River at Davis Road (Figure 52, Figure 53, Figure 54, Figure 55, and Figure 56). Note that some outliers were omitted from the plots since the intention is to visualize the overall trend of the data. In each case, there is no visual indication of trend during the time period of 1998 – 2013. Time series plots were examined for Salinas River at Gonzales River Road Bridge as well (not shown), and there was no indication of a temporal trend. This suggests that the distributions of concentrations of the analytes have been relatively stable through time.

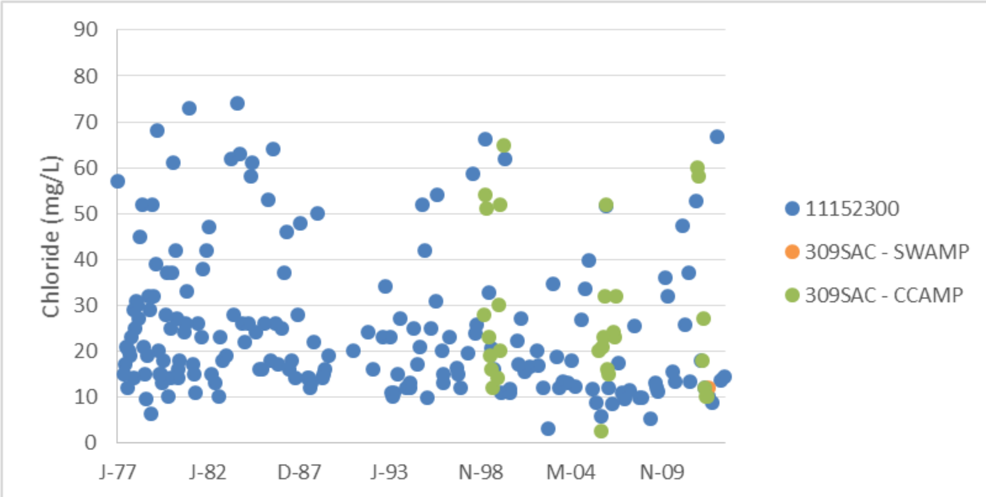

Figure 47. Time series of chloride at Salinas River at Chualar Bridge

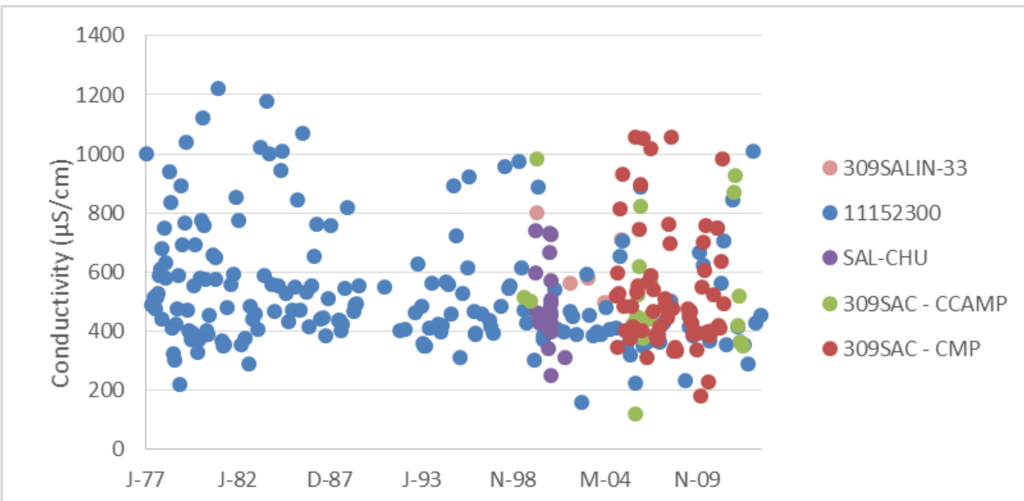

Figure 48. Time series of conductivity at Salinas River at Chualar Bridge

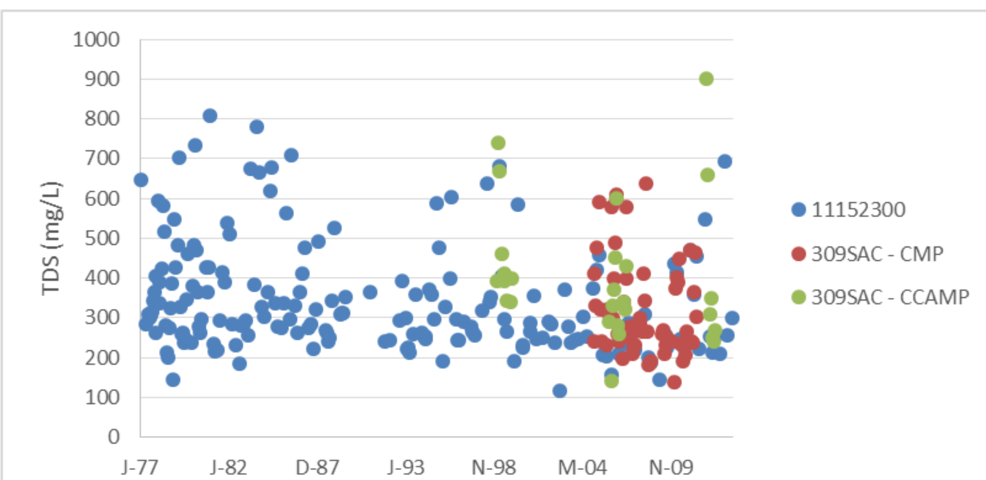

Figure 49. Time series of TDS at Salinas River at Chualar Bridge

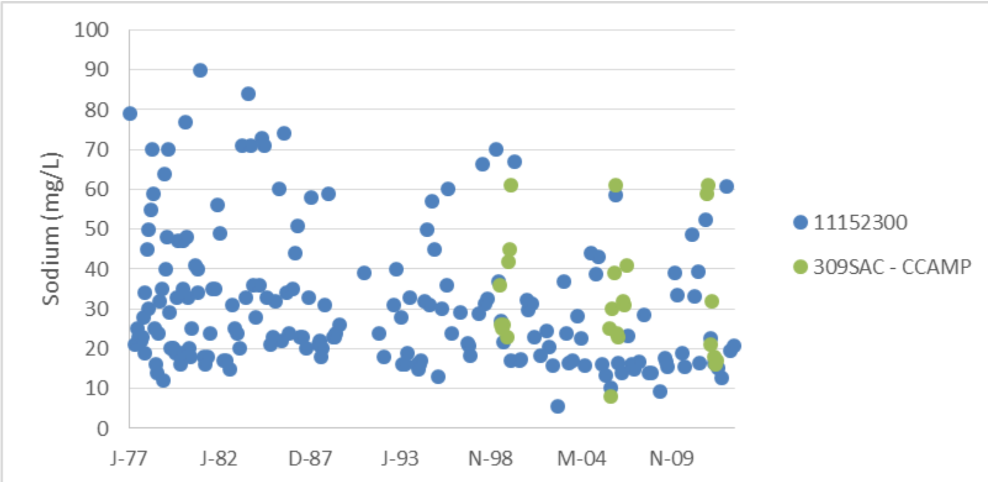

Figure 50. Time series of sodium at Salinas River at Chualar Bridge

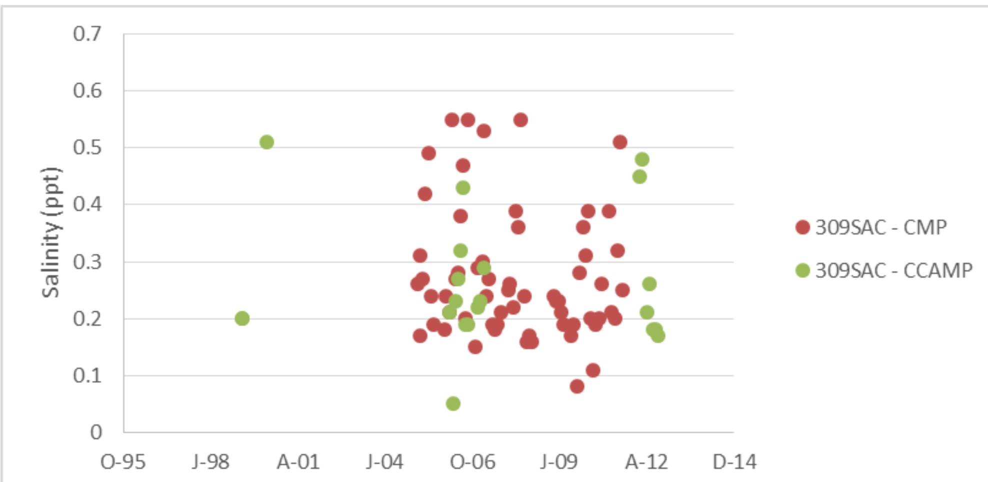

Figure 51. Time series of salinity at Salinas River at Chualar Bridge

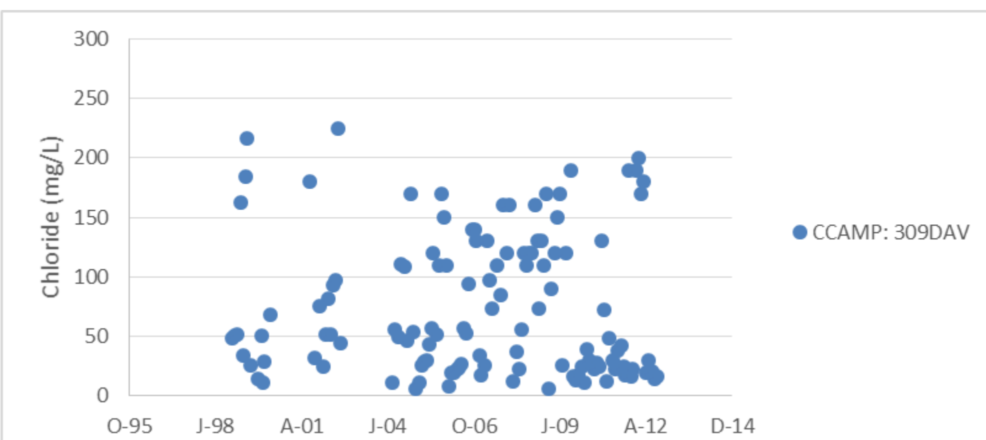

Figure 52. Time series of chloride at Salinas River at Davis Road

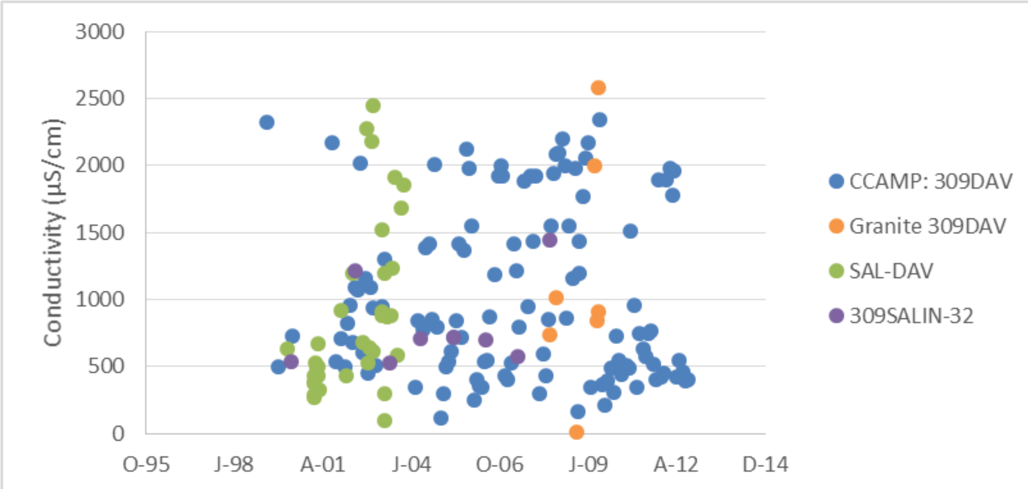

Figure 53. Time series of conductivity at Salinas River at Davis Road

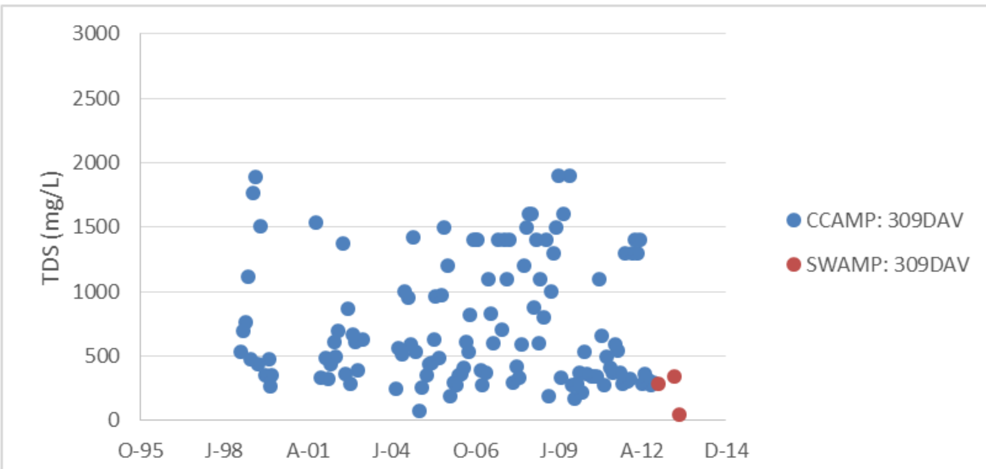

Figure 54. Time series of TDS at Salinas River at Davis Road

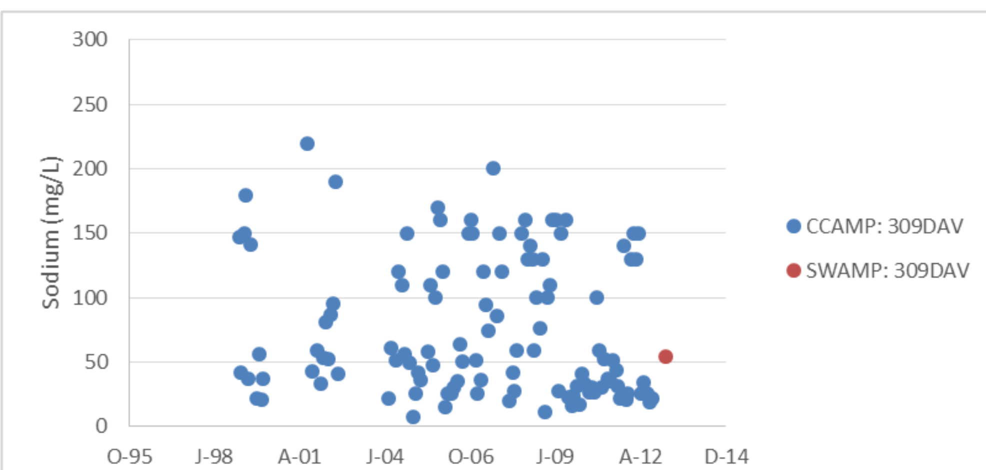

Figure 55. Time series of sodium at Salinas River at Davis Road

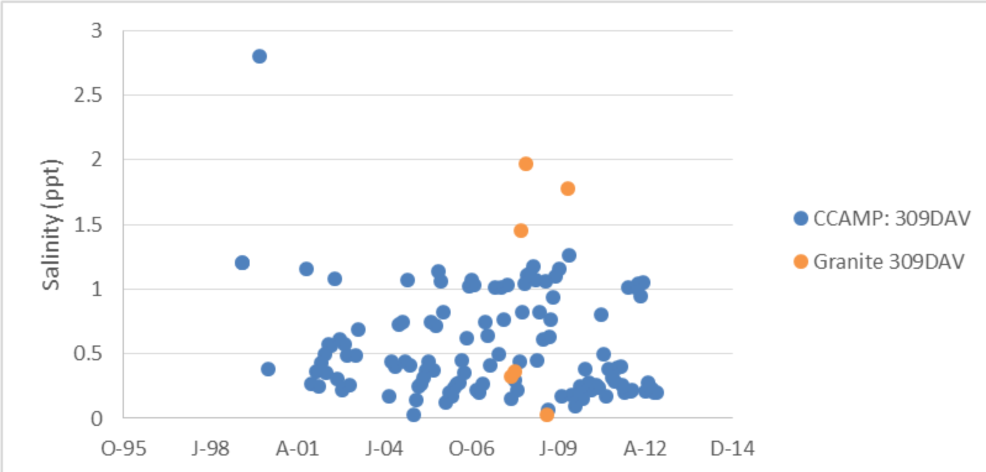

Figure 56. Time series of salinity at Salinas River at Davis Road

Another type of trend that might be present in the data is a seasonal trend. Monitoring data are plotted by month for each of the analytes at Salinas River at Chualar Bridge (Figure 57, Figure 58, Figure 59, Figure 60, and Figure 61). A strong seasonal trend is apparent at this station, a trend that is consistently repeated for all five analytes. Concentrations increase during the spring months and decrease into the summer; furthermore, the range of values decreases during the summer and is lowest during August through October or November. The same trends are observed at Salinas River at Gonzales River Road Bridge (not shown). However, essentially no trend is present in all of the analytes for Salinas River at Davis Road. Conductivity at this location is shown in Figure 62; plots of the other analytes look similar. Average monthly flow (in cfs) is also shown in this figure, and there is no apparent correlation between conductivity and flow. Figure 63 shows conductivity and average monthly flow for Salinas River at Chualar Bridge, and while low flow is coincident with low summer conductivity, there are also periods of low flow when conductivity is much higher. To further explore seasonal trends, a station was selected in the middle part of the watershed upstream of agricultural influence and immediately downstream of San Antonio and Nacimiento Reservoirs (Figure 64). Relatively fewer data were available at this station, but the data suggest a somewhat weaker seasonal trend. Concentrations (and the overall range) is lowest during the summer as seen at Chualar Bridge and Gonzales River Road Bridge. The impact of reservoir operations on average monthly flow can be seen, as there are no periods of extremely low flow. Other analytes at this location show the same pattern as conductivity. The reason for the seasonal trends in analyte magnitudes (and the lack of a seasonal pattern at Davis Road) are not known.

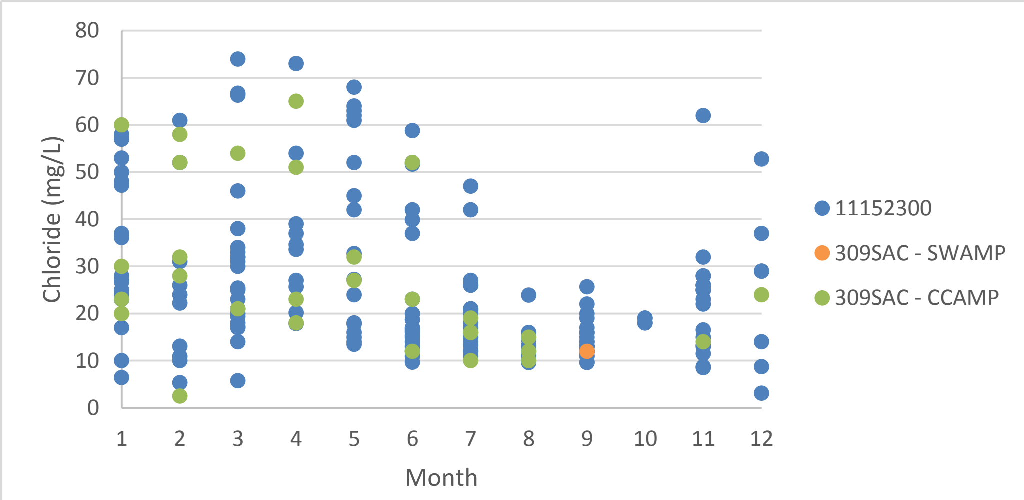

Figure 57. Seasonal distribution of chloride at Salinas River at Chualar Bridge

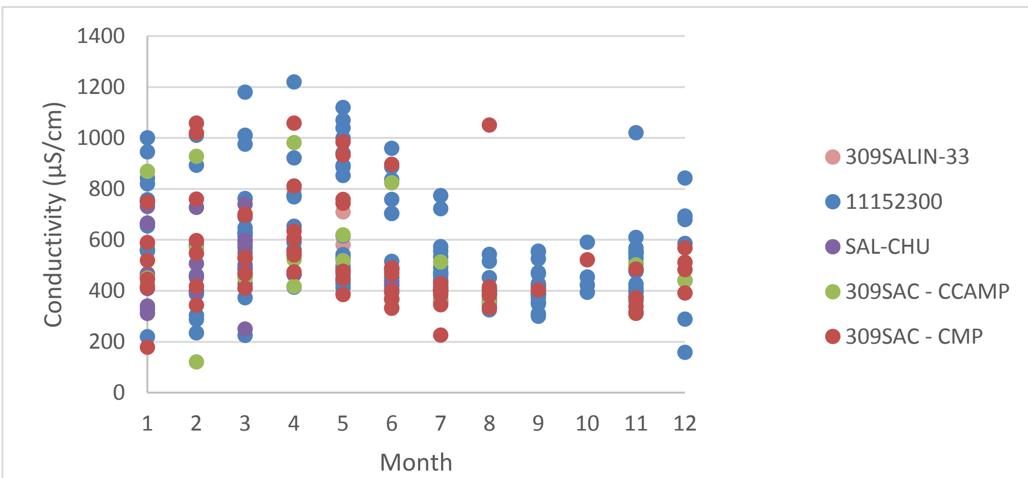

Figure 58. Seasonal distribution of conductivity at Salinas River at Chualar Bridge

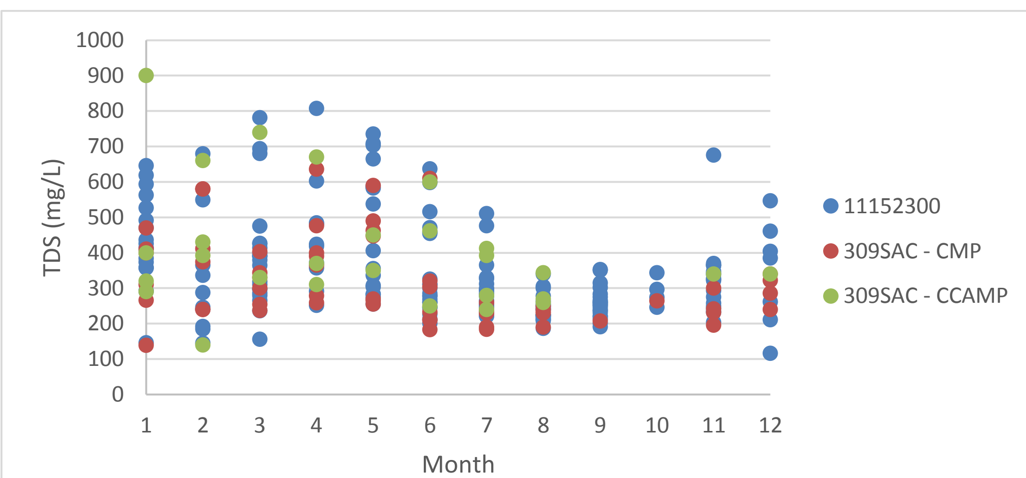

Figure 59. Seasonal distribution of TDS at Salinas River at Chualar Bridge

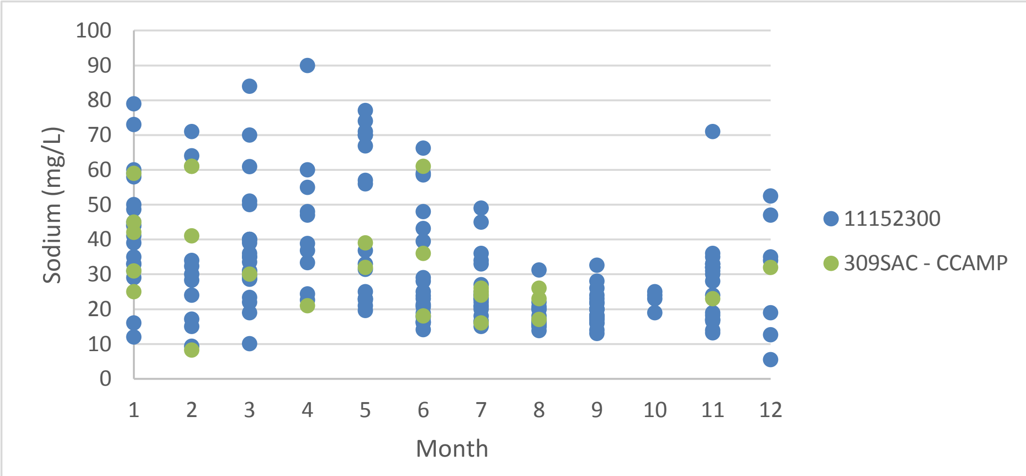

Figure 60. Seasonal distribution of sodium at Salinas River at Chualar Bridge

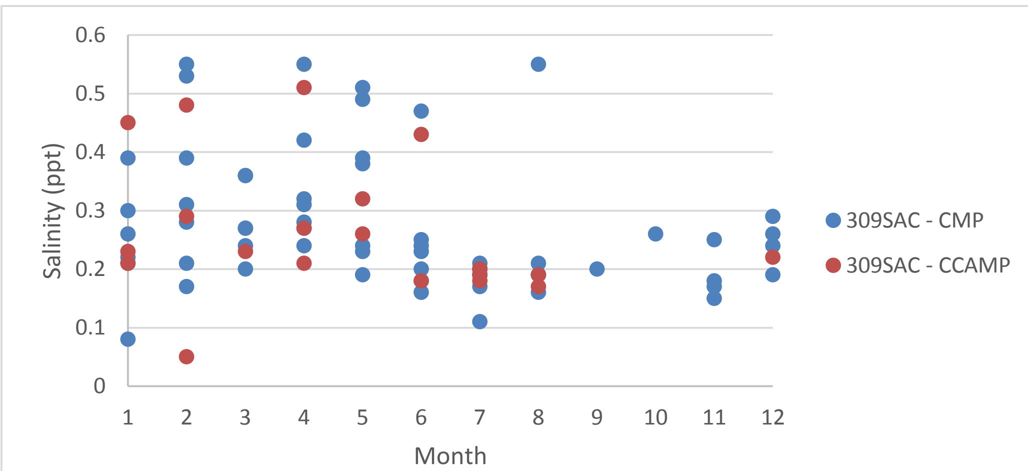

Figure 61. Seasonal distribution of salinity at Salinas River at Chualar Bridge

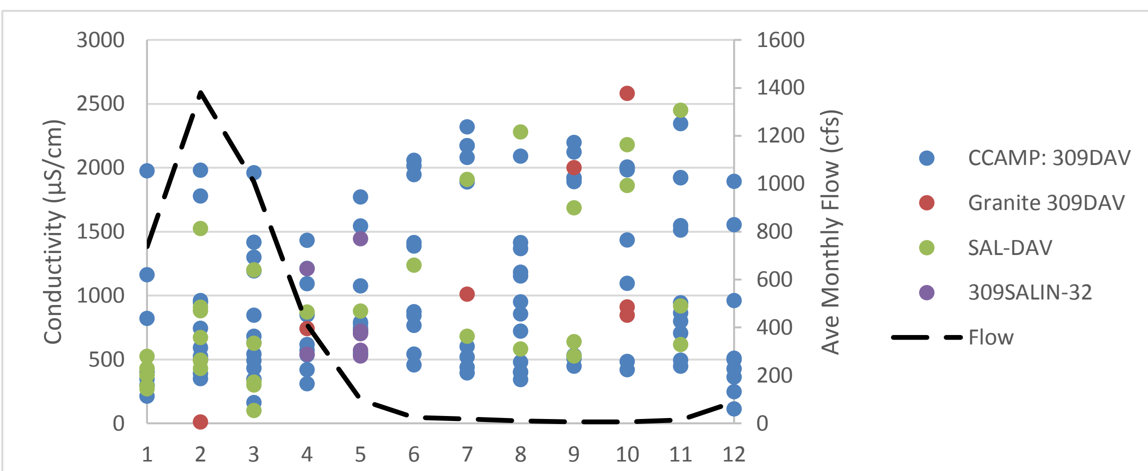

Figure 62. Seasonal conductivity and flow at Salinas River at Davis Road

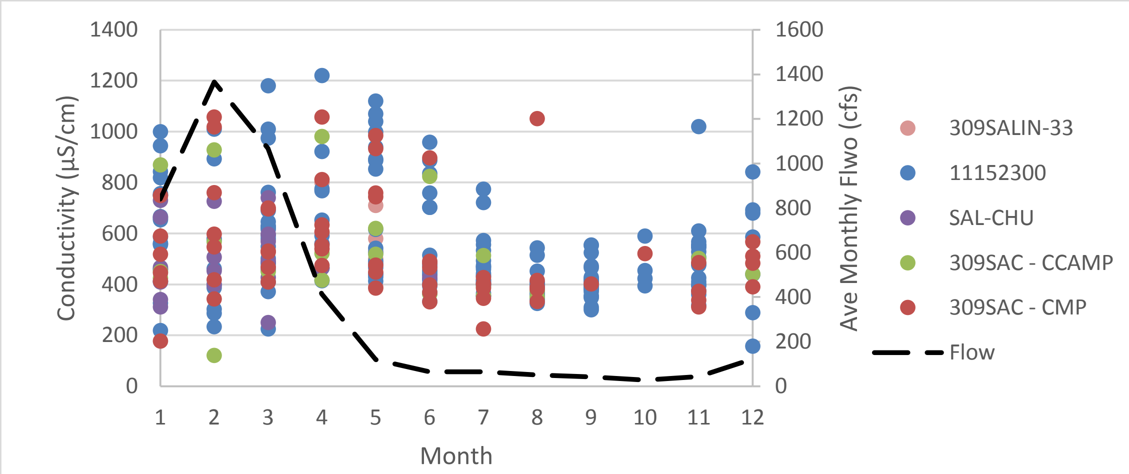

Figure 63. Seasonal conductivity and flow at Salinas River at Chualar Bridge

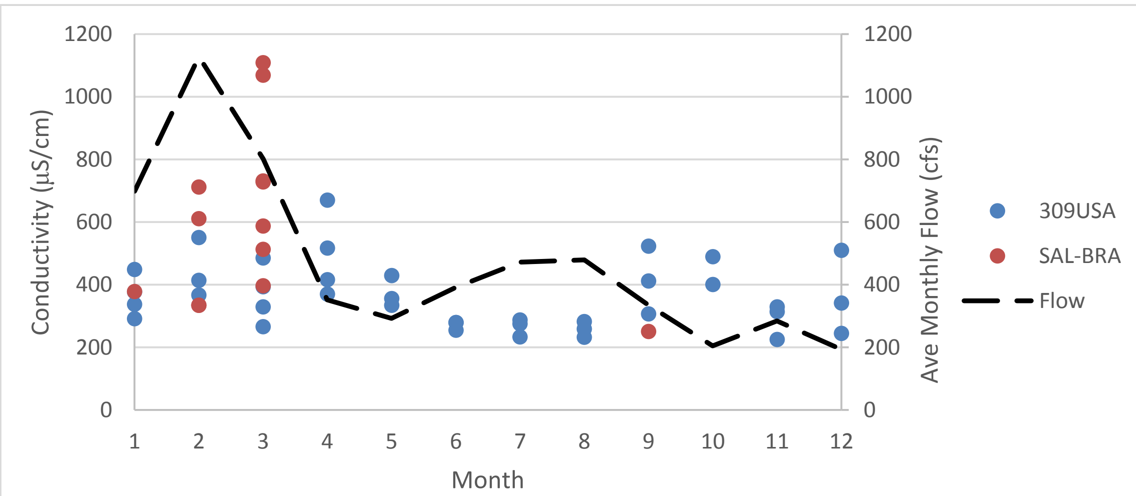

Figure 64. Seasonal conductivity and flow at Salinas River at Bradley Road

5.1.4 Water Quality: Groundwater

The well data provided by GAMA and USGS encompasses a large number of wells, which have generally a very small number of samples per well. Salinity (measured as ppt) was not monitored. Summary statistics were compiled based on geographic location associated with a groundwater aquifer. Aquifers within the Salinas Valley were selected for groupings in the table because of the density of monitoring in that region. The wells were assigned to aquifer geographically using their latitude/longitude data; for the most part the data did not include source aquifer, so a geographical assignment was considered to be the best method. Depth of sampling and identification of Pressure aquifers was also not available, so all data from the Pressure subarea are lumped together. This is a limitation in the presentation of the data since conditions may vary between each of the Pressure aquifers, but the results do provide an overall picture of conditions.

Note that in processing water quality data for surface water, the following steps were taken:

1. Samples recorded as “field replicates” were retained as individual samples.
2. Samples recorded as “lab replicates” were averaged.

3. Samples with results recorded as zero without other flags were removed.
4. Samples marked as “less than” were assigned the method detection limit.
5. For the ILRP data, some of the samples were marked as “non detect” but had results given, so the provided results were accepted.

For chloride, there is a great deal of variation between the means by aquifer (ranging from about 88 mg/L to 1,354 mg/L), but there is less variation in the medians (130 mg/L to 365 mg/L). Medians are sometimes lower and sometimes higher than the means, indicating a lack of consistency in the types of distributions seen in the aquifers. For sodium, the range of means is small (75 mg/L to 133 mg/L) while the range of medians is higher (32 mg/L to 650 mg/L). Again, medians are sometimes lower and sometimes higher than the means. Median conductivity values tend to be comparable to or lower than mean values, although the Pressure Coastal area is an exception. The range of means and medians is comparable for TDS, but again there is little correlation between means and medians.

Table 22. Summary statistics for groundwater water quality data by constituent, summarized by aquifer (GAMA, USGS, GAP, and ILRP data combined)

Groundwater Area	Summary Statistics					Period of Record
	Count of Samples	Min	Max	Mean	Median	
Chloride (mg/L)						
East Side	908	5	3,600	139.1	77.3	1971-2014
Forebay	539	3	580	78.4	67.0	1971-2014
Pressure: non-coastal	878	6	1,900	100.4	86.3	1971-2014
Pressure: coastal	352	40	22,000	547.8	73.9	1971-2014
Upper Valley	289	3	800	98.9	33.0	1971-2014
Sodium (mg/L)						
East Side	554	12	1,020	78.8	62.0	1971-2014
Forebay	533	11	442	63.8	64.5	1971-2014
Pressure: non-coastal	724	21	678	73.6	59.0	1971-2014
Pressure: coastal	166	27	9,600	436.4	90.5	1971-2014
Upper Valley	324	14	660	77.6	36.0	1971-2014
Conductivity (µS/cm)						
East Side	890	6	7,900	805.8	610.0	1971-2014
Forebay	699	287	4,123	988.3	790.0	1971-2014
Pressure: non-coastal	1016	3	3,700	879.7	780.0	1971-2014

Groundwater Area	Summary Statistics					Period of Record
	Count of Samples	Min	Max	Mean	Median	
Pressure: coastal	363	20	48,900	1,820.4	647.0	1971-2014
Upper Valley	314	352	4,670	1,182.6	657.5	1971-2014
Total Dissolved Solids (mg/L)						
East Side	610	168	69,000	782.6	479.8	1971-2014
Forebay	583	29	3,771	687.5	671.5	1971-2014
Pressure: non-coastal	688	45	18,900	709.4	500.0	1971-2014
Pressure: coastal	144	269	33,700	2,313.8	420.0	1971-2014
Upper Valley	561	140	3,780	615.0	387.0	1971-2014

Maps of median concentrations are used to explore the spatial distribution of analyte groundwater concentrations within the Salinas River Valley (chloride, Figure 65; sodium, Figure 66; conductivity, Figure 67; and TDS, Figure 68. Over 90 percent of the stations had only one or two samples, so strictly speaking there are not enough data at the majority of stations to calculate a median that is statistically relevant for representing the central tendency at a specific location. However, the density of monitoring does allow for distinguishing trends (or the lack thereof) on a spatial basis, even if the sampling frequency is very low.

For chloride (Figure 65), high values dominate the seawater intrusion area. The East Side Area tends to have higher values than the adjacent Pressure Area. Much of the Forebay Area has widespread low values, notably around Arroyo Seco and at the northern end of the Forebay Area. However, the southern end of the Forebay Area has a cluster of higher values. The Upper Valley Area has a mix of values, though they tend towards being lower. Sodium (Figure 66) shows similar trends in the Forebay Area and the Upper Valley Area, whereas the distribution of values in the Pressure Area and East Side Area are more similar. High concentrations are found in the seawater intrusion area, but medium and low values are found there as well. Spatial trends for conductivity (Figure 67) are harder to distinguish; a mix of values is found in the seawater intrusion area and throughout most of the aquifers. There are some low values associated with Arroyo Seco, and a cluster of high values around where the Upper Valley and Forebay aquifers meet. TDS (Figure 68) shows distributions and patterns very similar to conductivity.

It is important to note that there may be other explanatory variables that would help to explain the variability in the data (such as absolute sampling depth, sampling depth relative to the head of the well, composition of aquifer material, distance to agricultural operations, etc.).

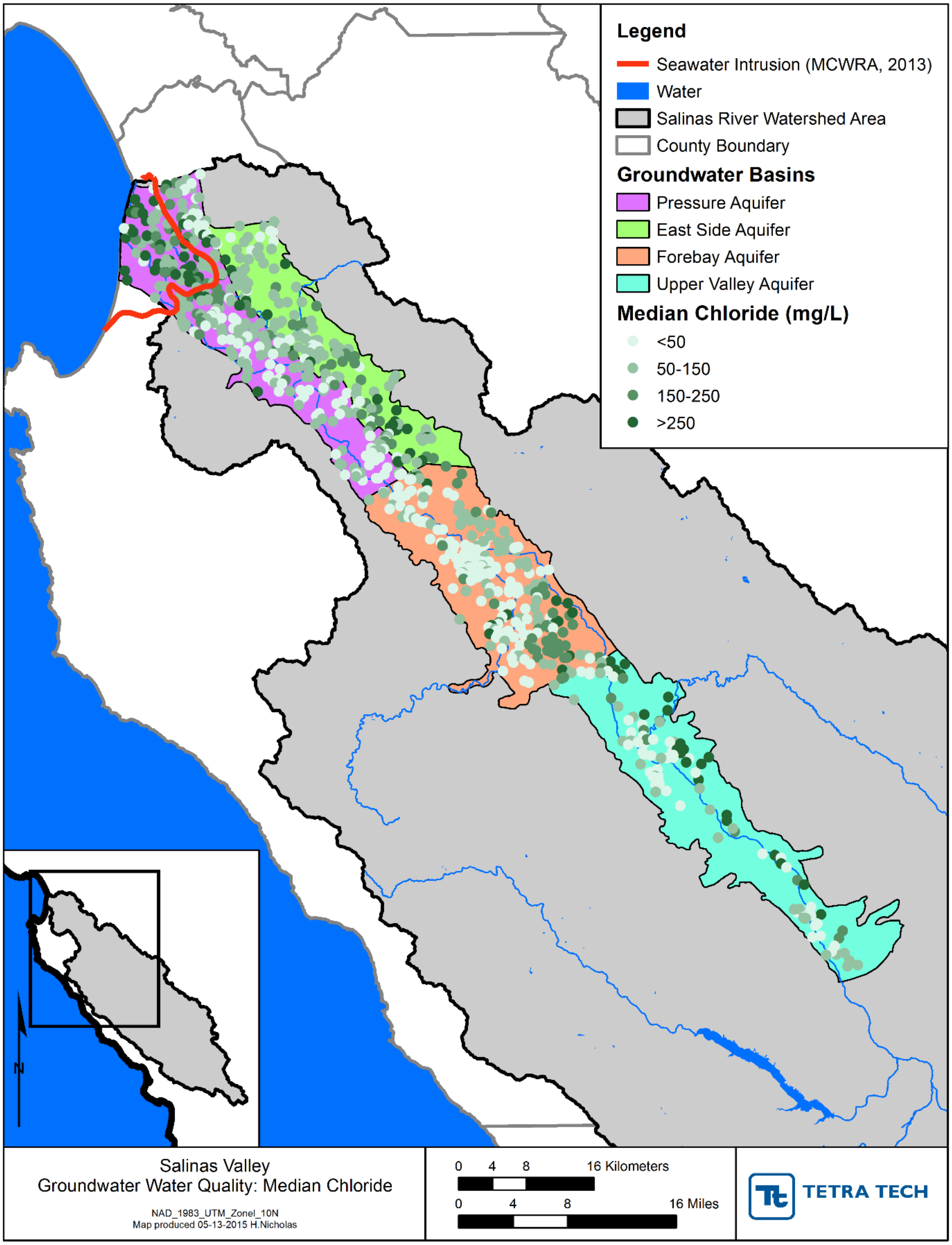

Figure 65. Seawater Intrusion and groundwater sampling data for the Salinas Valley: median chloride concentrations

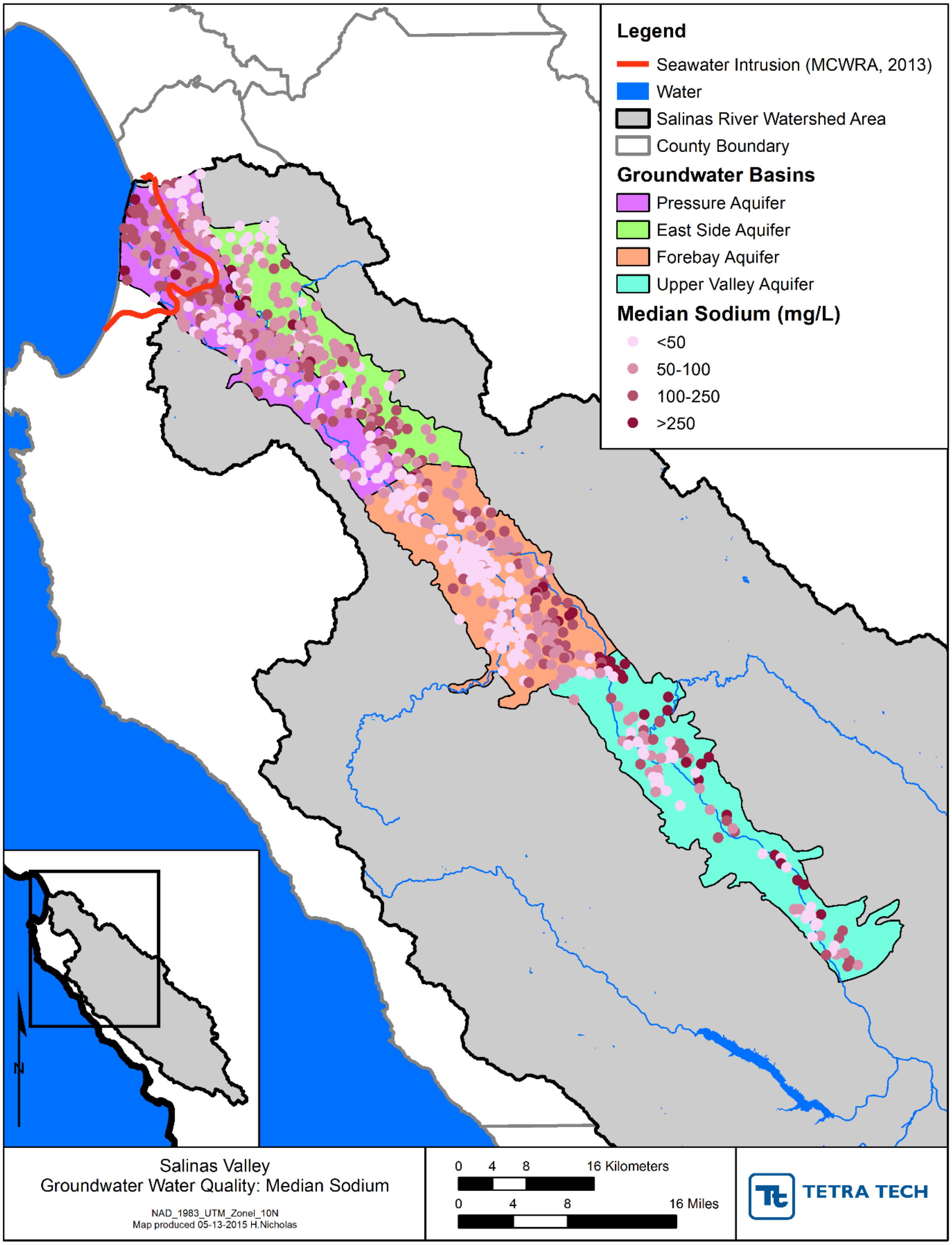

Figure 66. Seawater Intrusion and groundwater sampling data for the Salinas Valley: median sodium concentrations

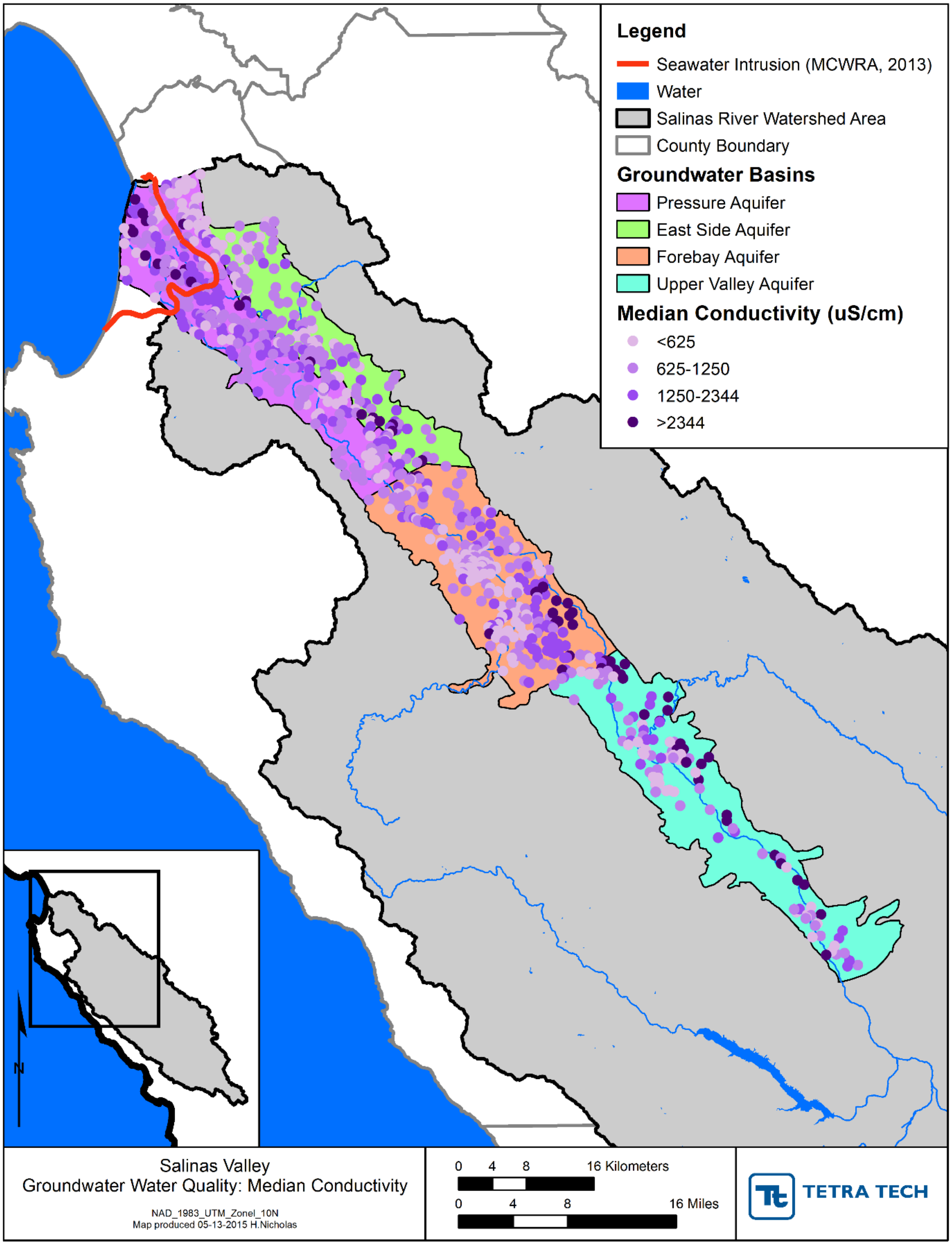

Figure 67. Seawater Intrusion and groundwater sampling data for the Salinas Valley: median conductivity concentrations

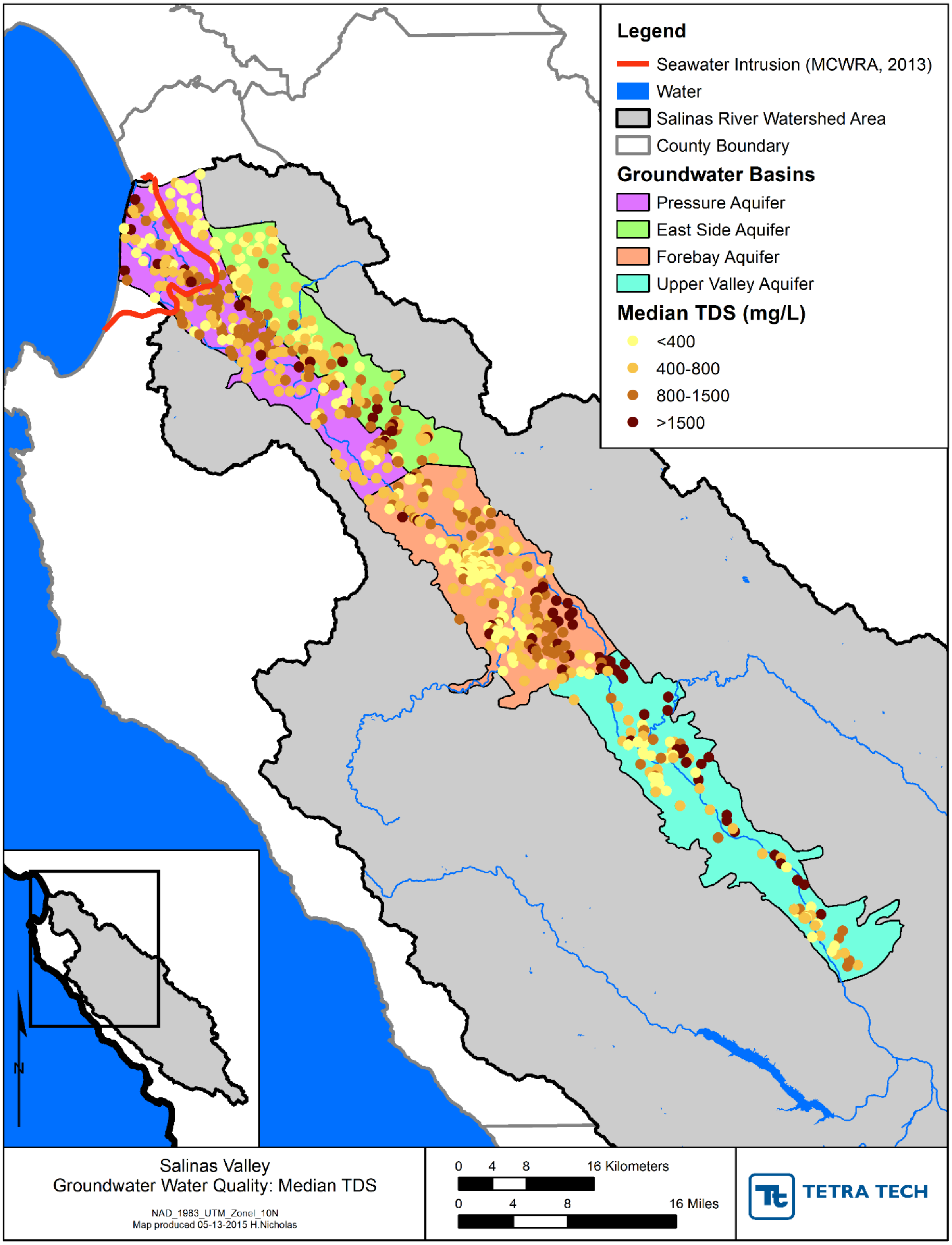

Figure 68. Seawater Intrusion and groundwater sampling data for the Salinas Valley: median TDS concentrations

5.2 ANALYSIS OF WATER QUALITY EXCURSIONS

The listed salt-related impairments for waters in the Lower Salinas River Watershed area include sodium, chloride, electrical conductivity, and total dissolved solids. An analysis of impairment by reach and by analyte is provided in this subsection. Table 23 provides summary statistics for each station/agency combination, organized by analyte and impaired reach. A count of samples exceeding the water quality guideline and water quality objective (discussed in Section 2.1.1.3, see Table 12) for the reach is provided in the table as well. It is important to note that the water quality objectives are intended to be assessed against annual mean values rather than single samples, so this presentation of exceedances is for comparative purposes only and should not be considered an indication of compliance or non-compliance with the objectives. Note that there are no objectives for Alisal Creek, and also that objectives apply to only a portion of the entire impaired length of the Lower Salinas River. Data counts differ from those published with the 2010 Integrated 303(d) List/305(b) Report Supporting Information website[3]. More recent data were available for this assessment, and some stations are included here that were not part of the 2010 supporting information.

Alisal Creek is impaired for sodium, and two stations measuring sodium are located along the lower third of the impaired reach (CCAMP 309ALU and CCAMP 309UAL). The Lower Salinas River segment from downstream of the town of Gonzales to the estuary has multiple monitoring stations and is impaired for chloride, sodium, electrical conductivity, and TDS. Salinity is related to TDS and conductivity, so those results are included as well. Note that stations along the Lower Salinas measuring these parameters are distributed throughout the impaired reach. The 2010 303(d) assessment defines the Lower Salinas River as extending from the "estuary to near Gonzales Rd crossing". The California State Water Resources Control Board 303(d) supporting information website indicates that data collected from Salinas River at CA Hwy 1 monitoring stations were used in the evaluation of salinity-based impairments for this reach. Furthermore, a large proportion of the exceedances within the Lower Salinas River occurred at the Hwy 1 monitoring stations. However, it appears that the Salinas River at Hwy 1 is within the estuary. As a result, the assessment in this report excludes Hwy 1 monitoring data from comparison to the water quality guidelines. Hwy 1 stations are still shown in Table 23 and subsequent figures for reference.

For sodium, at Alisal Creek nearly three quarters of the samples exceed the guideline. In the Lower Salinas River (with Hwy 1 stations excluded), the sodium guideline is exceeded about 17 percent of the samples, whereas the objective is exceeded (where applicable) about 7 percent of the time. The chloride guideline for Lower Salinas River is exceeded about 12 percent of the time, whereas the objective is exceeded less than 2 percent of the time. Conductivity for Lower Salinas River is never exceeded for the guideline, while the objective is exceeded about 7 percent of the time. The TDS guideline at Lower Salinas River is exceeded less than 1 percent of the time, but the objective is exceeded more than 7 percent of the time. For salinity, the guideline is exceeded about 22 percent of the time while the objective is exceeded less than 1 percent of the time for Lower Salinas River.

[3] http://www.waterboards.ca.gov/water_issues/programs/tmdl/2010state_ir_reports/table_of_contents.shtml

Table 23. Summary statistics and exceedances for each impaired reach in the Lower Salinas Watershed area, organized by analyte and reach

Waterbody	Station ID	Agency	Program	Summary Statistics							Period of Record
				Min	Max	Mean	Median	Count of Samples	Samples Exceed Guideline	Samples Exceed Objective	
Chloride (mg/L), WQ Guideline: 106 mg/L, WQ Objective: 80 mg/L											
Lower Salinas River											
Salinas	11152300	USGS	(blank)	3.1	144.0	26.8	20.0	199	4	4	1967-2013
Salinas	309DAV	CCWQCB	CCAMP	5.7	1070.0	83.0	52.0	123	42	No objective	1999-2012
Salinas	309SAC	CCWQCB	CCAMP	2.5	65.0	28.0	23.0	30	0	0	1999-2012
Salinas	309SAC	SWRCB	SWAMP	12.0	12.0	12.0	12.0	1	0	0	2012-2012
Salinas	309SBR	CCWQCB	CCAMP	27.0	6150.0	780.7	219.0	36	No guideline	No objective	1999-2012
Sodium (mg/L): WQ Guideline: 69 mg/L, WQ Objective: 70 mg/L											
Alisal Creek											
Alisal	309UAL	CCWQCB	CCAMP	76.0	107.0	91.7	92.5	6	6	No objective	1999-2000
Reclamation	309ALU	CCWQCB	CCAMP	8.7	495.0	103.1	83.0	33	23	No objective	1999-2012
Lower Salinas River											
Salinas	11152300	USGS	(blank)	5.5	143.0	33.3	25.5	198	16	16	1967-2013
Salinas	309DAV	CCWQCB	CCAMP	7.5	1500.0	88.9	54.5	114	48	No objective	1999-2012
Salinas	309DAV	SWRCB	SWAMP	54.0	54.0	54.0	54.0	1	0	No objective	2013-2013
Salinas	309SAC	CCWQCB	CCAMP	8.2	61.0	32.9	30.0	25	0	0	1999-2012
Salinas	309SBR	CCWQCB	CCAMP	36.0	9500.0	715.0	212.5	34	No guideline	No objective	1999-2012
Conductivity (uS/cm), WQ Guideline: 3000 uS/cm, WQ Objective: 937.5 mg/L											
Lower Salinas River											
Salinas	11152300	USGS	(blank)	158.0	1490.0	541.3	474.0	245	0	18	1967-2013
Salinas	309DAV	CCWQCB	CCAMP	92.4	2346.0	1011.6	797.6	120	0	No objective	1999-2012
Salinas	309DAV	UC Davis	Granite Canyon	10.0	2581.0	1156.7	910.0	7	0	No objective	2008-2009
Salinas	309SAC	CCWQCB	CCAMP	121.0	981.7	523.2	450.5	21	0	1	1999-2012
Salinas	309SAC	CCWQP	CMP	178.0	1058.0	540.2	482.8	61	0	5	2005-2011
Salinas	309SAG	CCWQP	CMP	132.0	1118.0	539.0	471.1	53	0	4	2006-2011

Waterbody	Station ID	Agency	Program	Summary Statistics							Period of Record
				Min	Max	Mean	Median	Count of Samples	Samples Exceed Guideline	Samples Exceed Objective	
Salinas	309-SALIN-31	MBNMS	SnapShotDay	470.0	5160.0	1884.8	1630.0	8	No guideline	No objective	2000-2008
Salinas	309-SALIN-32	MBNMS	SnapShotDay	527.0	1410.0	797.1	705.0	8	0	No objective	2000-2008
Salinas	309-SALIN-33	MBNMS	SnapShotDay	380.0	800.0	568.8	515.0	8	0	0	2000-2008
Salinas	309SBR	CCWQCB	CCAMP	500.4	19425.0	2926.5	2054.5	24	No guideline	No objective	1999-2012
Salinas	309SLRBRG	ESNERR	(blank)	24.7	53000.0	5682.5	2400.0	194	No guideline	No objective	1995-2014
Salinas	309SSP	CCWQP	CMP	206.5	1063.0	590.9	569.6	55	0	3	2005-2011
Salinas	D2112050	CA DWR	(blank)	233.0	2682.0	1528.3	1599.0	4	0	3	1999-2005
Salinas	SAL-BLA	CSUMB	CCoWs	386.0	963.0	588.9	657.0	14	0	1	2000-2001
Salinas	SAL-CHU	CSUMB	CCoWs	250.0	731.0	499.2	467.0	18	0	0	2000-2002
Salinas	SAL-DAV	CSUMB	CCoWs	100.0	2450.0	892.7	573.5	35	0	No objective	2000-2003
Salinas	SAL-GON	CSUMB	CCoWs	253.0	747.0	510.6	532.5	16	0	0	2000-2001
Salinas	SAL-SPR	CSUMB	CCoWs	365.0	683.0	473.5	431.0	10	0	0	2000-2001
Salinas Lagoon	309SAL_U	UC Davis	Granite Canyon	10.0	12700.0	3885.7	3640.0	15	No guideline	No objective	2008-2009
Total Dissolved Solids (mg/L), WQ Guideline: 1920 mg/L, WQ Objective: 600 mg/L											
Lower Salinas River											
Salinas	11152300	USGS	(blank)	116.0	807.0	347.6	298.0	195	0	16	1968-2013
Salinas	309DAV	CCWQCB	CCAMP	75.3	14200.0	842.6	550.0	126	1	No objective	1999-2012
Salinas	309DAV	SWRCB	SWAMP	40.0	340.0	220.0	280.0	3	0	No objective	2012-2013
Salinas	309SAC	CCWQCB	CCAMP	140.0	900.0	405.3	350.0	27	0	5	1999-2012
Salinas	309SAC	CCWQP	CMP	139.0	636.0	317.4	270.0	60	0	2	2005-2011
Salinas	309SAG	CCWQP	CMP	119.0	690.0	323.4	283.0	54	0	3	2006-2011
Salinas	309SBR	CCWQCB	CCAMP	350.0	14550.0	1971.9	1200.0	35	No guideline	No objective	1999-2012
Salinas	309SSP	CCWQP	CMP	135.0	610.0	356.1	334.0	55	0	2	2005-2011
Salinity (ppt): WQ Guideline: 1.92 ppt, WQ Objective: 0.60 ppt											
Lower Salinas River											
Salinas	309DAV	CCWQCB	CCAMP	0.03	2.80	0.56	0.44	121	1	No objective	1999-2012

Waterbody	Station ID	Agency	Program	Summary Statistics							Period of Record
				Min	Max	Mean	Median	Count of Samples	Samples Exceed Guideline	Samples Exceed Objective	
Salinas	309DAV	UC Davis	Granite Canyon	0.03	1.97	0.99	0.91	6	1	No objective	2008-2009
Salinas	309SAC	CCWQCB	CCAMP	0.05	4.70	0.46	0.23	22	1	1	1999-2012
Salinas	309SAC	CCWQP	CMP	0.08	0.55	0.27	0.24	61	0	0	2005-2011
Salinas	309SAG	CCWQP	CMP	0.06	0.59	0.27	0.24	53	0	0	2006-2011
Salinas	309SBR	CCWQCB	CCAMP	0.25	11.52	1.63	1.11	25	No guideline	No objective	1999-2012
Salinas	309SLRBRG	ESNERR	(blank)	0.01	35.05	3.77	1.50	263	No guideline	No objective	1989-2014
Salinas	309SSP	CCWQP	CMP	0.10	0.56	0.30	0.29	55	0	0	2005-2011
Salinas Lagoon	309SAL_U	UC Davis	Granite Canyon	0.02	21.15	6.90	6.62	15	No guideline	No objective	2008-2009

To visualize the statistical summaries of data for the impaired lower reaches in the Lower Salinas Watershed Area, box and whisker plots were constructed (sodium, Figure 69; chloride, Figure 70; conductivity, Figure 71; TDS, Figure 72; and salinity, Figure 73). These box plots display statistics for each station with measured data for each particular constituent for which the station's reach is impaired. For each station, the lower band of the gray box represents the first quartile, the middle band is the second quartile (median), and the upper band is the third quartile of the dataset. The whisker underneath the box captures the minimum, and the whisker above the box captures the maximum at that individual station. It is important to note that the objectives are assessed as annual means across a reporting waterbody, so a comparison to objectives is for comparative purposes only. As noted previously, stations located at Hwy 1 are shown for reference.

Frequent exceedances of the sodium guideline can be seen at nearly all of the stations in Figure 69, while exceedances of the objective are rare at the applicable stations at Chualar. Note that a log scale is used, so the medians and distributions of sodium at Chualar are quite a bit lower than at the other stations. Chloride exceedances can be seen at 11152300 at Chualar and 309DAV at Davis (Figure 70); note that the overall distribution is higher at the downstream stations. For conductivity (Figure 71), one can see that monitored values increase going downstream. The guideline is never exceeded, while the objective is infrequently exceeded for the upstream locations. For TDS (Figure 72), the guideline is exceeded infrequently at Davis, while the objective is exceeded occasionally at upstream stations. For salinity, (Figure 73), exceedances of the guideline and objective are rare at upstream stations, but exceedances of the guideline occur at Davis.

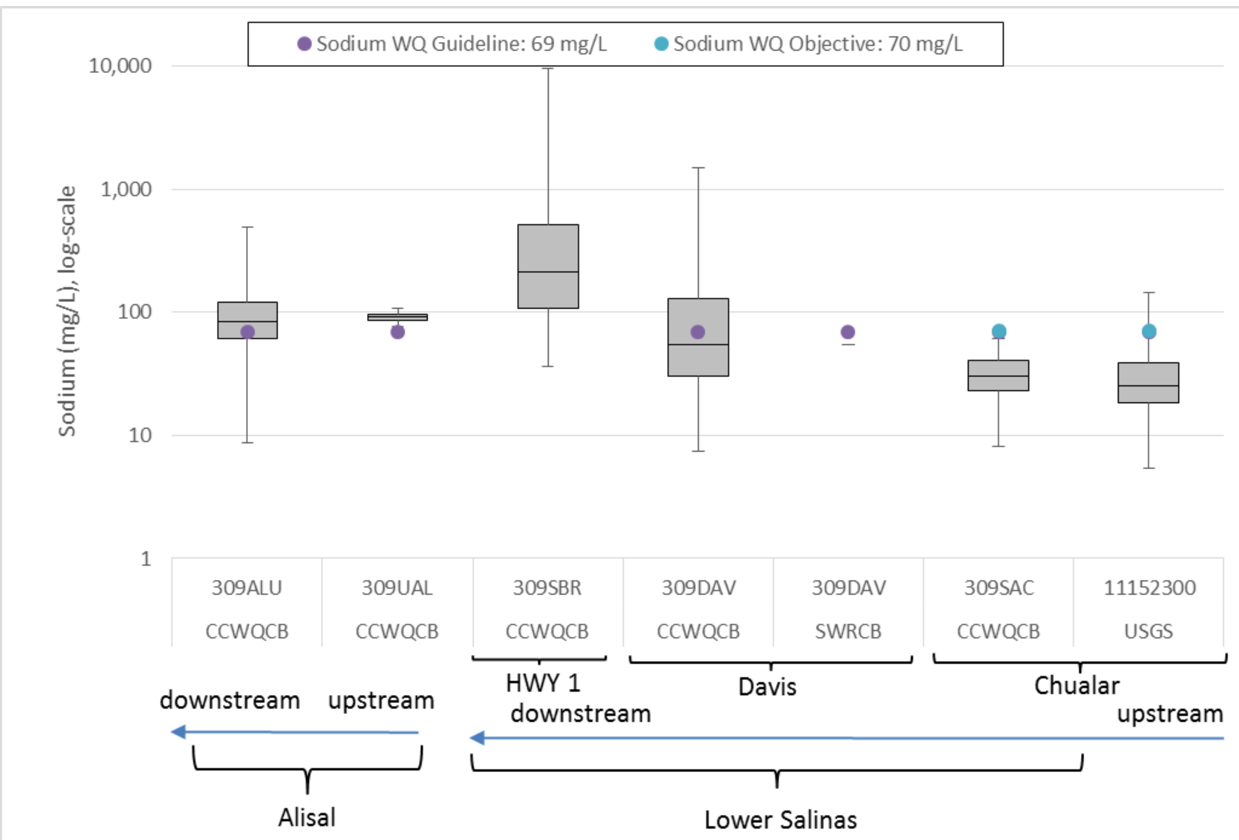

Figure 69. Box and whisker plot: sodium data for all measuring sites on both reaches in the Lower Salinas Watershed Area impaired for sodium

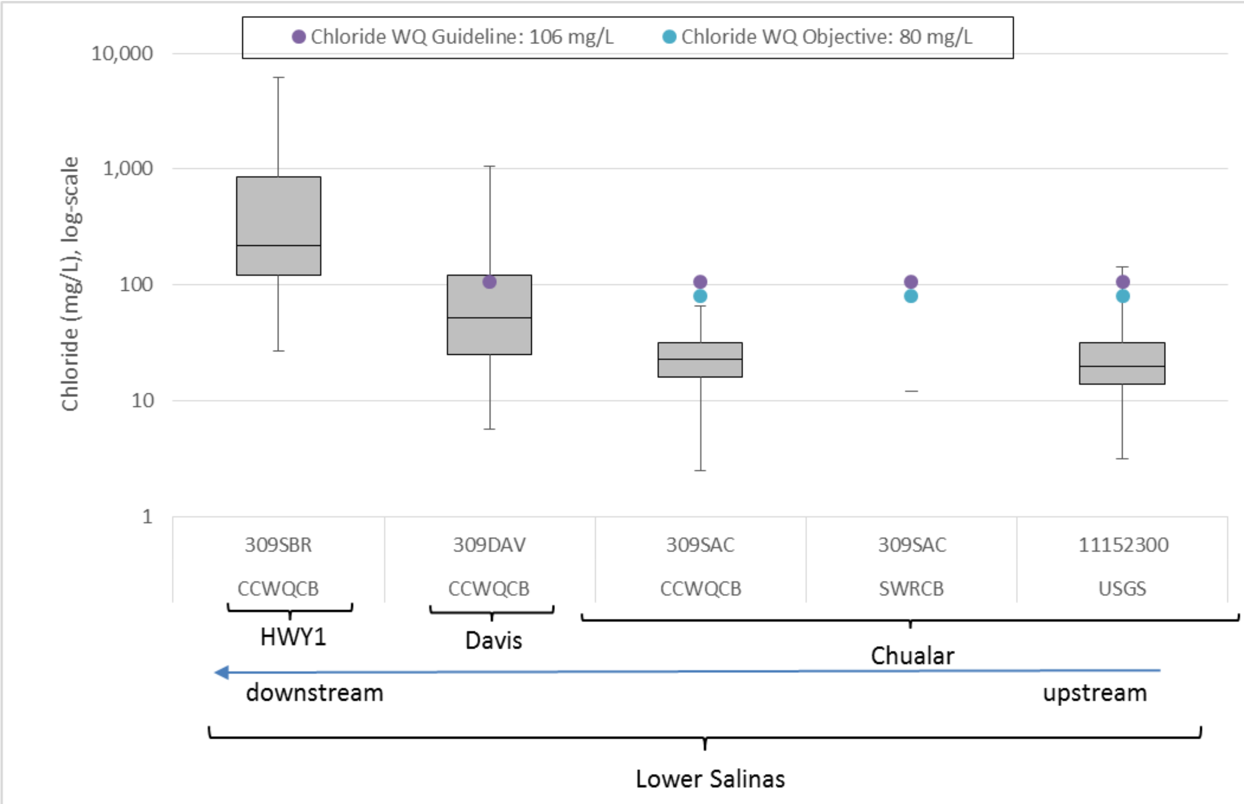

Figure 70. Box and whisker plot: chloride data for all measuring sites on the Lower Salinas River

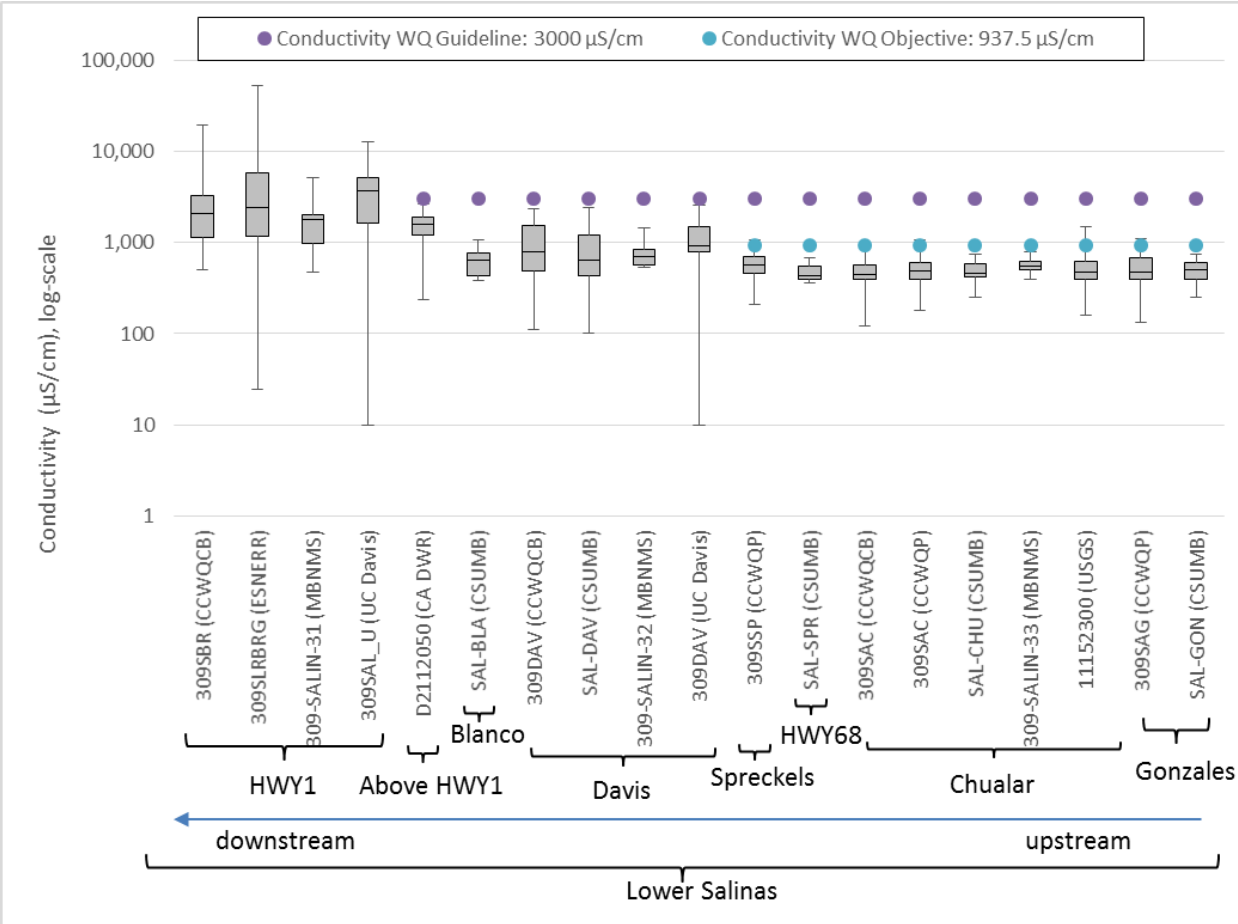

Figure 71. Box and whisker plot: conductivity data for all measuring sites on the Lower Salinas River

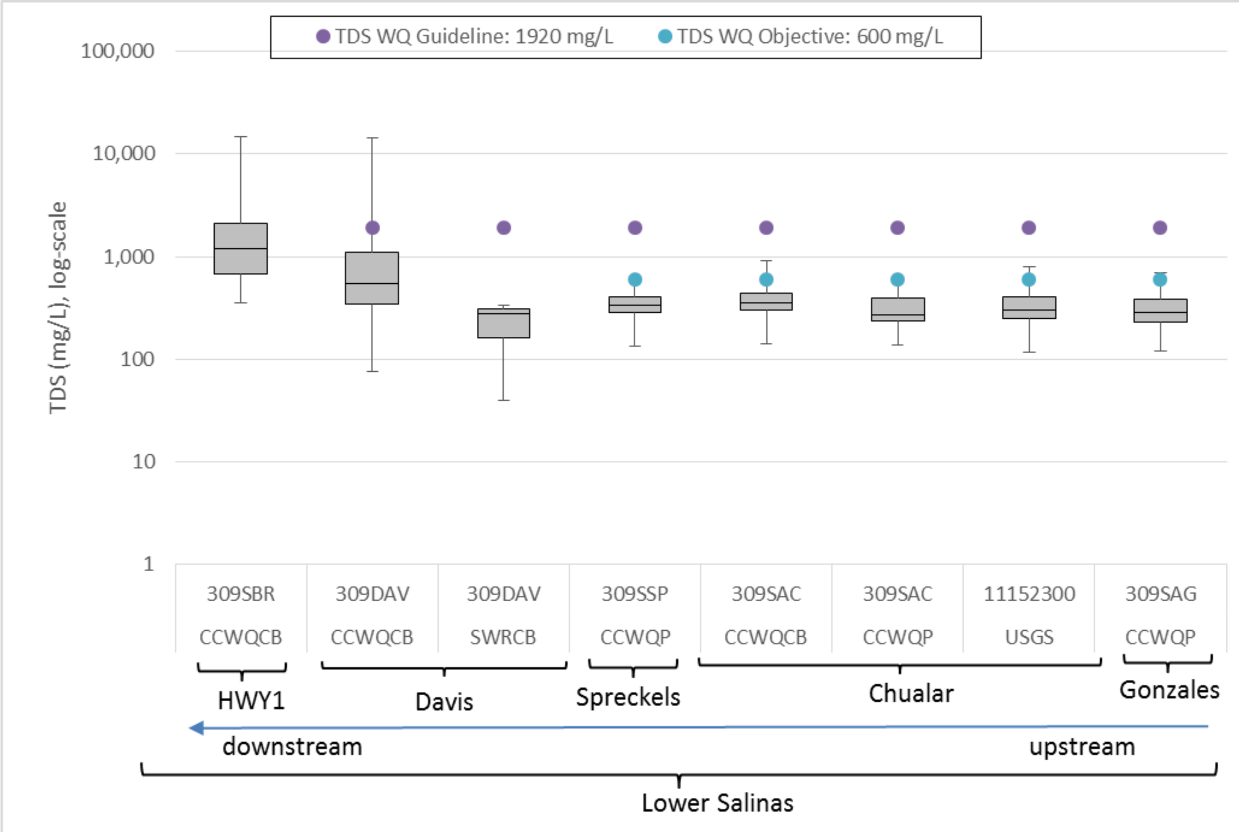

Figure 72. Box and whisker plot: TDS data for all measuring sites on the Lower Salinas River

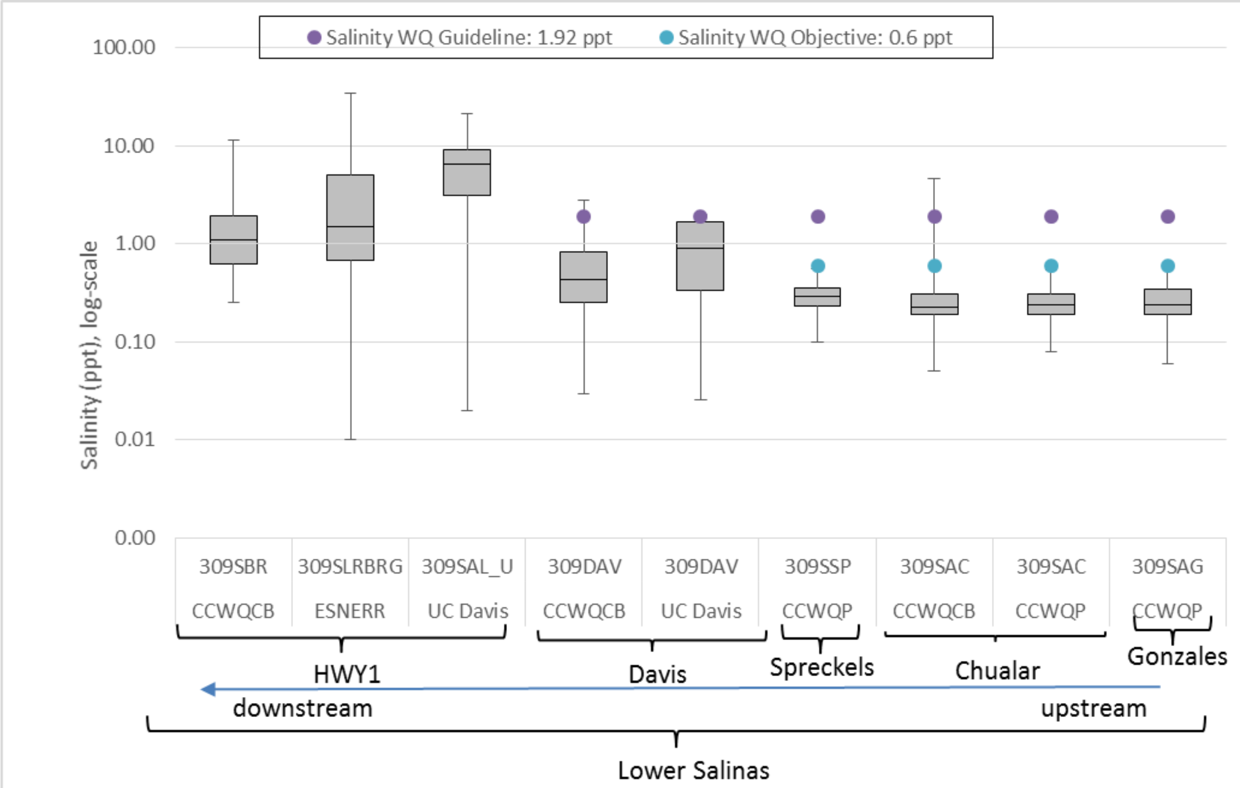

Figure 73. Box and whisker plot: salinity data for all measuring sites on the Lower Salinas River

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6 Conceptual Model Development

To support development of the Salinas River watershed salt tool, a salt mass balance analysis has been developed that captures the site specific factors driving salt concentrations. The first step in developing the mass balance is summation of existing knowledge in the form of a Conceptual Model that describes important cause-and-effect linkages that are associated with salinity impairments.

Given the complexity of the system, the Conceptual Model has several components. First, a basic representation of salt sources and transport is presented. Next, maps are provided and the various components of surface water connections and water management activities are discussed. The Conceptual Model concludes with a detailed diagram illustrating the interactions of flows and associated salt between land areas, streams, and the Salinas Valley aquifers.

A box-diagram Conceptual Model of salt sources and transport pathways is shown in Figure 74. It provides a starting point for visualizing the Salinas Valley system. Salt sources are shown in ovals, salt storages are shown in squares, and processes are shown in diamonds. Each is discussed below:

- **Land areas.** Major inputs include salt in irrigation water derived from aquifers, and within the Castroville area, salt in wastewater reuse from the Salinas Valley Reclamation Project applied to agriculture. Other inputs include direct atmospheric deposition, salts in fertilizers (and to a lesser extent pesticides) applied to land areas, and salt in surface water diversion that is blended with the reused wastewater.
- **Surface waters.** Major inputs include surface runoff and irrigation return flow from land areas. Salt in shallow groundwater is an input to gaining streams. A few water bodies receive salt inputs from the ocean in estuarine and tidally influenced areas by the coast. Surface waters also discharge salt to the ocean.
- **Soil storage/shallow groundwater.** A major input consists of salts carried by infiltration from land areas. Evapotranspiration can lead to the accumulation of salts in soils, especially in the presence of irrigation. Wastewater in rural areas contains salts associated with domestic uses and industrial process water, and enters soil and groundwater from septic systems and municipal/industrial percolation ponds. Losing streams also carry salts as they recharge groundwater. There may also be salts contained in the rocks of the soils that leach into groundwater.
- **Aquifers.** Inputs include salt carried from groundwater percolation and salt leaching from the rocks and sediments in the deep aquifer itself. The ocean is also a source of salt where seawater intrusion is occurring.
- **Salinas Valley Reclamation Project tertiary treatment plant.** Sources include salt in influent (from water softeners, industrial and household chemicals, food, etc.) as well as treatment chemicals. The plant discharges to the ocean when effluent volume exceeds demand for wastewater reuse.

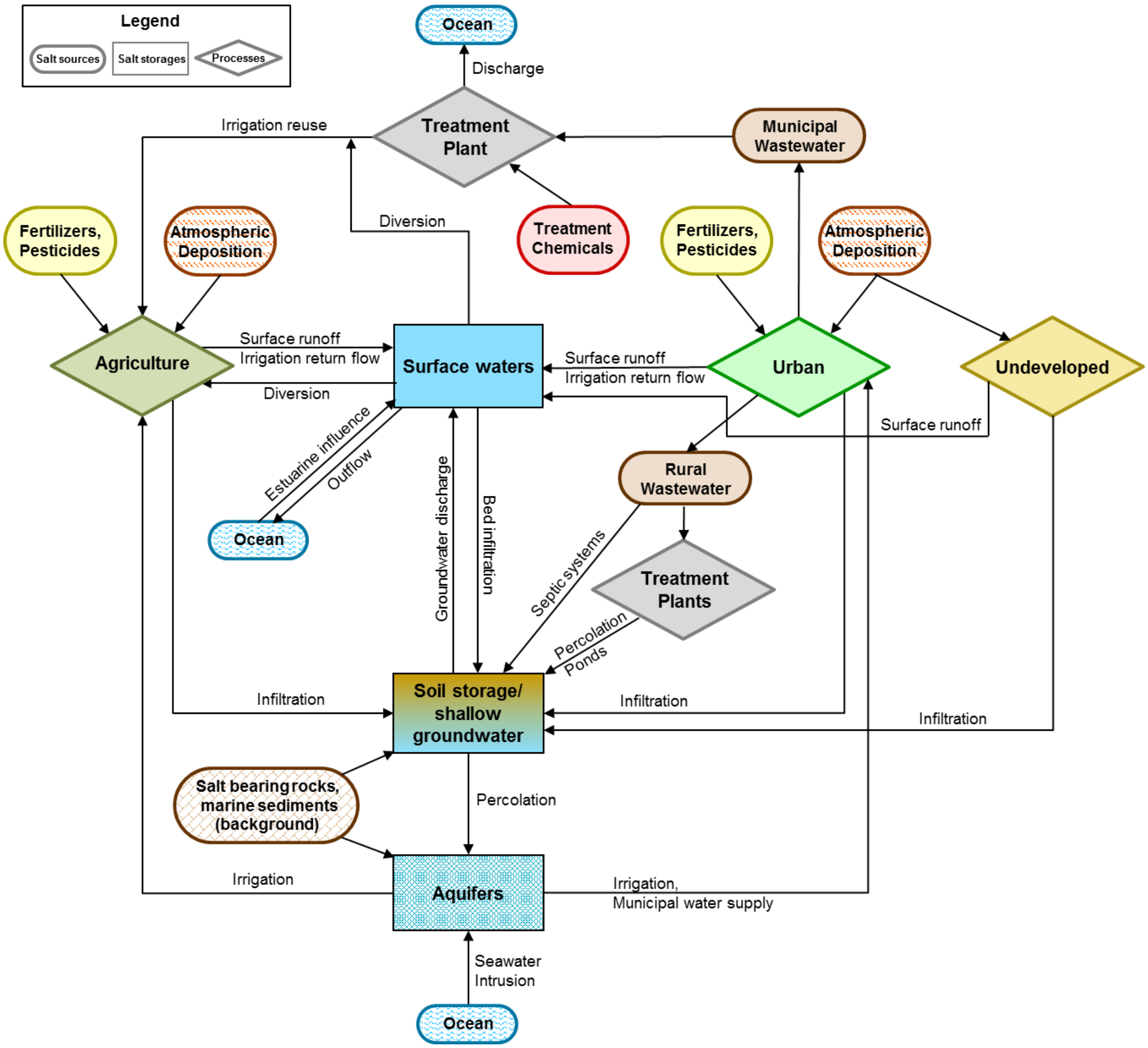


Figure 74. Conceptual model of salt sources and transport

While a box-diagram is useful for understanding the system at a conceptual level, it does not provide any insight into how water flows through the interconnected surface waters and aquifers of the Salinas Valley, nor show where water management activities are occurring. Figure 75 provides a map of the major water bodies and groundwater subareas in the Salinas Valley. As discussed previously in Section 1.1.6.2, the Salinas Valley has been divided into groundwater subareas based on sediment composition and recharge sources (Simpson, 1946, CA DWR, 2003). The most important in terms of groundwater capacity are the Pressure Subarea, East Side Subarea, Forebay Subarea, and the Upper Valley Subarea (note the Arroyo Seco Subarea has been lumped with the Forebay Subarea following MCWRA reporting convention). As illustrated in Figure 75, groundwater naturally flows more or less in the direction of the Salinas River from southeast to northwest. However, over-pumping near the coast has led to seawater intrusion into the Pressure 180-foot and Pressure 400-foot aquifers. In addition, groundwater flows from the Pressure Area to the East Side Area towards a region of depressed groundwater head associated with both municipal and agricultural pumping.

Prior to the construction of Nacimiento and San Antonio Reservoirs (1957 and 1967 respectively), aquifer recharge in the Valley was primarily dependent on precipitation, streamflow, and deep percolation from agricultural return flows. Today, from an estimated average total of about 504,000 acre-feet per year of inflow to the Salinas Valley Aquifer, about 30% occurs as recharge from conservation releases of the reservoirs, 20% from natural stream recharge, 44% occurs as deep percolation from agricultural return flows and precipitation, and 6% as subsurface inflow from adjacent groundwater basins (MW, 1998). Recharge to the aquifer from the Salinas River occurs between Bradley and Spreckels. Other streams provide recharge as well as they enter the aquifer area from the surrounding mountains.

In the Lower Salinas area (Figure 76), surface water flow and water management is complex. Wastewater from the Salinas Valley Reclamation Project tertiary treatment plant is delivered to agricultural users throughout the Castroville Seawater Intrusion Project (CSIP) area via a wastewater reuse distribution network. Peak demand occurs from April through October; any unused reclaimed wastewater is discharged directly to the ocean. During summer months, reservoir releases are operated to provide water for diversion at the Salinas River Diversion Facility, where a portion of flow in the Salinas River is diverted and blended with the tertiary plant wastewater to be sent to the CSIP area (some downstream flow is maintained in the Salinas River for support of Steelhead Trout habitat and migration). Flow from the Salinas River is joined by Blanco Drain (which primarily carries agricultural return flow) and goes into the Salinas River Lagoon adjacent to the ocean. The Lagoon is typically cut off from direct interaction with the ocean due to the presence of a sand bar, but the sand bar may become breached during high flow winter events and remain open through the spring. When this occurs, the salinity of the lagoon increases and estuarine conditions may extend beyond the Highway 1 Bridge. The Old Salinas River Canal (OSR) connects to the Salinas River Lagoon near the ocean and flows to Moss Landing and Elkhorn Slough to the north. When the sand bar is closed, a slide gate, which is located between the Lagoon and the OSR, is operated to maintain a minimum elevation in the Lagoon.

The OSR continues north and is joined by Tembladero Slough, which receives drainage from the Reclamation Canal watershed. From there, the OSR flows north until it reaches the Potrero Road tide gate. The tide gate is a series of culverts with flap gates that allow downstream flow but prevents reverse flow due to tidal action. Even so, there is some leakage and introduction of saline water into the OSR. Beyond the Potrero Road tide gate, the OSR is joined by the Moro Cojo Slough (which is also protected in a similar fashion by its own tide gate), then the OSR discharges into Moss Landing Harbor. Moss Landing is open to the ocean throughout the year. Due to the complex interaction of tides, winter flood flows, and the operation of the ORS slide gate, the salinity of the OSR is highly variable.

The Reclamation Canal captures flows from Gabilan, Natividad, and Alisal Creeks as they flow through the City of Salinas. The Canal flows northwest and is joined by Santa Rita Creek. At the Canal's confluence with the Merritt Lake drainage, it becomes the Tembladero Slough. Alisal Slough (likely the former path of Alisal Creek prior to extensive historical flow modifications and creation of the Reclamation Canal) joins the Tembladero Slough prior to its confluence with the OSR. The drainage contributing to the Reclamation Canal tends to be dry in the summer, but the Canal accumulates both urban and irrigation return flow, to the point that the Reclamation Canal nearly always has measurable discharge. Flows are higher in the Canal during storm events during the winter.

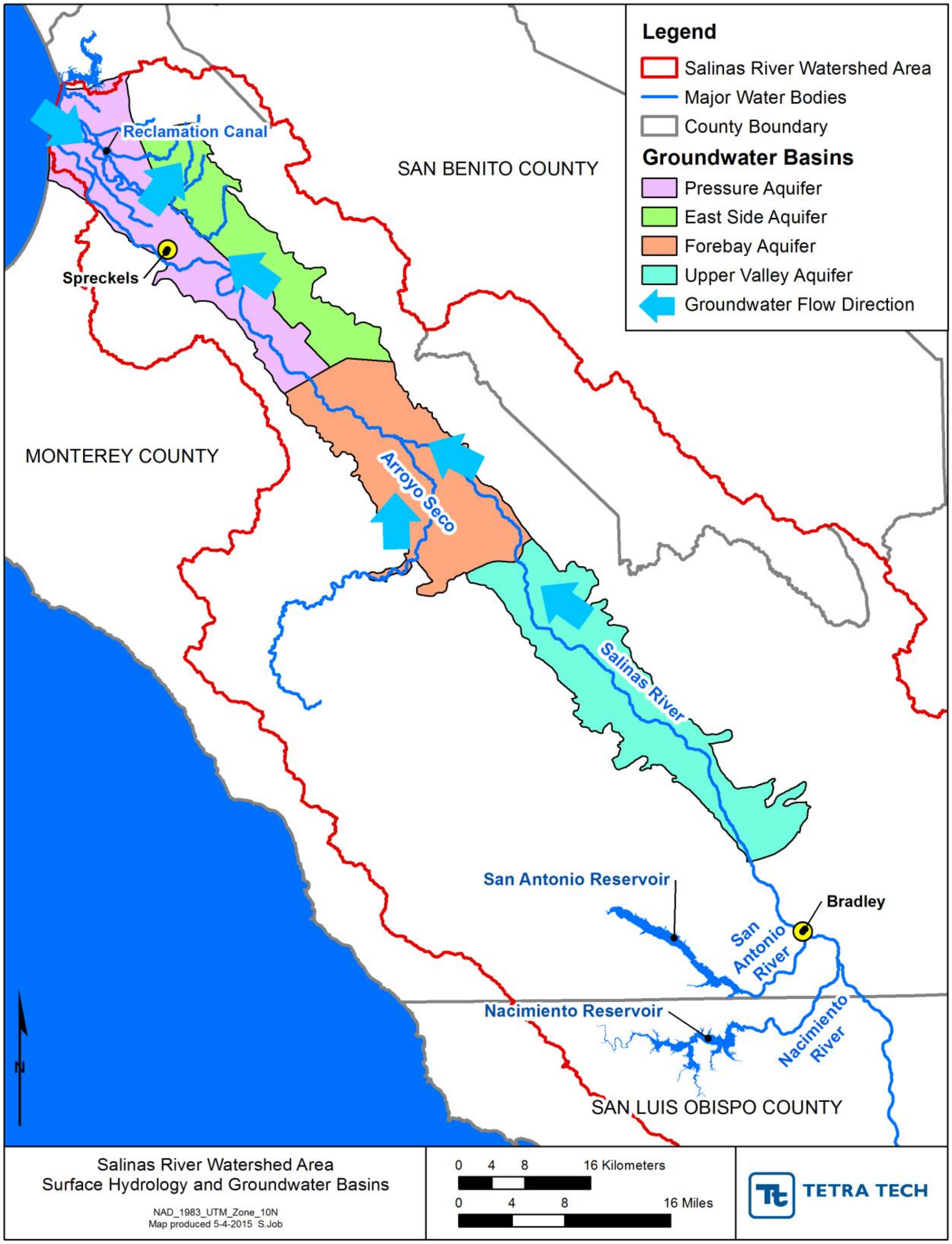


Figure 75. Major water bodies and groundwater basins in the Salinas Valley

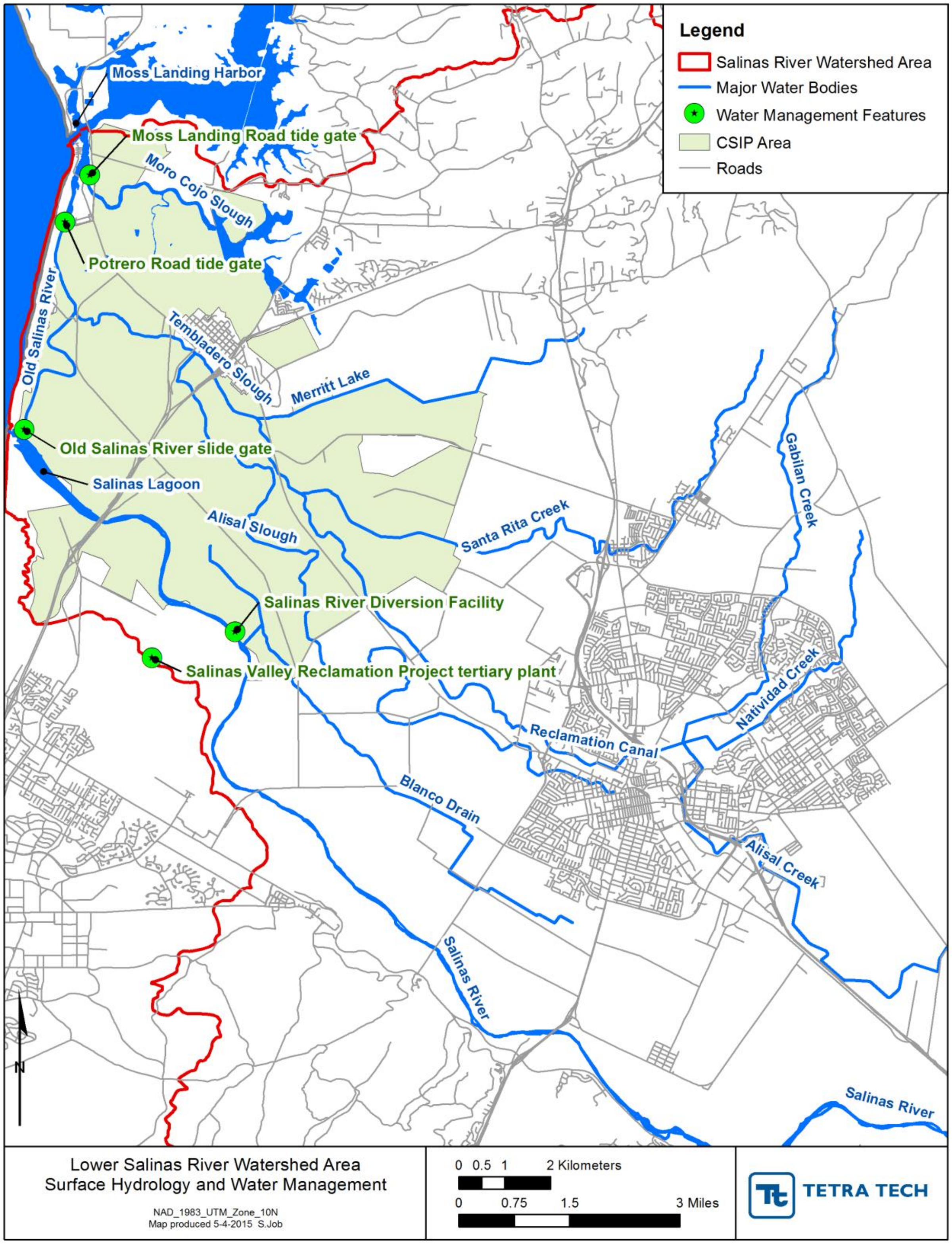


Figure 76. Water bodies and water management features in the Lower Salinas River and Reclamation Canal watersheds

Figure 77 provides a more detailed diagram of water and salt flows in the Salinas Valley system in a cross-section format, which is useful for visualizing components and linkages. All transfers include water fluxes and associated salt (note there is no salt associated with evapotranspiration (ET), and dry atmospheric deposition of salt occurs without a water flux). Surface transfers of water and salt are shown with solid blue arrows, while groundwater and aquifer transfers are shown with dashed blue arrows. Water management activities imposed on the system are shown with red arrows. Land area inputs include precipitation, irrigation water, and atmospheric deposition, while outputs include surface flow and interflow, groundwater recharge, and tile drain flow for agriculture (note that the position of the land area inputs is not intended to connote location in the watershed; each can be found throughout the study area). Stream water and salt balance includes surface inflow/interflow, gains from or losses to the shallow aquifer, and the estuarine influence on coastal streams. Inflows may be represented as a boundary condition (i.e., headwater streams and the Salinas River at Bradley) or may be comprised of inflow from upstream reaches. The aquifers are shown as a cross section representing the Upper Valley and Forebay areas to the right, and the Pressure aquifer area to the left. The East Side Area is not shown, but runs parallel to the Pressure Area. The various aquifers in the Pressure Area are shown with the aquitards between them, with gaps that allow for some exchange between the aquifers. Seawater intrusion is shown into the Pressure 180-foot and Pressure 400-foot aquifers. Pumping from the aquifers shows the transfer of groundwater to land areas. Water from the Salinas River at the Salinas Valley Water Project diversion is blended with reclaimed wastewater from the Salinas Valley Reclamation Project plant, and applied to agricultural land in the CSIP area. Inflow to the Salinas River from the reservoirs is shown at the right. Minor transfers/exchanges not shown in the figure include septic system discharges and municipal wastewater and industrial process water discharge to percolation ponds (which is added to groundwater recharge to aquifers).

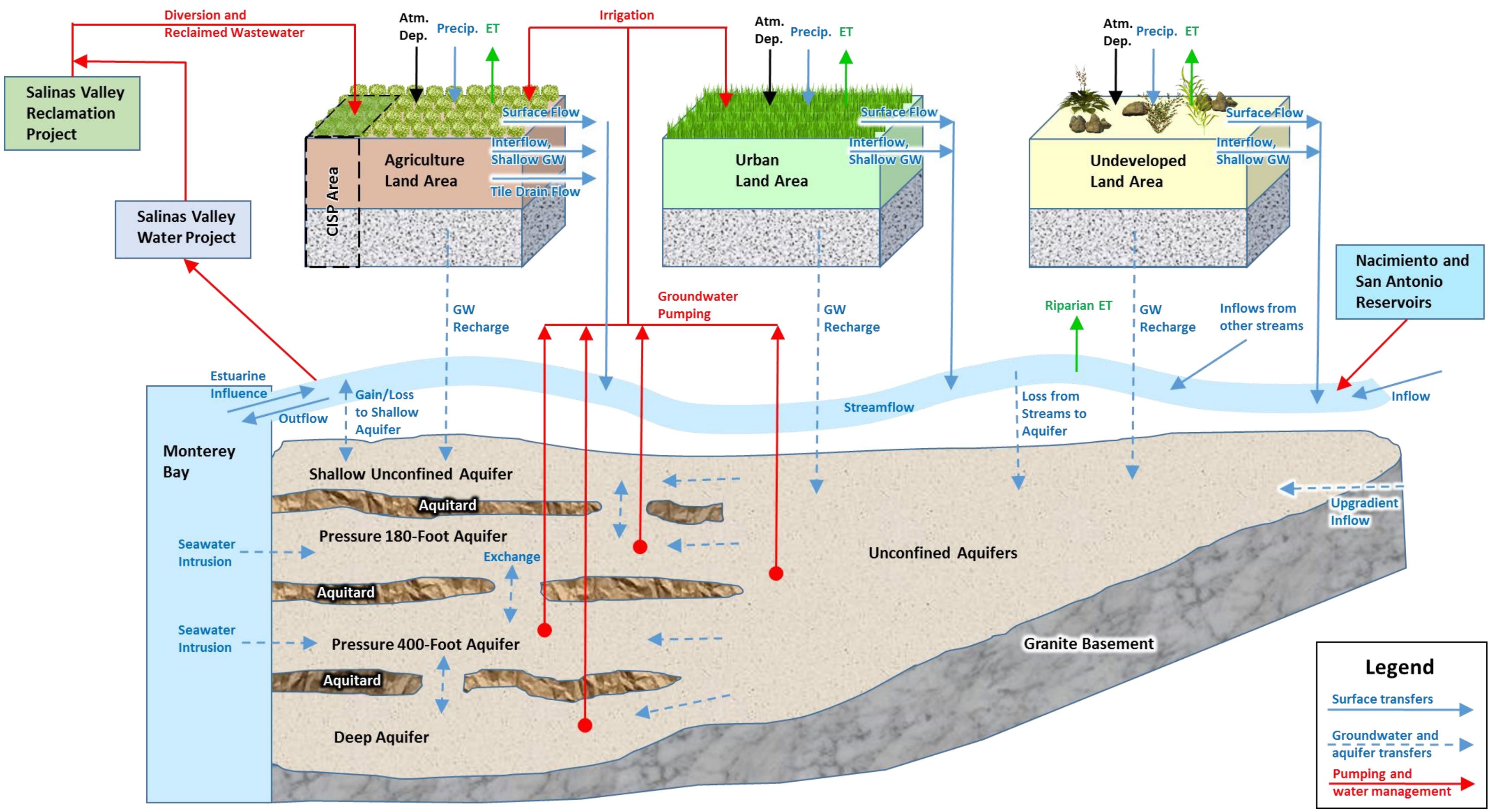


Figure 77. Conceptual Model cross section of water and salt movement in the Salinas Valley

6.1 Mass Balance of Basin Inflows and Outflows

Numerous previous studies have estimated the mass balance inflows and outflows of water in the Salinas Valley groundwater basin. Outflow from the groundwater basin under current management conditions is dominated by pumping (~90 to 95% of outflow) with the remainder as evapotranspiration by riparian vegetation. MCWRA (1995) estimated basin inflow at 532,000 AFY and basin outflow at 550,000 AFY. Brown and Caldwell (2015) cite inflow of 504,000 AFY with 50 percent as stream recharge and 44 percent as deep percolation from agricultural return flows and precipitation. As documented in the Draft Environmental Impact Report/Environmental Impact Statement for the Salinas Valley Water Project (MCWRA, 2001), basin overdraft has averaged approximately 19,000 AFY during the 1949 to 1994 hydrologic period, with an average annual seawater intrusion rate of 11,000 AF and a decline in storage. The recent analysis by Brown and Caldwell (2015) suggest that the basin is currently out of balance by 17,000 to 24, 000 AFY. Current uses of groundwater in the basin are primarily agricultural irrigation throughout the Salinas Valley, municipal supply for towns and cities, and, to a lesser extent, peak irrigation supply within the Castroville Seawater Intrusion Program (CSIP) area to supplement recycled water supplies (MCWRA, 2006).

Seawater intrusion is considered to be a major source of groundwater contamination in the lower end of the Salinas Valley adjacent to the coast. It is the result of sustained overdraft in the Pressure and Eastside subareas for municipal and agricultural uses. Analysis of water samples from wells in the Pressure Area has indicated that seawater has been intruding the aquifers for approximately 80 years. The intrusion has moved progressively landward within the 180-foot and 400-foot aquifers during this time. The intrusion has moved as much as 8 miles inland within the Pressure subarea, rendering wells in the intruded area unusable and decreasing usable basin storage (Brown and Caldwell, 2015). Between 1970 and 1992, the annual decrease in usable basin storage for groundwater because of seawater intrusion was estimated to be an average of 17,000 acre feet per year (MCWRA, 1995). While the average was 17,000 acre feet per year, it varied from 2,000 acre feet per year to 30,000 acre feet per year. The cumulative total of seawater intrusion during the period 1970 to 1992 was estimated to be 374,000 acre feet (MCWRA, 1995). Other more recent estimates of storage loss include 11,000 acre feet per year reported by DQR in 2003 and 14,000 acre feet per year reported by MCWRA in 2001 (Brown and Caldwell, 2015). Figure 78 shows current extent of seawater intrusion in the Basin. In addition to the lateral encroachment of sea water, contaminated water can move vertically through breaches in the various aquitards, through improperly constructed wells, wells that were abandoned but not destroyed, or through failed well casings.

Notable observations from previous studies include the following:

- Recharge is primarily from infiltration from Salinas River, Arroyo Seco Cone, and, to a much lesser extent, from deep percolation of rainfall on the land surface.
- Deep percolation of applied irrigation water is the second largest component of the groundwater budget (MCWRA, 1995).
- Infiltration of water from Salinas River is relatively constant from year to year, partly because river flows are partially regulated by Nacimiento and San Antonio reservoirs (Figure 26). However, groundwater extraction increases the amount of infiltration from the river upstream of Salinas.
- Irrigation increases the amount of rainfall that percolates past the root zone by increasing antecedent soil moisture at the beginning of the rainy season.
- The low permeability of the Salinas Valley aquitard in the Pressure Area decreases but does not altogether eliminate deep percolation of rainfall and irrigation return flow directly to the 180-foot aquifer in the Pressure Area (MCWRA, 1995).

- In the Upper Valley and Forebay Areas recharge from Salinas River is rapid process, so that the effects of dry years on groundwater levels are rapidly reversed in subsequent normal and wet years (MCWRA, 1995).
- Since 1998, MWCRA and the MRWPCA have cooperated in the implementation of the Monterey County Water Recycling Projects, which include the CSIP and the Salinas Valley Reclamation Plant to provide tertiary treatment of municipal wastewater and deliver it to replace groundwater pumping for agricultural irrigation on about 12,000 acres in Castroville (MCWRA, 2006).

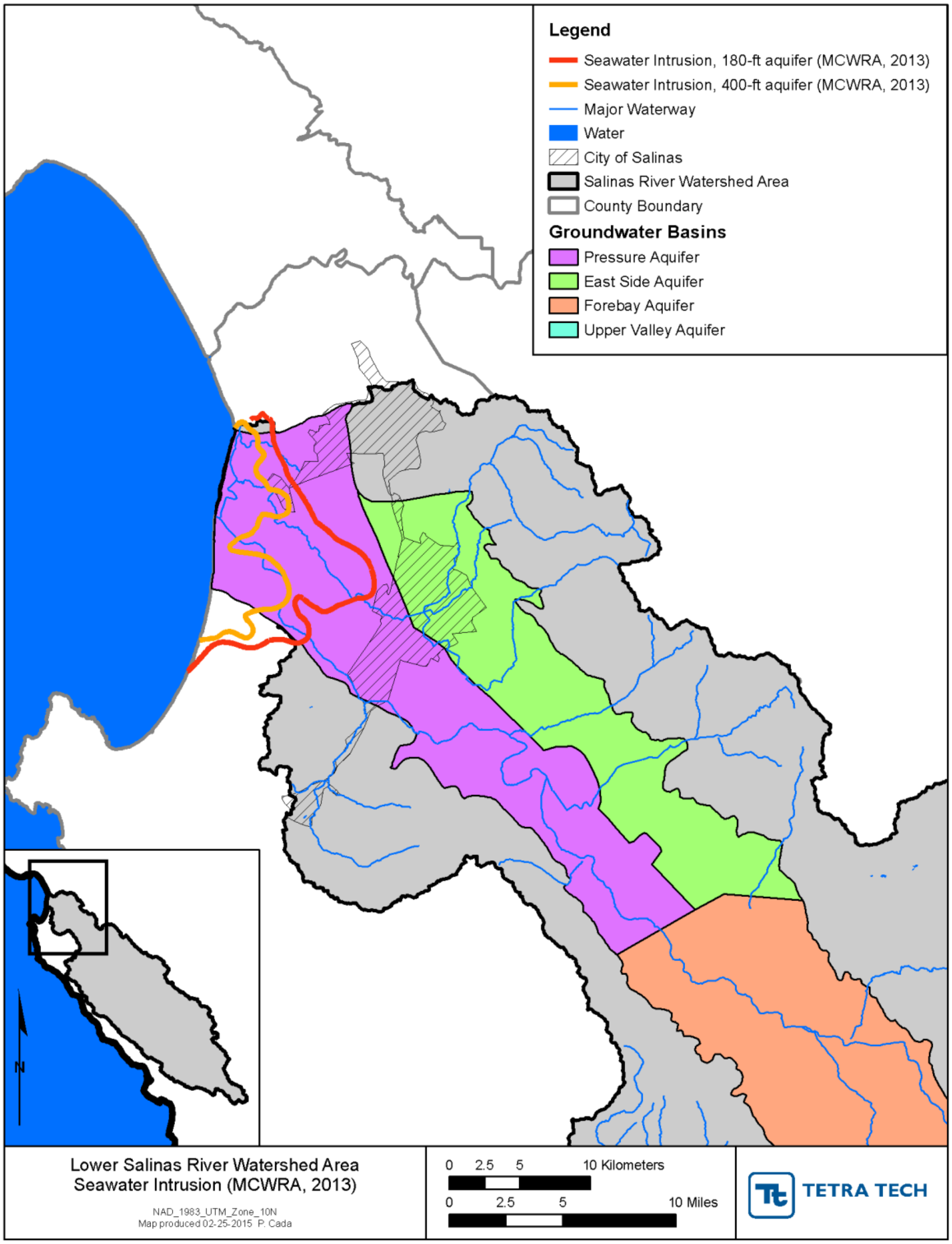


Figure 78. Salt water intrusion in the Salinas Valley Pressure Area (MCWRA, 2013)

7 Tool Development

This section describes the development of a Salt Balance Tool (the "Tool") for quantifying major inputs and outputs of water volume and salt mass in the Salinas River Watershed and Salinas Valley aquifer subareas. The primary purposes and uses of the Tool are to support source assessment of reaches impaired for salt-related measures, and to support development of a salt and nutrient management plan for the Salinas Valley aquifers. In addition, the Tool can be used to test the impacts of proposed management strategies on the salinity of water resources, both surface and aquifer.

The Tool quantifies the interaction of land use with surface waters and aquifers, and is therefore focused on the Salinas Valley area, beginning at the USGS Bradley gage on Salinas River about 7 miles downstream of where San Antonio and Nacimiento Rivers enter the Salinas, and extending to the mouth of the Salinas River at Monterey Bay. Inflow volume and salt mass from the Salinas River upstream of Bradley is quantified from monitoring data and used as an input, but the source assessment does not quantify specific source areas upstream of Bradley. In addition, the Reclamation Canal watershed, Moro Coho Slough, and the Old Salinas River (OSR) are included.

7.1 Structure of the Salt Tool

The Tool is built using MS Excel™. Excel provides a platform for storing the seasonal time series and performing calculations between all of the interacting components.

The Tool includes the following components:

- The Tool represents three characteristic types of years based on annual precipitation – normal, wet, and dry. Each year is divided into four seasons. The seasons are defined based on annual cycles of climate and irrigation volume:
    - Season 1: December – March (4 months)
    - Season 2: April – May (2 months)
    - Season 3: June – September (4 months)
    - Season 4: October – November (2 months)
- Each surface water body (reach segment) is represented individually. Some streams (such as the Salinas River) have multiple reach segments with breaks typically occurring where major tributaries connect, or at flow gaging stations. Land area draining to each reach segment comprises a subbasin. Reach segments and subbasins are shown in Figure 79 and Table 24.
- The four primary aquifers (Pressure, East Side, Forebay, and Upper Valley) are represented individually. However, due to the complexity of the aquifer system, the Tool does not attempt to represent water table depths, aquifer storage, the complex interactions between the aquifer subareas, and the salt balance of the aquifers. The degree to which salt dissolves or precipitates within the subareas is not known. Inflow/outflow volumes and salt mass will be reported for reference.
- Land use/land cover (LULC) has been developed for the study area to represent relevant agricultural crop characteristics, developed pervious areas, impervious areas, and undeveloped land.
- Each model land use class is represented with the seasonal time series of water and salt storages and fluxes on a unit area basis (i.e., ft/season and average concentration in mg/L). The unit-area SaltMod model was used to estimate many of these time series, notably those associated with agricultural uses. SaltMod (Oosterbaan, 2002) is a simplified seasonal balance model that can be

used to simulate seasonally averaged irrigation, percolation, flow to drains, and accompanying salt balances and concentrations for irrigated lands in the watershed. The model provides estimates of salt concentrations in drainage water, the soil profile, shallow groundwater, and recharge to the deep aquifer, under various combinations of meteorology, crops, irrigation, and drainage practices.

- Specific zones were developed for the SaltMod modeling to represent spatial differences in climate (CIMIS ETo and PRISM rainfall), irrigation sources (aquifer versus SVRP), and underlying aquifer subareas. SaltMod zones are shown in Figure 80 and described in Table 25.The CSIP area is designated as a separate area since irrigation water is derived from the SVRP. The SaltMod zones are focused on the Salinas Valley where nearly all of the agricultural land is located, as well as most of the urban land. Land areas in the watershed outside of the Salinas Valley were not included in the SaltMod modeling, but were represented using other methods.
- Salinas River inflow at Bradley is represented as a boundary condition – a point of inflow to the model where both volume and salt loads enter. Other water management features are also represented, including the Salinas Valley Reclamation Project and the Salinas River Diversion Facility. Outflows from the Salinas River and the OSR are reported.
- Several data sources and models were used to specify various components of the Tool. These are described in detail in Section 7.2 and summarized in Section 7.2.7.

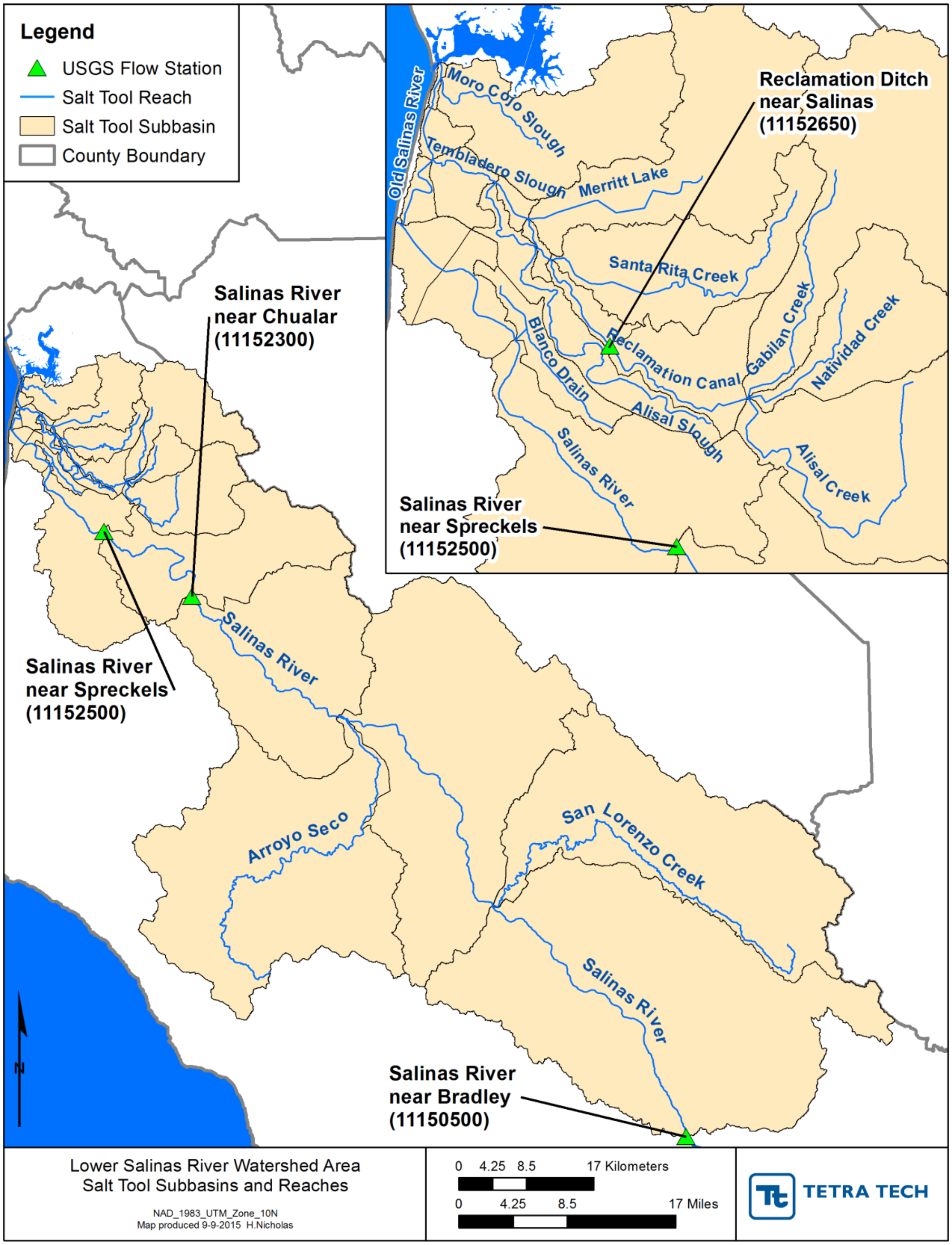


Figure 79. Salt Tool reach segments and subbasins

Table 24. Assignment of reach segments and subbasin/reach numbers

Subbasin/Reach	Area, Sq Mi	Length, Miles	Reach Name
1	296.28	49.7	Arroyo Seco
2	171.40	21.3	Salinas River, Arroyo Seco to Chualar gage
3	447.47	31.8	Salinas River, Bradley gage to San Lorenzo
4	260.67	53.9	San Lorenzo Creek
5	109.74	16.7	Salinas River, Chualar gage to Spreckels gage
6	73.25	9.7	Salinas River, Spreckels gage to Blanco Drain
7	328.83	28.2	Salinas River, San Lorenzo to Arroyo Seco
8	6.74	15.5	Alisal Slough
9	14.24	11.4	Santa Rita Creek/Espinosa Slough
10	7.32	5.6	Reclamation Canal, beg to gage
11	11.54	5.5	Natividad Creek
12	0.53	1.5	Reclamation Canal, Santa Rita to Merritt Lake
13	2.48	2.4	Tembladero Slough, Alisal Slough to OSR
14	44.59	13.1	Alisal Creek
15	15.30	4.9	Moro Cojo Slough
16	0.72	1.5	Tembladero Slough, Merritt Lake to Alisal Slough
17	1.05	3.1	Old Salinas River, Salinas Lagoon to Tembladero
18	1.16	1.7	Old Salinas River, Tembladero to tide gate
19	22.29	6.2	Merritt Lake
20	43.18	8.6	Gabilan Creek
21	4.14	6.3	Blanco Drain
22	0.23	1.4	Old Salinas River, tide gate to Moss Landing
23	2.84	2.0	Salinas River, Hwy 1 bridge to Salinas Lagoon
24	1.53	3.5	Reclamation Canal, gage to Santa Rita
25	4.39	3.8	Salinas River, Blanco Drain to Hwy 1 bridge

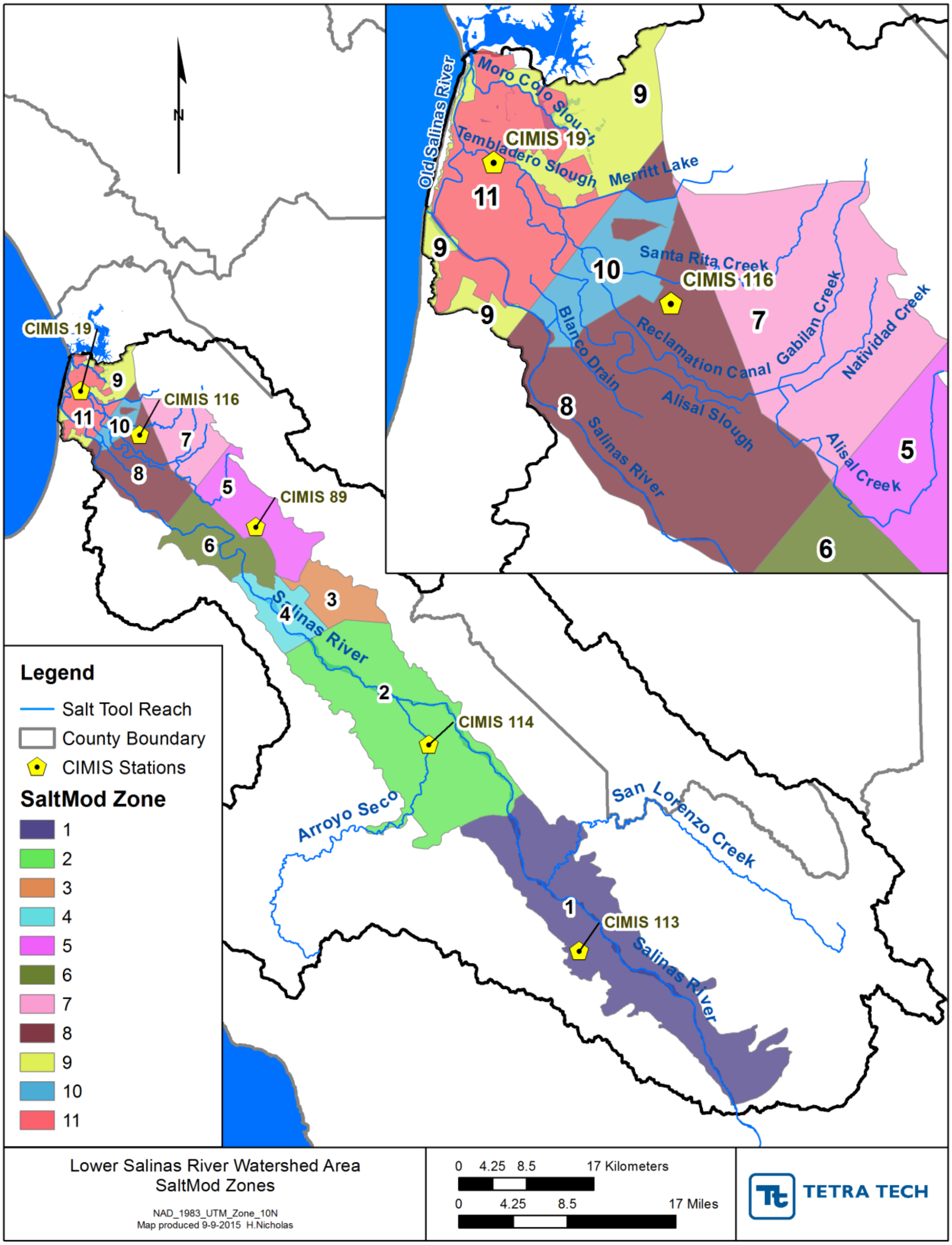


Figure 80. SaltMod Zones for Irrigation Analysis

Table 25. Properties of SaltMod zones

SaltMod Zone	Aquifer Subarea	CIMIS Station	Annual Average Rainfall (in)*	SVRP Area
1	Upper Valley	113	10.22	No
2	Forebay	114	10.94	No
3	East Side	89	10.89	No
4	Pressure	89	12.87	No
5	East Side	89	12.95	No
6	Pressure	89	13.62	No
7	East Side	116	13.91	No
8	Pressure	116	13.17	No
9	Pressure	19	14.22	No
10	Pressure	116	13.36	Yes
11	Pressure	19	13.80	Yes

*Area-averaged PRISM data 2003 – 2013

Representative years for normal, wet, and dry conditions were selected based on an analysis of monthly rainfall spanning 2003 – 2013. Spatial data from the PRISM Climate Group at Oregon State University (see Section 1.1.3) were used to develop average annual totals across the study area (Figure 81). The annual totals spanned December – November, consistent with the selection of seasons. Representative years were selected as follows:

- Normal – 2004
- Wet – 2010
- Dry – 2013

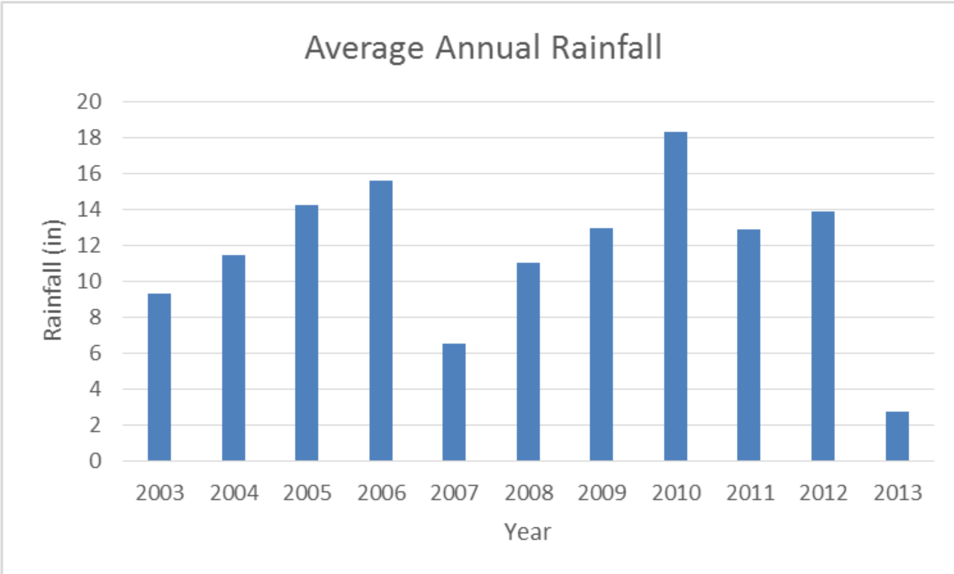


Figure 81. Average annual rainfall in the study area using PRISM data

The product of LULC unit area fluxes and contributing land area is used to estimate outflows to receiving streams and direct inputs to the aquifer subareas (Figure 82). Streams also interact with the aquifers, via gains from shallow groundwater and infiltration losses from channels.

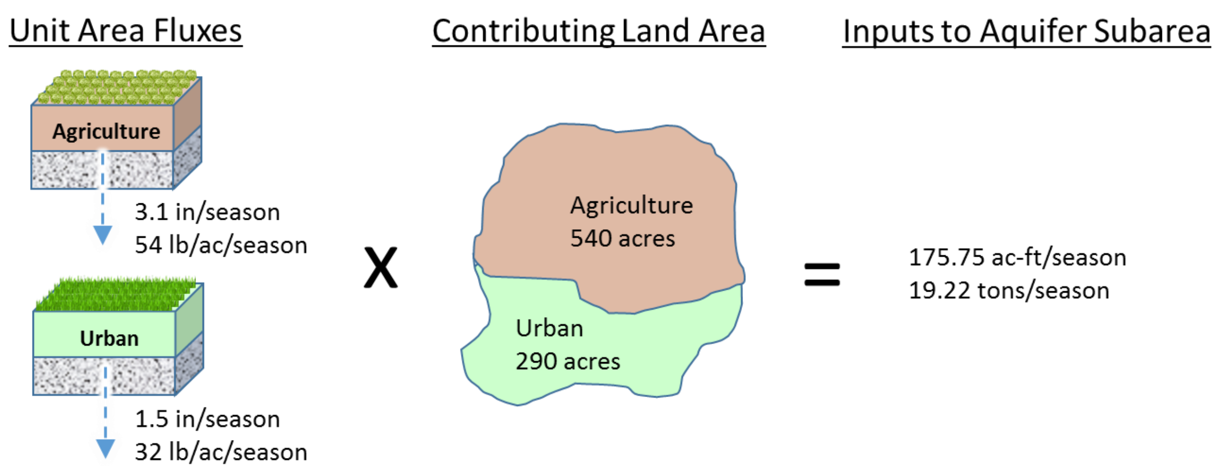


Figure 82. Example calculation of seasonal inputs from groundwater to aquifer subarea

Further information about the development of inputs is provided in the next section.

7.2 Model Components and Data Sources

Several data sources and models were used to develop the components of the Tool. Multiple options for each source were evaluated carefully, and the most optimal source selected based on the needs of the specific analysis.

7.2.1 Land Use/Land Cover Data

Agricultural land use data were provided from the Monterey County Agricultural Commission. The data are based on agricultural pesticide reporting, and include a list of agricultural commodities grown on each polygon. The spatial extent of the Agricultural Commission data was compared to recent aerial photography; in many cases, there were polygons whose area included land that was clearly in an undeveloped, non-agricultural state. It appears that the data are based on land parcel records, and it is likely that the stated crops are grown on only a portion of the parcel. Other agricultural data sources were reviewed, and the spatial extent of the Farmland Mapping & Monitoring Program (FMMP) was found to align well with aerial photographs. However, FMMP does not contain any information regarding specific crops. As a result, the two datasets were combined, with FMMP providing the spatial location of agricultural land and the Agricultural Commission data providing crop-specific data.

The Agricultural Commission data included over one hundred unique categories, indicating either combinations of crops grown on the parcels, or rotations that take place over the course of the year. Some of the categories are simple (e.g., “Strawberry”, “Grape, wine”). Others indicate a number of crops either in combination or in rotation, such as “Strawberry, Avocado” and “Asparagus, Carrot, Rotational Crops”). The most common category was the generic “Rotational Crops”. An analysis was conducted to simplify the groups into a manageable number of combinations. Crops or crop groups were included when their area exceeded two percent within each SaltMod zone. The remaining miscellaneous categories were lumped with the “Rotational Crops” category.

Developed uses in the study area were represented using NLCD data from 2011 (discussed in Section 1.1.4). All remaining areas were classified as undeveloped. A map of all the land uses is shown in Figure 83. Impervious area was also tabulated from NLCD 2011 data, which is reported by NLCD as a percentage of developed uses. Section 7.2.6 discusses adjustments made to impervious area to account for the portion of impervious surfaces that are directly connected to the drainage system.

For the purposes of salt mass estimation, only the irrigated portions of lawns are expected to produce significant outflow of salt. All other unirrigated developed land use is assumed to behave like undeveloped land and produce background loading rates of salt (see Section 7.2.4). In urban areas, only a fraction of groundwater is diverted to irrigation. However, local data were not available to directly estimate the proportion of water used for watering lawns and landscaped areas, so an alternative approach was used. CA DWR (2010) published the 20x2020 Water Conservation Plan detailing a vision for implementing the declaration of a statewide per capita urban water use reduction of 20 percent by the year 2020. A technical memorandum supporting the plan (CA DWR, 2008) provides an estimate of 66 gallons per capita per day of indoor water use in the Central Coast Region. The CA State Water Board has published monthly water use data from 2013 – 2014 for water supply utilities throughout the state. Population weighted average per capita water use (indoor and outdoor) was calculated from the data for water supply utilities within the study area (Figure 84). Volume in excess of 66 gallons per capita per day was tabulated from the monthly total average use to derive the ratio of outdoor water use to total water use of 28 percent.

Data were also not available to characterize irrigated lawn acreage. A review of aerial photographs revealed a patchwork of urban irrigation practices; in one neighborhood there were housing units that irrigated the entire yard, other units that irrigated only the front yard, and some that did not appear to use any irrigation. To address this gap, the following method was used to estimate irrigated lawn area. Unit area seasonal irrigation volumes for lawns were calculated as discussed subsequently in Section 7.2.3.2. Using the outdoor water use by aquifer subarea calculated previously, irrigated lawn area was back-calculated from the total volume applied within each aquifer subarea and the estimated irrigation volume used in SaltMod. Land area was then assigned by apportioning it to the relative percent of low, medium, or high intensity land use specified by NLCD. The adjusted area was tabulated by Salt Tool subbasin and SaltMod zone.

A final tally of land use/land cover used in the Salt Tool is shown in Table 26.

Table 26. Salt Tool land use/land cover totals

Land use/land cover	Acres
Asparagus	3,528
Brussel Sprouts/ Rotational Veg	655
Carrots/Rotational Veg	1,541
Grapes	52,449
Lemons	350
Rotational Vegetables	131,648
Strawberries	7,837
Strawberries/Broccoli	45
Strawberries/Celery	4,261
Impervious	1,883
Irrigated Lawns	5,394
Undeveloped/unirrigated	987,875

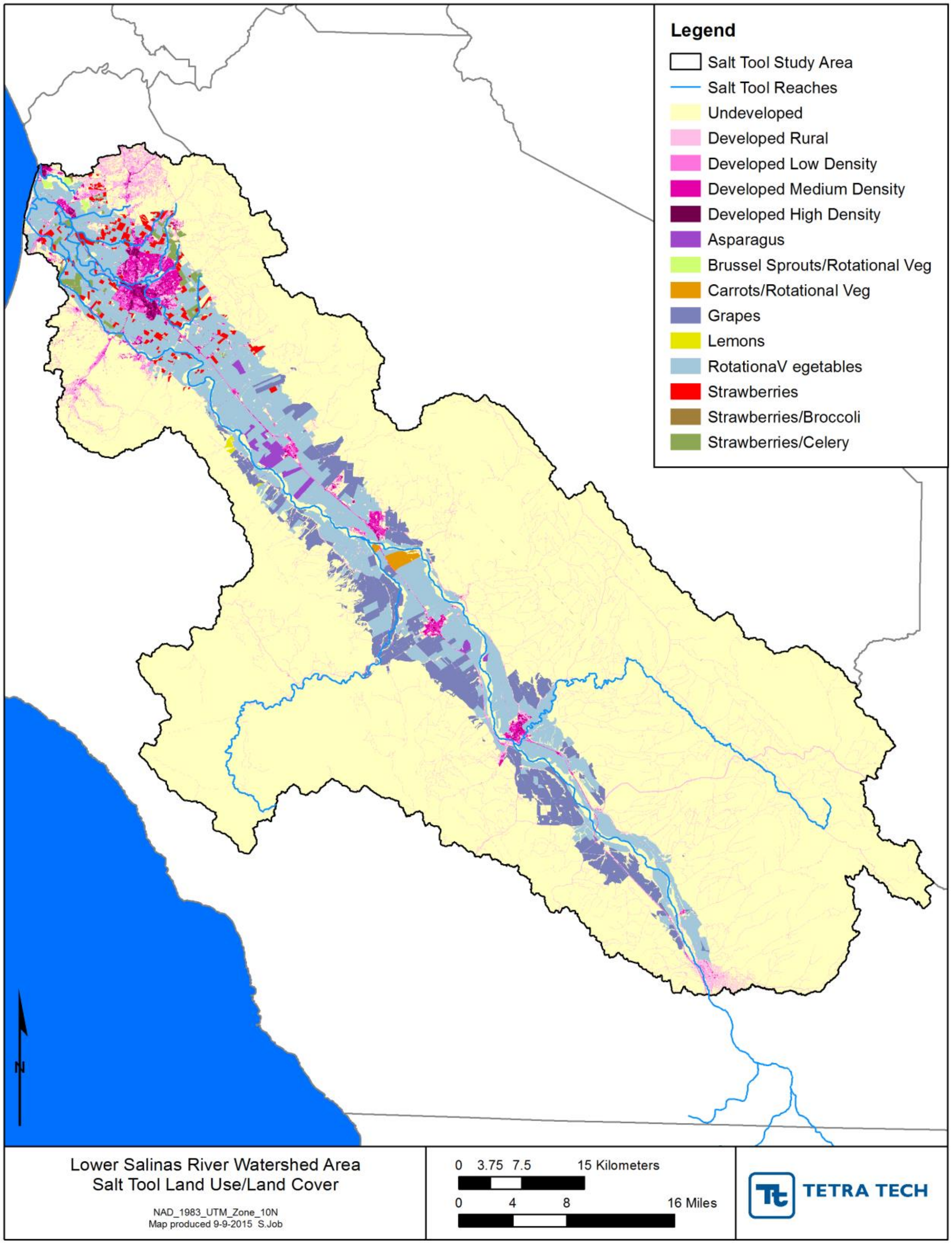


Figure 83. Salt Tool land use/land cover

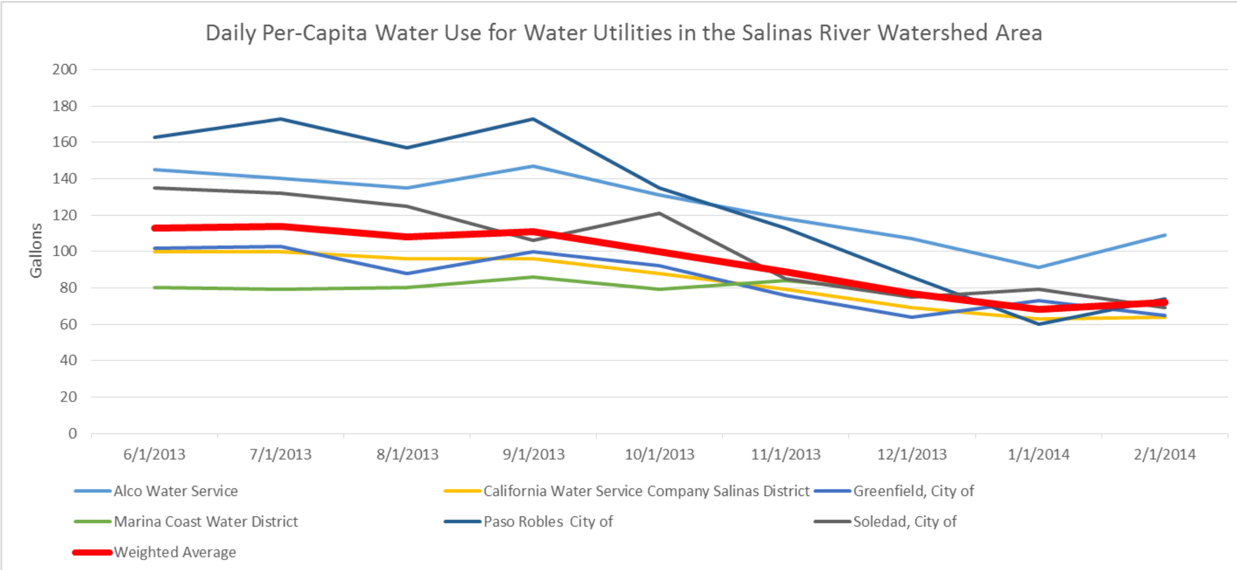


Figure 84. Per-capita water use in the Salinas River Watershed Area

7.2.2 Meteorology

Two types of meteorological data were needed to support the analysis – precipitation and evapotranspiration. The meteorological data were used to support several source models described subsequently: SaltMod (Section 7.2.3), USGS SPARROW (Section 7.2.4), EnviroAtlas (Section 7.2.5), and impervious area runoff (Section 7.2.6). Data sources used for the development of the climate files include Parameter-elevation Regressions on Independent Slopes Model (PRISM) rainfall and California Irrigation Management Information System (CIMIS) evapotranspiration monitoring.

The PRISM Climate Group at Oregon State University maintains a meteorological data set that incorporates observed point data, a digital elevation model (DEM), and expert knowledge of complex climatic extremes (including rain shadows, coastal effects, and temperature inversions). PRISM data are provided at a 4-square-kilometer resolution for the entire contiguous United States and are summarized as monthly precipitation totals. Because the PRISM approach takes into account elevation in the spatial interpolation process, these data are able to better quantify orographic influences in ungaged areas. Long-term PRISM average annual precipitation is shown previously in Figure 5.

In addition, daily evaporation data available through the CIMIS were compiled. The CIMIS is a program in the Office of Water Use Efficiency (OWUE), California Department of Water Resources (DWR) that manages a network of over 120 automated weather stations in the state of California. Five CIMIS stations were used to characterize evapotranspiration in the model segments. The stations were shown previously in Figure 6. The resolution and spacing of the stations is considered sufficient for the purposes of the Salt Tool.

- Station 19 (Castroville): Located in a set-aside portion of an artichoke field adjacent to Tembladero Slough, which is tidal field drain conduit.
- Station 89 (Salinas South): No site description.
- Station 113 (King City-Oasis Rd.): No site description.
- Station 114 (Arroyo Seco): Located on a large farming operation, the station was installed in a turf area between vineyards.

- Station 116 (Salinas North): The station was installed in a small turf area in the middle of an artichoke field. It is sprinkler irrigated.

CIMIS is focused on providing data beneficial to irrigators to assist with efficient water use. CIMIS estimates evapotranspiration (ETo) for a reference crop (well-watered grass) using a modified version of the Penman-Monteith equation, and provides hourly and daily values. CIMIS data have good utility for meeting the needs of the SaltMod modeling, both in terms of input ET as well as estimated irrigation volume. Much of the irrigation literature developed for California uses CIMIS ETo as the reference for estimating crop-specific ET. Time series of monthly ETo values at each of the stations from 2003 – 2014 are shown in Figure 85, while monthly average values from the same time period are shown in Figure 86. Data were not available at the Salinas South station (89) beginning in water year 2013, so the missing values were estimated using the historic monthly average ratio of Salinas South values to Arroyo Seco (114) values.

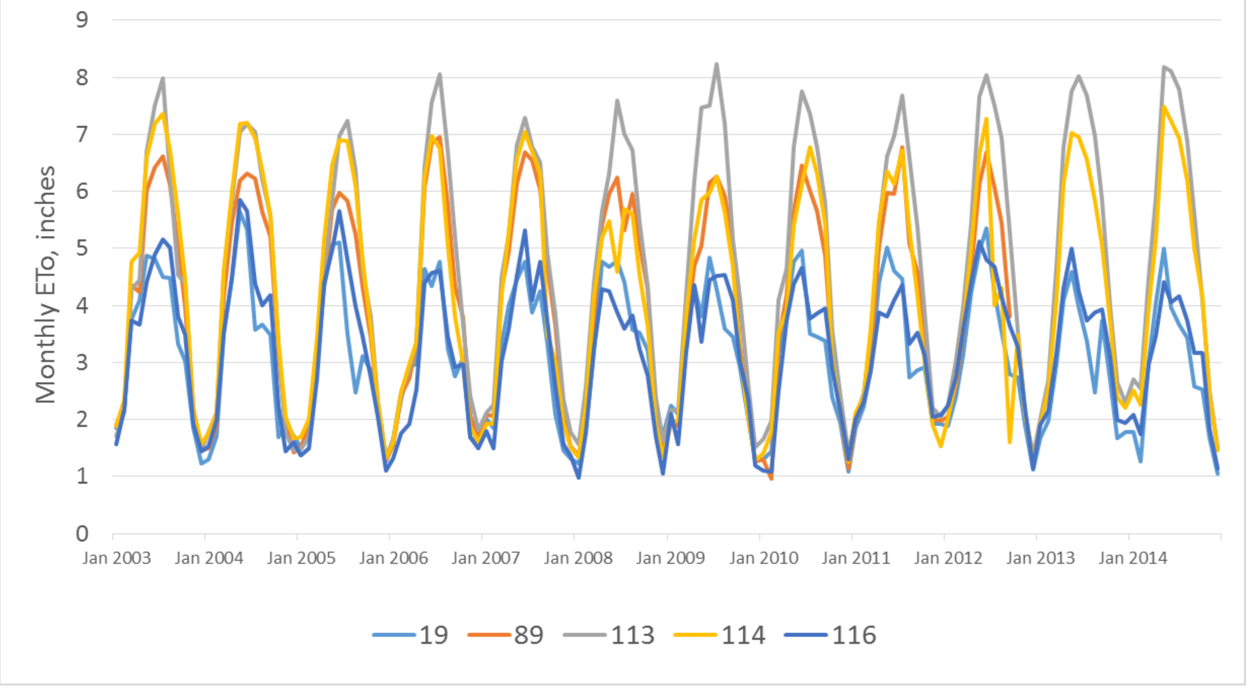


Figure 85. Time series of monthly CIMIS ETo, 2003 - 2014

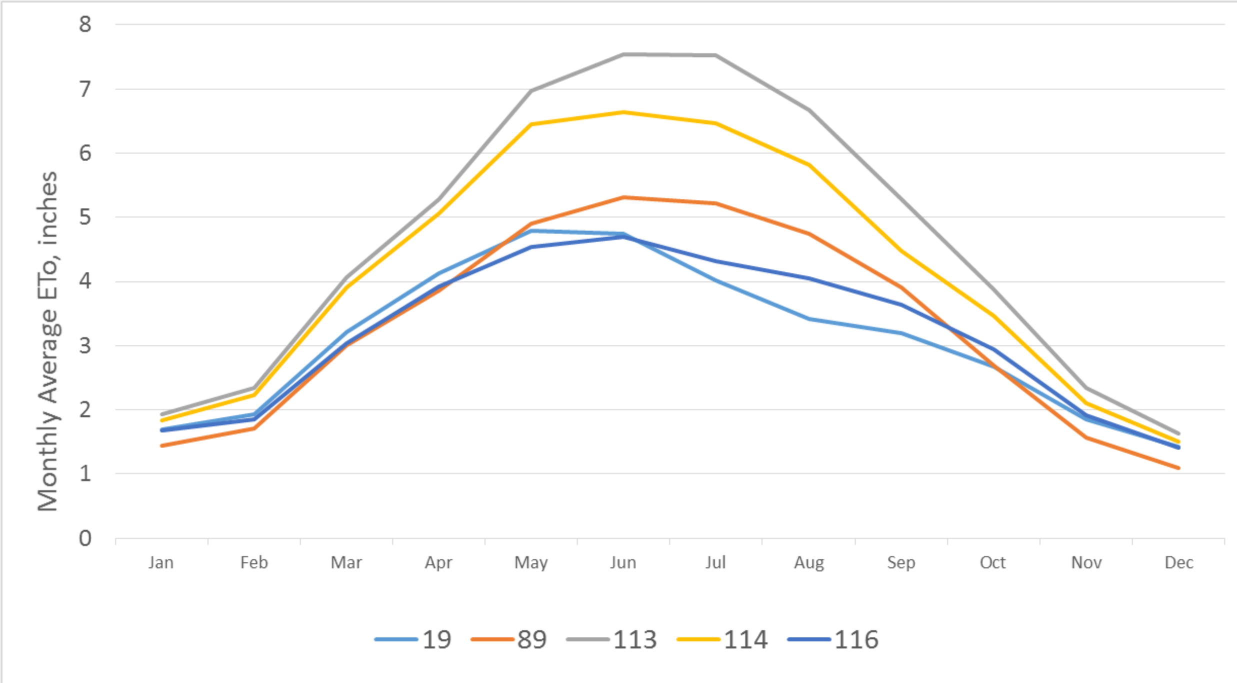


Figure 86. Monthly average CIMIS ETo

7.2.3 SaltMod

SaltMod is a simplified soil leaching model for predicting the salinity (as electric conductivity, EC) of soils, soil moisture, infiltrated water, irrigation return flow, and groundwater; along with the depth to the water table, and drain discharge rates for irrigated lands on a seasonally averaged basis. It allows for the specification of different (geo)hydrologic conditions, varying water management options, including the use of groundwater for irrigation, use of tile drains, and cropping rotation schedules. SaltMod was developed by the International Institute for Land Reclamation and Improvement (Wageningen, The Netherlands) and is designed as a relatively simple tool that uses input data that are generally available, can be estimated with reasonable accuracy, or can be measured with relative ease.

For this study, SaltMod was used to develop the following inputs to the Salt Tool for each combination of agricultural crop/irrigated lawn and the eleven SaltMod zones:

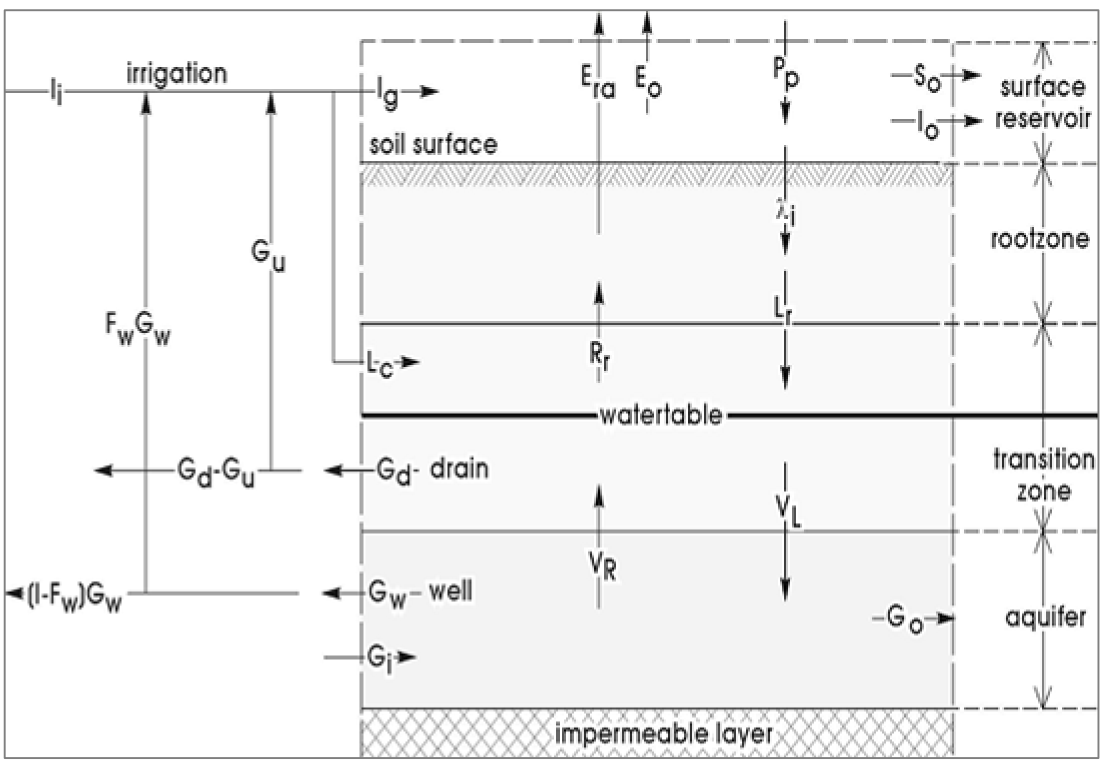
- Where tile drainage exists, unit area tile drain outflow volume and salt concentration
- Unit area percolation volume and salt concentration to the underlying aquifer (note that where there are confined aquifers with an aquitard, only the surficial aquifer and its water table are modeled. The confined aquifers are not represented in SaltMod).
- Unit area surface runoff concentration (volume estimated separately as discussed in Section 7.2.5)

The computation method used in SaltMod is based on seasonal water balances of irrigated lands. Up to four seasons in one year can be distinguished (e.g. dry, wet, cold, hot, irrigation or fallow seasons). SaltMod model applications for a variety of crop types were configured to simulate the salt balance in irrigated lands in the Salinas watershed for wet, dry, and normal conditions over a ten year period. In the Salinas watershed, each year was divided into four seasons corresponding to winter, spring, summer, and fall. Input data on irrigation, evaporation, and surface runoff are varied by season for up to three kinds of agricultural crops or management practices in a single run, which include two types of irrigated land uses and one fallow land use. Multiple model runs are used to represent a large number of crop types and land uses.

SaltMod considers four different zones (or "reservoirs", using SaltMod terminology) as shown in Figure 87:

1. Water ponding on top of the soil (surface reservoir in Figure 87)
2. An upper (shallow) soil reservoir (root zone in Figure 87)
3. An intermediate reservoir (transition zone in Figure 87)
4. A deep reservoir or aquifer (aquifer in Figure 87)

The upper soil reservoir is defined by the soil depth from which water can evaporate or be taken up by plant roots, referred to as the root zone. The transition zone is the portion of the profile that separates the root zone from the aquifer, and may consist of a combination of soil and unconsolidated material. These two zones can be saturated, unsaturated, or partly saturated, depending on the water balance and water table depth. All flows in the top two zones are vertical, except the flow to subsurface drains, which must occur in the transition zone (below the root zone and above the aquifer). The aquifer represents the continuously saturated portion of the profile, and may be deep or shallow depending on local conditions. Flows in this zone include both vertical components (seepage) and seasonally defined horizontal inflows and outflows. Confined aquifers (i.e., below an aquatard) are not considered by SaltMod.



Note: see Oosterbaan, 2002 for description of variables

Figure 87. SaltMod model reservoirs and water balances

The water and salt balances are calculated for each reservoir separately. The three soil reservoirs are assigned thickness and storage coefficients and the excess water leaving one reservoir is converted into incoming water for the next reservoir. Salt concentrations of outgoing water (either from one reservoir into the other or by subsurface drainage) are computed on the basis of salt balances, using different leaching and storage efficiencies.

SaltMod uses seasonal water balance components as input data. These are related to the surface hydrology, including rainfall, evaporation, irrigation, use of drain and well water for irrigation, and surface runoff. They also include data related to the aquifer hydrology including upward seepage, natural drainage, and pumping from wells. The other water balance components (downward percolation, upward capillary rise, and subsurface drainage) are given as output.

The configuration of SaltMod for the Salinas watershed includes agricultural crops and urban lawns, parameters related to crop types, soils data, and climatic and physical conditions throughout the basin. Therefore, vegetation characteristics, irrigation practices, climatic conditions, evapotranspiration assumptions, and subsurface soil and geological characteristics, including soil types, sediment and rock formations that determine infiltration rates, porosity, specific yield, and permeability are critical in setting up SaltMod. All of these various factors were calculated or estimated for the Salinas watershed and used as input to SaltMod for predicting the soil salinities of irrigated lands.

Agricultural land uses simulated by SaltMod are located throughout the Salinas groundwater basin, which also includes areas of urban development and irrigated lawns. Simulation of the salt balance in irrigated lands is organized to match the underlying groundwater basins and to capture variability in precipitation, evapotranspiration, and any special irrigation practices including SVRP areas and tile drains. These characteristics were used to define the model segments and a SaltMod model was configured for each of the major crops grown and irrigated lawn land covers in that area. The following sections discuss the data and assumptions that went into the development of the various model input parameters for irrigated lands.

7.2.3.1 Soil and Aquifer Physical Properties

The physical properties of soils and the aquifer in the Salinas watershed are the basis for various inputs to SaltMod. As noted above, SaltMod considers four different reservoirs, including the land surface, root zone, transition zone between the root zone and aquifer, and deep reservoir or aquifer. A variety of data sources were used to characterize these soil zones for input to SaltMod. As with all inputs to SaltMod, soil zone characteristics were evaluated for each model segment to maintain the linkage to the Tool.

Soil characteristics were defined as input for the three SaltMod soil layers. These characteristics include:

- Zone thickness
- Zone Soil Properties
    - Porosity and effective porosity
    - Critical water table depth for capillary rise into the root zone
    - Leaching efficiency

The thicknesses of the three subsurface zones (root zone, transition zone, and aquifer) were estimated from various sources. Root zone thicknesses for the modeled crops were obtained from FAO (1998) Irrigation and Drainage Papers (Table 27).

Table 27. Root zone depths

Crop	Root Zone (m)
Lettuce	0.15
Celery	0.30
Broccoli	0.46
Cauliflower	0.46
Carrots	0.46

Crop	Root Zone (m)
Spinach	0.15
Brussel Sprouts	0.46
Asparagus	0.91
Strawberries	0.15
Grapes	0.91
Lemons	1.19
Urban Lawn	0.30

Transition zone thickness is estimated as:

$$Wt - Rz + 3$$

Where:

Wt: mean water table depth (m) calculated from available USGS monitoring data as described in the following section

Rz: root zone depth (m)

The additional three meters is in consideration of the transition zone extending into the water table as is recommended in the SaltMod documentation. Aquifer thickness (i.e. the depth from the top of the saturated zone to underlying bedrock) was estimated from the geologic cross sections provided in the Monterey County Groundwater Management Plan (MCWRA 2006), which showed depth to the bedrock or aquatard underlying the aquifer. Aquifer thickness was calculated as: aquifer depth – (root zone thickness + transition zone thickness) for each model segment.

The SSURGO soil database, developed by the Natural Resources Conservation Service (NRCS), was used to characterize the substrates of the three modeled soil zones. Soil properties that need to be defined as input to SaltMod include porosity, effective porosity, capillary rise, and leaching efficiency. The SSURGO database provides detailed soil media information and was designed primarily for site-scale natural resource planning and management. Using NRCS mapping standards, soil maps in the SSURGO database are made using field methods, including observing soils along delineation boundaries and determining map unit composition by field traverses and transects (USDA 1995).

SSURGO soil units represent the most detailed level of assessment available and provide the framework for extracting more detailed soil characteristics. The assignment of soils data at the model segment scale was done by overlaying the SSURGO soil units with the model segment delineation. Soil characteristics were then calculated as an area-weighted average according to the percent composition of soil units in each segment. In general, the SSURGO soil surveys do not include soil attributes below a depth of five feet. Soils data are, therefore, only available for a portion of the transition zone and completely unavailable for the aquifer. As a result, available soils data were used to characterize the entire transition zone, and transition zone media characteristics were also applied to the aquifer, where necessary.

The porosities of the soil and aquifer layers were derived from SSURGO bulk density and particle density data for the watershed soil maps. SSURGO soil map units include data by horizon depths, which were matched to calculated SaltMod soil zone depths to assign porosity values. Porosity was calculated as:

$$\phi = 1 - \frac{\rho_{\text{bulk}}}{\rho_{\text{particle}}}$$

where:

ϕ: porosity

ρ: density

Particle density was assumed to be a baseline of 2.65 g/cm^3 adjusted for organic matter fraction (OM) according to 2.65 – 0.01 × %OM (Reid 1973). Effective porosity was calculated from porosity based on sand, silt composition of the soil map units and typical variations between porosity and effective porosity for the respective sediment classes (Yu et al. 1993).

Capillary rise is vertical water movement against the force of gravity through the interstitial spaces in soil. It has the potential to cause the accumulation of salts as saline water from a shallow water table moves into the evaporative zone. The critical water table depth for capillary rise to the surface was calculated based on estimates of the particle size and void ratio of soils in each model zone. Void ratio was calculated from porosity, while particle size was estimated from a weighted average of the sieve data. Capillary rise was then calculated as described by Tabor (1930):

$$h_c = \frac{C}{(e)(D_{10})}$$

where:

h_c: capillary rise (cm)

C: a constant (ranging from 0.1 to 0.5 cm^2)

e: void ratio

D_{10}: 10th percentile soil particle size (cm)

The leaching efficiencies of the soil zones describe the movement of salt through the soil profile as water percolates to the aquifer. Owing to the irregular distribution of salt in the soil or to irregularity of the soil structure, the leaching efficiency can be different from unity and result in salt accumulation in the soil profile. Like root zone water storage efficiency, the leaching efficiencies of the soil zones are not known. Both root zone storage efficiency and leaching efficiency were adjusted during calibration as discussed in Section 7.2.3.6.

Accurate representation of the aquifer system in the Salinas watershed is critical for simulating the salt balance of agricultural lands in the area. Because nearly all agricultural irrigation water is drawn from wells, the mass balance describing aquifer gains and losses determines the groundwater quality and ultimately the salinity of irrigation water. This section describes the methodology used to estimate the aquifer specific parameters in SaltMod, which include initial aquifer depth and salinity.

Initial water table depth was estimated based on typical depths reported by MCWRA over the modeling time period. Initial aquifer depths of the model segments are shown in Table 28.

Table 28. Initial water table depths in SaltMod

Location	Initial Depth (m)
Upper Valley (Zone 1).	13.7
Forebay (Zone 2).	19.3
East Side, and Pressure southeast of Salinas (Zones 3 – 7, part of Zone 8).	41.4

Location	Initial Depth (m)
Shallow aquifer above aquatard in Pressure subarea northeast of Salinas (Part of Zone 8, and Zones 9 – 11). Corresponds to area with tile drainage	2.0

7.2.3.2 Crop Properties

Cropland occupies large portions of the Salinas Valley floor. The agricultural areas are some of the most productive in California, with primary crops including strawberries, lettuce, broccoli, wine grapes, celery, cauliflower, spinach, carrots, and lemons. The vast majority of agricultural water requirements in the Valley are supplied by local groundwater pumping. Urban lawns are associated with developed areas, which are concentrated in and around the City of Salinas, although there are urban areas throughout the watershed.

Crop data for the model segments were derived from GIS data developed for Monterey County by the Agricultural Commissioner's Offices, as discussed in Section 7.2.1. It is assumed that agricultural production has been relatively consistent over the modeling time period.

The Salinas watershed includes both permanent and rotational agriculture. Crop rotation refers to the practice of sequencing different crops on the same plot of land within a single growing season or over multiple growing seasons. SaltMod allows for the representation of various crop rotation schemes ranging from none (all crops are fixed to an area) to full rotation, where different crops are continuously moved over the represented area. Crop scheduling and rotation schedules were represented for the modeled crops according to the categories specified in the GIS spatial data and general practices outlined in the Basic Irrigation Schedule (BIS) application (University of California Regents 2007) and available crop profiles for the Central Coastal Production Region available through the USDA Regional IPM Centers[4]:

- Lemons: permanent crop grown and irrigated year round.
- Grapes: permanent crop grown year round, but irrigated only in the spring–fall.
- Asparagus: Grown year round.
- Rotational vegetables: crop grown and irrigated year round. The main varieties of rotational vegetables as described in Monterey County Agricultural Commissioner (2013) crop report (lettuce, celery, broccoli, cauliflower, carrots and spinach) have similar water requirements and evapotranspiration characteristics, but different planting and harvest dates. These can be combined into a variety of feasible rotations.
- Where specified in the GIS data as having a dominant crop component, rotational vegetable are simulated in rotation with the dominant crop. These include:
    - Carrots: Planted in winter, harvested in spring.
    - Brussel Sprouts: Planted in winter, harvested in summer.
- Strawberries: crop grown and irrigated year round, except for portions of the fall and winter when the soil is readied for next year crop or it is rotated with a vegetable. Where specified in the GIS data, strawberries are represented in rotation with celery, which is assumed to be planted in fall and harvested in winter.

[4] http://www.ipmcenters.org/CropProfiles/cropprofiles.cfm?typeorg=state&USDARegion=National%20Site

- Strawberries/Broccoli: Since both are spring/summer crops, this is represented as 50% strawberries and 50% broccoli.

Various parameters are used to differentiate crop types in SaltMod. These include effective root zone depth, root zone water storage efficiency, root zone leaching efficiency, evapotranspiration coefficients, and distribution uniformity. Each parameter is related to irrigation practices for the associated crop, but root zone depth and root zone water storage efficiency values do not directly impact irrigation volume projections.

Effective root zone depth is the depth of soil to which soil moisture is managed. Typical crop root zone depths were obtained from the Food and Agriculture Organization of the United Nations (FAO 1998), and were shown previously in Table 27. Root zone depth for the Rotational Vegetables crop type was calculated as the average of the top six vegetables in the 2013 Monterey County Crop Report (Monterey County Agricultural Commissioner, 2013).

Root zone water storage efficiency is an estimate of the fraction of water necessary for a crop that can be stored in the root zone. It is expressed as the percentage of water needed that is supplied by water stored in the root zone during irrigation. Root zone water storage efficiency was adjusted during calibration to achieve expected water balance. Root zone leaching efficiency governs the rate at which salts are flushed out of the root zone. These leaching efficiency factors were estimated then calibrated based on modeled root zone salt concentrations for the selected crops over time as described in the Calibration section (2.4.1). Specifically, root zone leaching efficiency was calibrated to adjust root zone salt levels to maintain between 100 and 90 percent productivity based on crop-specific salt tolerance levels presented in Farm Water Quality Planning (FWQP) Reference Sheet 9.10 (UC ANR 2002).

Initial salt concentration of surface soils in the model segments were determined from the SSURGO data. Calculated soil salinities are shown previously in Figure 12. Only salinity data for soil layers within the literature root zone depths were used for the characterization. Where SSURGO reported soil salinity exceeds 2.0 dS/m, it is assumed that agricultural soils have been leached to equal this value as it represents a threshold above which many crops show decreases in productivity (Regents of the University of California 2011).

Irrigation water contains dissolved salts to varying degrees. When irrigation water is applied, uptake by crops and evaporation leaves salts in the soil, which can build up over time. Salt accumulation in the root zone from irrigation occurs when salts are left in the soil due to insufficient leaching. The upward movement of a shallow saline water table can also cause salt accumulation (Regents of the University of California 2002). As excess salts impair crop growth, growers must apply enough water to ensure that there is sufficient flushing to maintain root zone salt concentrations within crop tolerance levels. Published crop tolerances for salt are shown in Table 33 and discussed subsequently in Section 7.2.7.

In the Salinas watershed, growers generally rely on a combination of winter rains and excess irrigation prior to planting ("pre-irrigation"), if needed, to ensure sufficient flushing. Irrigation during the growing season occurs primarily via sprinkler or drip irrigation depending on the crop. For example strawberries use drip irrigation systems almost exclusively, while vegetables use a mix of drip and sprinkler irrigation, typically corresponding with stages of growth. Drip irrigation is a more efficient means of water delivery, but the reduced water volumes used can cause a greater accumulation of salts in soils due to decreased leaching.

Salt accumulation in agricultural soils is a contributing factor to salinity impairments of surface waters in the Salinas watershed. To estimate the volume of water used to irrigate crops included in SaltMod simulations, applied irrigation water was calculated as the seasonal difference between crop specific potential evapotranspiration and effective precipitation, divided by distribution uniformity. Distribution uniformity measures the irrigation system uniformity across a specific field using a known irrigation system – in other words, it is a measure of how evenly water soaks into the ground during irrigation. As an example, sprinkler overlap reduces distribution uniformity since some areas receive more water than others. Distribution uniformity is scaled from theoretical values of 0 to 1. The higher the value, the lower the over-application of water. Typical values range from 0.75 to 0.92. The distribution uniformity is an important factor to account for when calculating irrigation volume, since it is a measure of the degree of over-irrigation needed to deliver water to crops. Distribution uniformity should not be confused with irrigation efficiency, which is the ratio of beneficially used water to the total volume applied. The calculation of irrigation volume used as an input to SaltMod does not include irrigation efficiency. Rather, SaltMod performs a dynamic simulation to estimate seasonal crop water use using multiple inputs in addition to irrigation volume.

Crop evapotranspiration water requirements (ETc) were calculated using CIMIS evapotranspiration (ETo) data and seasonal crop coefficients (Kc) given in the BIS. Table 29 provides monthly assumed Kc values used to estimate irrigation volume.

Table 29. Assumed monthly Kc values for each crop

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Asparagus	0.99	0.94	0.81	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	0.89
Broccoli	0	0	0.3	0.56	0.99	0.95	0.03	0	0	0	0	0
Brussel Sprouts	0	0	0.3	0.49	1.02	1.05	1.05	1.05	1.05	0.95	0	0
Carrots	0.57	0.95	0.94	0.95	0.41	0	0	0	0	0	0	0
Celery	0.47	0	0	0	0	0	0	0	0.43	0.86	0.95	0.95
Grapes	0	0	0	0.9	0.9	0.9	0.9	0.9	0.9	0.03	0	0
Lemons	1.2	1.2	1.08	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.08
Rotational Vegetables[1]	0.5	0	0.41	0.74	0.85	0.84	0.3	0.37	0.72	0.9	0.85	0.62
Rotational Vegetables Low[2]	0.29	0.47	0.62	0.75	0.7	0.47	0.01	0.37	0.72	0.9	0.64	0.19
Strawberries	0	0	0	0	0.33	0.46	0.69	0.7	0.7	0	0	0
Turfgrass	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Fallow land	0.75	0.95	0.9	0.6	0.35	0.3	0.25	0.2	0.2	0.25	0.45	0.65

Notes: 1. Rotational vegetable Kc factors were developed as the average of factors for predominant rotated vegetable crops that can feasibly be combined into a rotation based on planting and harvest dates.

2. The Rotational Vegetables, Low crop type is separately developed for SaltMod zones 1 and 2.

CIMIS evapotranspiration and PRISM rainfall data were spatially averaged within each of the eleven SaltMod Zones to characterize, thus accounting for spatial variability in meteorology. Each month of the three representative years was processed separately, so temporal variability was addressed as well. Effective rainfall was then subtracted from ETc giving the evapotranspiration of applied water (ETaw). Effective rainfall P_e is the fraction of precipitation that is stored in the soil and available to plants. USDA (1993) provides a method for estimating P_e (inches) on a monthly basis:

$$P_e = SF \cdot \left(0.70917\, P_t^{0.82416} - 0.11556\right) \cdot \left(10^{0.02426 ET_c}\right), \text{ with}$$

$$SF = \left(0.531747 + 0.295164\ D - 0.057697\ D^2 + 0.003804\ D^3\right)$$

Here, P_t is the monthly total precipitation (in.), D is equal to 50 percent of the available water capacity of the soil (in.), and ETc is the monthly crop evapotranspiration demand. The use of D helps account for the variability among different soil types. Following USDA (1993), the resulting value of P_e is then limited to the smaller of the value calculated above, monthly total precipitation, and monthly crop evapotranspiration demand.

Distribution uniformity values for modeled crops were estimated based on guidance from the Resource Conservation District of Monterey County (date unknown). Distribution uniformity ranged from 0.87 to 0.92 for the most efficient practices. As a result, a value of 0.90 was used for all of the crops, except for irrigated lawn (turf grass) which was assumed to have a distribution uniformity of 0.85. This reflects the shift to more efficient irrigation management with drip irrigation and the evolution of field measurement technologies over the past 15 to 20 years.

7.2.3.3 Cumulative Irrigation Volume

As a check on the reasonableness of the irrigation assumptions used in SaltMod, the unit-area irrigation volumes were multiplied by the agricultural land use areas to give the total irrigation volume for the wet, dry, and average precipitation conditions (with the CSIP area excluded). These totals were then compared to the volumes reported by MCWRA in annual reports as shown in Table 30 (MCWRA 2005; MCWRA 2011, MCWRA 2014). The annual reports are compiled from groundwater extraction data reported by well operators, as required by County ordinances.

In general, the values calculated for SaltMod input are reasonably similar to those reported to the MCWRA. Total error ranges from 4 percent to 17 percent. Some errors for individual aquifer subareas are higher, but for the most part errors are less than 10 percent. Differences between the simulated and reported irrigation volumes can likely be attributed to various factors including:

- Differences between the crop areas represented in the available agricultural land use data and the actual crop areas on the ground during the simulated years
- Differences between the general crop irrigation assumption used in SaltMod and the actual irrigation practices employed on a farm-by-farm basis
- Crop failures where a crop is planted, but not irrigated all the way to harvest.

Table 30. Comparison of SaltMod and MCWRA irrigation volumes

Condition	Aquifer Subarea	SaltMod Volumes (af)	MCWRA Volumes (af)	Percent Difference
Wet (2010)	Pressure	87,102	87,880	-1%
	East Side	62,675	74,512	-16%
	Forebay	148,675	125,145	19%
	Upper Valley	134,852	128,883	5%
	Total:	*433,305*	*416,420*	*4%*
Normal (2004)	Pressure	101,912	102,137	0%
	East Side	76,345	95,313	-20%
	Forebay	184,271	146,718	26%
	Upper Valley	138,932	126,884	9%
	Total:	*501,459*	*471,052*	*6%*
Dry (2013)	Pressure	107,445	98,141	9%
	East Side	82,456	82,895	-1%
	Forebay	186,621	140,574	33%
	Upper Valley	163,731	141,263	16%
	Total:	*540,253*	*462,873*	*17%*

The same comparison was done for the CSIP area, with SaltMod irrigation volumes multiplied by land area and compared to reported volumes from the SVRP. Errors are low, ranging from -4 percent to 7 percent.

Table 31. Comparison of SaltMod and SVRP irrigation volumes

Source	Irrig Vol, ac-ft		
	Wet	Average	Dry
Modeled	18,377	24,051	23,114
SVRP reported	18,140	22,488	23,974
Error	1%	7%	-4%

7.2.3.4 Irrigation Salt Concentration

SaltMod requires specification of irrigation salt concentrations (as electrical conductivity). The Central Coast Water Board provided a database of groundwater quality collected between 2012 and 2014, which included data from individual growers and the Central Coast Groundwater Coalition. The data identify source aquifer area and well type (domestic versus agricultural irrigation). Statistical analyses were performed on the data to characterize the central tendency salt concentrations, separately by aquifer area and well type. Histograms indicated that the data distributions were log-normal (tending towards having a greater frequency of low concentrations), so the median was selected as the best indicator of central tendency. For SVRP irrigation water, the average TDS concentration from several years of monitoring data for recycled wastewater is 853 mg/L. However, about 33% of the SVRP irrigation water is supplemented from wells, which are assumed to have the same concentration as reported for the Pressure subarea. The weighted average concentration for the SVRP is therefore 773 mg/L of TDS. Table 32 provides salt concentrations used in the model. TDS was converted to EC using a conversion factor from the SaltMod manual (Oosterbaan, 2002).

Table 32. Irrigation salt concentrations used in SaltMod

Aquifer Subarea	Agricultural Irrigation		Urban Use	
	TDS (mg/L)	EC (dS/m)	TDS (mg/L)	EC (dS/m)
Pressure	607	1.03	680	1.16
East Side	590	1.00	694	1.18
Forebay	408	0.69	616	1.05
Upper Valley	500	0.85	1183	2.01
SVRP	773	1.16	(n/a)	

7.2.3.5 Tile Drains

A confining layer separating a surface perched aquifer from the underlying main aquifer underlies the Pressure aquifer area. In certain areas, the confining layer causes groundwater levels to potentially extend into the root zone of crops. To reduce the effects of soil water logging and soil salinization due to capillary rise, tile drains have been installed in fields in the affected areas, which include all of zones 9, 10, and 11 and parts of zone 8 (generally west of Salinas in flat areas).

To represent the tile drainage system, SaltMod uses Hooghoudt's formula (Van Beers 1979). Drain flows in meters per day (m/d) are calculated as:

$$q = \frac{8K_2dh + 4K_1h^2}{L^2}$$

Where:

q: drain discharge (m/day)

K2: hydraulic conductivity of the layer below the drains (m/day)

K1: hydraulic conductivity of the layer above the drains (m/day)

h: height of the water table above the drain level midway between drains (m) d: thickness of the equivalent layer (m)—value dependent on drain spacing, drain radius, and depth of the impermeable layer

L: drain spacing (m)

Parameters for the representation of agricultural tile drainage systems were based on the best available information. Data sources and assumptions included:

- Hydraulic conductivity of the soils were derived from SURRGO soils data
- Height of the water table above drain level midway between drains is assumed to be equal to the depth of the water table minus the drain depth. The depth of the water table was estimated as the mean depth of nearby well monitoring stations. Drain depth was estimated to be 6.5 feet (Kirk Schmidt, Cental Coast Water Quality Preservation Inc., May 2015, personal communication)
- The thickness of the equivalent layer was estimated from Hooghoudt d-tables (Van Beers 1979).
- Drain spacing was estimated as 20 feet. (Kirk Schmidt, Cental Coast Water Quality Preservation Inc., May 2015, personal communication)
- A typical drain radius was estimated to be 4 inches.

7.2.3.6 Model Calibration

Model calibration is an iterative procedure of parameter evaluation and adjustment to achieve a best fit with observed measurements, as well as a reasonable representation of processes that cannot necessarily be measured. Calibration is necessary to ensure that the model predicts observed conditions well, at similar magnitudes and frequencies, so that the model results can be used to quantify watershed source loading. It is important to note that monitoring data have an inherent degree of uncertainty. However, monitoring data collection follows strict sampling protocols and approved EPA analytical procedures. Salt measures are well above detection limits and are expected to be an un-biased indicator of overall conditions.

Each crop-model segment combination was calibrated to achieve:

- Stable seasonal root zone salinity.
- Root zone salinity generally less than published crop tolerances for 90% yield as shown Table 33 (FAO, 2002). It is important to note that salt tolerances should be considered guidelines only, and that artful management may allow farmers to grow healthy crops in soils with salinities higher than the published tolerances.
- Model predicted evaporation consistent with expected values (seasonal sums of ETo x Kc).

Adjustment of applicable input parameters during the calibration process focused on these measures.

Table 33. EC_e for 90 percent crop yield potential (FAO, 2002)

Crop	EC_e (dS/m) for 90% Yield Potential
Grapes	1.65
Rotational Vegetables	1.4
Asparagus	4.1

Crop	EC_e (dS/m) for 90% Yield Potential
Carrots/Rotational	1.06
Lemons	1.6
Strawberries	1.03
Strawberries/Celery	1.03
Brussel Sprouts/Rotational	1.4
Strawberries/Broccoli	1.03
Turf grass (Bermuda)	7.9

Note: Crop tolerances are expressed on the basis of saturation extract (EC_e), which is generally one half of the EC at soil saturation reported by SaltMod.

Root zone water storage efficiency was adjusted for each combination of crop type, zone, and year type until model ET was within 10% of expected ET. Results are shown in Table 34. Most errors are less than 5 percent. In a few cases, error exceeds the goal of 10 percent, notably for strawberries during the dry year (2013). Even so, errors never exceed 20 percent.

Table 34. Percent difference between SaltMod and expected ET

Zone	Crop_Name	Percent Difference		
		Avg	Dry	Wet
2	Asparagus	-1%	-1%	-3%
4	Asparagus	0%	-1%	-3%
5	Asparagus	-1%	-1%	-3%
9	Brussel Sprouts/Rotational Veg	-5%	-4%	-1%
11	Brussel Sprouts/Rotational Veg	-5%	-4%	-1%
2	Carrots/Rotational Veg	0%	0%	0%
1	Grapes	-5%	-12%	0%
2	Grapes	-1%	-8%	0%
3	Grapes	0%	-7%	0%
4	Grapes	0%	-3%	0%
5	Grapes	0%	-3%	0%
4	Lemons	0%	-2%	-3%
1	Rotational Vegetables	-1%	0%	0%
2	Rotational Vegetables	0%	0%	0%
3	Rotational Vegetables	0%	0%	0%
4	Rotational Vegetables	0%	0%	0%
5	Rotational Vegetables	0%	0%	0%

Zone	Crop_Name	Percent Difference		
		Avg	Dry	Wet
6	Rotational Vegetables	0%	0%	0%
7	Rotational Vegetables	0%	0%	0%
8	Rotational Vegetables	-1%	0%	0%
9	Rotational Vegetables	0%	0%	0%
10	Rotational Vegetables	-1%	-1%	0%
11	Rotational Vegetables	-1%	0%	0%
5	Strawberries	-6%	-15%	-1%
6	Strawberries	-6%	-15%	-1%
7	Strawberries	-6%	-14%	0%
8	Strawberries	-6%	-14%	0%
9	Strawberries	-7%	-18%	0%
10	Strawberries	-7%	-16%	0%
11	Strawberries	-7%	-15%	-1%
9	Strawberries/Broccoli	-7%	-15%	-3%
5	Strawberries/Celery	-4%	-5%	0%
7	Strawberries/Celery	-3%	-4%	1%
8	Strawberries/Celery	-6%	-5%	1%
9	Strawberries/Celery	-5%	-6%	1%
10	Strawberries/Celery	-6%	-4%	1%
11	Strawberries/Celery	-6%	-5%	1%
1	Turf grass	-3%	-4%	-3%
2	Turf grass	-3%	-4%	-3%
3	Turf grass	-3%	-4%	-3%
4	Turf grass	-3%	-4%	-3%
5	Turf grass	-3%	-4%	-3%
6	Turf grass	-3%	-4%	-3%
7	Turf grass	-3%	-3%	-3%
8	Turf grass	-3%	-4%	-3%
9	Turf grass	-2%	-2%	-3%
10	Turf grass	-3%	-3%	-3%
11	Turf grass	-3%	-2%	-3%

Following water balance calibration, the root zone leaching efficiencies were adjusted to achieve the salinity goals. For the majority of crop/zone/year type/seasons, the soil salinity did not exceed the 90 percent threshold for yield potential. In a few cases, predictions for a single season exceeded the value, but soil salinities quickly dropped the following season. It is important to note that the model uses median reported well concentrations, but there is considerable variability in well concentrations. It is possible that sensitive crops use irrigation water with lower salinities than those used in the model. The seasonal averages reported by SaltMod also may not reproduce the actual day-by-day time series of soil salinities.

7.2.4 USGS SPARROW Estimates for Undeveloped Land

While SaltMod provides many of the water balance and salt concentration components needed to develop the Tool for agriculture and urban lawns in the Salinas Valley, there is considerable amount of land in the study area that is undeveloped. Salts naturally dissolve in water and are transported to streams and aquifers. The USGS SPARROW model was used to estimate salt emanating from undeveloped land. In addition, inputs to SPARROW were used to estimate surface/groundwater volumes from undeveloped land.

USGS developed a SPARROW (SPAtially-Referenced Regression on Watershed Attributes) model to estimate salt loads, instream concentrations, and sources from land areas to receiving surface waters (Anning and Flynn, 2014). SPARROW is a modeling framework that ties land use and other watershed attributes to receiving water bodies with defined upstream to downstream connectivity (Smith et al, 1997; Preston et al, 2009). Non-linear regression is used to predict source loading parameters to observed instream concentrations from monitoring data. SPARROW has been used successfully for a variety of pollutants across a range of regions. The SPARROW model developed by Anning and Flynn covers the entire conterminous United States. Only total dissolved solids is predicted, and the model cannot distinguish between loads from surface runoff versus loads from groundwater discharged to streams. Numerous source and delivery inputs are used to predict loads and concentrations. In the Salinas River Watershed Area, the primary sources are background loads due to geologic weathering, additional loading from urban lands, and additional loading from agricultural lands. Loads from background sources arise from weathering of surficial and subsurface materials, which can contribute varying amounts of dissolved solids depending on geologic classification.

The Anning and Flynn SPARROW salt model output was used to compile salt loads in the Salinas River watershed. Background TDS loading rates are shown in Figure 88, and represent conditions for a baseline water year 2000. Higher loads are correlated with geology types as well as total precipitation. The highest rates are associated with the mountain ranges surrounding the Salinas Valley, notably in the drainages of San Lorenzo Creek, Arroyo Seco, Nacimiento River, several smaller creeks in the middle of the Salinas River Watershed, and the Salinas River headwaters. Rates are the lowest in the Lower Salinas area and the Reclamation Canal watershed. SPARROW background loading rates were area-weighted by the Salt Tool subbasins to produce undeveloped land loading rates.

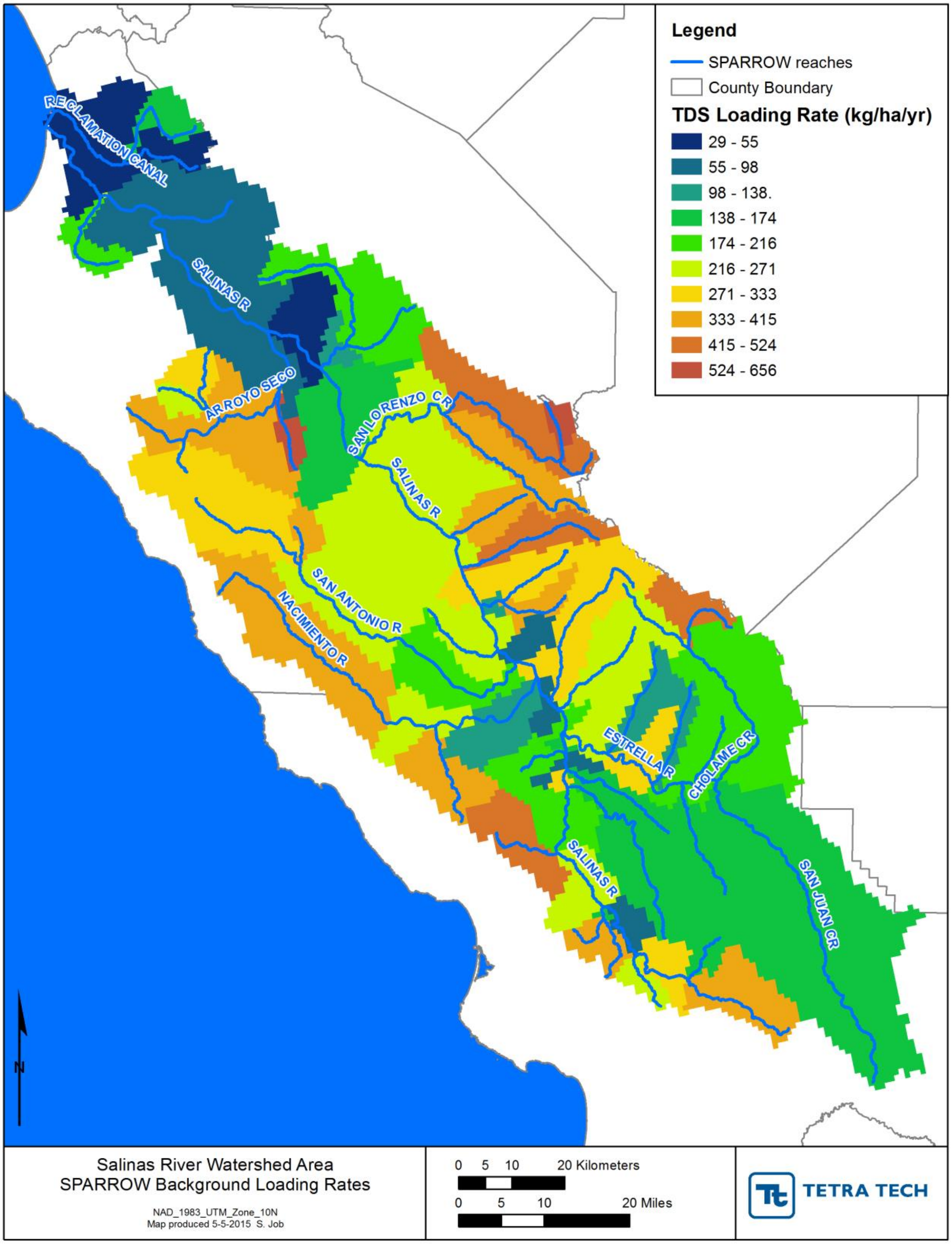


Figure 88. SPARROW Background TDS Loading Rates to Water Bodies

The SPARROW model includes a table of all the model parameters considered in the development of the regressions, including both SPARROW subbasin and reach characteristics. Average annual discharge (adjusted to represent water year 2000) was included for each subbasin, and was used to calculate unit area outflow (in inches) from each subbasin. Note that stream flow is comprised of both surface storm event runoff and baseflow. Streams in the Salinas watershed generally become losing reaches as they enter the Valley, so stream flow could not be reliably used to calculate unit area flow. To address this gap, a multiple regression was developed using headwater reaches to predict unit area flow. The regression used several descriptive subbasin parameters tabulated by Anning and Flynn, including annual precipitation adjusted to water year 2000, average elevation, average slope, base flow index, two measures related to runoff generation potential, and soil permeability. Unit area flow estimated by the regression was reasonably comparable to observed unit area flow, with an R^2 of 0.58. The same parameters were then used to estimate unit area runoff for the remainder of the subbasins where unit area flow was not available. Finally, unit area flows were developed for each of the Salt Tool subbasins using the spatially averaged SPARROW-derived values. Yearly precipitation totals for the normal, wet, and dry years were then substituted for the water year 2000 precipitation values used in the multiple regression to predict unique values unit area runoff values for each of the three year types.

During development of the Tool, it was noted that the unit area flow value for Arroyo Seco did not produce nearly enough outflow compared to USGS gaging data. Arroyo Seco receives a considerably higher volume of rainfall than the rest of the study area. It is likely that the multiple linear regression is not accounting for a non-linear in runoff response to high rainfall totals. To address this, a simple Soil and Water Assessment Tool (SWAT) model (Neitsch et al., 2011) was developed for Arroyo Seco using the HUMUS (Hydrologic Unit Modeling of the United States) website (https://humus.tamu.edu/). While the model was essentially uncalibrated, it did provide reasonable unit area flows that were more comparable to monitoring data. The SWAT values were substituted for the SPARROW values for the Arroyo Seco subbasin.

7.2.5 EnviroAtlas

One of the remaining gaps for development of the Salt Tool was an estimate of surface runoff from irrigated land. While irrigation alone is generally not expected to produce significant surface runoff (except in areas with tile drainage systems), storm events can quickly saturate soil and produce direct runoff. This is most likely to occur during the rainy season in the fall and winter. Methods used by Tetra Tech to support development of EPA's EnviroAtlas were employed to provide surface runoff volume estimates for irrigated land. (The EnviroAtlas is a collection of interactive tools and resources that allows users to explore the many benefits people receive from nature, often referred to as ecosystem services. The EnviroAtlas is a collaborative project developed by EPA, in cooperation with the US Geological Survey (USGS), the US Department of Agriculture's Natural Resources Conservation Service (NRCS) and Forest Service, and Landscope America.)

One of the metrics used to support development of indices of natural hydrologic condition was an estimate of monthly average storm event runoff (Tetra Tech, 2015). The NRCS Curve Number Approach (USDA, 1986) was adapted to predict storm event volume for the entire continental United States with a resolution of 30 meter grid cells. The method assigns land cover to each grid cell, including several varieties of crops as defined in the USDA Cropland Data Layer (http://www.nass.usda.gov/research/Cropland/Release/index.htm). The method also takes antecedent soil moisture into account using satellite data. Since irrigation results in wet soils, agricultural land in the Salinas Valley has a higher runoff potential during storm events than is typical for vegetated land in a semi-arid environment. Thirty years of PRISM data were used for rainfall and storm event depth estimates. The resulting data product was monthly average runoff for each grid cell.

The data from the project was used to develop monthly fractions of precipitation that become surface runoff. The fractions were averaged over each of the eleven SaltMod zones. The product of the fractions and monthly rainfall for each of the three year types (2004, normal; 2010, wet; 2013, dry) was calculated and summed for each of the four seasons, resulting in seasonal runoff depths for each combination of zone and year type. Results are shown in Table 35. Runoff in the Salt Tool was calculated as the product of runoff depth and contributing land area.

Table 35. Storm event cumulative runoff depths for irrigated land (inches)

Zone	Normal				Wet				Dry			
	Sea 1	Sea 2	Sea 3	Sea 4	Sea 1	Sea 2	Sea 3	Sea 4	Sea 1	Sea 2	Sea 3	Sea 4
1	0.81	0	0	0.06	1.35	0.05	0	0.02	0.3	0	0	0
2	0.83	0	0	0.05	1.02	0.04	0	0.03	0.3	0	0	0
3	1.33	0	0	0.06	1.63	0.07	0	0.03	0.6	0	0	0.01
4	1.36	0	0	0.08	1.62	0.11	0	0.04	0.61	0.01	0	0.01
5	1.29	0	0	0.06	1.8	0.15	0	0.04	0.7	0.01	0	0.01
6	1.42	0	0	0.09	2.04	0.21	0	0.05	0.76	0.02	0	0.01
7	1.65	0	0	0.08	2.44	0.27	0	0.06	1	0.02	0	0.01
8	1.55	0	0	0.09	2.69	0.34	0	0.06	0.94	0.03	0	0.01
9	2.11	0	0	0.11	3.75	0.44	0	0.11	1.31	0.04	0	0.02
10	1.92	0	0	0.11	3.62	0.49	0	0.09	1.22	0.05	0	0.02
11	1.57	0	0	0.09	2.94	0.33	0	0.08	0.99	0.03	0	0.01

7.2.6 Impervious Area Runoff and Concentration

Impervious areas can produce a significant volume of runoff compared to pervious land. In the developed portions of the watershed, impervious land runoff is an important component of the water balance. However, impervious surfaces are not a direct source of salts (with the exception of cold climates where road salt is used). In the study area, atmospheric deposition of salt is expected to be the only source.

Effective Impervious Area (EIA) represents the portion of total, or Mapped Impervious Area (MIA), that is directly connected to the drainage collection system. Impervious area runoff that is not connected to the drainage network has the opportunity to flow onto pervious surfaces, infiltrate, and become part of pervious surface overland flow, and disconnected impervious area is often represented as pervious land in watershed modeling. In practice, runoff from disconnected impervious surfaces often overwhelms the infiltration capacity of adjacent pervious surfaces, and the runoff may reconnect to nearby impervious surfaces once again. Finding the right balance between MIA and EIA can be an important part of estimating impervious runoff, especially in urban areas.

Sutherland (1995) describes a series of equations for MIA to EIA relationships spanning four levels of impervious disconnection, from “extremely disconnected basins” to “highly connected basins.” The equations take the form of:

$$EIA = a(MIA)^b$$

where a and b are empirical factors; as a and b approach 1, EIA converges to MIA.

Rather than choosing one of Sutherland's relationships over another, all four were utilized to describe the varying levels of impervious area in the study area subbasins. Instead of choosing thresholds for jumping from one relationship to the next, a regression analysis was performed on the a and b factors, and unique a and b factors were assigned to each increment in impervious area. The relationship is shown in Figure 89. MIA was first calculated using NLCD 2011 data. Percent MIA was calculated in each Salt Tool subbasin, and was then reduced to represent EIA. The product of EIA and subbasin area provided the area of impervious surface within each subbasin. The product of seasonal rainfall and impervious area provided the runoff volume from impervious surfaces. Runoff was then reduced by five percent to account for initial abstraction. The percent reduction is based on the Simple Method (Schueler, 1987).

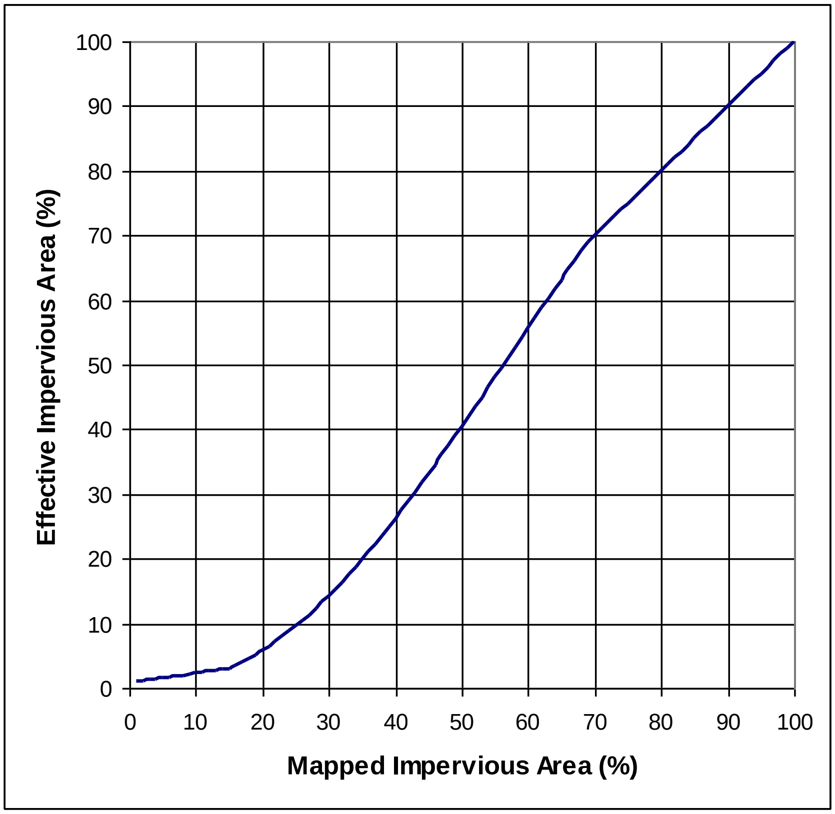


Figure 89. Effective impervious area to mapped impervious area relationship

Atmospheric deposition is a source of a variety of constituents that are part of salt. Wet deposition (comprised of dissolved constituents in rainfall) includes measureable ionic calcium, magnesium, potassium, sodium, ammonia, nitrate, chloride, and sulfate. Dry deposition occurs as well (made up of dust and other particles), and includes the same constituents, though much of it is made up of nitrate and nitric acid. Wet deposition is monitored throughout the country by the National Trends Network (NTN) of the National Acid Deposition Program (NADP). Dry deposition is subject to much greater uncertainty than wet deposition because it is difficult to directly measure net dry deposition, which reflects trapping on leaves, ground, and other surfaces balanced by re-emission. EPA's CASTNET system monitors air concentrations and calculates net dry deposition fluxes using the Multi-Layer Model (MLM). Both wet and dry deposition are monitored near the watershed in Pinnacles National Park at NADP station CA66 and CASTNET station PIN414. Data were obtained for both stations, and annual average deposition calculated (Table 2). Wet deposition data spanned 2000 – 2014, while dry deposition data were available from 2004 – 2014. The average wet deposition loading rate was 5.13 kg/ha, while the average dry deposition loading rate was 4.84 kg/ha, for a total of 9.97 kg/ha. When the loading rate is combined with rainfall volume for each of the three representative years, the TDS concentrations in impervious runoff range from only 1.4 mg/L to 7.8 mg/L.

7.2.7 Salt Tool Construction and Calibration

Each of the previous components described previously was tabulated and used for inputs to the Tool:

1. Land areas for each combination of land use/land cover, SaltMod zone, and Salt Tool subbasins. Impervious land area adjusted to account for EIA.
2. SaltMod
    a. Unit area tile drain flow (ft) and concentration (mg/L) for irrigated land
    b. Unit area percolation flow (ft) and concentration (mg/L) to the underlying aquifer for irrigated land
    c. Storm event runoff concentration, using root zone salinity for irrigated land
3. SPARROW
    a. Unit area surface/groundwater outflow (ft) and salt mass (kg/ha) for undeveloped land. Since the SPARROW model provided load estimations for water year 2000 only, the same salt mass was used for all three year types; however, salt concentrations were back-calculated from runoff volume (which did vary) and the salt mass, resulting in variable concentrations by year type.
    b. SWAT model used for unit area outflow for Arroyo Seco
4. EnviroAtlas
    a. Unit area storm event runoff flow (ft) for irrigated land
5. Impervious land
    a. Unit area outflow (ft) using rainfall totals and salt loads (kg/ha) using wet and dry aerial deposition data.
6. Boundary inflow at Bradley
    a. Seasonal volume for each representative year summed from USGS flow records at the Bradley gage
    b. Seasonal concentrations estimated by finding the median seasonal values from TDS monitoring at Bradley (note there were not enough data to calculate seasonal concentrations for the specific representative years).

Table 36 provides an overview of the Salt Tool land area outputs (flow and salt) for each discharge type.

Table 36. Salt Tool land area outputs and data sources

Discharge Type	Unit Area Flow (ft/ac)	Salt Concentration (mg/L)
Undeveloped Surface + Groundwater Flow	SPARROW	SPARROW
Irrigated Land Surface Runoff	EnviroAtlas	SaltMod
Tile Drain Discharge	SaltMod	SaltMod
Impervious Land Runoff	Rainfall – Abstraction	Atmospheric Deposition
Percolation to Aquifers	SaltMod	SaltMod

The product of unit area flows and contributing land areas in combination of SaltMod zone, subbasin, land use, and year type provided the runoff volume. The product of runoff volume and salt concentration was then used to calculate salt mass. Contributing runoff volume and salt mass from each subbasin to its reach segment was summed from the inputs. Boundary inflow and salt concentration/mass for Salinas River upstream of the model area was set based on monitoring data. Seasonal runoff volumes were compared to flow monitoring data where available. Reach infiltration to the aquifer subareas is known to occur for both the Salinas River and its tributaries as they enter the Salinas Valley, as well as Gabilan Creek prior to entering the Reclamation Canal. Reach infiltration volumes were estimated for each monitored reach by performing a regression on simulated flow versus the difference between simulated and observed flow. This allows for a reasonable attribution of seasonal infiltration across the three representative years without *a priori* assuming the infiltration volume equals the difference between the simulated and observed volumes. One adjustment was made – simulated volumes during Season 1 of the wet year were too low for San Lorenzo Creek and the Salinas River locations, so the infiltration volume was reduced by 35 percent. It is possible that reach infiltration was limited by the water table elevation during this period, leading to less infiltration. In addition, direct ET loss from the Salinas River due to the presence of deep-rooted vegetation reaching the water table was added, using the annual estimate of 16,700 ac-ft/yr (Montgomery Watson, 1997).

Seasonal volumes estimated by the tool are shown in Figure 90 through Figure 96. The simulated volumes match the pattern of observed volumes, though there is some disagreement for individual seasons. The simple methods used to estimate runoff volume cannot account for daily patterns and variations in rainfall, ET, soils properties, and the interaction of losing reaches with the water table.

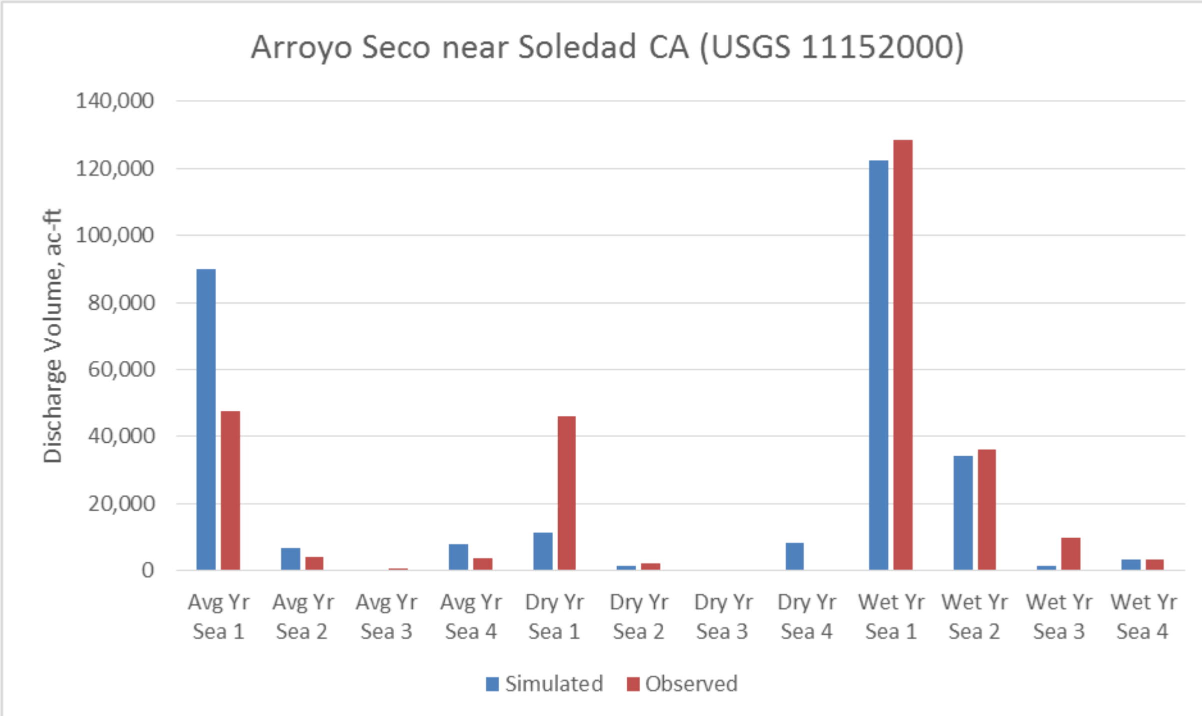


Figure 90. Simulated and observed seasonal volumes at Arroyo Seco

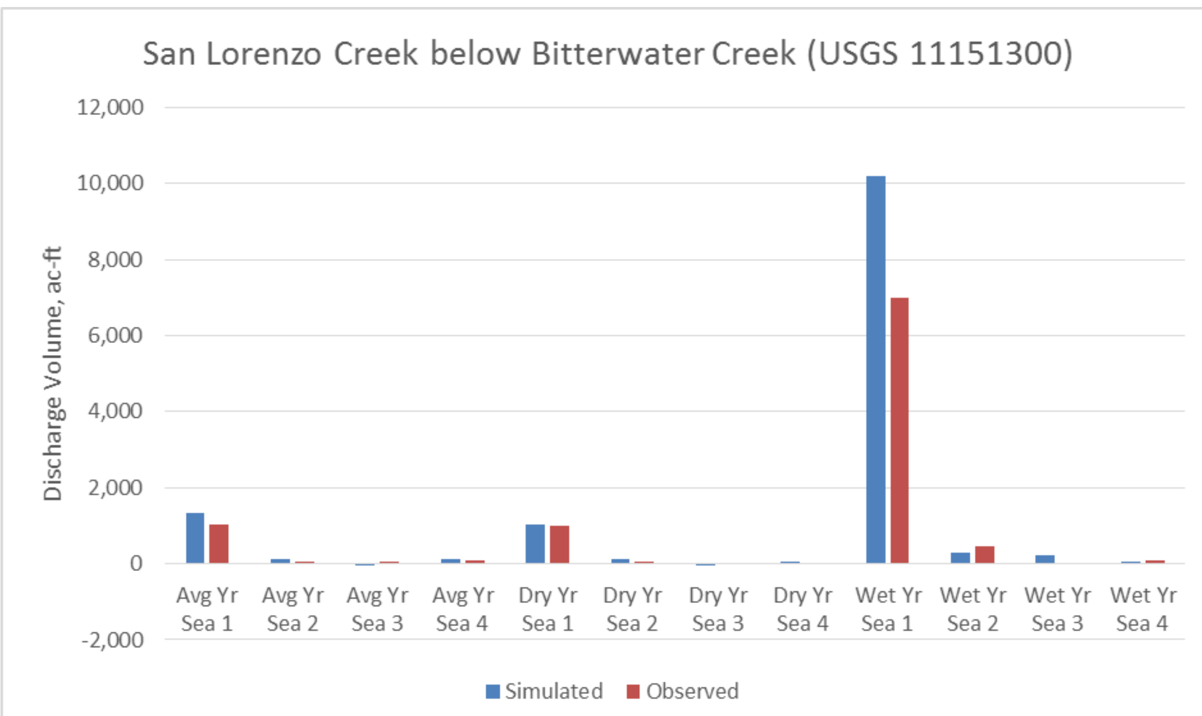


Figure 91. Simulated and observed seasonal volumes at San Lorenzo Creek

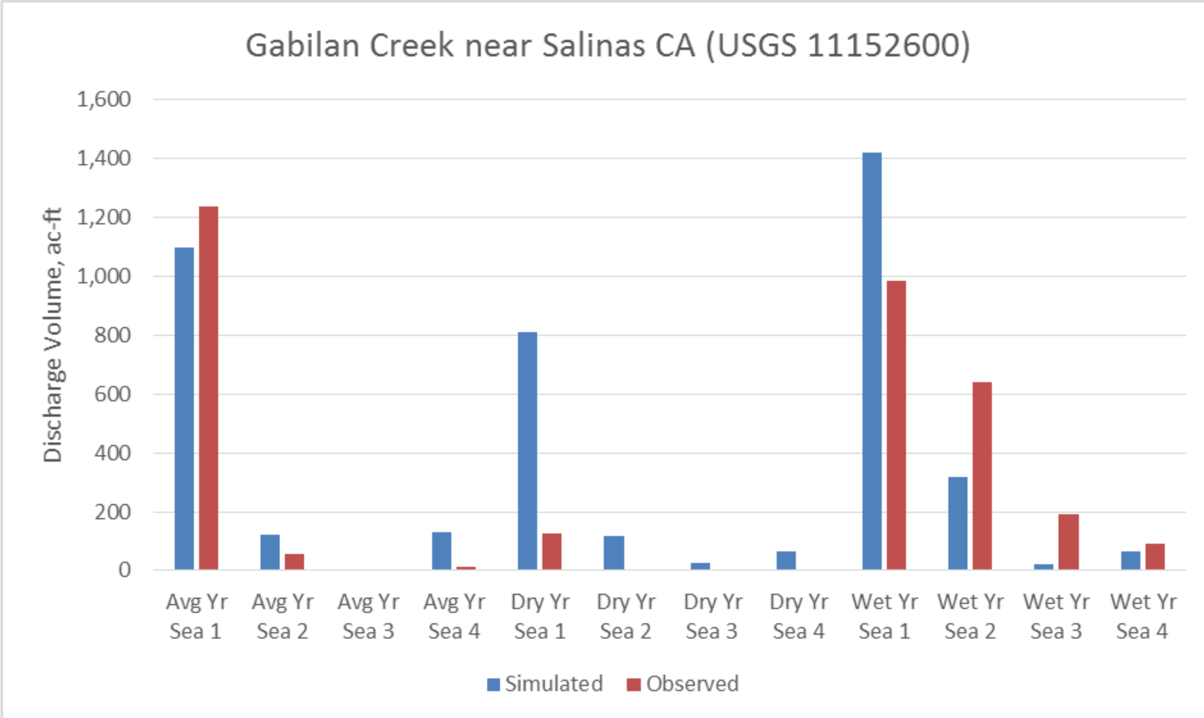


Figure 92. Simulated and observed seasonal volumes at Gabilan Creek

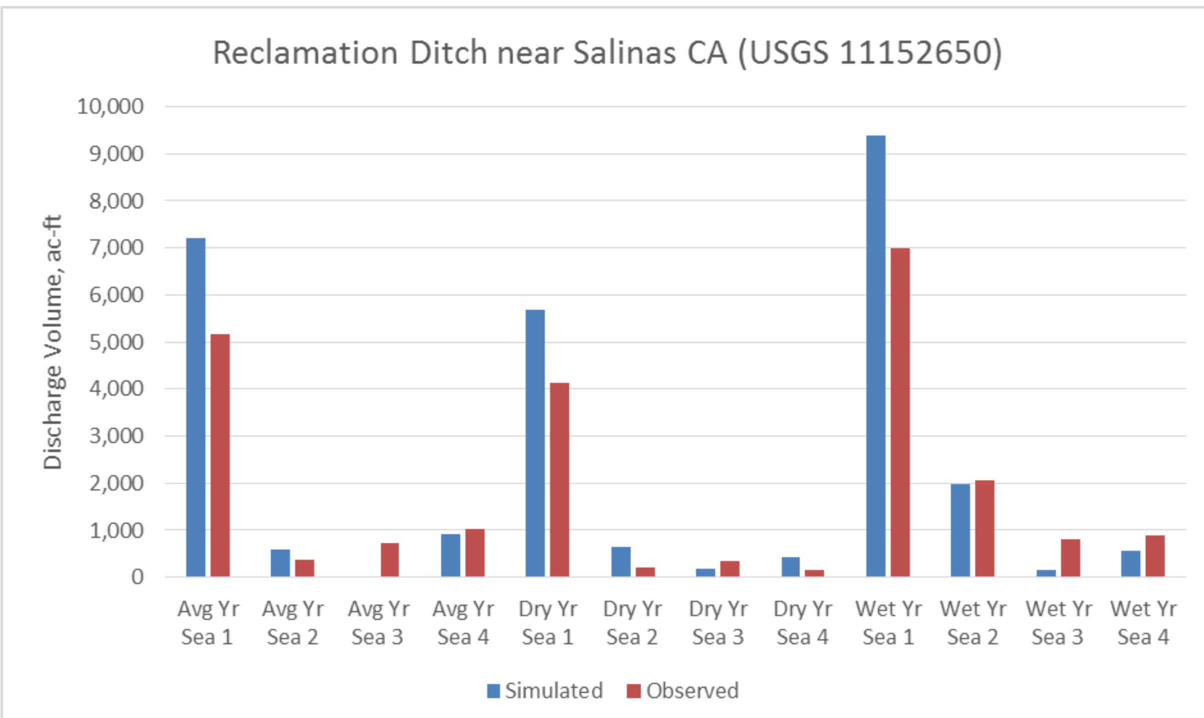


Figure 93. Simulated and observed seasonal volumes at Reclamation Ditch

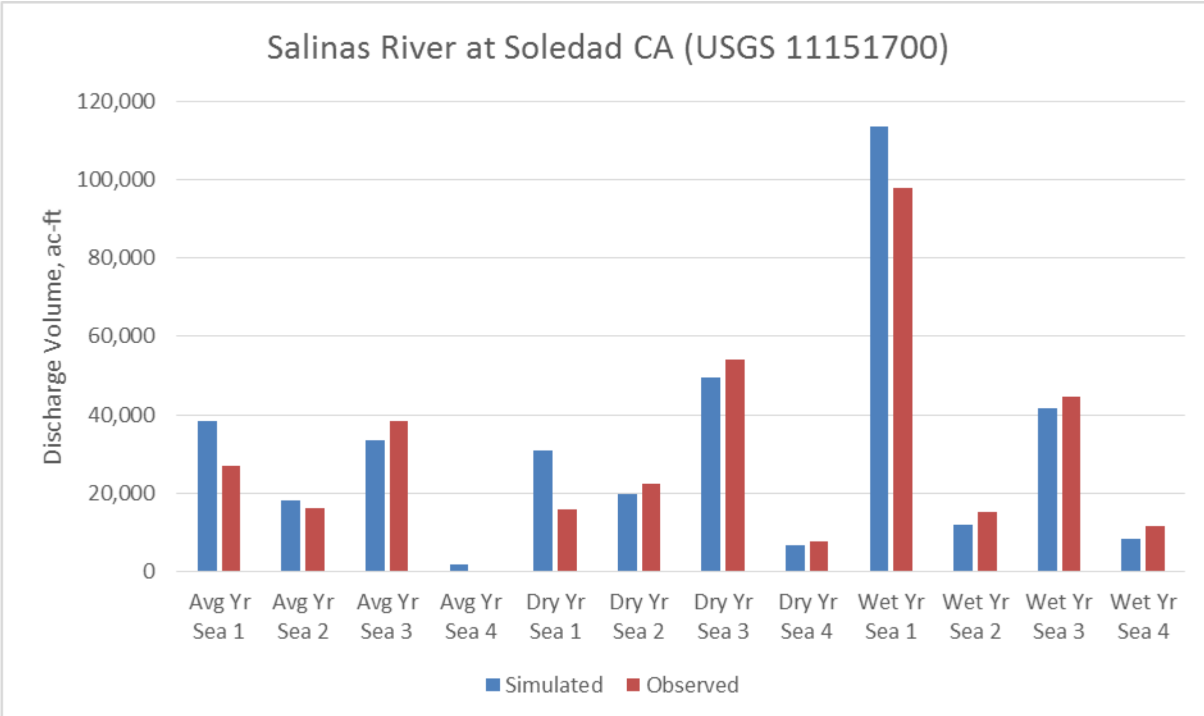


Figure 94. Simulated and observed seasonal volumes at Salinas River at Soledad

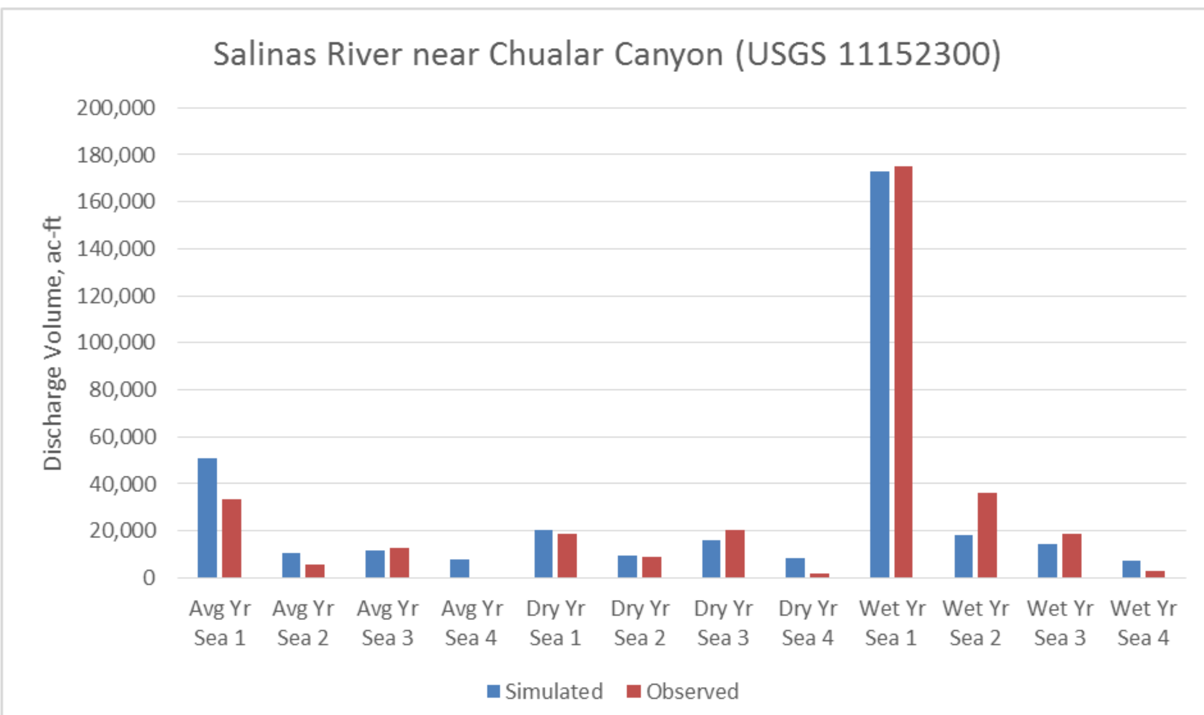


Figure 95. Simulated and observed seasonal volumes at Salinas River at Chualar

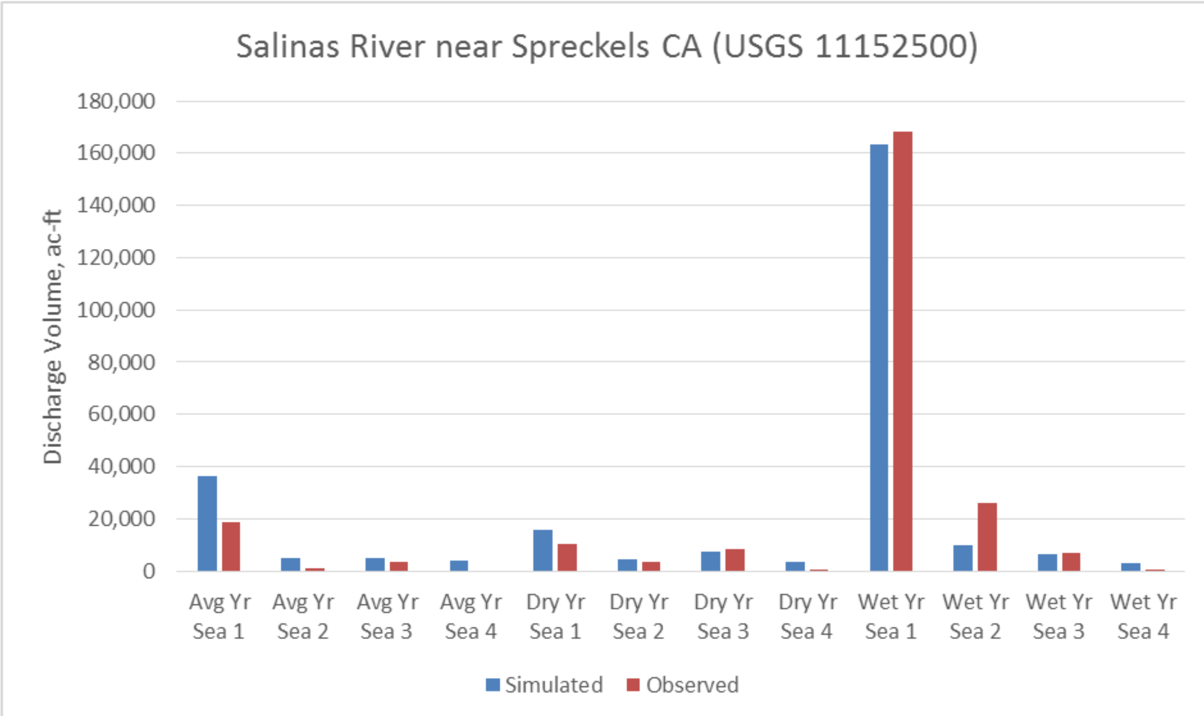


Figure 96. Simulated and observed seasonal volumes at Salinas River at Spreckels

Next, salinity concentration in individual reaches predicted by the Tool were compared to monitoring data using box and whiskers plots. Concentrations were low compared to monitoring data, so the undeveloped land area export rates were increased by a factor of 2.0 in Arroyo Seco, a factor of 3.5 in San Lorenzo Creek, and a factor of 1.5 in the rest of the study area. The result is that predicted concentrations generally match the range of observed values in most locations. Results are shown in Figure 97 through Figure 101. Concentrations are well matched in upper Salinas tributaries (Figure 97) and at Salinas River monitoring stations between Bradley and Chualar (Figure 98 – note there are two monitoring stations within each Salt Tool reach segment as indicated by the grouping boxes). Concentrations at Spreckels are also comparable, but observed concentrations are much higher at Davis Rd and Highway 1 (Figure 99). It is likely the Highway 1 location is influenced by estuarine conditions extending upstream of the Salinas Lagoon. The reason for the elevated concentrations at the Davis Rd site is unknown, but there appear to be sources of salt affecting this location that are not accounted for in the Salt Tool. Concentrations compare well at upstream locations in the Reclamation Canal watershed (Figure 100), but are under predicted in Alisal Slough and Blanco Drain (Figure 101). Both are located in tile-drained areas of the study area; the salinity of the soil matrix and the transition may be locally higher than indicted by the SSURGO data used to parameterize SaltMod.

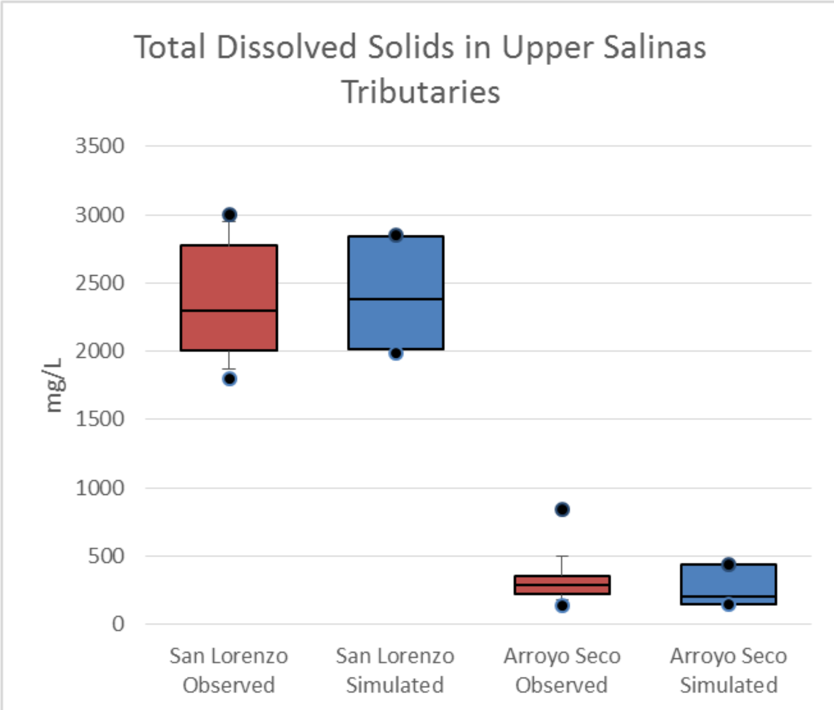


Figure 97. Comparison of simulated and observed TDS in upper Salinas tributaries

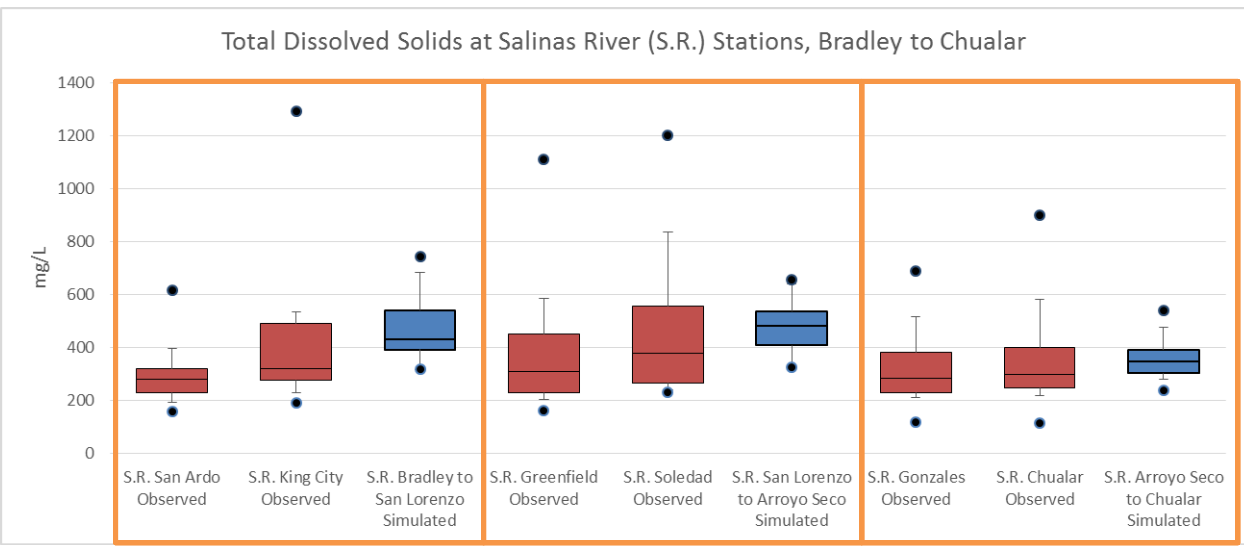


Figure 98. Comparison of simulated and observed TDS at upstream Salinas River locations

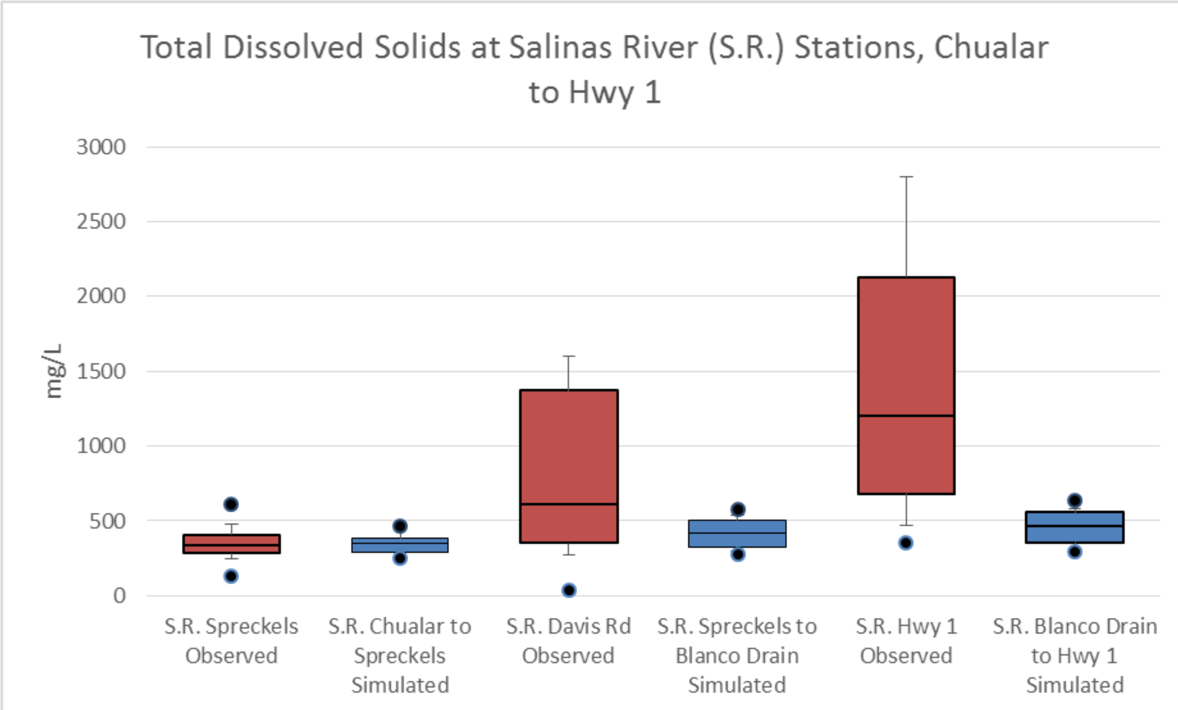


Figure 99. Comparison of simulated and observed TDS at downstream Salinas River locations

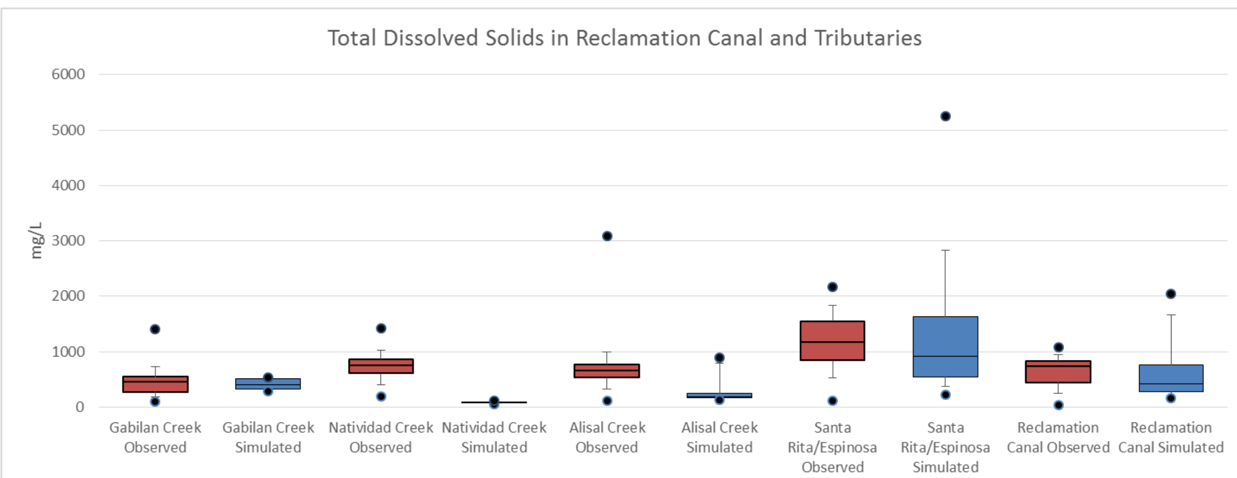


Figure 100. Comparison of simulated and observed TDS at Reclamation Canal tributaries

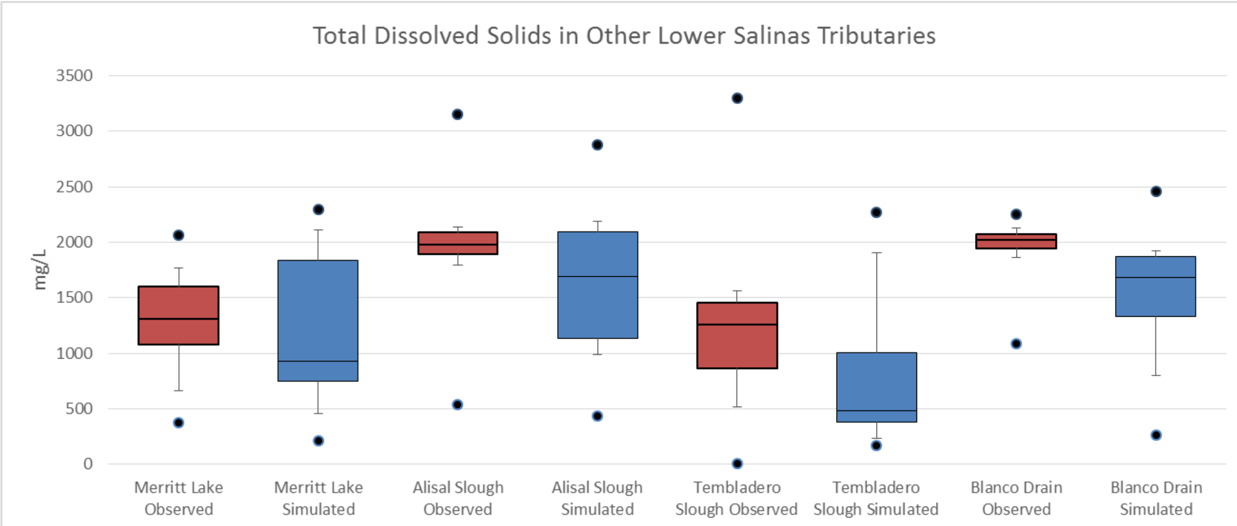


Figure 101. Comparison of simulated and observed TDS at other lower Salinas and Reclamation Canal tributaries

8 Model Tool Results

In this section, results from the Salt Tool are summarized. The tool provides a significant amount of information, including seasonal volumes and salt concentrations for each representative year for the model land uses (separately by zone), cumulative reach inflows and salt mass from each source type by season and year type, salt concentrations for each reach by season and year type, volumes infiltrating to the aquifers from each subbasin and reach, boundary inflows and concentrations, and reach evapotranspiration. This information is distilled and presented into three topics: annual volumes and salt fluxes for each model component and year type across the Salt Tool study area, examples of predicted seasonal reach concentrations, and examples of unit area summaries of crop salt mass fluxes. Inputs and calculations were discussed in Section 7.2.7.

8.1 Annual Summary

A summary of annual hydrology volumes is shown in Table 37. The largest inflows to water bodies are from undeveloped land and from boundary inflow at Bradley. Reach infiltration to aquifers is the most significant loss from water bodies, but outflow from the watersheds to Monterey Bay is relatively high, especially during the wet year. Outflow to Monterey Bay is represented in the Salt Tool as discharge from the Salinas River and the Old Salinas River reaches, but it is possible some outflow occurs via groundwater from areas adjacent to the coastline. Percolation from irrigated land to aquifers is significant, representing an average of about seven inches per year.

Table 37. Salt Tool study area hydrology volumes

Model components	Normal (ac-ft/yr)	Dry (ac-ft/yr)	Wet (ac-ft/yr)	Average (ac-ft/yr)
Undeveloped land discharge to water bodies	335,790	210,310	428,179	324,760
Impervious land storm event runoff to water bodies	1,806	1,354	2,824	1,995
Irrigated land storm event runoff to water bodies	20,493	9,557	31,685	20,578
Tile drain outflow discharge to water bodies	7,186	5,438	12,280	8,301
Boundary inflow at Bradley to Salinas River	185,903	250,145	264,976	233,675
Reach infiltration to aquifers	457,670	410,090	498,115	455,292
Reach evapotranspiration	16,700	16,700	16,700	16,700
Net outflow to Monterey Bay	76,807	50,014	225,128	117,316
Irrigated land percolation to aquifers	116,833	100,390	139,594	118,939

To provide context, the results are presented in a series of pie charts using the average of the three year types. Figure 102 provides a comparison of the relative magnitude of volumes entering water bodies. Runoff from undeveloped land (much of which is comprised of baseflow from streams entering the Salinas Valley from the surrounding mountains) is the largest source at 55 percent. Salinas River inflow at Bradley is also large, at 40 percent (note that most of this also originates from undeveloped land in the upper part of the watershed). Contributions from irrigated land and impervious surfaces are small relative to the other sources.

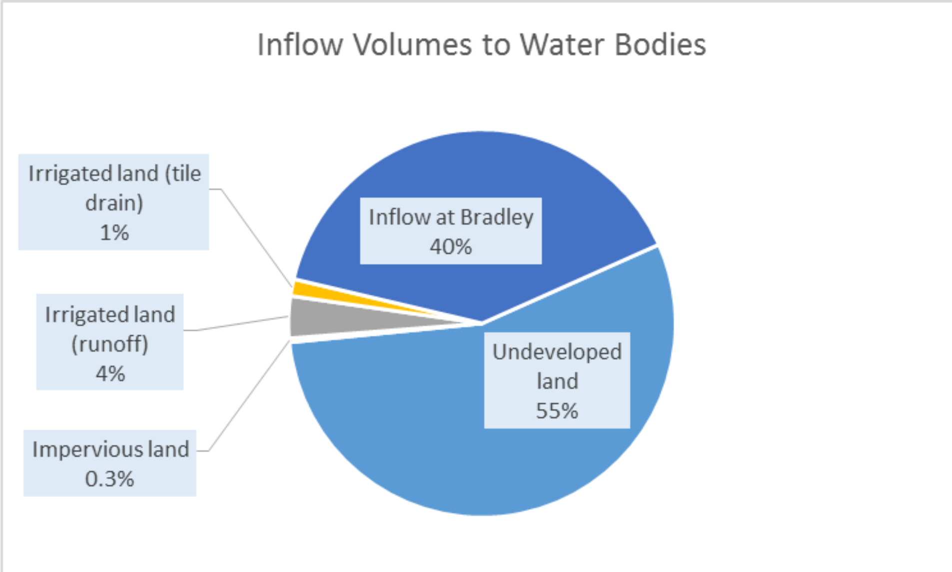


Figure 102. Average inflow volumes to water bodies in the Salt Tool study area

Losses from water bodies in the Salt Tool study area are shown in Figure 103. The majority of the water in the reaches is lost to infiltration into the Valley aquifers. Outflow to Monterey Bay from Salinas River and Old Salinas River make up only 14 percent of the losses. Evapotranspiration from channel vegetation accounts for only 3 percent.

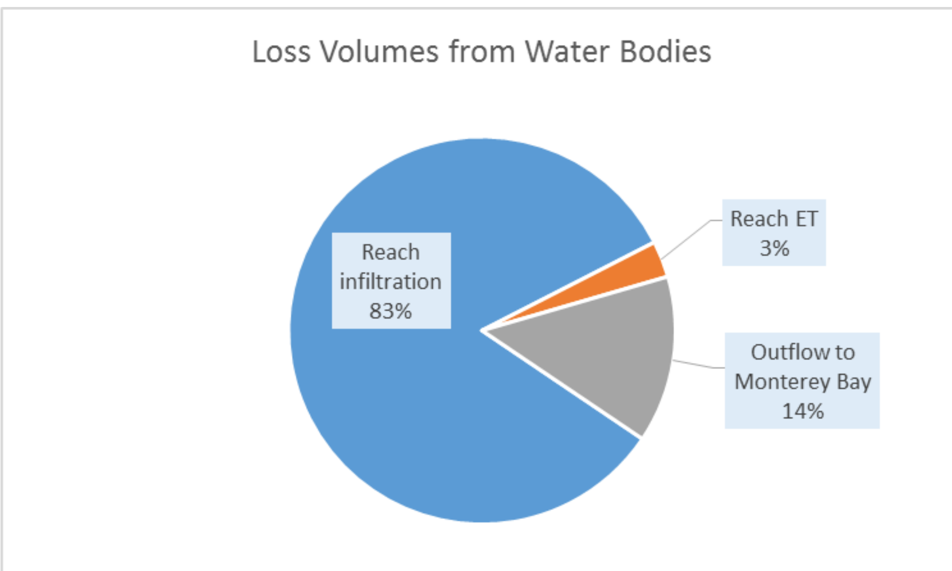


Figure 103. Average loss volumes from water bodies in the Salt Tool study area

Cumulative outflows from all irrigated land in the study area are presented as a special case in Figure 104 given its importance in the hydrology of the Salinas River Watershed Area. Most of the water that does not return to the atmosphere via evapotranspiration leaves via percolation to the aquifers (80 percent). Other losses include surface runoff at 14 percent and tile drain outflow at 6 percent.

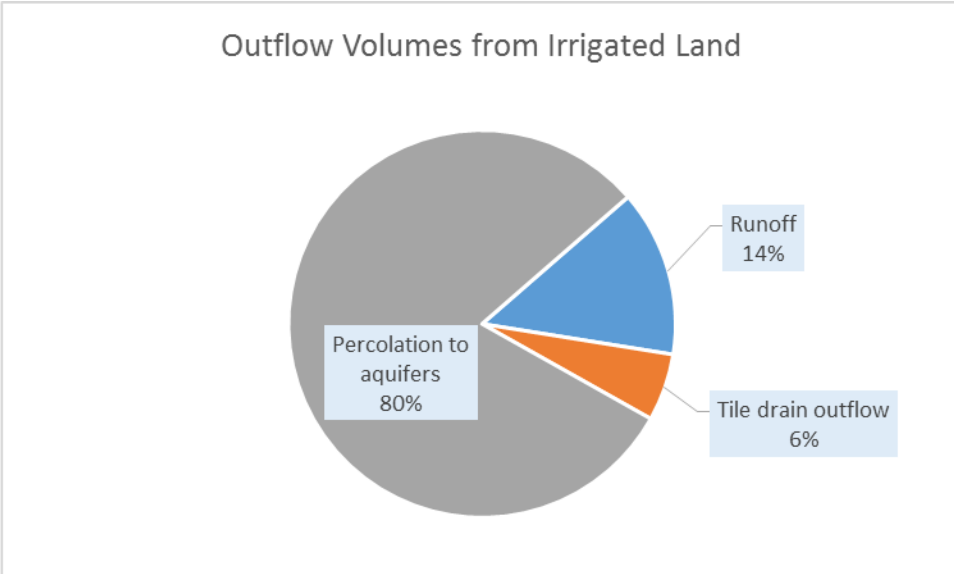


Figure 104. Average outflow volumes from irrigated land in the Salt Tool study area

Figure 105 provides a comparison of the relative magnitude of sources of water percolation to the Valley aquifers. Infiltration from the Salinas River and other reaches is the dominant source at 79 percent, while percolation directly from irrigated land makes up 21 percent.

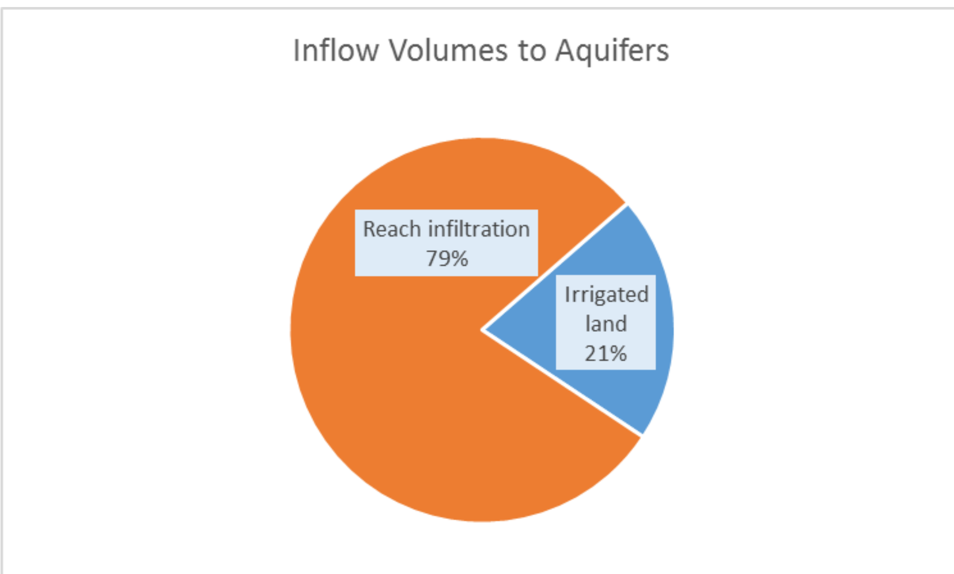


Figure 105. Average inflow volumes to Valley aquifers in the Salt Tool study area

Annual salt fluxes are provided in Table 38. The largest source of salt entering the watershed is from undeveloped land. The largest losses are from reach infiltration and irrigation percolation to the aquifers. Salt mass fluxes are discussed in more detail in Section 9.

Table 38. Salt Tool study area salt fluxes

Model components	Normal (ton/yr)	Dry (ton/yr)	Wet (ton/yr)	Average (ton/yr)
Undeveloped land loads to water bodies	236,453	236,453	236,453	236,453
Impervious land storm event loads to water bodies	8	8	8	8
Irrigated land storm event loads to water bodies	141	995	3,288	1,475
Tile drain outflow loads to water bodies	22,925	17,109	46,134	28,723
Boundary inflow loads at Bradley to Salinas River	57,395	77,150	84,713	73,086
Reach infiltration loads to aquifers	268,719	290,876	243,224	267,606
Net outflow loads to Monterey Bay	48,204	40,840	127,373	72,139
Irrigated land percolation loads to aquifers	255,367	227,479	269,427	250,758

Pie charts of salt loads are presented using the average of the three years types corresponding to the water volume pie charts. Figure 106 provides the relative magnitudes of salt entering water bodies in the study area. As before, undeveloped land is the largest contributor of salt mass at 70 percent. Salt also enters the system at Bradley; boundary inflow salt mass is 22 percent, much lower than the fraction of water volume at 40 percent. Since most of the land upstream of Bradley is undeveloped, this suggests that the aerial loading rates of salt in the upper watershed is lower than in the study area. Salt loads from irrigated land tile drainage make up 8 percent of the load, while the other sources are less than one percent.

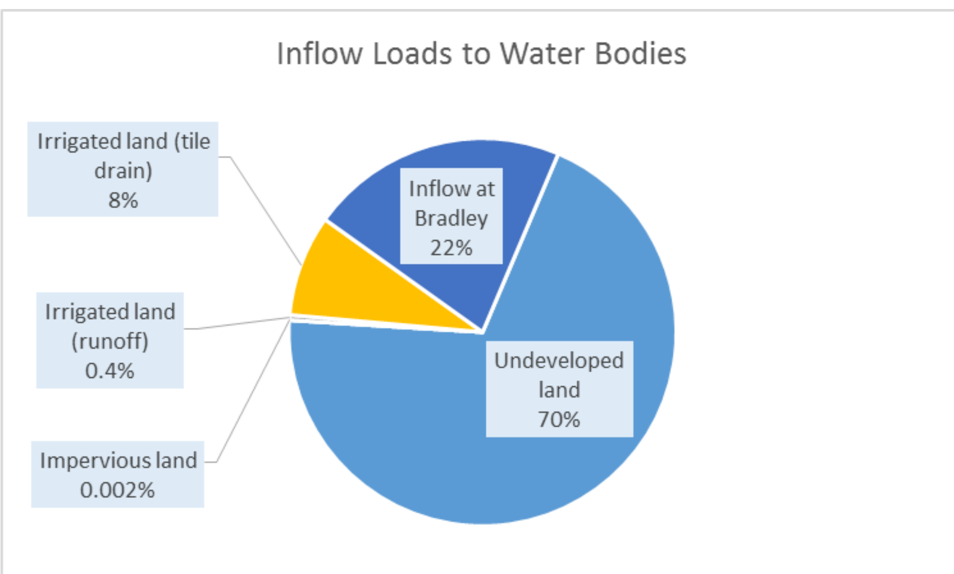


Figure 106. Average inflow TDS loads to water bodies in the Salt Tool study area

Salt loads leave the steam system either via infiltration to the Valley aquifers from losing reaches (primarily the Salinas River), or via outflow to Monterey Bay. Reach infiltration is by far the largest loss at 85 percent, with the remaining 15 percent leaving the watersheds from Salinas River and Old Salinas River (Figure 107).

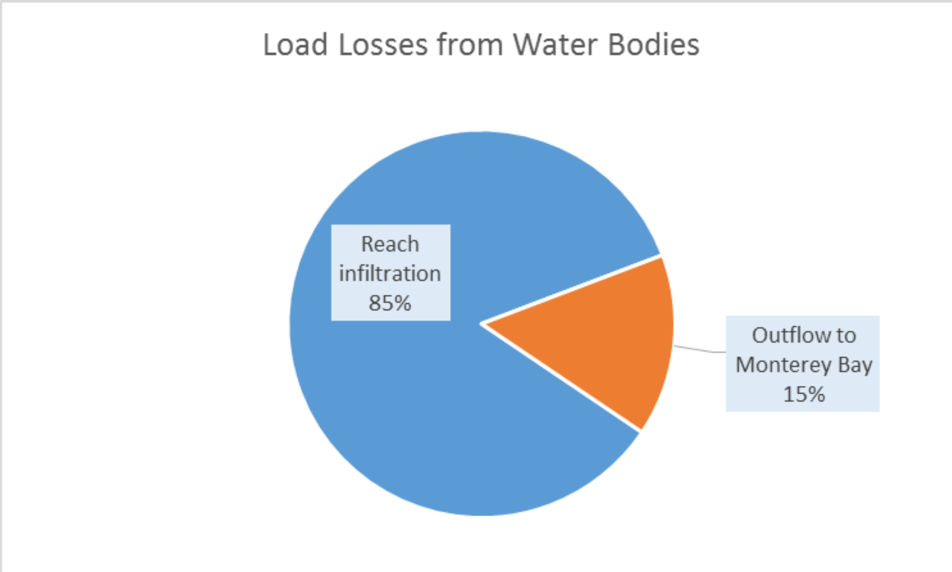


Figure 107. Average loss TDS loads from water bodies in the Salt Tool study area

As was the case for water volume, salt percolation to the aquifers represents the largest salt export from irrigated land (Figure 108). Runoff salt loads are very small, reflecting low salt concentrations in the root zone. Salt loss via tile drains comprises 10 percent.

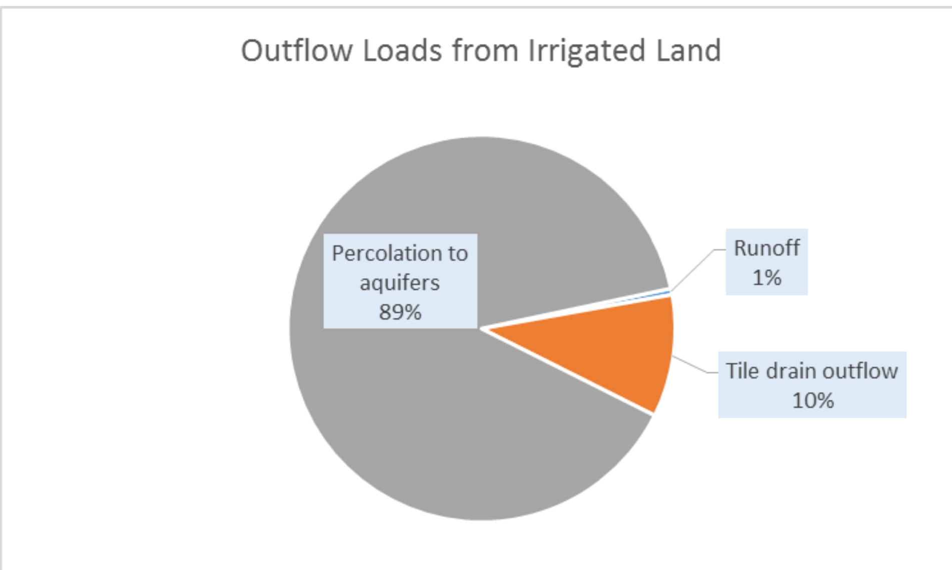


Figure 108. Average outflow TDS loads from irrigated land in the Salt Tool study area

The Salt Tool includes two pathways for salt loads to enter the aquifers – reach infiltration and percolation from irrigated land. Each contributes about the same proportion (Figure 109). However, this pattern is distinctly different than water volume inflows to aquifers, where nearly 80 percent originated from reach infiltration. The reason the relative proportion of salt load is higher for irrigated land is due to higher salt concentrations in irrigation water compared to the salt concentrations found in the reaches.

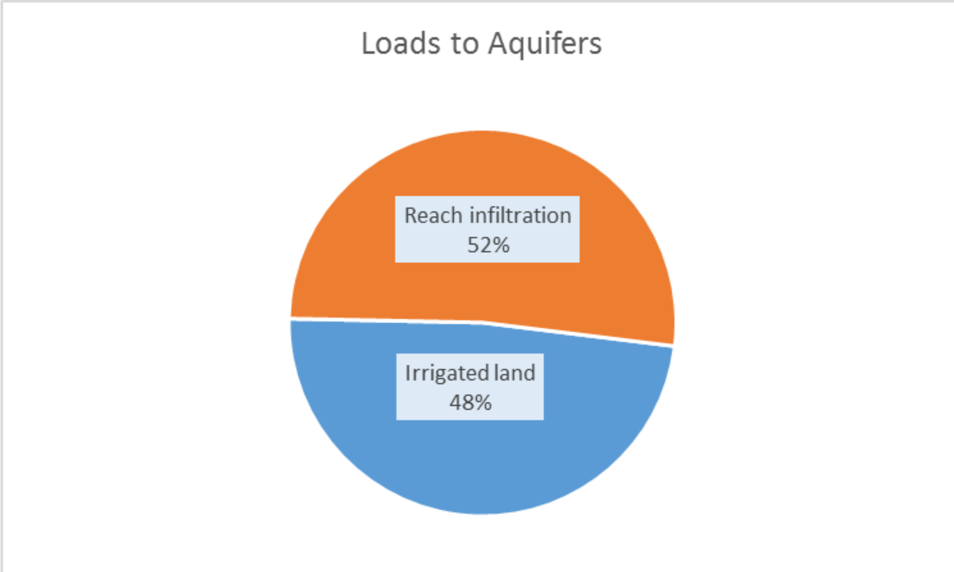


Figure 109. Average inflow TDS loads to Valley aquifers in the Salt Tool study area

8.2 Reach Concentrations

A selection of Salt Tool seasonal average TDS concentrations are shown in Figure 110through Figure 114, and compared to TDS monitoring data. The first two figures show results at the two reaches impaired for salt measures in the 303(d) list. At Salinas River from Blanco Drain to the Highway 1 bridge (Figure 110), Salt Tool concentrations are fairly uniform across years, but are much lower than observed data. As noted in the discussion for Figure 99, the Highway 1 location is likely influenced by estuarine conditions which are not accounted for in the Salt Tool. Alisal Creek concentrations (Figure 111) are similar across years in the Salt Tool for the most part, and also show high Season 3 concentrations during normal and dry years. However, the monitoring data show uniformly high concentrations across seasons, suggesting that the Salt Tool may not be accounting for locally high loading rates not captured by the USGS SPARROW analysis for undeveloped land. The remaining figures show examples from other locations in the study area. The Salt Tool results for the Reclamation Canal from Santa Rite to Merritt Lake (Figure 112) shows a similar pattern to Alisal Creek, whereas the monitoring data are comparable to the lower concentrations but not the season 3 spike. The Salt Tool spikes are due to high tile drain outflow concentrations during season 3 associated with salt accumulation in the transition zone. It is likely that the Salt Tool representation in these areas is not capturing some aspect of irrigation management. Further details of this are discussed in Section 10. Concentrations are more variable at Blanco Drain (Figure 113), and are generally comparable to the monitoring data. Figure 114 shows Salinas River farther upstream in the study area, between Arroyo Seco and the gage at Chualar. Results compare well to monitoring data.

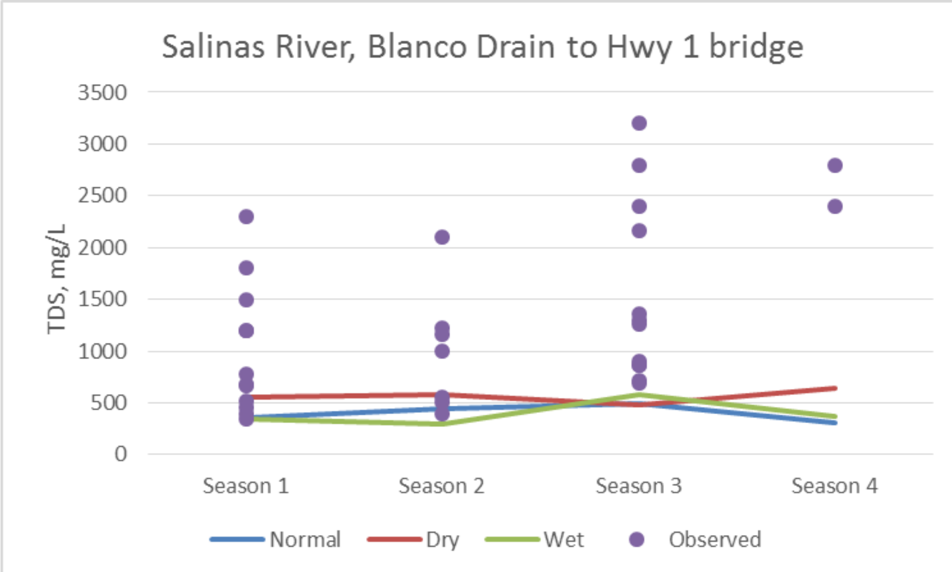


Figure 110. Salt Tool concentrations and seasonal observed data for Salinas River, Blanco Drain to Hwy 1 bridge

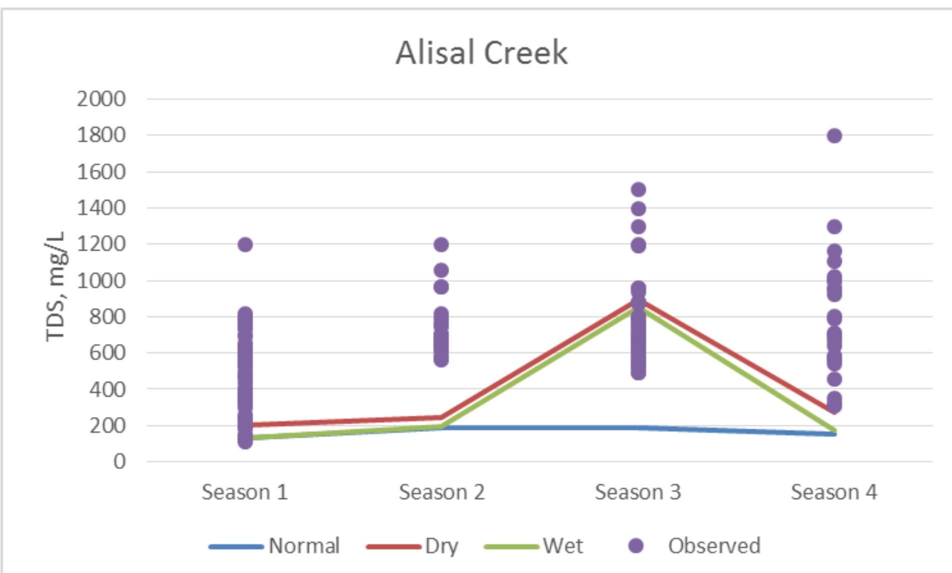


Figure 111. Salt Tool concentrations and seasonal observed data for Alisal Creek

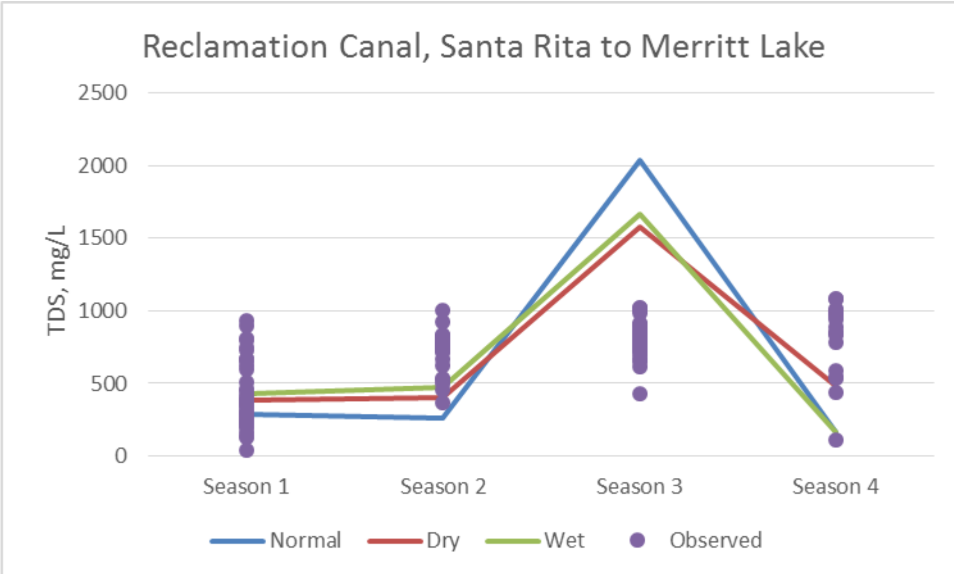


Figure 112. Salt Tool concentrations and seasonal observed data for Reclamation Canal, Santa Rita to Merritt Lake

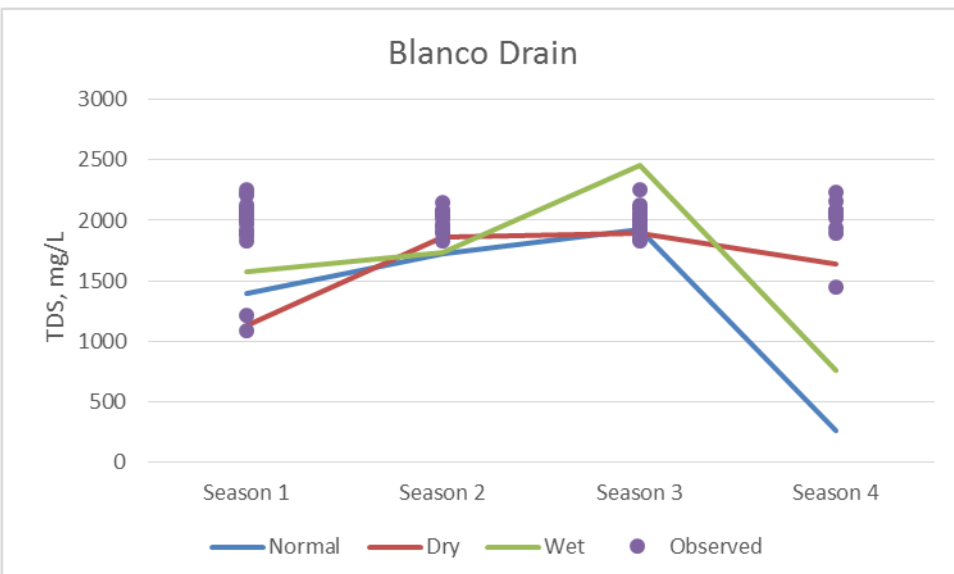


Figure 113. Salt Tool concentrations and seasonal observed data for Blanco Drain

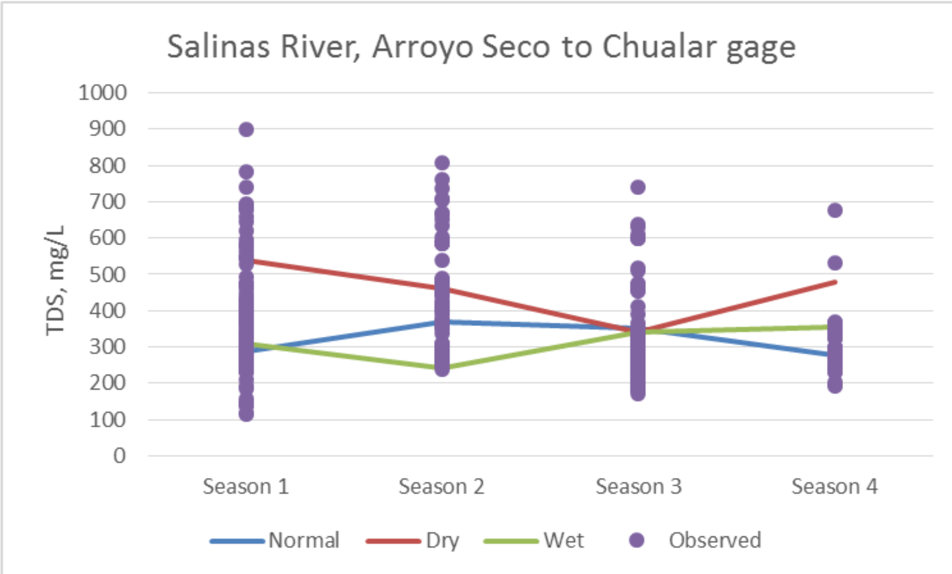


Figure 114. Salt Tool concentrations and seasonal observed data for Salinas River, Arroyo Seco to Chualar gage

8.3 Unit Area Crop Summaries

A selection of salt mass export pie charts is shown below. The values represent annual averages across the three year types. Figure 115 provides an example of a crop in a location with tile drainage, strawberries in zone 10. While much of the salt leaves via the tile drain, a large proportion percolates beyond the tile drain into the shallow aquifer. For rotational vegetables in zone 3 (Figure 116) and grapes in zone 5 (Figure 117), export is dominated by percolation to the aquifer. See Figure 80 for zone locations and Table 25 for zone descriptive properties.

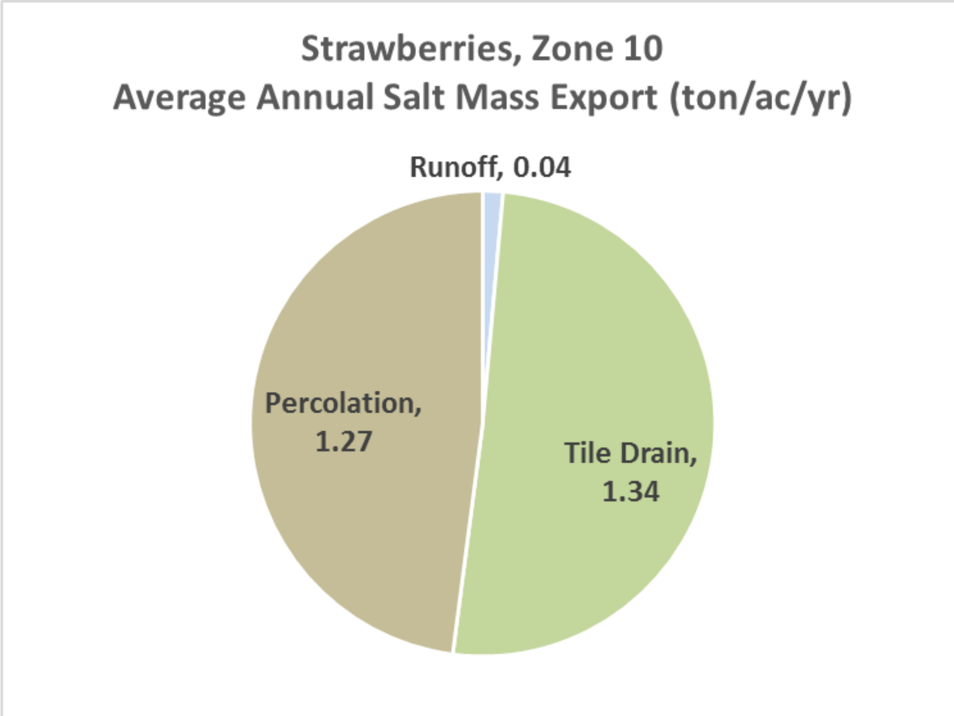


Figure 115. Salt mass export from strawberries in Zone 10

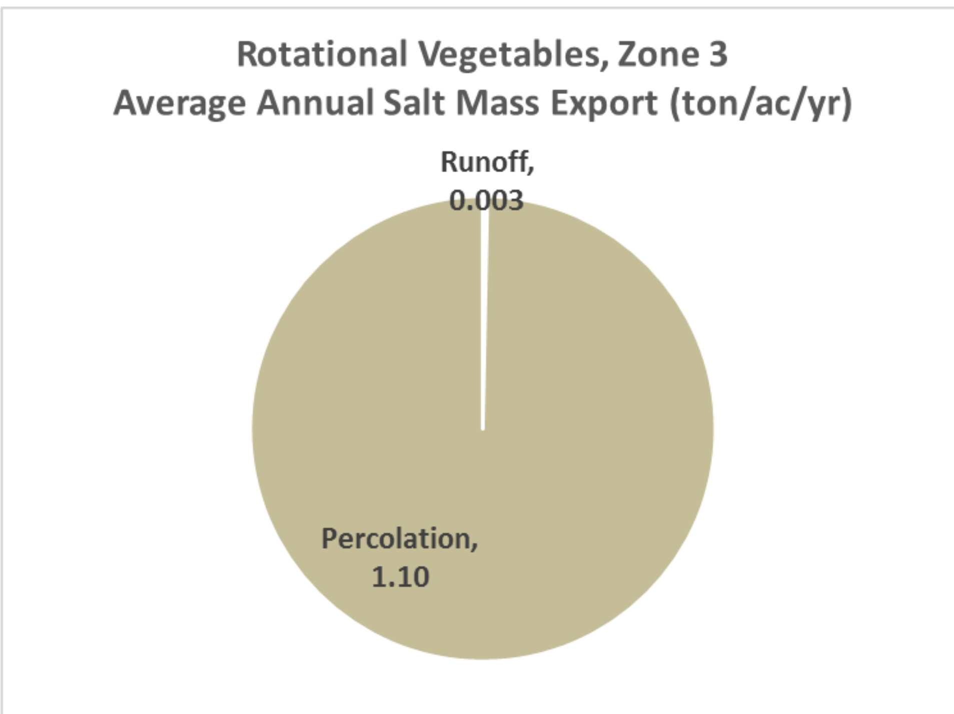


Figure 116. Salt mass export from rotational vegetables in Zone 3

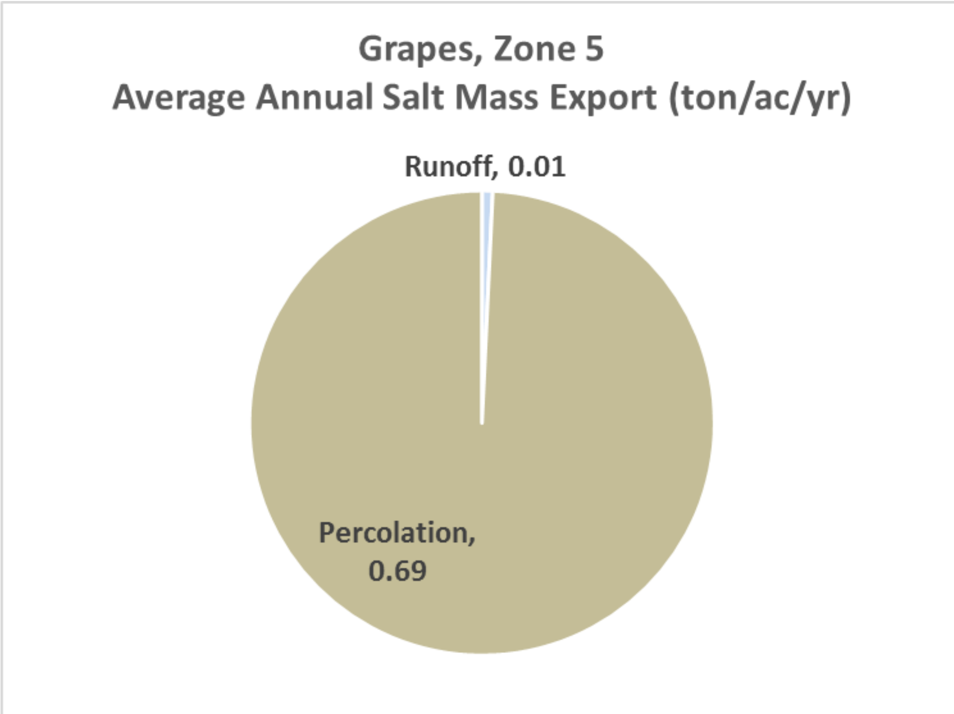


Figure 117. Salt mass export from grapes in Zone 5

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9 Salt Source Analysis

This section presents an analysis of major sources of salt that are inputs to the surface waters and aquifers of the larger project study area, referred to as the Salinas River Watershed Area. The following sources are quantified using a combination of monitoring data, data from reports, and the Salt Tool as discussed in Section 7. Where available, loads are quantified for sodium and chloride in addition to TDS.

Not all source types are quantified directly. For instance, wastewater contains salts from a variety of sources, including food, cleansers and chemicals, water softeners, and industrial processes. Wastewater treatment plants may apply additional chemicals containing salts during the treatment process. Fertilizers and other soil treatments may be applied to agricultural and urban land. However, the analysis captures the major inputs and outputs of salt in the watershed.

9.1 Undeveloped Land

Salt loads from undeveloped land are modeled using the USGS SPARROW results from Section 7.2.4, and include salt carried to surface waters by surface runoff and groundwater discharge. This includes loads from geologic weathering and atmospheric deposition. The majority of the undeveloped land is located outside of the Salinas Valley. These streams then enter the Salinas Valley, where much of the salt load is infiltrated to the aquifers from the streams themselves or from the Salinas River. As a result, much of the load entering the aquifers originates from undeveloped land.

The Salt Tool predicted that 236,453 tons of salt originate from undeveloped land in the Salinas watershed downstream of Bradley. Much of this load infiltrates to the Valley aquifers from the Salinas River and its tributaries. This value represents conditions from water year 2000 as predicted by the Anning and Flynn (2014) USGS SPARROW model. It is likely that loads from undeveloped land vary from year to year, but the SPARROW results did not provide a way to estimate variation by year type.

The Salt Tool conceptually represents loads from all of the undeveloped land as being transported by either surface runoff or shallow groundwater directly to reaches, and infiltration directly to the Valley aquifer subareas is not considered. This is likely accurate for the majority of the undeveloped land, which is found outside of the extent of the Valley aquifer subareas. That said, about 12 percent of the undeveloped land in the Salt Tool study area is located above the Valley aquifers (notably for the Upper and Forebay subareas). In reality, some fraction of annual discharge from these areas likely percolates to the aquifer subareas rather than directly to the streams. However, the volumes and salt loads are expected to be minimal, since undeveloped land is not irrigated and annual rainfall is low. In addition, discharge and loads from undeveloped land has the opportunity to infiltrate to the aquifer subareas directly from the Salinas River.

9.2 Land Upstream of Bradley

The Salt Tool analysis was focused on the lower portion of the Salinas River watershed and did not cover the watershed upstream of Bradley. Salt loading can be estimated using monitoring data at the Bradley gage. Median TDS concentrations for SaltMod seasons 1 – 4 are 260 mg/L, 239 mg/L, 210 mg/L, and 260 mg/L respectively. The product of the concentrations and seasonal volumes result in an estimated load of 57,395 tons/yr for the normal year, 77,150 tons/yr for the dry year, and 84,713 tons/yr for the wet year. The overall average across the three years is about 73,100 tons/yr. These volumes and loads were represented in the Salt Tool seasonally as inflows into reach 3 (Salinas River from Bradley to San Lorenzo), and were mixed with the incoming volumes and loads from the land area in subbasin 3.

9.3 Agricultural Land

Salt loads from agricultural land in the Salinas Valley are modeled as being delivered to surface waters (from surface runoff) and percolating to the aquifers as predicted by the Salt Tool. Salt sources include irrigation water and salt dissolution in soil. Fertilizers and other soil inputs were not considered due to lack of available data to characterize applied rates. In addition, the degree to which these inputs bind to soils or are taken up by plants versus dissolve in runoff or infiltration is unknown. Loads from agricultural land from areas outside of the Salinas Valley were not considered; while there is some agricultural land outside of the Valley, the area is small relative to agricultural land in the Valley itself.

Agricultural land contributes salt loads to streams via surface runoff during storm events, and through tile drains in the area generally west of Salinas (Table 39). Sources of salt exported from agricultural land represented in the modeling framework include salt in irrigation water and salt from weathering of soils. Storm event loads are small compared to tile drain loads. The average total load across the three years is about 27,000 tons/yr.

Table 39. Loads to surface waters from agricultural land

Source	Loads, tons/yr			
	Normal Year	Dry Year	Wet Year	Average
Storm event loads	120	967	3,176	2,072
Tile drain loads	22,297	12,518	43,002	25,939
Total	*22,417*	*13,485*	*46,178*	*28,011*

Percolation loads to the aquifer subareas are much higher as shown in Table 40. This is expected since the majority of loads from irrigation water do not discharge to surface waters and therefore are flushed from the soil from rainfall and irrigation. The average load across the three years percolating to the aquifers is about 236,200 tons/yr.

Table 40. Loads to aquifers from agricultural land

Source	Loads, tons/yr			
	Normal Year	Dry Year	Wet Year	Average
Percolation loads	235,102	214,923	258,579	236,201

As noted above, fertilizer and other soil inputs were not considered in the source analysis or the SaltMod modeling. Much of the fertilizer and other inputs is taken up by plants or binds to the soil. An unknown fraction dissolves in surface runoff and infiltrated water, and contributes to the overall salt load leaving agricultural land. This reflects a source of uncertainty in the representation of salt in this analysis. However, the amount of salt contributed by the sources is expected to be small relative to salt in irrigation water and from weathering of soils.

In the Salinas River Watershed Area, groundwater is the primary source of water used for agricultural irrigation. In addition, the Salinas Valley Reclamation Project (SVRP) provides a source of irrigation water to agricultural growers in the Castroville area. While groundwater quality is considered good in most of the Salinas River Watershed Area (when used as a water supply), it does contain low concentrations of salt

As discussed in Section 7.2.3.3, MCWRA publishes annual water use reports that tabulate groundwater extraction by location (the four primary aquifer subareas), municipality, and destination (agriculture versus urban). Volumes were tabulated and averaged from 2004 – 2013. In addition, the Central Coast Water Board provided a database of groundwater quality collected between 2012 and 2014; the data included source aquifer area and well type (domestic versus agricultural irrigation). Statistical analyses were performed on the data to characterize the central tendency salt concentrations, separately by aquifer area and well type. Histograms indicated that the data distributions were log-normal (tending towards having a greater frequency of low concentrations), so the median was selected as the best indicator of central tendency (Table 41). The Student's t-test was conducted on the log-transformed data to determine whether there a significant difference in the geometric means between well types within each aquifer area. In nearly all cases, there was a significant difference, with lower concentrations associated with agriculture irrigation wells compared to domestic use wells. The product of average annual agricultural irrigation volume and median concentrations by aquifer area was calculated, providing annual average loads (Table 42).

Table 41. Median concentrations of salt constituents from wells

Aquifer Subarea	Agricultural Irrigation			Urban Use		
	TDS (mg/L)	Sodium (mg/L)	Chloride (mg/L)	TDS (mg/L)	Sodium (mg/L)	Chloride (mg/L)
Pressure	607	54	63	680	66	67
East Side	590	71	93	694	72	109
Forebay	408	33	36	616	38	38
Upper Valley	500	42	32	1183	125	136

Table 42. Annual average loads and loading rates of salt applied to agricultural land in Monterey County from wells

Aquifer Subarea	TDS Load (ton/yr)	Sodium Load (ton/yr)	Chloride Load (ton/yr)	TDS Rate (ton/ac/yr)	Sodium Rate (ton/ac/yr)	Chloride Rate (ton/ac/yr)
Pressure	80,257	7,154	8,355	1.89	0.168	0.197
East Side	67,142	8,023	10,527	1.97	0.235	0.309
Forebay	76,631	6,104	6,668	1.25	0.100	0.109
Upper Valley	87,883	7,382	5,537	1.71	0.143	0.108
Total/Average	*311,913*	*28,663*	*31,086*	*1.65*	*0.151*	*0.164*

MRWPCA provided monitoring data spanning the entire time period of the SVRP. The product of monthly discharge volume from the tertiary treatment plant and monthly average salt concentrations was tabulated into annual loads (Table 43). Average concentrations across the monitored period were 847 mg/L, 175 mg/L, and 260 mg/L for TDS, sodium, and chloride respectively from the tertiary plant, and 686 mg/L, 81 mg/L, and 86 mg/L for TDS, sodium, and chloride respectively from the SRDP.

Loads from the secondary treatment plant discharged directly to Monterey Bay were not calculated. MRWPCA began operating the Salinas River Diversion Project (SRDP) in 2010. Separate water quality monitoring data were collected for water diverted from the River, and were used to calculate annual salt loads associated with the SRDP. Outflow from the tertiary treatment plant and the diversion are blended in a holding pond and delivered to the Castroville Seawater Intrusion Project (CSIP) area for irrigation use. It is important to note that a portion of the TDS in the SVRP recycled wastewater is comprised of nitrates which are in part consumed by the crops, and would not pass through the root zone and transition zone to tile drain discharge.

Table 43. Loads of salt applied to agricultural land in the CSIP Area

Year	Tertiary Plant Load (ton/yr)			SRDP Load (ton/yr)		
	TDS	Sodium	Chloride	TDS	Sodium	Chloride
1998	6,540	1,470	2,148	-	-	-
1999	11,448	2,400	3,609	-	-	-
2000	11,113	2,329	3,422	-	-	-
2001	14,101	2,882	4,133	-	-	-
2002	15,110	3,095	4,757	-	-	-
2003	14,973	3,278	4,765	-	-	-
2004	15,718	3,381	5,180	-	-	-
2005	12,325	2,659	3,556	-	-	-
2006	13,174	2,704	3,905	-	-	-
2007	15,756	3,189	4,571	-	-	-
2008	17,959	3,567	5,418	-	-	-
2009	13,251	2,684	4,069	-	-	-
2010	12,477	2,481	3,965	4,614	547	593
2011	13,607	2,731	4,207	2,175	281	294
2012	15,162	3,251	4,958	3,580	462	514
2013	17,636	3,666	5,478	5,377	603	625
2014	17,826	3,666	5,577	-	-	-

Year	Tertiary Plant Load (ton/yr)			SRDP Load (ton/yr)		
	TDS	Sodium	Chloride	TDS	Sodium	Chloride
	Average 2001-2014			Average 2010-2013		
	14,934	3,088	4,610	3,936	474	507

When the well water irrigation loads (Table 42) and SVRP irrigation loads (Table 43) are combined, they total approximately 331,000 tons/yr. The average sum of the outflow loads from storm events/tile drain discharge (Table 39) and percolation to the aquifers (Table 40) is about 264,000 tons/yr. The difference is significant, about 67,000 ton/yr. The SaltMod simulation suggests that the salt is being stranded in the transition zone between the bottom of the root zone and the water table. The areal stranding rate for agricultural is about 0.35 ton/ac/yr, or about 1.5 teaspoons/ft^2/yr. Salt deposition in soil profiles is well understood under a variety of irrigation practices (FAO, 1988). Deposition tends to occur at the depth at which the infiltrated water evaporates. Concentrations increase to a maximum value close to the wetting front, and drop to background values below the wetting depth. When evaporation occurs, salt moves both up and down in the profile, allowing some salt to migrate down with the percolated water. With sprinkler irrigation, upward movement is limited when compared to flood irrigation. Water table depths in most of the Salinas Valley exceed thirty feet (Table 28), so the depth at which salt can be stranded is typically limited by evaporation depth rather than the water table depth.

9.4 URBAN LAND

Salt sources from urban land include irrigation water, dissolution of salts in soil, and atmospheric deposition to impervious surfaces.

Urban land is represented as contributing salt loads to streams via a few pathways:

- Loads associated with runoff from connected impervious areas.
- Loads associated with storm event runoff from lawns, notable those that are irrigated.
- In the area generally west of Salinas, infiltrating groundwater is likely to encounter the water table and discharge to streams via baseflow. In SaltMod, irrigated lawns in this area were modeled with tile drains as a proxy for the process of baseflow.

Predicted loads from the Salt Tool are shown in Table 44. Impervious area loads are very small, owing to the low loading rates associated with atmospheric deposition. Storm event loads from irrigated lawns are also a small source. The largest contributor for urban loads is baseflow loads in the confined portion of the Pressure Area.

Table 44. Loads to surface water from urban land

Source	Loads, tons/yr		
	Normal Year	Dry Year	Wet Year
Impervious area	8.4	8.4	8.4
Storm event runoff from irrigated lawns	21.4	28.2	112
Baseflow in the confined portion of the Pressure subarea	628	4,591	3,132
Total	*658*	*4,628*	*3,252*

As was the case for agricultural land, percolation loads to the aquifer subareas from irrigated lawns are much higher than loads discharged to surface waters (Table 45). The three-year average is about 14,600 tons/yr. The normal year percolation load is nearly double the wet year percolation load, which is counterintuitive and does not follow the same trend as for agricultural land. There are a number of contributing factors to this outcome. Urban land is concentrated in the upper part of the watershed, while agricultural land is spread throughout the Salinas Valley, and climatic conditions are different in the upper part of the watershed. Most of the urban land is located over the aquitard, and was simulated as tile drained land as a proxy for shallow aquifer baseflow discharge to storm drains (a limitation of SaltMod). As a result, a greater proportion of salt load is discharged to baseflow (i.e. tile drain) during the wet year compared to the dry year. Other factors influence the outcome including seasonal rainfall/ET patterns, baseline salinity of the soils, and other factors.

Table 45. Loads to aquifers from urban land

Source	Loads, tons/yr		
	Normal Year	Dry Year	Wet Year
Percolation loads	20,265	12,556	10,848

MCWRA well extraction volumes for urban use were tabulated and averaged by aquifer subarea for 2004 – 2013. Not all of the water is used for irrigation; the analysis shown in Section 7.2.1 indicates that about 28 percent of domestic water use is utilized for lawn irrigation. Using reported MCWRA adjusted for irrigation use and the median urban well concentrations in Table 41, total salt mass in irrigation water for outdoor urban use can be estimated (Table 46). The total TDS load is somewhat lower but comparable to the total estimated load from the Salt Tool analysis.

Table 46. Annual average loads of salt applied to urban land in Monterey County from wells

Aquifer Subarea	TDS (ton/yr)	Sodium (ton/yr)	Chloride (ton/yr)
Pressure	5,175	502	510
East Side	4,014	416	630
Forebay	1,900	117	116
Upper Valley	1,924	203	220
Total	*13,012*	*1,239*	*1,476*

9.5 Loads Infiltrated from Streams to the Aquifer

The Salt Tool provided a prediction of loads infiltrating from reach segments to the aquifers below (Table 47). The average across the three years is about 267,000 tons/yr. Loads were calculated as the product of infiltration volume and reach-average seasonal concentration. Loads may originate from any of the upstream sources, including loads from land areas, loads from upstream reaches, and boundary inflow at Bradley. As shown in Table 37, net reach infiltration is highest during the wet year and lowest during the dry year. However, the trend with salt mass infiltration is the opposite – the highest loads infiltrate during the dry year, while the lowest loads infiltrate during the wet year. The reason is that salt concentrations in surface waters are modeled as being the highest during the dry year and the lowest during the wet year.

Table 47. Loads to aquifers from reach infiltration

Source	Loads, tons/yr		
	Normal Year	Dry Year	Wet Year
Salinas River, Bradley gage to San Lorenzo	21,565	13,856	20,644
San Lorenzo Creek	96,789	69,890	97,410
Salinas River, San Lorenzo to Arroyo Seco	52,203	56,793	62,416
Arroyo Seco	17,513	12,890	37,398
Salinas River, Arroyo Seco to Chualar gage	62,424	70,536	53,290
Salinas River, Chualar gage to Spreckels gage	16,818	17,864	18,298
Gabilan Creek	1,407	1,395	1,419
Total	*268,719*	*290,876*	*243,224*

9.6 LOADS EXPORTED FROM THE SALINAS RIVER WATERSHED AREA

Salt loads are exported from the Salinas River watershed at the Salinas Lagoon, and from the Reclamation Canal watershed via the OSR at Moss Landing. The Salt Tool provides a way to estimate the mass of salt exported from the watersheds independent of the influence of estuarine conditions in coastal water bodies (Table 48). Loads are calculated as the product of seasonal outflow volume and TDS concentrations. The Salinas River and OSR certainty do carry tidal salt back out to Monterey Bay, but the ebb and flow of salt from tidal action should be constant over time assuming no long term changes in outflow volume. The average load across the three years is about 71,210 tons/yr, though it is important to note that the wet year has a much higher load than the normal or dry years.

Table 48. Loads exported to Monterey Bay

Source	Loads, tons/yr			
	Normal Year	Dry Year	Wet Year	Average
Salinas River	31,418	28,246	96,746	52,137
Old Salinas River	16,786	12,594	30,626	20,002
Total	*48,204*	*40,840*	*127,372*	72,139

9.7 OTHER WASTEWATER SOURCES

While wastewater in the MRWPCA service area is either delivered to the CSIP for irrigation use or discharged to Monterey Bay, the remaining sewered municipalities in the Salinas River Watershed Area discharge to percolation ponds or land application fields near their treatment plants. There are also a number of industrial facilities that discharge process water to percolation ponds or fields. Households outside of sewer service areas are assumed to discharge wastewater to private septic systems.

9.7.1 Municipal and Industrial Percolation Ponds and Land Application

Wastewater treatment plants and industrial facilities that discharge to percolation ponds or fields were summarized and screened to those with design flow greater than 0.05 MGD using monitoring reports provided by the facilities to the Central Coast Water Board. Annual outflow and effluent values were averaged from the reports, and used to calculate discharge loads (Table 49). The fate of the salt loads is not known, but likely depends on the location of the facilities relative to the Valley aquifers, the aquitard in the Pressure subarea, and proximity to surface waters. Many of the municipal wastewater discharge facilities are located close to the Salinas River, and infiltrated salt may be readily transported to the river via shallow groundwater.

Table 49. Annual average loads from municipal and industrial percolation ponds and land application

Facility	Reported Flow (MGD)	TDS Load (ton/yr)	Sodium (ton/yr)	Chloride Load (ton/yr)
Atascadero State Hospital	0.17	319	51	91
Atascadero WWTP	1.33	1878	378	501
California Utilities	0.12	237	55	95
FT. Hunter Liggett WWTP	0.08	50	7	8
Gonzales Winery	0.12	319	29	22
Gonzales WW	0.69	790	127	133
Greenfield WWTP, City of	0.98	1309	206	213
King City Domestic WWTF	0.86	1009	182	181
Las Palmas Ranch WWTP	0.14	327	54	54
Monterey CSA - Chualar WWTP	0.06	68	13	13
Salinas Industrial WWTP	2.88	4767	1128	1304
San Miguel SD WWTP	0.10	140	27	34
Soledad Sewage Treatment Plant	2.17	2578	457	582
Spreckels Sugar Division	0.07	162	26	38
Texaco San Ardo Reclamation PL	1.09	191	15	12
Total	*10.84*	*14,143*	*2,755*	*3,280*

9.7.2 Septic System Loads

U.S. Census spatial data from 2010 (at the block group level) was obtained to characterize the population distribution within the Salinas River Watershed Area. An analysis indicated an estimated 2010 population of about 360,000. MRWPCA provided a sewer service boundary, which overlaid on the Census spatial data to classify the portion of population served by MRWPCA. Sewer service area boundaries were not available for the remaining municipalities in the study area, so municipal boundaries and aerial photography were used to assign Census block groups to the municipalities. The population in the rest of the study area outside of assumed sewer service areas was tabulated and totals to about 116,300. We assumed that this entire population was served by septic systems.

The CA DWR (2008) estimate of per capita indoor water use of 66 gallons per day in the Central Coast Region was used to estimate total septic effluent volume, which totaled 7.68 MGD for the entire study area. Septic effluent values were assumed to be equivalent to the average of those reported for domestic WWTP plants shown in Table 49 (921 mg/L for TDS, 164 mg/L for sodium, and 183 mg/L for chloride).

The product of population, per capita water use, and salt concentrations is shown in Table 50. Note this analysis assumes there is no attenuation of salt loads in the septic tank or field, which is conservative.

As was the case with the municipal and industrial facilities, the fate of salt from septic systems is unknown. Some may enter the aquifers, be transported to surface waters via shallow groundwater, or may be stranded in the transition zone.

Table 50. Estimated Septic System Salt Loads in the Salinas River Watershed Area

Source	TDS Load (ton/yr)	Sodium Load (ton/yr)	Chloride Load (ton/yr)
Septic Systems	10,774	1,919	2,141

9.8 Atmospheric Deposition

Atmospheric deposition of salt is reported here for reference, though from pervious land it is inherently included as part of other sources. Methods used to estimate atmospheric deposition of salt were discussed previously in Section 7.2.6. The product of the deposition rates and the land area of the Salinas River Watershed Area produce the totals shown in Table 51.

Table 51. Annual Atmospheric Deposition of Salt

Source	TDS Load (ton/yr)	Sodium Load (ton/yr)	Chloride Load (ton/yr)
Wet Deposition	6,458	1,321	2,343
Dry Deposition	6,088	340	271
Total:	*12,556*	*1,661*	*2,614*

Sea salt can be an additional source of atmospheric deposition. However, it is likely that sea salt is not is significant component of salt deposition. Plant studies of coastal salt spray deposition typically show a dramatic drop in rates over very short distances, on the order of tens of meters (Barbour, 1978; Cheplick and Demetri, 1999).

9.9 Summary

The results of the source analysis are summarized by destination – loads to surface waters and loads to the aquifers. The presentation here differs from results presented in Section 7.2.7 in that loads from developed lands are tabulated by type (i.e., agricultural and urban) rather than by Salt Tool category (i.e., all irrigated land which includes both urban and agricultural uses).

Total salt loads entering surface waters in the Salinas River Watershed Area as predicted by the Salt Tool are tabulated in Table 52. The largest source is from background loads within the portion of the Salinas River covered by the Salt Tool analysis. A large fraction of this load infiltrates to the aquifers from the Salinas River and other tributaries. An unknown amount of salt likely enters water bodies from septic systems and municipal/industrial facilities discharging to percolation ponds and land application sites.

Table 52. Summary of loads by source entering surface waters

Source	Normal	Dry	Wet	Average
Upstream of Bradley	57,395	77,150	84,713	73,086
Undeveloped land	236,453	236,453	236,453	236,453
Agricultural land	22,417	13,485	46,177	27,360
Urban land	658	4,628	3,252	2,846
Total	*316,923*	*331,716*	*370,595*	*339,745*

The average of the three year types is shown graphically in Figure 118. Undeveloped land is the largest source at 70 percent, with loads upstream of the study area comprise 21 percent. Agricultural and urban land contribute relatively little load to surface waters, 8 percent and 1 percent respectively.

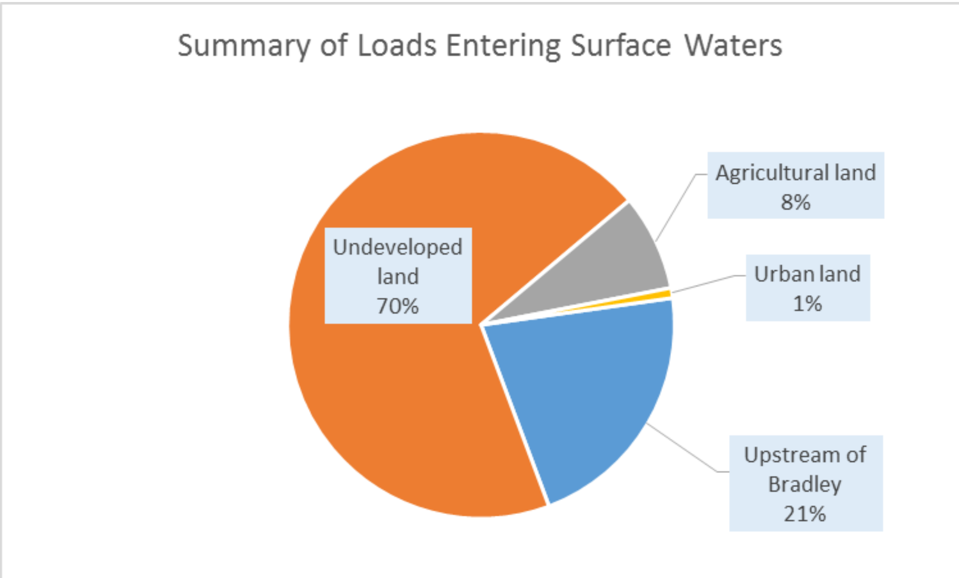

Figure 118. Summary of loads by source type entering surface waters

Total loads entering the aquifers are shown in Table 53. Percolation from agricultural land and infiltration from reaches are the largest sources of salt to the aquifer. Loads infiltrating from the reaches originate from other sources, but the analysis did not allow for tracking source types; however, it is likely that the majority of the load is from undeveloped land. Note that a considerable amount of this total is pulled out of the aquifers with irrigation water, and therefore is recycled back to the aquifer via irrigation percolation. An unknown amount of salt likely enters the aquifers from septic systems and municipal/industrial facilities discharging to percolation ponds and land application sites.

Table 53.Summary of loads by source entering the Salinas Valley aquifers

Source	Normal (ton/yr)	Dry (ton/yr	Wet (ton/yr	Average (ton/yr
Agricultural land percolation	235,102	214,923	258,579	236,201
Urban land percolation	20,265	12,556	10,848	14,556
Reach infiltration	268,719	290,876	243,224	267,606
Total	*524,086*	*518,355*	*512,651*	*518,364*

The average of the three year types is shown graphically in Figure 119. Infiltrated loads from reaches and from percolation from agricultural land comprise the majority of the loads, and are similar in magnitude at 52 percent and 45 percent, respectively. Urban land contributes only three percent of the load to the aquifers.

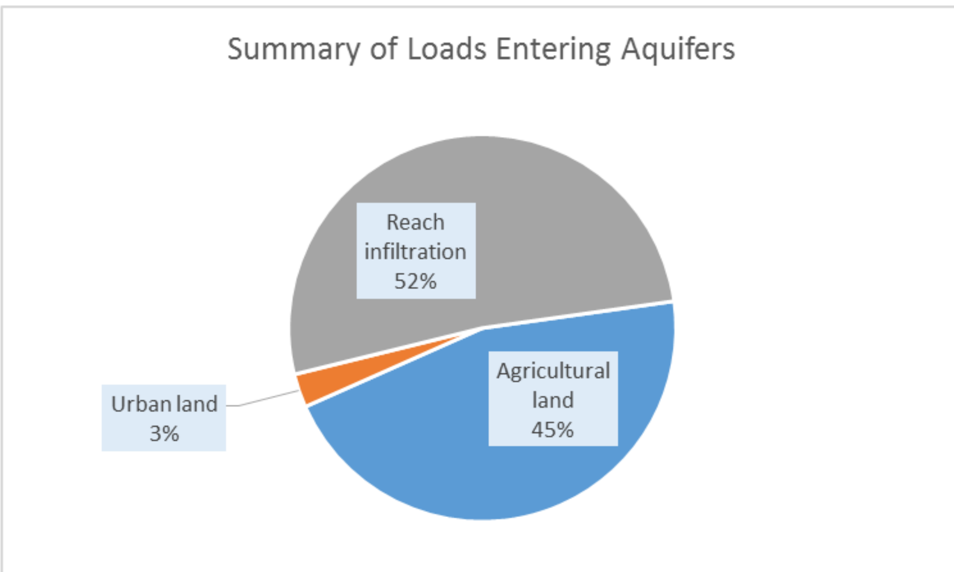

Figure 119. Summary of loads by source type entering aquifers

Loads entering the aquifers are broken down by aquifer subarea for the average of the three year types in Table 54 and graphically in Figure 120. Percolation from agricultural land dominates in the Pressure and Eastside subareas, but still is a major source in the Forebay and Upper Valley. Urban land is a relatively small source in the Pressure and Eastside subareas, but is nearly absent as a source from the Forebay and Upper Valley. Reach infiltration is the dominant source in the Forebay and Upper Valley subarea, an important but diminishing source in the Pressure subarea, and a minor source in the Forebay.

Table 54. Loads by source entering the Salinas Valley aquifers by subarea (average of three year types)

Source	Pressure (ton/yr	Eastside (ton/yr	Forebay (ton/yr	Upper Valley (ton/yr
Agricultural land	89,746	32,010	68,032	46,413
Urban land	8,065	2,827	1,967	1,698
Reach infiltration	48,702	1,407	91,924	125,574
Total	*146,513*	*36,243*	*161,923*	*173,685*

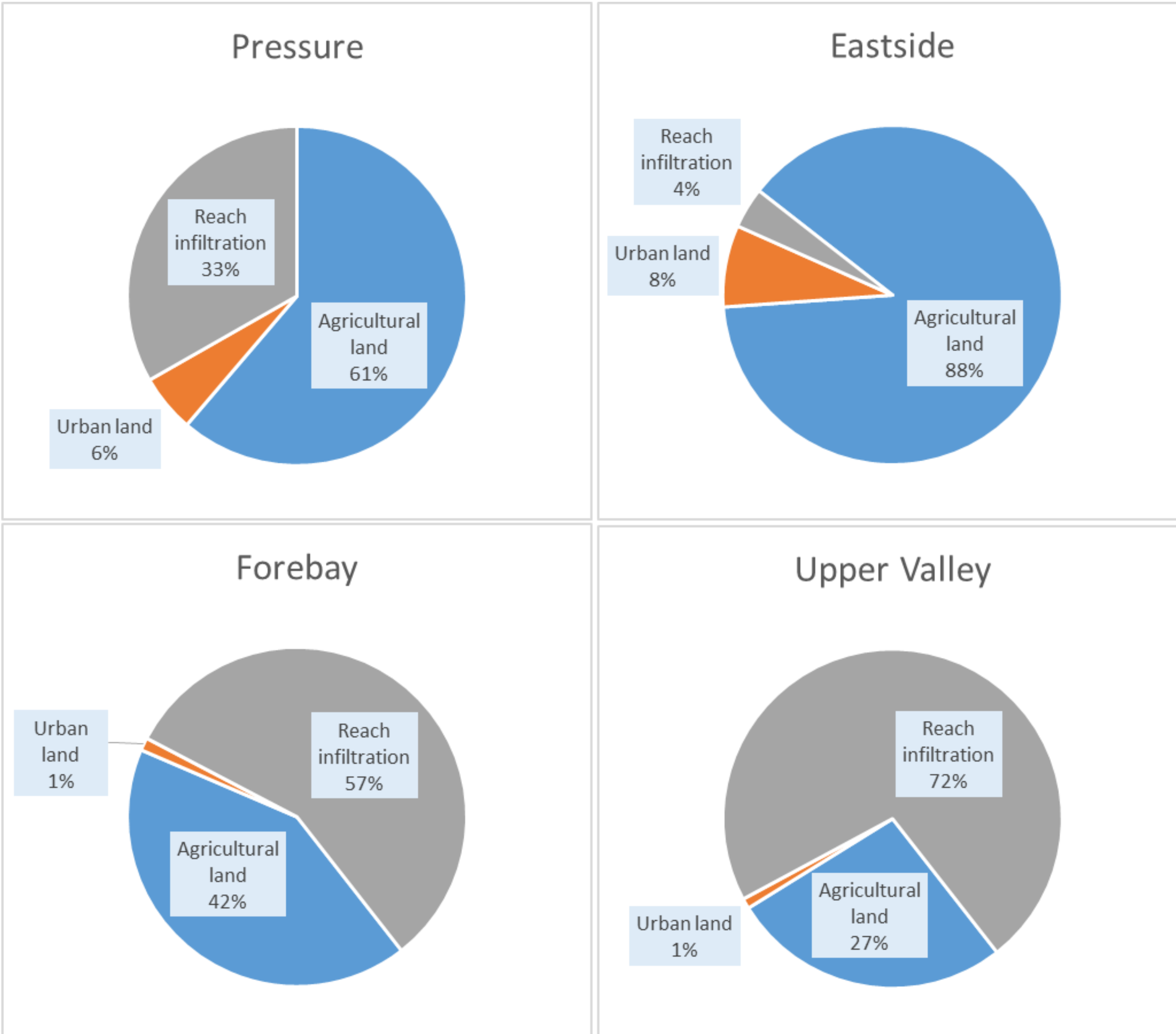

Figure 120. Summary of loads by source type entering the Salinas Valley aquifer subareas (average of three year types)

10 Recommendations

The goals of this project were to support development of salt-related TMDLs for impaired reaches by the CCRWQCB as well as to contribute information towards developing a salt and nutrient management plan for the Salinas Valley aquifers. A Salt Tool was constructed which focused on quantifying salt export from land to surfaces waters and to the Salinas Valley aquifers. In addition supporting TMDL and management plan development, the Salt Tool can be used to test the impacts of proposed management strategies on the salinity of water resources, both surface and sub-surface.

A major component of the analyses used to develop the Salt Tool involved using the SaltMod model to predict seasonal hydrology and salt fate and transport from irrigated land, both urban and agricultural. SaltMod is a process-based model and requires numerous inputs to drive predictions of irrigated land hydrology, soil processes, and salt accumulation, leaching, and export via multiple potential pathways. These inputs were estimated to the extent possible from local, regional, or State resources. Some of the most important inputs were associated with developing representations of crops types, rotations, and spatial distribution, and characterizing seasonal irrigation volumes based on crop characteristics, meteorology, and local practices. Crop types/rotations and their spatial distribution were estimated from a GIS database prepared by the Monterey County Agricultural Commissioner, while the main source of data for seasonal irrigation volume was the Basic Irrigation Schedule (BIS) application, using the Salinas South profile.

There are a number of avenues for potential improvement of the analyses. During review of the draft version of this report, stakeholders from the agricultural community noted that there appeared to be some discrepancies between the representations used in the SaltMod modeling and local knowledge. The comments fall into a few categories:

- Seasonal crop coefficients (Kc) given in the BIS (shown in Table 29) used to estimate irrigation volume were not entirely consistent with local knowledge regarding rotations and irrigation volumes.
- Spatial crop and rotational information indicated by the GIS data from the Agricultural Commissioner did not entirely agree with local knowledge. In many cases, the GIS data were too general and did not provide sufficient detail about crop and rotation patterns.
- The modeling assumed for the majority of the land that rotations took place year round. Stakeholders noted that in many locations in the Valley, land is left fallow for much of the year.
- The modeling did not account for irrigation tailwater runoff, which is known to occur locally on about 20 percent of the farms in the Valley.

The SaltMod modeling and its integration with the Salt Tool provide a good starting point for understand salt dynamics in the Salinas Valley Watershed Area. However, the modeling could be refined by incorporating updates to the SaltMod modeling framework drawing on additional local knowledge. Potential refinements include improved spatial representation of crop locations and rotations, as well as irrigation volumes and timing.

During SaltMod calibration, cumulative irrigation volumes predicted by the analysis were adjusted to match published irrigation volumes. The result was that the irrigation volume supplied was assumed to be just sufficient for meeting crop needs, and no additional volume was assumed to be applied for purposes of flushing excess salt from the soils. As a result, a very high root zone leaching efficiency (20) was used to prevent toxic levels of salt accumulation. While this is theoretically possible, typical values used in SaltMod studies range from 0.5 to 0.85 (Yao et al, 2013). It is likely that the cumulative irrigation requirement is overestimated since the analysis assumes year-round rotations, whereas in practice much of the land is fallow part of the time. Rectifying this would allow some of the irrigation volume to be used to flush excess salts in the SaltMod simulation, and the recalibrated root zone leaching efficiency would be lowered to a more reasonable value.

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