SUMMARY

Title: Salinas River Groundwater Basin Investigation, Salinas Valley, California
Cooperating Agency: Monterey County
Project Chief: Randy Hanson, USGS **Period of Project:** Federal Fiscal Years 2016-19

Problem: Groundwater and surface water are conjunctively used for the water supply in the Salinas Valley. Groundwater withdrawals, mainly for the irrigation of agricultural crops, have resulted in water-level declines and related seawater intrusion since the 1940s. To plan for sustainable future use, it will be important to define the quantity and quality of the groundwater supply and establish tools to allow users to efficiently utilize the available water resources.

Objective: The objectives of this study are to: (1) refine the geohydrologic framework of the Salinas Valley, (2) develop integrated hydrologic models, (3) quantify the historical hydrologic budget of the valley and evaluate total water demand for existing and future uses, (4) provide the required deliverables of the settlement agreement, Salinas Valley Water Coalition et al v. County of Monterey: Monterey County (MC, 2010), (5) develop hydrologic modeling tools to help evaluate and manage the water resources, and (6) incorporate climate model results into the integrated hydrologic model and evaluate the potential effects of climate change for selected scenarios. The study will develop a greater understanding of the geohydrology of the Salinas Valley and evaluate the potential hydrologic effects of future ground-water development on different parts of the valley which would aide in the potential development of a new management plan. These modeling tools will specifically be used to evaluate, on an annual basis during the study period (2014 – 2018), groundwater-level elevations and the extent of seawater intrusion.

Benefits: This study will benefit local water users by providing an improved understanding of the source, movement and use of surface water and groundwater, and help to predict the potential effects of continued groundwater overdraft and related seawater intrusion. Benefits to the nation include quantifying the resources of a sole-source aquifer, through the development information and tools necessary to assess and manage a water resource used for irrigation, drinking-water supply, and support of critical habitat of a distinct population of federally listed threatened South-Central California Coast steelhead (*Oncorhynchus mykiss*).

Approach: The proposed study will include five main tasks: (1) geohydrologic model development, (2) surface-water hydrologic models development, (3) development of an integrated groundwater/surface-water hydrologic model, (4) analysis of water availability, and (5) report/information preparation. The previously compiled geologic information and databases will be used to develop the geohydrologic framework of the Salinas Valley. This framework will include the creation of a texture model and related layering and structural barriers to groundwater flow. Climate, land-use, geologic, hydrologic, and water-quality data previously compiled and assembled into databases and a Geographic Information System along with current monitoring networks will be used to develop models and comparison information needed to calibrate hydrologic models. Geohydrologic and hydrologic models will be developed as part of this study to more accurately assess and simulate the storage and flow of water in the Salinas River Groundwater Basin. The hydrologic model will be used to evaluate how selected land- and water-use and climate scenarios affect the availability of surface water and groundwater in the Salinas Valley, and will include a predictive analysis of groundwater and surface water conditions under two proposed buildout conditions: year 2030 for the General Plan settlement, and year 2042 for the Sustainable Groundwater Management Act (CADWR, 2014). Of particular importance will be using the hydrologic model to analyze changes in surface-water and groundwater flow, as well as changes in groundwater storage and related seawater intrusion, in different hydrologic regions of Salinas Valley as influenced by current and projected water use and potential climate change.

Salinas River Groundwater Basin Investigation, Salinas Valley, California

By

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October 3, 2015

Problem and Study Area

The Salinas River Groundwater Basin is the largest coastal groundwater basin in Central California. It lies within the southern Coast Ranges between the San Joaquin Valley and the Pacific Ocean, and is drained by the Salinas River. The valley extends approximately 150 miles from the La Panza Range north-northwest to its mouth at Monterey Bay, draining approximately 5,000 square miles in Monterey and San Luis Obispo Counties. The valley is bounded on the west by the Santa Lucia Range and Sierra de Salinas and on the east by the Gabilan and Diablo Ranges. The Monterey Bay acts as the northwestern boundary of the Basin (Baillie and others, 2015b) (fig. 1A). The basin is part of the Monterey County Water resources Agency (MCWRA) Benefit Zone 2C (Zone 2C), and consists of 7 subareas named as follows: Above Dam, Below Dam, Upper Valley, Arroyo Seco, Forebay, East Side, and Pressure. The analyses detailed in this report cover the four primary water-producing subareas, the Pressure, East Side, Forebay (including the Arroyo Seco), and Upper Valley Subareas (fig. 1A). These four subareas include most of the land area and account for nearly all of the reported groundwater usage within Zone 2C (Baillie and others, 2015b). In addition to these four subareas, an additional assessment will be made for the "Below Dam" subarea that is directly below the San Antonio Dam/Reservoir and has been a region of recent agricultural developments. A recent summary of the state of the basin was completed by Brown and Caldwell hydrologists for Monterey County in preparation for developing a new integrated hydrologic model (Baillie and others, 2015b). The region covered by part of the five-layer Seaside Basin model (Hydrometrics, 2009) of the Seaside subbasin, is an additional subarea that will be evaluated and simulated separately because it was adjudicated separately (fig. 1B).

This project is the result of the lawsuit by several parties concerning the over-exploitation of water resources in the Salinas Valley and the resulting settlement agreement, Salinas Valley Water Coalition et al v. County of Monterey: Monterey County (MC, 2010). The settlement requires that Monterey County, among other things, evaluate total water demand for existing and future uses, seawater intrusion and groundwater levels, and on an annual basis for the study period, groundwater-level elevations and the extent of the seawater intrusion boundary. The evaluation is to be completed between October 31, 2017 and March 31, 2018, and the period of study is to extend to 2030.

Currently, surface water and groundwater are conjunctively used for irrigation and public water supply in the Salinas Valley. Groundwater withdrawals, mainly for the irrigation of agricultural crops, have resulted in water-level declines throughout the Basin. In the Pressure Subarea, water-level declines have led to seawater intrusion of as much as 11,000 to 18,000 ac-ft/yr since the 1930s (Baillie and others, 2015b). An evaluation of conjunctive use and groundwater overdraft in the Salinas groundwater basin by Montgomery Watson for MCWRA (Baillie and others, 2015b; MW, 1998) indicated that during the period from 1959 to 2013, Zone 2C was out of groundwater balance with a loss of fresh-water storage of 17,000 to 24,000 ac-ft/yr, which includes storage loss due to seawater intrusion (Baillie and others, 2015). A Salinas Valley water budget for 2013 indicated a total pumpage of 509,000 acre-ft, as reported to MCWRA, (Table 1) with an estimated cumulative storage depletion of 559,000 ac-ft from 1944 to 2013 (Baillie and others, 2015b) (fig 2).

With the implementation of the Salinas Valley Water Project (SVWP) in 2010, there was an expectation among residents and water managers that the advancement of the seawater intrusion would slow, or even halt, and the balance of the basin would improve. Under current drought conditions many are concerned about the effectiveness of the SVWP and whether the groundwater basin will continue to be overdrafted. In addition, there is concern that the groundwater-level declines have or will result in potential impediment to surface-water transmission via the Salinas River to the Salinas River Diversion Facility (SRDF) because of increased infiltration induced from pumping of high-capacity wells adjacent to the Salinas River.

Recent studies of the Salinas River Groundwater Basin (Baillie and others, 2015b) have documented the geohydrologic conditions of the area when groundwater development was substantially developed. The goal of this project is to delineate characterize the major aquifers and simulate groundwater flow and storage in all of the major aquifers above the Monterey Formation, as well as the movement and use of water across the landscape of the valley floor and surface-water flow in all drainages influenced by surrounding the major aquifers (fig. 3). Because the Salinas Valley is a conjunctive use system, it will be important to define the water-bearing and water-quality properties of the deeper aquifers and their relation to surface-water in the groundwater basin. To plan for future use, it will be important to define the quantity and quality of the groundwater supply and establish tools to allow users to efficiently and optimally utilize the available groundwater resources without incurring unacceptable, deleterious effects, and to evaluate the effects of potential changes in climate and land use on these resources.

Objectives

The objectives of this study are to: (1) refine the geohydrologic framework of the Salinas Valley, (2) develop integrated hydrologic models, (3) quantify the historical hydrologic budget of the valley and evaluate total water demand for existing and future uses, (4) provide the required deliverables of the settlement agreement Salinas Valley Water Coalition et al v. County of Monterey: Monterey County (MC, 2010), (5) develop hydrologic modeling tools (models and related preparation and analysis tools) to help evaluate and manage the water resources, and (6) incorporate climate model results into the integrated hydrologic model and evaluate the potential effects of climate change for selected scenarios. The study will develop a greater understanding of the geohydrology of the Salinas Valley and evaluate the potential hydrologic effects of future water-resource and land-use development as well as changes in natural land cover in the valley, and can be used aide in the potential development of a new resource management plan. These modeling tools will specifically be used to evaluate, on an annual basis during the study period (2014 – 2018), groundwater-level elevations and the extent of seawater intrusion.

Study Area

Climate

The Salinas Valley has a Mediterranean climate. Summers are generally dry and mild, and winters are generally wetter and cool. Precipitation is almost entirely rain, with approximately 90 percent falling during the six-month period from November to April. Year to year variability in precipitation is high; very dry years are common and droughts can extend over several years, such as the eight-year drought of Water Years (WY) 1984 to 1991 (Baillie and others, 2015b) and the current drought, which is in its fifth year. Average annual precipitation measured at 11 climate stations located in the lowland areas within and adjacent to the Salinas Valley watershed is 12.5 inches for WY 1907 to 2015, and varies from 6.1 inches for WY 1972 to 47 inches for WY 1998 (fig. 4). Average annual precipitation measured at 15 climate stations located in upland areas within and adjacent to the Salinas Valley watershed is 20.1 inches, and varies from less than 10 inches for WY 1924 and 1977 to more than 40 inches for WY 1941, 1983, 1995, and 1998 (fig. 4).

Topography and proximity to the Pacific Ocean have a strong effect on the spatial distribution of precipitation within the Salinas River watershed. Average annual precipitation for 1981 to 2010, calculated using the Parameter Regression on Independent Slopes Model (PRISM), averages 18.4 inches per year and varies from about 30 to 52 inches per year along the crest of the Santa Lucia Range to about 9 to 12 inches/year along the valley floor (fig. 5) (Daly and others, 2004).

Topography and proximity to the Pacific Ocean also affect air temperature within the Salinas River watershed. Average 1981-2010 air temperature using PRISM is 59 degrees Fahrenheit for the Salinas River watershed and varies from 60 to 62 degrees along the Salinas River in the central and southern parts of Monterey County to between 54 and 56.5 degrees along the coastal region and the higher elevations of the Santa Lucia Range (Daly and others, 2004). Variations between maximum and minimum air temperature are much higher for inland areas compared to the coastal region. Average 1981-2010 maximum daily air temperature using PRISM is 59 to 64 degrees Fahrenheit along the coastal areas, compared with 76 to 79 degrees for the inland valleys (fig. 6) [Daly and others, 2004]. In contrast, average 1981-2010 minimum daily air temperature using PRISM is highest in the coastal region and mountain summits, with values of 48 to 52 degrees Fahrenheit, and lowest in the inland valleys, with values of 39 to 43 degrees (fig. 7) (Daly and others, 2004).

For most locations within the Salinas Valley watershed, the average annual reference evapotranspiration (ETo) rate, calculated by the California Irrigation Management Information System (CIMIS), exceeds average annual precipitation (CIMIS, 2005). The ETo rate is the lowest in the northern-most part of the valley (the coastal region), averaging about 39 to 46 inches per year. Monthly ETo varies seasonally from minimum values 1 to 2 inches for January to a maximum of about 6 inches for July. Higher ETo rates of about 49 to 50 inches per year occur in the upland areas on either side of the valley. The highest ETo rates of 53 to 62 inches per year occur in the lowlands defining the valley floor in the central and southern parts of the Salinas River watershed. Average monthly ETo rates for these locations vary from 1 to 1.5 inches for December to 8 to 9 inches for July (CIMIS, 2005).

Land Use

Land cover within the Salinas River watershed, as mapped by the 2011 National Land Cover Data (NLCD) (Jin and others, 2013), consists primarily of native vegetation, with 36 percent of the land area covered by grasslands, 29 percent covered by shrub-land, and 14 percent covered by forests (deciduous and evergreen)(fig. 8). Developed lands, including open space as well as low, medium, and high intensity developed residential, commercial, industrial, and transportation land uses, covers about 7 percent of the total land area. Farmland, including pasture, hay, and cultivated crop lands, covers about 10 percent of the total land area. Barren soil and bedrock areas cover about 2 percent of the land area, and open water covers only about 0.5 percent of the land area.

Geologic Structure and Units

The Salinas Valley Groundwater Basin is a structural basin (i.e., formed by tectonic processes) consisting of as much as 10,000 to 15,000 feet of terrigenous and marine sediments overlying a basement of crystalline bedrock. The sediments are a combination of gravels, sands, silts, and clays that are organized into sequences of relatively coarse-grained and fine-grained materials. When layers within these sequences are spatially extensive and continuous; they form aquifers that are relatively coarse-grained and are able to transmit significant quantities of groundwater to wells, and aquitards that are relatively fine-grained and act to impede the movement of groundwater. Figure 3 is a generalized schematic cross-section across the Pressure Subarea illustrating its general hydrostratigraphy (Baillie and others, 2015b). The geologic units that comprise the aquifers and confining units above the Monterey Formation include the recent Alluvium, Aromas Formation, Paso Robles Formation, and Purisima Formation. The spatial extents of these units vary across the Salinas Valley (Feeney and Rosenberg, 2003; Kennedy/Jenks, 2004; Hanson and others, 2002).

Aquifer System

The main water-bearing deposits in the study area are divided into four to five aquifer systems that are separated by regionally extensive confining units (fig. 3). These include the saturated portions of the younger and older alluvium that represent the shallow aquifer that is underlain by the Salinas Valley Aquitard (fig. 3). These units overlie the Pressure 180-Foot Aquifer and the Pressure 180/400-Foot Aquitard, which in turn overlies the Pressure 400-Foot Aquifer, and the underlying aquitard. The deepest units are the Pressure Deep Aquifers that also alternate with aquitards and fine-grained interbeds that may be related to the Purisima Formation (fig. 3). These aquifer systems are similar to the major systems that were delineated in other coastal alluvial aquifer systems such as the Ventura-Oxnard region (Hanson and others, 2003) and Santa Barbara region to the south (Hanson and Sweetkind, 2014), and Pajaro Valley (Hanson and others, 2014) to the north.

Relevance and Benefits

This project is directly relevant to two science strategies presented in USGS Science in the Decade 2007-2017 (USGS, 2008), Water Census of the United States (USGS, 2007), and Climate Variability and Change. The study will benefit local water users by providing an improved understanding of the source, use, and movement of conjunctively used water. The combination of surface water, precipitation, and existing production wells provide a network of water supply to satisfy the demand from agriculture, municipal-industrial, domestic and other water uses. New integrated hydrologic models will provide the tools needed to predict the potential effects of continued groundwater overdraft and related seawater intrusion. Benefits to the nation include quantifying the resources of a major aquifer, and developing the information and tools necessary to assess and manage a water resource used for drinking-water supply and irrigation. The study will utilize recently developed model features of the MODFLOW-based “One Water” integrated hydrologic model (MF-OWHM) (Hanson and others, 2014) to simulate conjunctive use of water and linkages to reservoirs and seawater intrusion. This project will also develop a formal connection between the precipitation-runoff models developed with the Hydrologic Simulation Program – FORTRAN (HSPF) (Bicknell and others, 1997) and the Basin Characteristics Model (BCM) (Flint and Flint, 2007 a,b,c,) and MF-OWHM to provide complete coupled hydrologic simulations of ungaged runoff for regional-scaled hydrologic models. In addition to simulating runoff and streamflow, the precipitation-runoff models will provide estimates of recharge, soil moisture, and evapotranspiration for areas within the Salinas River drainage basin but outside of the

MF-OWHM domain, and will also provide an efficient coupling with historic and potential future climate inputs, including monthly, daily, and hourly records and model outputs.

Approach

The proposed study will include five main tasks: (1) geohydrologic model development, (2) surface-water hydrologic models development, (3) development of an integrated groundwater/surface-water hydrologic model, (4) analysis of water availability, and (5) report/information preparation. The previously compiled geologic information and databases will be used to develop the geohydrologic framework of the Salinas Valley. This framework will include the creation of a texture model and related layering and structural barriers to groundwater flow. Climate, land-use, geologic, hydrologic, and water-quality data previously compiled and assembled into databases and a Geographic Information System (GIS) will be used with current monitoring networks to develop GIS coverages, models, and comparison information needed to calibrate hydrologic models.

Geohydrologic and hydrologic models will be developed as part of this study to more accurately assess and simulate the storage and flow of water in Salinas Valley. The culmination of the data and models will the development of the Salinas Valley Integrated Hydrologic Model (SVIHM) using MODFLOW-OWHM (MF-OWHM) (Hanson and others, 2014). The SVIHM will be used to analyze changes in the use and movement of water throughout the landscape, surface-water networks and aquifers, as well as changes in groundwater storage and related seawater intrusion in different hydrologic regions of Salinas Valley caused by current and projected water use and potential climate change.

Tasks 1-3: Models Development

Geohydrologic and hydrologic models will be developed as part of this study to more accurately assess and simulate the storage, use, and movement of water in the Salinas Valley. The models will be developed utilizing the data compiled and collected in recent studies by the County of Monterey and their consultants. Currently there is no plan to collect any new additional data beyond the ongoing monitoring by the USGS and Monterey County.

Task 1 --Geohydrologic Model

A geohydrologic model will be developed to delineate the three-dimensional geohydrologic framework of the Salinas Valley (Objective 1). The model will incorporate information from existing drillers and geophysical logs, cross sections, and geologic maps. The geohydrologic model will be constructed in cooperation with the USGS Geologic Discipline Western Earth Surface Processes Group (Vickie Langenheim ,Don Sweetkind, and Emily Taylor) and leverage results from a previous regional project to analyze basins adjacent to the San Andreas Fault System called the Coast Ranges Basins Project from Santa Barbara up to Santa Cruz, California. The geohydrologic model will delineate the volumes of the aquifer system bounded by faults and depositional or formational boundaries based on previous studies of the Salinas Valley geohydrologic framework and stratigraphy (Kennedy/Jenks, 2004; Feeney and Rosenberg, 2003) and recent USGS Geologic investigations (Taylor and Sweetkind, 2014; Colgan and others, 2012; Langenheim and others, 2012). The framework model will define the aquifers and select confining units and their relation to faults and folds that will represent the model layers in the SVIHM. Estimates of textural data from drillers and geophysical logs will be used to spatially distribute the hydraulic properties of the aquifers, similar to previous USGS regional hydrologic models (Hanson and others, 1990; Hanson and Benedict, 1993; Hanson and others, 2003, 2004, 2014; Sweetkind and others, 2013; Phillips and others, 2007; Faunt and others, 2009a,b). The MCWRS lithologic database will be imported into our Access database for deriving the equivalent textural data needed for each model layer. This textural data will be filtered between the surfaces of each model layer and then used to create 2-dimensional lateral estimates of texture within each model layer. These estimates of texture will be used to estimate the percent coarse-grained and fine-grained sediments for each model layer, which will form the basis for estimating the hydraulic properties for the different aquifers in the hydrologic model within selected sedimentary subregions, similar to the recently developed Pajaro Valley Hydrologic Model (Hanson and others, 2014) and Cuyama Geologic and Textural Model (Sweetkind and others, 2013). The textural data will be combined with the hydraulic property values from the previous Salinas Valley Integrated Groundwater Surface water Model (SVIGSM) (MW, 1997) to provide initial distributions of aquifer hydraulic properties.

Task 2 -- Surface-Water Hydrologic Models

Precipitation-runoff models will be linked with an integrated hydrologic flow model to simulate peripheral recharge as runoff and potential underflow to groundwater flow in the Salinas Valley (part of Objective 2, Objectives 5 and 6). The development of a precipitation-runoff model using HSPF has been initiated by Monterey County (Baillie and others, 2015a) as part of this ongoing model development project (fig. 9). The HSPF model was extended to include the entire Salinas Valley watershed, which covers Monterey and portions of San Luis Obispo Counties; further development of this model will continue at this scale, but may require two subregional models for Monterey and San Luis Obispo County watersheds if HSPF cannot accommodate this large of an area. The HSPF model will be used to simulate daily and hourly streamflow for the Salinas River and its tributaries over a continuous multi-year simulation period. The HSPF model will also be used to develop estimates of water budgets, including soil moisture, evapotranspiration, recharge, and stream baseflow for sub-drainages. In addition to the HSPF model, the BCM (Flint et al., 2007a,b,c) will be used to develop monthly and daily spatially-distributed climate inputs (precipitation, air temperature, and potential evapotranspiration) and to simulate a monthly and daily time series of ungaged runoff and recharge from the mountains that surround Salinas Valley within the entire watershed. While the Baseline Model, that will be used as a basis of comparison, spans the period

WYs 1967-2014, the calibration of this model will extend further back in time, in part, on the inflow and outflow stream gage data on the Salinas River between 1948 and 2014. The runoff from this watershed-scale model will be linked to a hydrologic model of the groundwater basin. The estimates from both HSPF and BCM will be compared and will provide a useful perspective and alternatives for simulation of historical periods as well as the proposed Salinas and Carmel River Basins Study under the WaterSmart program of the U.S. Bureau of Reclamation (USBR, 2015).

Hydrologic Simulation Program-Fortran (HSPF) – The HSPF is a comprehensive surface-water and water-quality modeling code that uses long-term continuous meteorological data to simulate hydrologic processes, including rainfall-runoff from land surfaces and water bodies, soil moisture, evapotranspiration, recharge, interflow, and baseflow discharge from soil zones and groundwater reservoirs to streams (Bicknell and others, 1997). The HSPF model will represent the Salinas River watershed using an interconnected drainage network of pervious and impervious hydrologic response units (PERLNDs and IMPLNDs) and stream and reservoir segments (RCHRESs) (Hevesi and others, 2011). The hydrologic response units (HRUs) will be defined on the basis of topography, hydrography, land cover, soil properties, and geology. The HSPF model will provide a basis for estimating surface-water runoff and potential groundwater underflow (from both stream channel infiltration and mountain-block recharge) from the ungaged HUC-12 watersheds surrounding the Salinas Valley (fig. 9). These results will be used to define monthly surface-water inflows for the Streamflow Routing package (SFR) network for ungaged inflows and also to define recharge boundary conditions for locations potentially affected by mountain block recharge. The HSPF model will be used to simulate in-stream surface water flows and gaining and losing stream reaches for drainages outside of the SVIHM. In addition to water flow, the HSPF code can be used to model water transport processes to simulate water temperature, advective and reactive constituents, pathogens, nutrients, and sediment erosion and deposition (Bicknell and others, 1997; Hevesi and others, 2011). The parts of the HSPF model that overlap the SVIHM model stream network may also be used as forms of observations for the SFR Package simulation of streamflow throughout the Salinas Valley Floor within Zone 2C. Because HSPF does not simulate the groundwater interaction component these will be considered as "soft" observations for reaches where baseflow and significant surface-water/groundwater interactions are known to occur. With the HSPF simulations spanning the entire Salinas Valley watershed, including the San Luis Obispo portions, the HSPF results will also be used to help refine the simulated estimates of recharge and runoff made with the BCM model for the historical periods so that the BCM will be potentially more accurate when applied to the Climate Change scenarios evaluated in the U.S. Bureau of Reclamation (USBR) Water Smart evaluations of climate change and sustainability (USBR, 2015).

Basin Characterization Model (BCM) – The BCM uses a deterministic water-balance approach that includes the estimation of spatially and temporally-distributed precipitation, air temperature, solar radiation, and potential evapotranspiration. The BCM simulates soil-water storage, actual evapotranspiration, runoff, and in-place recharge as a function of climate, vegetation, soil properties, soil thickness, and bedrock permeability (Flint and others, 2004). Unlike HSPF, the BCM does not rout runoff as overland flow and streamflow through a network of interconnected reach and reservoir segments, does not explicitly simulate surface-water infiltration and recharge along stream reaches, and does not simulate water transport processes. Similar to HSPF, the BCM will be used with available and comparable GIS data (digital elevation model, geology, soils, vegetation, precipitation, and air temperature maps). The BCM can be used to identify locations and climatic conditions that allow for excess water, quantifying the amount of water available either as runoff or as in-place recharge on a monthly and daily basis, and allows inter-basin comparison of recharge mechanisms. A critical objective of applying the BCM to the Salinas River watershed is the estimation of spatially and temporally distributed climate inputs and the simulation of potential evapotranspiration based on the climate inputs and topography. In general, available climate records within and adjacent to the Salinas River watershed are sparsely distributed in many areas, and contain significant data gaps. The BCM results will provide a high-resolution and continuous time series of spatially-distributed climate and potential evapotranspiration using interpolation methods and inputs consisting of monthly PRISM maps, topography, and available climate records. Similar to HSPF, the BCM will use the time series of climate inputs to develop a time-series analyses of basin recharge in order to provide more accurate estimates of recharge because of the non-linear influence of precipitation on recharge. The Salinas Valley has significant year to year variability in precipitation which can lead to highly variable recharge. Wet years greatly influence the sequence of years with significant recharge. The Central California area is greatly influenced by the Pacific Decadal Oscillation, occasional Atmospheric Rivers, and El Niño and La Niña events. These together have a marked effect on precipitation, runoff, and related recharge. The BCM estimates of historical inflows and recharge from the surrounding HUC-12 watersheds will also be used along with the HSPF results to provide input to the SVIHM model. Combined with the HSPF, the results from the BCM will provide Monterey and San Luis Obispo County with a comprehensive estimate of precipitation throughout the Salinas Valley and how much of this water is available for capture or ecological uses.

Task 3 – Salinas Valley Integrated Hydrologic Flow Model (SVIHM)

"One Water" Integrated Hydrologic Flow Model (MF-OWHM) – This MODFLOW-based integrated hydrologic flow model will be developed using MF-OWHM (Hanson and others, 2014), which is a three-dimensional finite-difference fully integrated hydrologic flow model (part of Objective 2, Objectives 5 and 6). The model simulates flow where all the water is simulated all the time everywhere in the active model region. Inflows and outflows related to stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated across the groundwater system, surface-water network, and landscape, and they are fully coupled to represent all of the use, movement and potential reuse of water.

The model represents the use and movement of water in a supply-and demand framework using the Farm Process (FMP) (Schmid and others, 2006; Schmid and Hanson, 2009; Hanson and others, 2014) to simulate agricultural processes, the Unsaturated Zone Flow package (UZF1) (Niswonger and others, 2006) to simulate the delay of recharge through a thick unsaturated zone, the Streamflow Routing package (SFR2) (Niswonger and Prudic, 2005) to simulate streamflow routing, the Multi-node Well package (MNW2) to simulate wells screened over multiple aquifers (Halford and Hanson, 2002; Konikow and others, 2009), the Seawater Intrusion package (SWI) to simulate seawater intrusion (Bakker and others, 2013), the Surface-Water Routing process (SWR) to simulate canal flows (Hughes and others, 2012), and the Drain package (DRT) to simulate drains and drain return flows to capture agricultural discharge and reuse (Harbaugh, 2005). The model will also use the new reservoir linkage with the Surface-water Operations Process (SWO) developed by the USBR/USGS (Fergusen and others, 2015, 2016) to further evaluate the modifications to releases and reservoir operations under the new water management plans.

The SVIHM will be constructed on the structure and layering delineated from the geohydrologic model (Task 1) and calibrated to historical water-level and streamflow/diversion flows, and water-use data for the period of 1939-2014 (Task 3). The hydrologic model will cover the extent of Zone 2C in the Salinas Valley in Monterey County and near shore regions (fig. 5). The inflows from surrounding watersheds will be modeled and calibrated with rainfall-runoff models (HSPF/BCM) and provide inflows to the valley-wide stream and canal network. All specified flows and heads will be specified on daily time steps within monthly stress periods for the final model configuration, but may use bimonthly time steps and monthly stress periods and a subset historical period for model calibration.

After historical calibration the model will be linked to the new SWO to verify that historical operational demands can be simulated for projections of future hydrologic supply and demand subject to climate variability and change. Naciemento Reservoir began operations in 1957 and San Antonio Reservoir came on line in 1967. The SVIHM will be calibrated to historical conditions starting with the period when both reservoirs were operating, October, 1967, and ending in September, 2014. This baseline model simulation will provide an analysis of the historical water use and provide a means to analyze future water availability under different water-use scenarios or different water projects that may shift the source, use or movement of water or rescale the components of supply and demand for selected subregions.

The simulation of the Seaside Basin Model requires either simulation of the boundary between the models as a General Head Boundary, use of a child model for the Seaside Basin Model, or treating the two models as adjacent models. A refinement of these approaches that will reduce the potential for multiple results in this region will be selected during the project. The approach taken for the Salinas Valley Boundary in the Seaside Basin Model (Hydrometrics, 2009) was to use a string of constant heads derived from the simulated heads from the previous Salinas Valley model (SVIGSM, MC, 1997). Because the extent of the Seaside Basin Model includes a portion of the Salinas Valley, we may be able to extract simulated heads from the interior of the Salinas Basin Model corresponding to the extent of the Salinas Valley instead of using time-varying fixed heads derived from the SVIGSM model from within the Salinas Basin Model.

The initial historical model calibration will require additional updates and analysis for federal fiscal years (FFYs) 2017-19. Along with report and model documentation, these additional updates and analysis will be phases of work that will be completed in these years, and are not included as part of the current budget for FFYs 2016-17. The SVIHM will be constructed as a "self-updating" model, so part of the task in FFY 2017 will be to complete the data stream structure for the self-updating temporal and spatial components of the model. In concert with this effort, the USGS will train Monterey County staff scientists and engineers to develop these updates themselves and learn how to use the "self-updating" data structures and scripts. In FFY 2018, there will be a combined USGS/Monterey County effort for the update, and in FFY 2019 the Monterey County staff will make the updates with oversight from the USGS. The goal of this process is that the Monterey County staff will be able to update, maintain, run, and analyze the results from SVIHM and the related surface-water models.

Task 4: Analysis of Water Availability

The SVIHM hydrologic model developed in Task 3 will be used to evaluate how historical water-use has affected overdraft, seawater intrusion, and the availability of surface water and groundwater in the Salinas Valley (Objectives 3, 4, 5, and 6). The SVIHM could also be used to evaluate potential land-use and water-use scenarios include changes in cropping patterns, increased urbanization, extension of the Castroville Seawater Intrusion Project (CSIP, http://www.mrwpca.org/about_facilities_water_recycling.php) reclaimed water reuse project, and potential artificial recharge. In addition to anthropogenic factors affecting the hydrologic system, the SVIHM could be used to evaluate the hydrologic effects of changes in native vegetation resulting from fire or climate change. The USGS will meet with water managers and other stakeholders to help define the water-use and climate scenarios that will be formulated and completed in the related USBR Water Smart study (USBR, 2015) that will be the focus of climate change analysis. The formulation and assessment of these scenarios will provide the stakeholders with a clearer picture of potential options for mitigating differences between supply and demand, the overall limits and climate-cycle limits of the resources, the connection between the supply and demand components of water use, potential alternative uses and reuses of water, and the potential availability of the water resources under current and alternative climatic and cultural water-use scenarios.

Of particular importance will be the use of the hydrologic model to analyze changes in groundwater and surface-water flow, groundwater storage, and seawater intrusion in the different zones of the Salinas Valley caused by current and projected changes in land and water use. The geohydrologic and hydrologic models will be used to estimate the volume of water resources that have been depleted, still remain, and may be unusable owing to poor water quality and seawater intrusion. A specific analysis of seawater intrusion will be estimated using the sharp interface approximation simulated using the SWI package of MF-OWHM and compared to the composite estimates of intrusion for the upper aquifers (fig 10a) and lower aquifers (fig 10b) for selected time periods between 1969 and 2013. Based on historical simulation and analysis we will create a baseline 2014 Seawater Intrusion (SWI) and groundwater level (GWL) contour maps from Monterey County. In subsequent years updates will be made to the model input in a "self-updating" model data structure. These updates will occur annually for 2015 through 2019. With each update new SWI and GWL maps will be constructed from simulated and measured data in cooperation with Monterey County staff.

The Settlement agreement requires model results extended to 2030, which is an additional 16 years past the historical calibration period that ends in 2014. The model results will also be extended to 2042, which is an additional 29 years past the historical calibration period, in order to coincide with timelines for achieving groundwater sustainability as set forth in the Sustainable Groundwater Management Act (SGMA). These model projections will assume 2014 land use and reuse historical climate, streamflow, and reservoir releases mirrored back from the historical period to 1998 for the Settlement Agreement projection and back to 1985 for the SGMA projection. The 2012-2014 land use will be constructed based on a variety of sources that include local county ranch maps, the California pesticide databases, CropScape, and previous land use and parcel maps. For example, a similar analysis was completed for Pajaro Valley for existing projects projected as a baseline analysis, prior to analysis of new projects and policies developed under the new Basin Management Plan (Hanson et al., 2014b). Similarly, projections were made for bounding supply and demand alternatives for Cuyama Valley to assess the limits and effects of these bounding alternatives of reduced pumpage and reduced agricultural demand (Hanson and Sweetkind, 2014). Additional climate change analysis will be performed with the SVIHM and related rainfall-runoff models during the Water Smart project with USBR.

Future use of optimization techniques could also facilitate the analysis of land use and related groundwater pumpage or water reuse (Ahlfeld and others, 2005; Barlow; 2005). These types of assessment of alternative water use and future climate scenarios also are similar to the analysis performed for the Santa Clara-Calleguas Basin in Ventura County (Hanson and others, 2003; Hanson and Dettinger, 2005), in adjacent Pajaro Valley (Hanson and others, 2014), and in the Central Valley (Hanson and others, 2013). This analysis to find the best possible proportions of various supply and demand components could be an additional phase of the project after new policies and projects are identified by the County and stakeholder groups, but is not included as a deliverable under this current proposal structure and scope.

The three-dimensional character of the aquifer flow and hydrochemistry could constrain future or continued water use in the valley. For example, if sustained poor water quality from seawater intrusion is initiated in the Deep Aquifer then the estimates of useable water in storage could be reduced significantly. The effect of seawater intrusion subject to reduced coastal pumpage could also be evaluated similar to the analysis performed in Pajaro Valley. Additional pumpage of the deeper aquifers may also be subject to other constraints such as the initiation of land subsidence. For example, this was the case in the Oxnard Plain where the policy to switch to deep pumpage resulted in land subsidence and subsequently a reversal of this policy after model analysis (Hanson and others, 2003).

Task 5: Report/Information Preparation

A USGS Scientific-Investigation Report (SIR) summarizing the hydrologic model (SVIHM), hydrologic budget, and results from the linked precipitation-runoff/hydrologic-flow model will be published by September 30, 2017. An SIR reports documenting the geologic framework would also be completed in FFY 2017. A USGS Fact Sheet briefly summarizing the water-availability analysis from the model results will help to answer the stakeholder's questions of zone interaction and would provide the technical information for stakeholders to pursue a new revised basin-wide Basin Management Plan to protect and sustain water resources of the basin as required by SGMA. If needed by Monterey County, a public web site also will be developed in cooperation with the County of Monterey to allow direct access to analysis and model data sets for SVIHM of Salinas Valley (USGS approved Web page). The additional GIS deliverables will be developed with assistance from Monterey County staff and will be completed in phases for the end of the historical period for 2014, and after subsequent updates for 2015-18 during FFYs 2016-19. In addition, each of the hydrologic models developed as part of this project will be archived in the USGS Model Archive based on the current USGS standards for Fundamental Science Practices and Water Mission Area model archiving policies/guidelines. Meta data created as part of the model development process will be archived with the models. Even though USGS model archives are not publicly accessible, the archived models will be publically available (upon request) following publication of the respective model reports.

Staffing

The project chief will be Randy Hanson. Scott Boyce, Joe Hevesi, Lorrie Flint, Alan Flint, Wes Henson, D.J. Martin, Jon Traum, and Celia Rosecrans from the USGS California Water Science Center (CAWSC), and Andre Richie and Amy Galanter from the USGS New Mexico Water Science Center (NMWSC) will be part of the team that will complete the project. Development of the geologic framework will include the participation of Don

Sweetkind and Emily Taylor from the USGS Geologic Discipline. Additional help will be provided by Ian Ferguson of the U.S. Bureau of Reclamation (USBR) and his colleagues through the USBR Water Smart project.

Deliverables

The project will deliver the following specific items:

(1) **GIS Products** (with metadata):

(a) FFY 2016
Baseline 2014 Seawater intrusion (SWI) and groundwater-level (GWL) contour maps;
2030 model results as required by the Settlement Agreement;
(b) FFY 2017
2015 SWI and GWL contour maps, Fall 2016;
2016 SWI and GWL contour maps, Spring 2017;
(c) FFY 2018
2017 SWI and GWL contour maps, Spring 2018;
2018 SWI and GWL contour maps, Fall 2018;
(d) FFY 2019
2042 model results as required by SGMA

(2) **Reports**:

Two USGS Scientific Investigations Reports (SIR) will individually summarize the geohydrologic framework and the historical baseline results from the suite of hydrologic models. A USGS Fact Sheet summarizing the geohydrologic framework, changes in water and land availability and use, as well as hydrologic and landscape budgets that are derived from the more complete Hydrologic SIR report. The USGS staff will also help to build a "user's manual" for maintaining the self-updating temporal components of the hydrologic model inputs so that the County or MCWRA staff can maintain and update the model and help to produce more current hydrologic and landscape budgets and related maps.

Cooperators/Collaborators

The cooperating agency will be the County of the Monterey. Howard Franklin and his staff at Monterey County Water Resources Agency (MCWRA) are tasked to develop this study and address the water-resource issues in Salinas Valley as part of the court settlement (MC, 2010). The Western Earth Surface Process Team of the USGS Geologic Discipline will contribute to geologic analysis, and assist with hydrogeologic framework model construction. The USGS will also contribute additional water chemistry analysis, and interpretation of selected water-chemistry features related to seawater intrusion and agricultural return flows in the Salinas Valley that will include the data collected by local agencies, previous land mark geochemical studies (e.g. Vengosh and others, 1994, 2002) and recent geochemical data of water quality for water supply (Belitz and others, 2003). This project will be supplemented by the USBR Water Smart project scheduled for FFYs 2016-18 that will cover most of the climate change and alternative land and water use/reuse project, scenario, and policy analysis. The majority of the work on the Water Smart project will be a funded partnership between USGS and USBR in collaboration with local staff scientists and engineers from Monterey County and Monterey County Water Resources Agency, and local stakeholders.

Budget

The budgets for the different study tasks are listed below by Federal fiscal year (FFY) (table 1). The total cost to Monterey County for FFFYs 2016-17 is $757,300. The potential additional USGS federal matching funds (FMF) may be available for FFFYs 2017-19. The potential additional FMF that could potentially be available for FFY 2017 is about $68,300, which brings the total potential FFYs 2016-17 budget to $825,600. Additional budget estimates for Monterey County and FMF cost shares will need to be made for FFYs 2018 and 2019 after completion of the initial products and deliverables. However, the cooperative agreement signed with the County of Monterey will span the entire period of the proposed project for FFYs 2016 through 2019.

Table 1. Detailed cost For Monterey County of work-plan tasks[1]

[1] All funding estimates reported in Federal Fiscal Years (FFY) October 1 – September 30.

[2] Web Products not included in FFYs 2016-17 Cost Estimates

[3] Selected products occur in FFYs 2018-19 and costs are not estimated for these additional deliverables/products.

STUDY COMPONENTS	**TASKS**	**FFY 2016**	**FFY 2017**	**FFY 2018**	**FFY 2019**	**Total Cost**
Model Development	Task 1—Geohydrologic Framework Model	$89,300		====	====	$89,300
	Task 2—Surface-Water Hydrologic Models	$263,300		====	====	$263,300
	Task 3—SVIHM	$214,400	$5,900	====	====	$220,100
Total Cost Model Development		**$566,800**	**$5,900**			**$572,700**
Water Availability	**Task 4—Analysis of Water Availability**	**$21,900**	**$70,000**	====	====	**$91,900**
Reports/GIS/Web[2]	Task 5. -- SIR Geohydrologic Framework	====	$29,200	====	====	$29,200
	Task 5. -- SIR Hydrologic Models	8700	$48,900	====	====	$57,600
	Task 5. -- Water Availability Fact Sheet	====	====	====[3]	====	
	Task 5. -- GIS Products		$5,900	====[3]	====[3]	$5,900
Total Cost Reporting		**$8,700**	**$84,000**			**$92,700**
Total Costs		**$597,400**	**$159,900**			**$757,300**

Work Plan

This proposed study will require parts of four Federal Fiscal Years (FFYs) to complete. A generalized work plan (by quarter, with I = Fall, II = Winter, III = Spring, and IV = Summer) is as follows:

Quarter =>	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Fiscal year =>	FY16	FY16	FY16	FY17	FY17	FY17	FY17	FY18	FY18	FY18	FY18	FY19	FY19	FY19	FY19
Project Task	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Task 1-Geologic Framework Model															
Estimate Geologic Surfaces	■														
Construct Equivalent Model Layers/Facies Maps	■	■													
Geologic Framework Report			■	■	■	■	■								
Task 2a - Rainfall Runoff Model (HSPF)															
Compile & Process HRU Climate Data	■														
Compilation of Surface-water Data	■														
Develop HSPF Input and Observations	■														
Construct and Calibrate HSPF model	■	■													
Annual Model Update			■	■			■	■			■	■			
Task 2b - Climate Data and BCM Model															
Compile & Process Gridded Climate Data	■														
Compilation of Surface-water Data	■														
Develop BCM Input and Observations	■														
Construct and Calibrate BCM model	■	■													
Annual Model Update			■	■			■	■			■	■			
Task 3 - SVIHM Modeling															
Build Monthly BCs and full Farm Process	■	■													
Rebuild Model Layers & Geohydrolic framework	■	■													
Develop SVIHM Input and Observations	■														
Calibrate model	■	■													
Annual Model Update			■	■			■	■			■	■			
Task 4 - Analysis of Water Availability															
Add Surface-water Operations	■	■	■	■											
Add other Updates/Upgrades	■	■	■	■	■										
Perform 2030 Analysis (Settlement Agreement)	■	■	■	■	■										
Perform 2042 Analysis (SGMA)	■	■	■	■	■	■	■								
Task 5 - Reporting															
Scientific & TAC Presentations			■				■				■				■
GIS Products (SWI and GWL)		■	■		■	■	■		■	■	■		■	■	■
Geologic Framework Report						■	■								
SVIHM Model Report				■	■	■	■								
Water Availability Fact Sheet						■	■	■	■						
Model Transfer to Coopertors			■				■				■				■
Model and Project Records Archive	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

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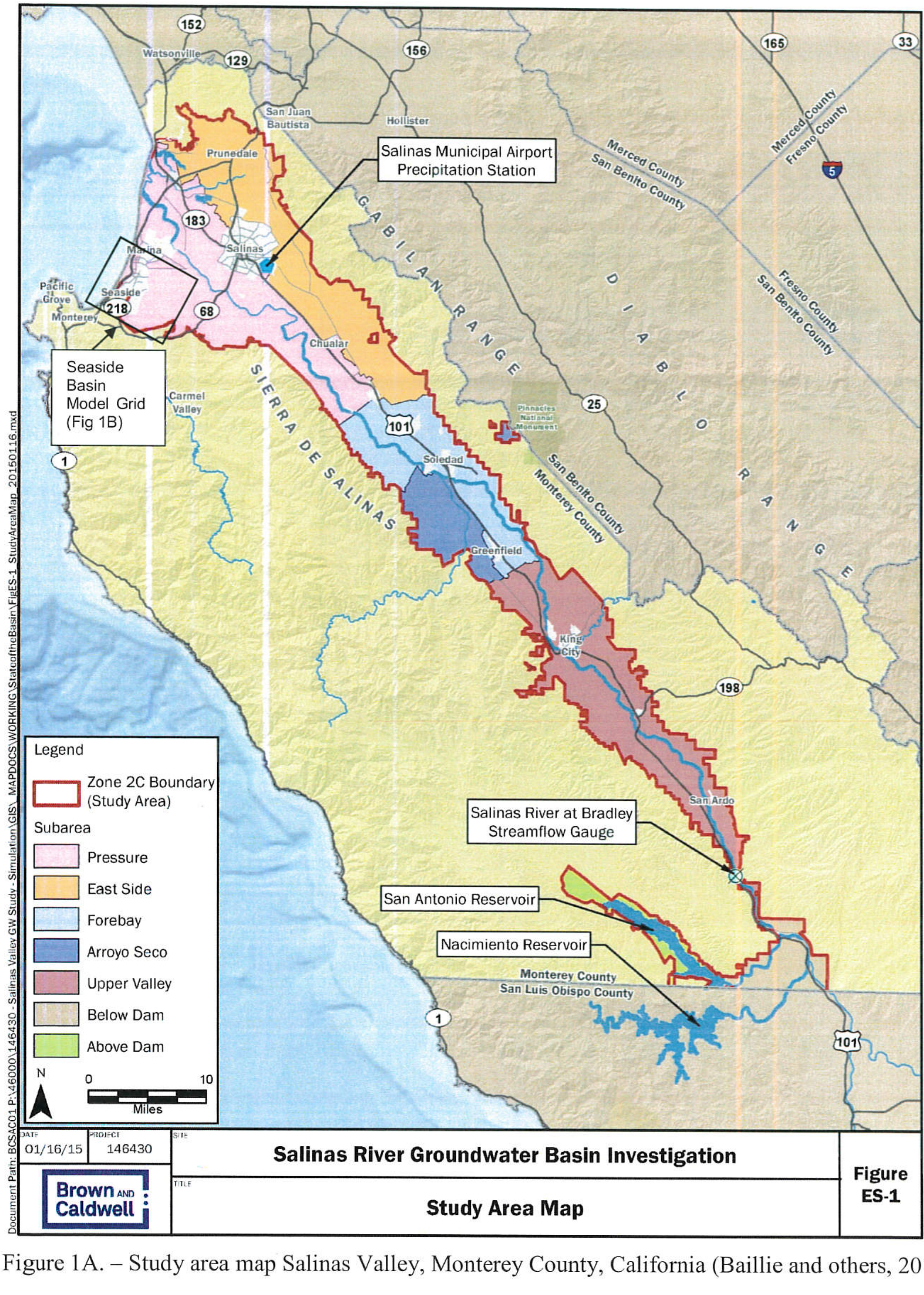

Figure 1A. – Study area map Salinas Valley, Monterey County, California (Baillie and others, 2015b).

Figure 1B. –Extent of subregional Seaside Model grid (Hydrometrics, 2009).

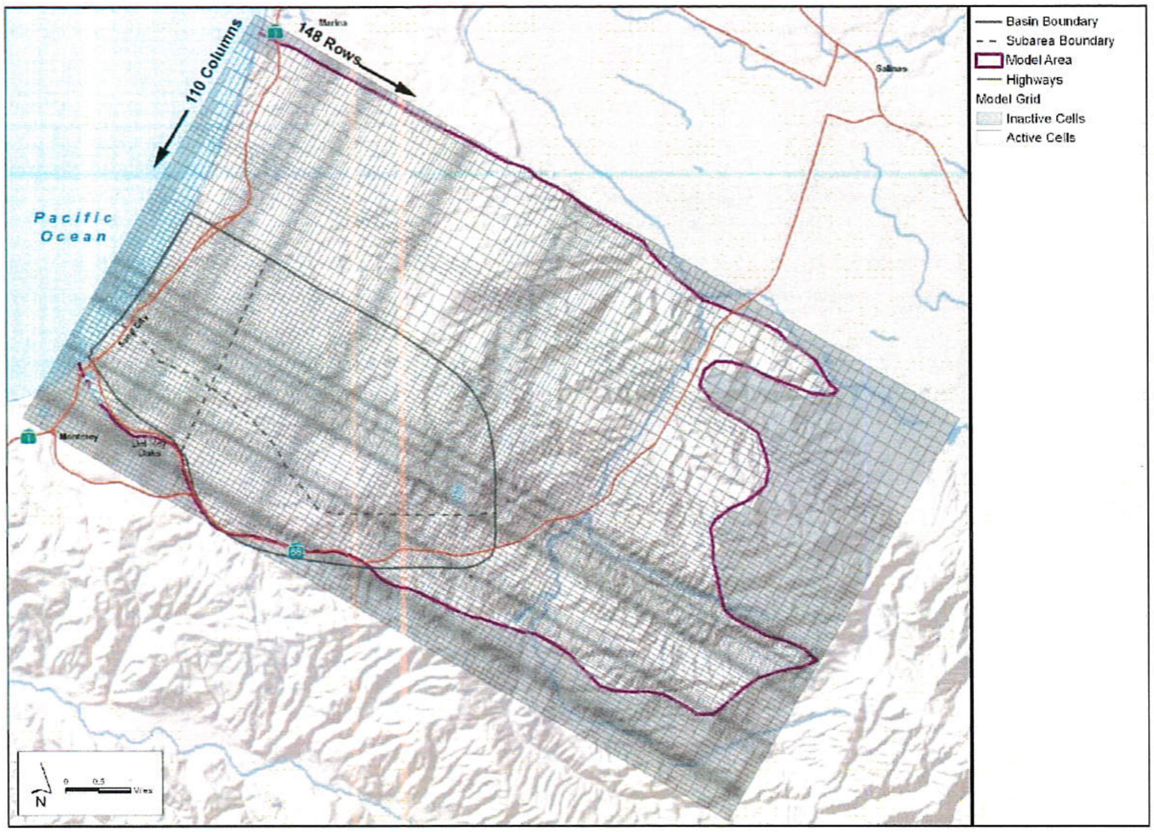

Table ES-1. Water Budget Components by Subarea

Subarea	Average of WY 1958-1994 (from MW, 1998)				2013 Groundwater Pumping (reported by MCWRA)[c]
	Inflow		Outflow		
	Natural Recharge[a]	Subsurface Inflow	Groundwater Pumping[b]	Subsurface Outflow	
Pressure	117,000	17,000	130,000	8,000	118,000
East Side	41,000	17,000	86,000	0	98,000
Forebay	154,000	31,000	160,000	20,000	148,000
Upper Valley	165,000	7,000	153,000	17,000	145,000

Note: All estimates in acre-feet per year (afy).

[a] *Includes agricultural return flow, stream recharge, and precipitation.*

[b] *Groundwater pumping as reported by MW (1998) is presented to provide a complete water budget.*

[c] *The 2013 groundwater pumping totals are provided for comparison.*

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Table 1. -- Summary of Hydrologic Budget estimates for 1998 and 2013 (Baillie and others, 2015b; MW, 1998)

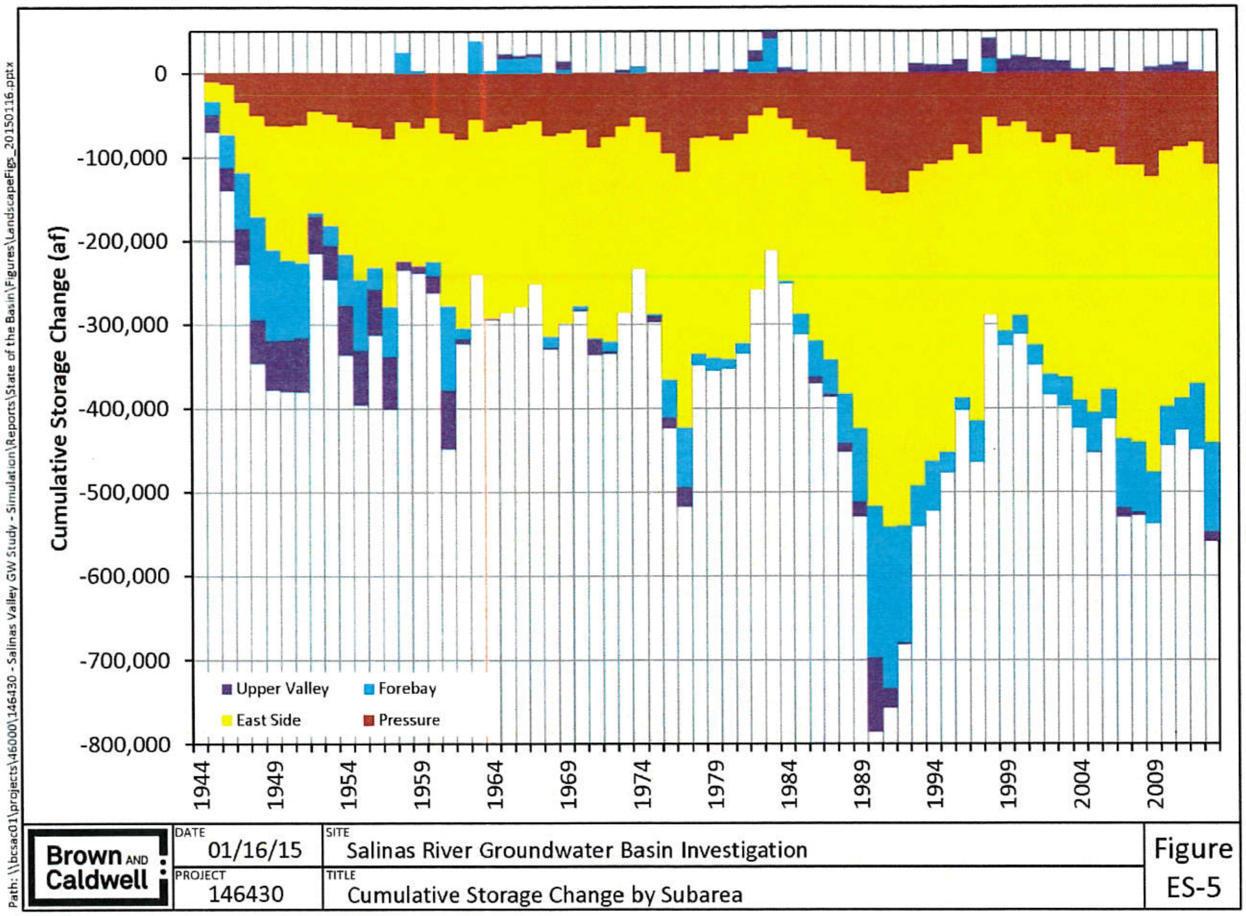
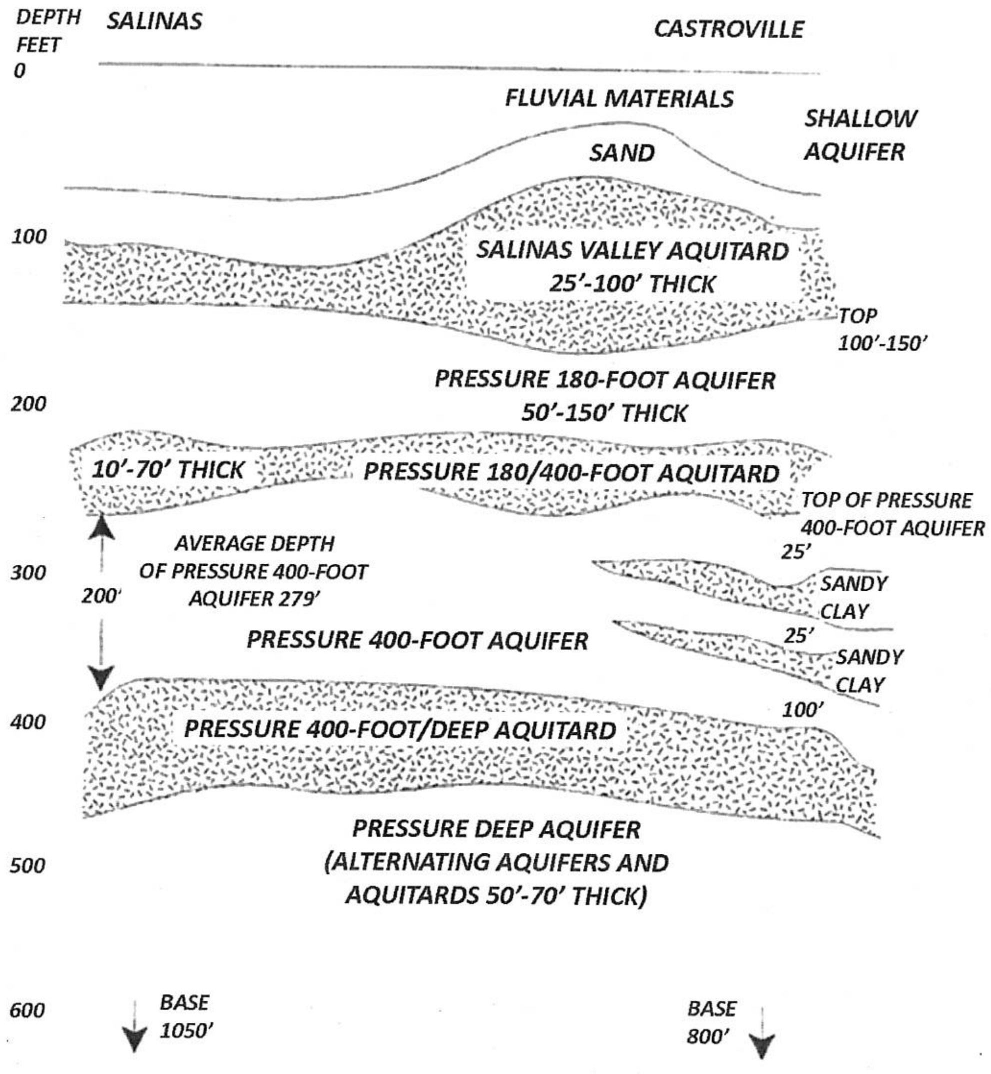


Figure 2. – Cumulative change in storage estimated for the subregions of the Salinas Valley (Baillie and others, 2015b).



Modified from Hall and Earthware of California, 1992.

Brown AND Caldwell	DATE 01/16/15	SITE Salinas River Groundwater Basin Investigation	Figure ES-2
	PROJECT 146430	TITLE Conceptual Hydrostratigraphic Section in the Pressure Subarea	

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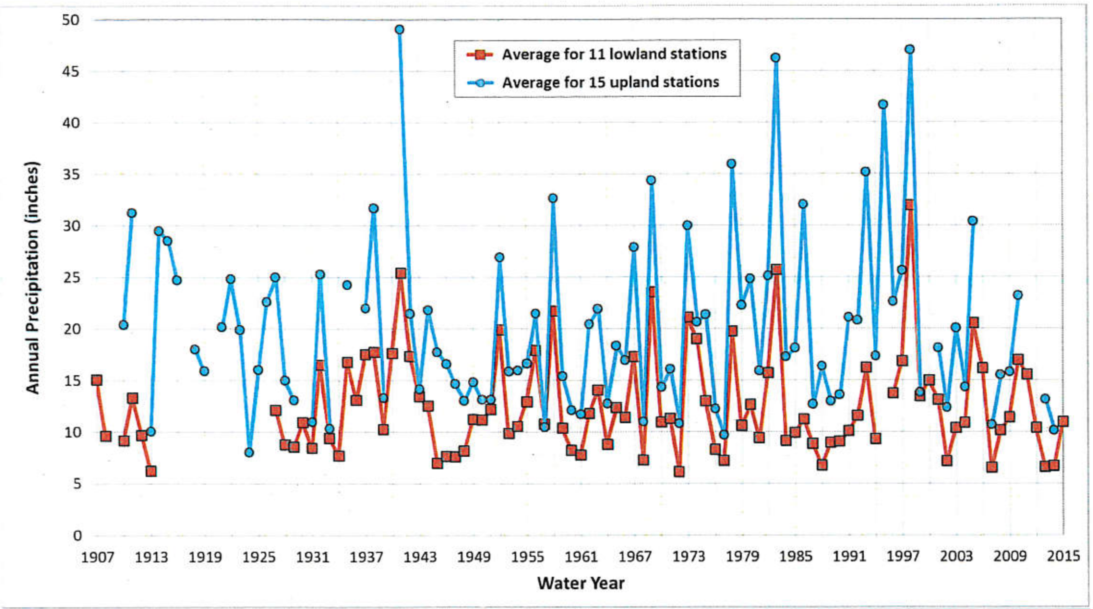
Figure 3. – Diagrammatic vertical profile showing the major aquifers within the Salinas Valley (Baillie and others, 2015b).



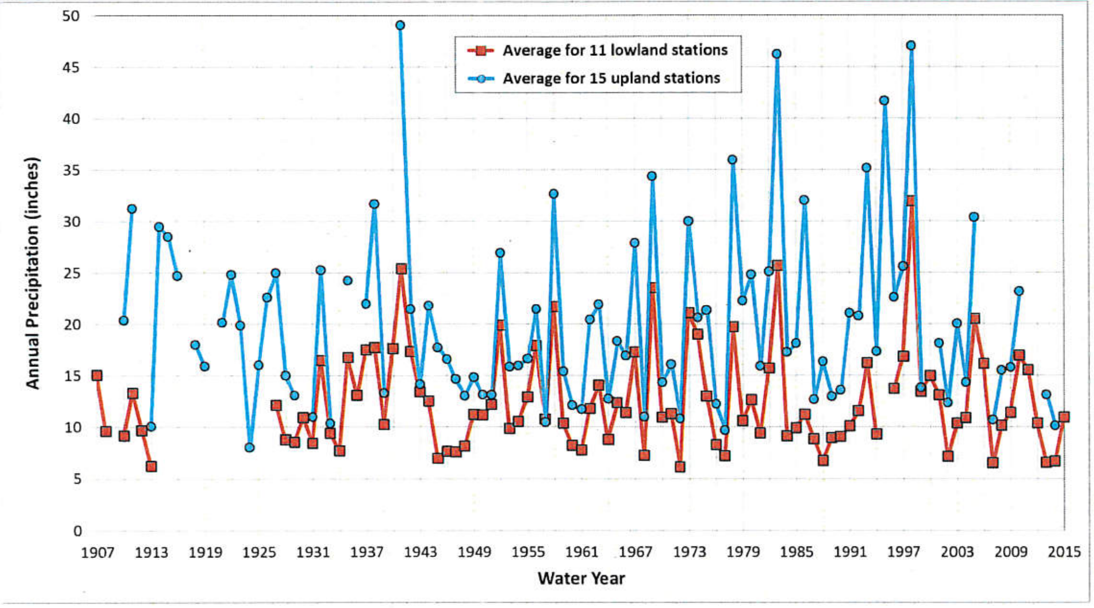


Figure 4. – Annual precipitation measured at 11 lowland and 15 upland climate stations within and adjacent to the Salinas River watershed, water years 1907 to 2015.

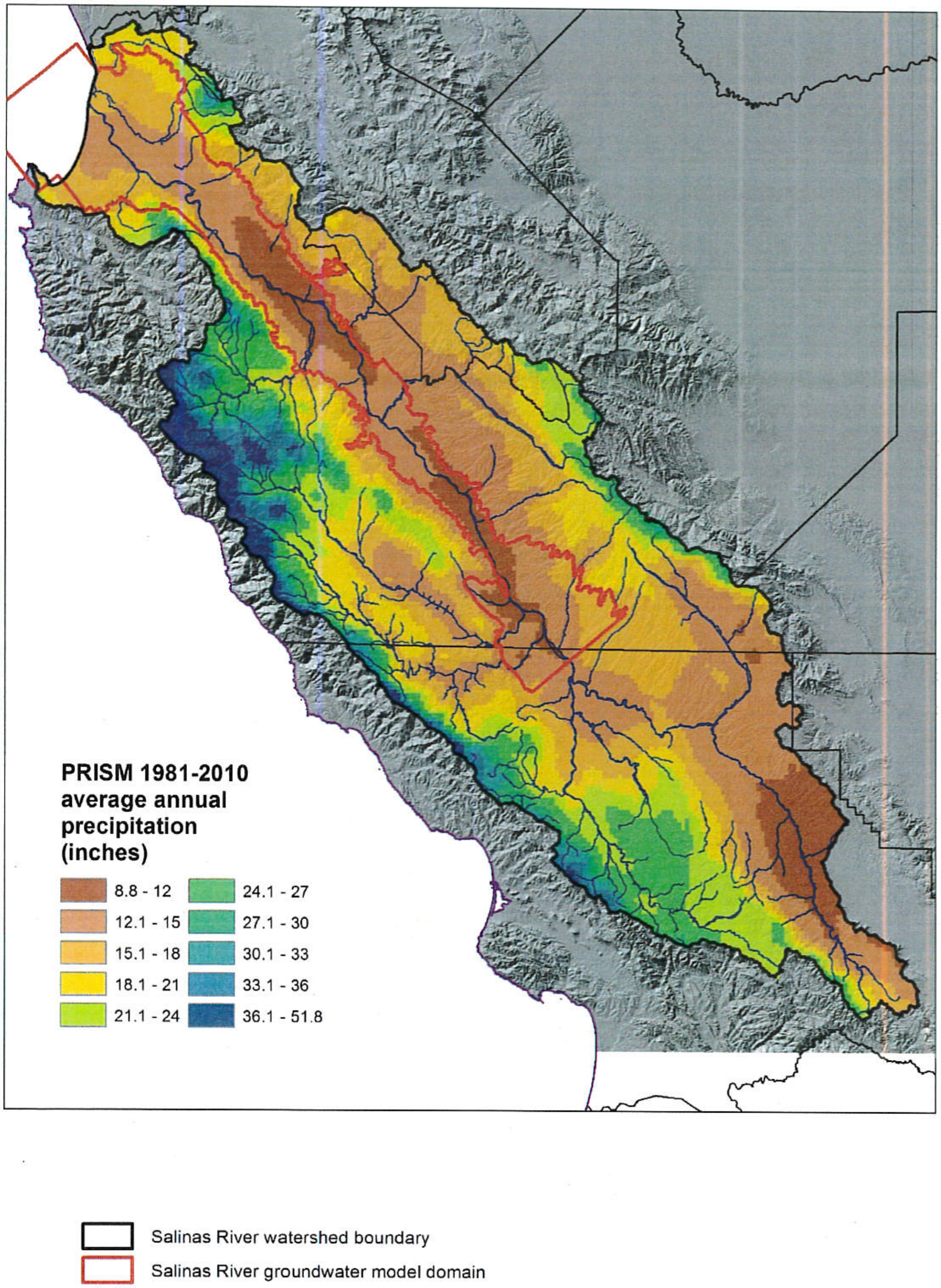


Figure 5. – PRISM 1981-2010 average annual precipitation within the Salinas Valley watershed (Daly and others, 2004).

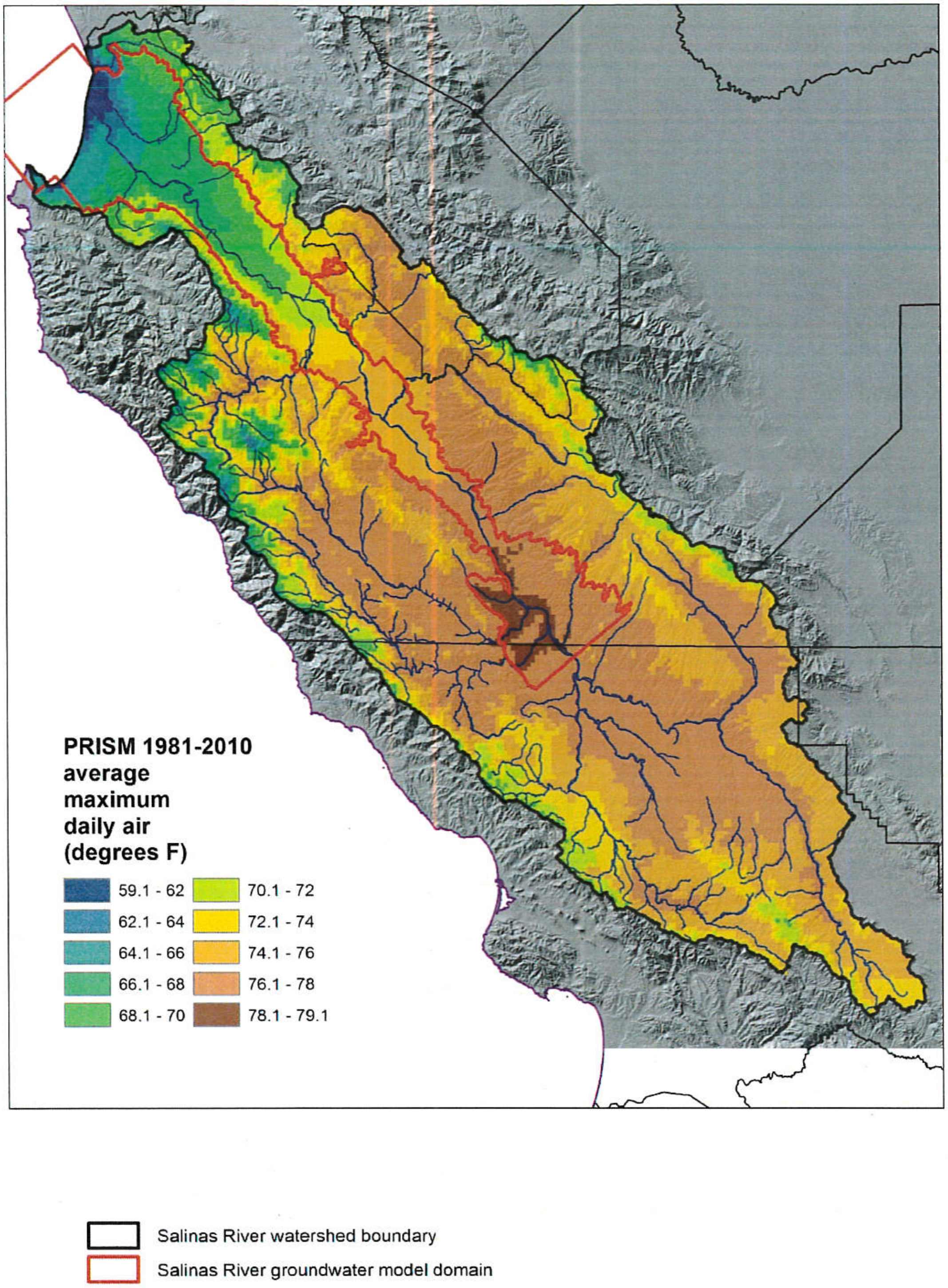


Figure 6. – PRISM 1981-2010 average maximum daily air temperature (Daly and others, 2004).

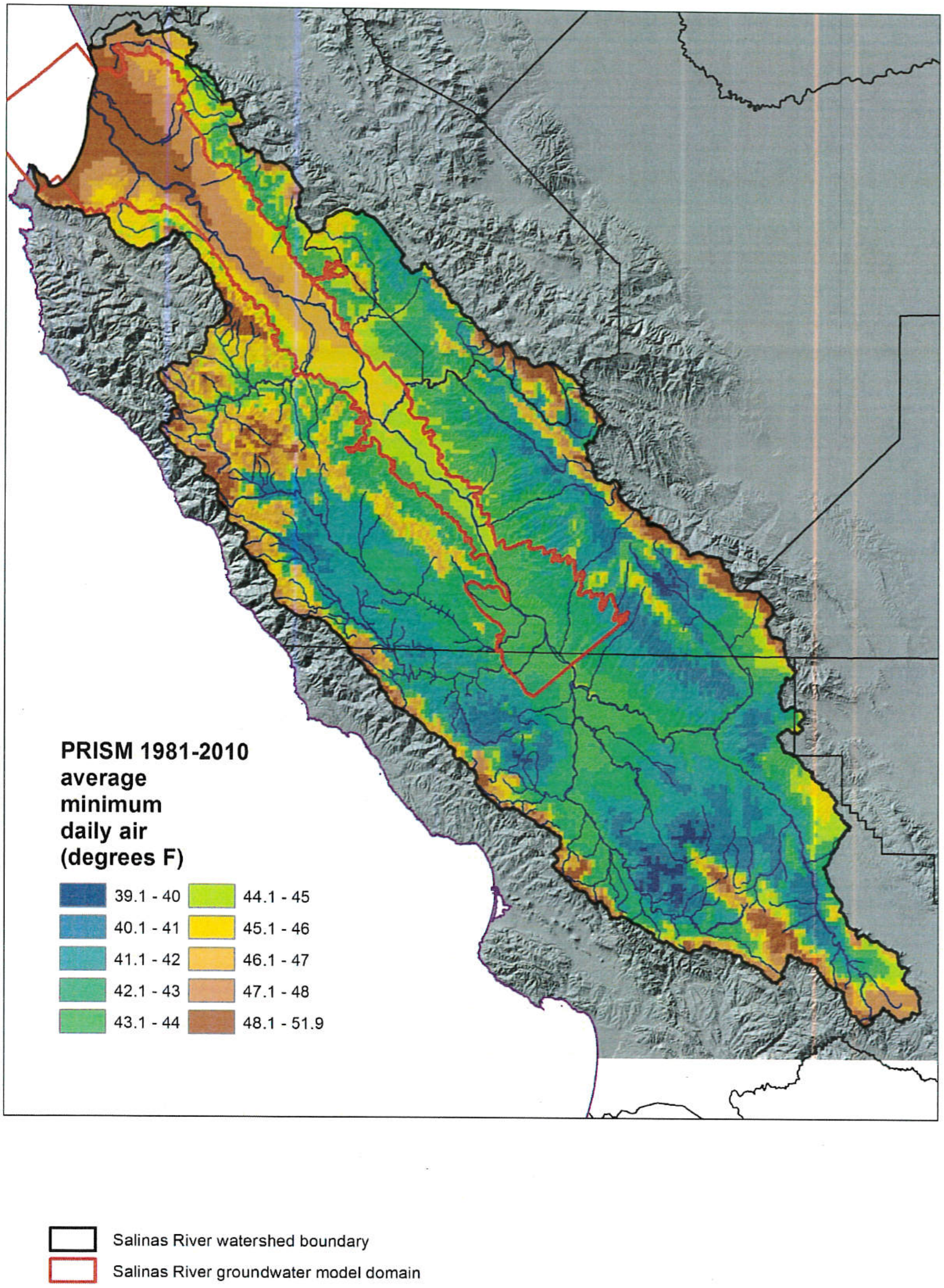


Figure 7. – PRISM 1981-2010 average minimum daily air temperature (Daly and others, 2004).

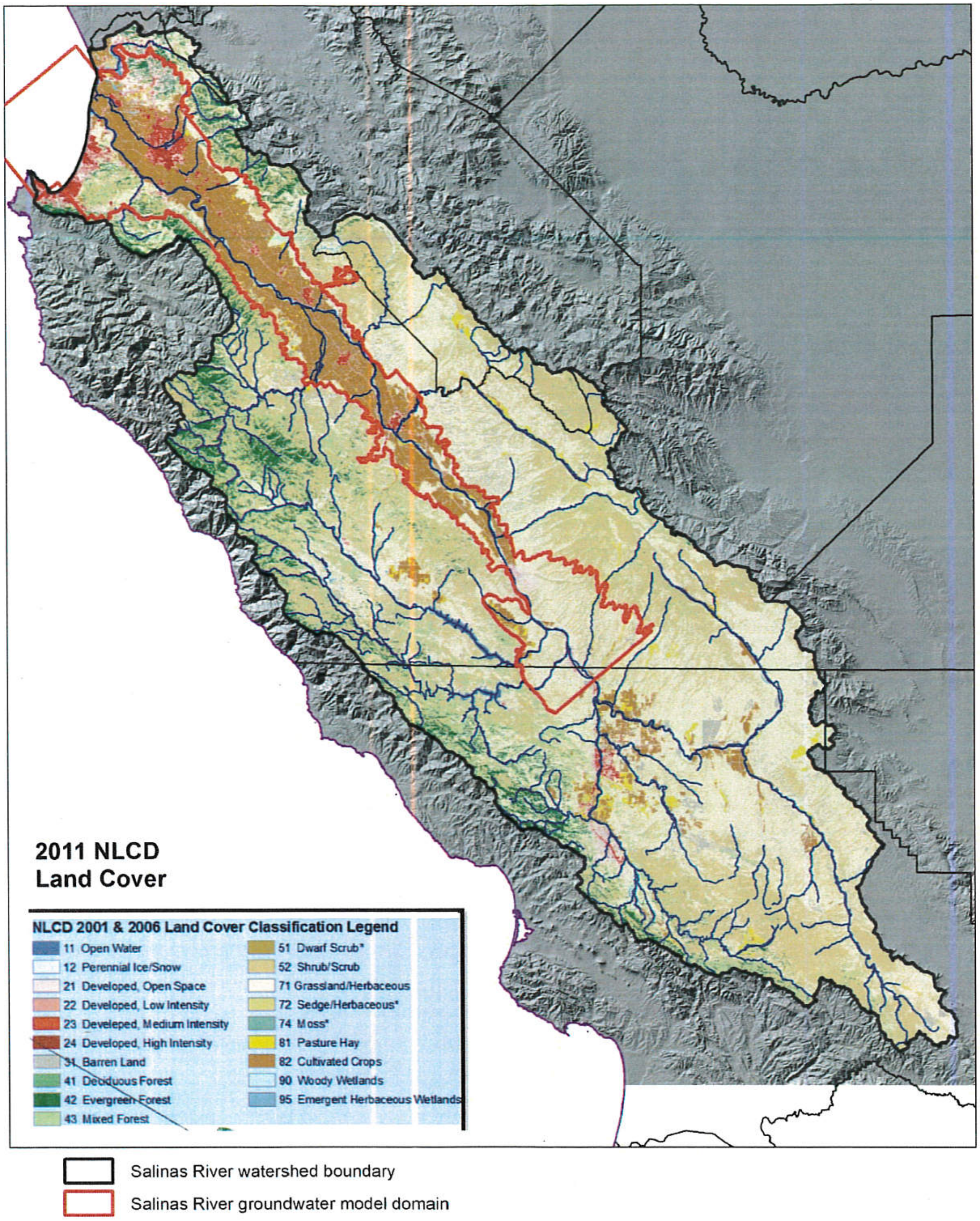


Figure 8. – NLCD 2011 land cover for the Salinas River watershed study area (Jin and others, 2013).

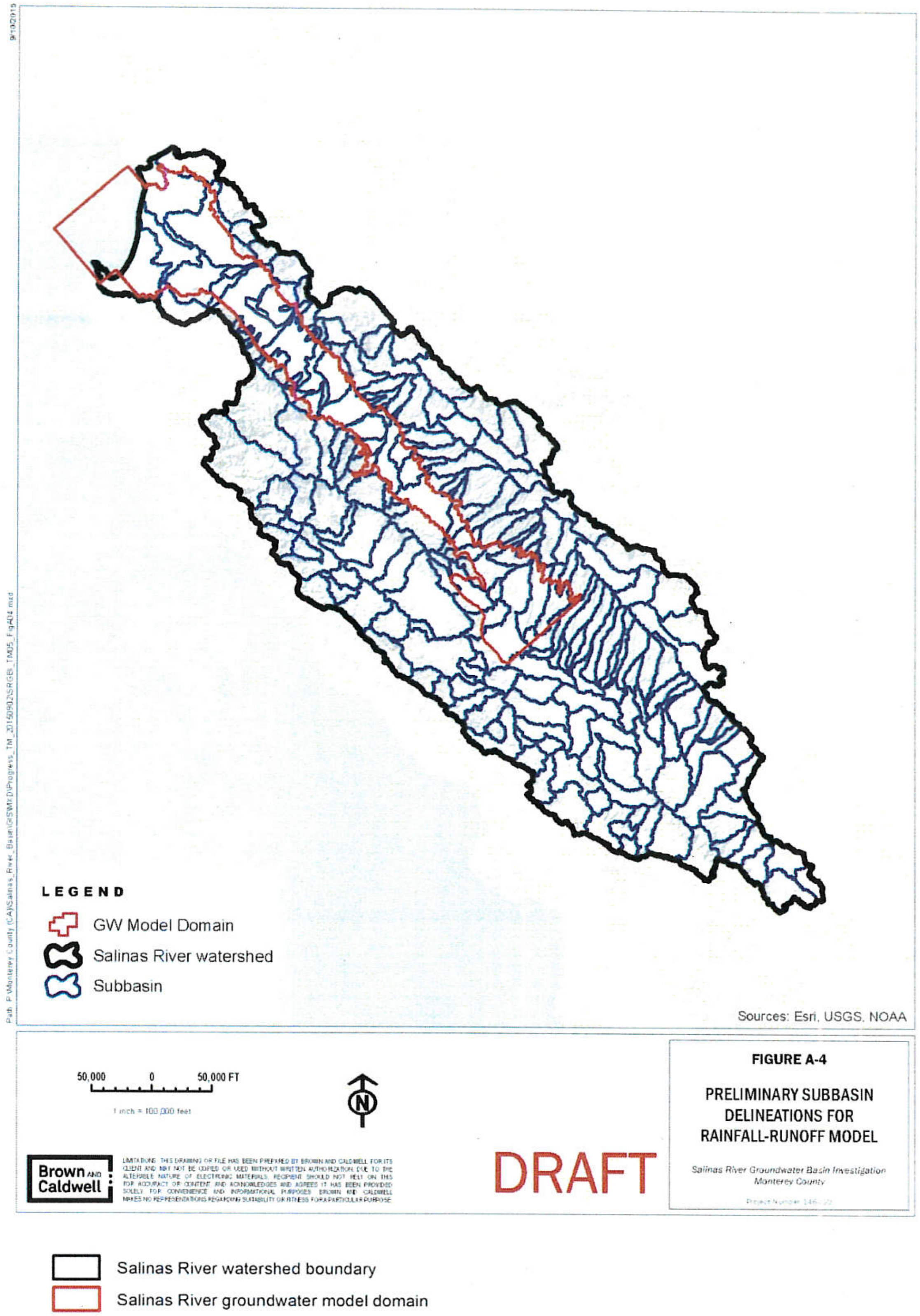


Figure 9. – Map showing extent of Salinas Valley watershed and related HSPF and BCM models including the subwatersheds and SVIHM model grid boundary (Baillie and others, 2015a).

A

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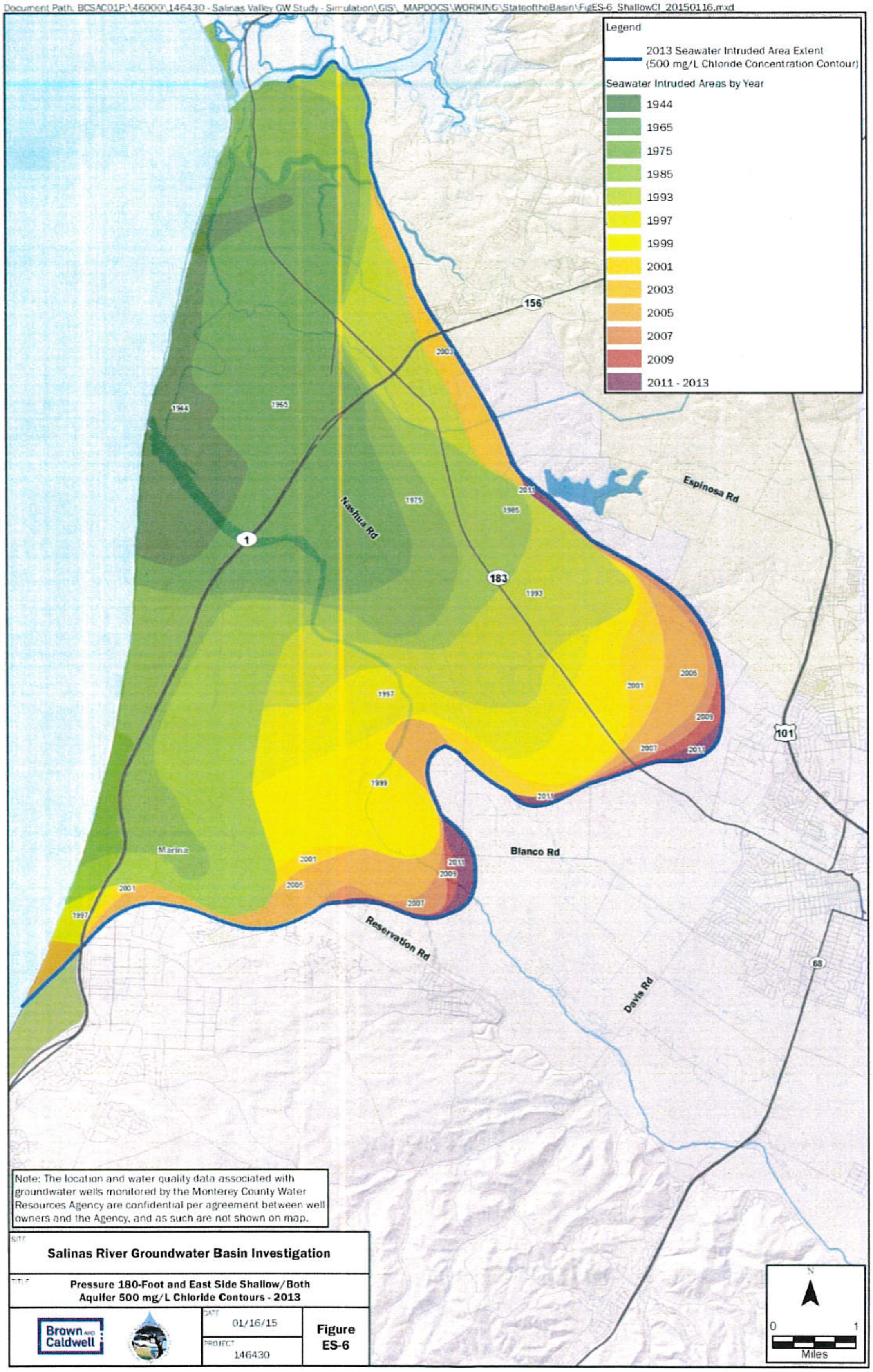

Note: The location and water quality data associated with groundwater wells monitored by the Monterey County Water Resources Agency are confidential per agreement between well owners and the Agency, and as such are not shown on map.

SITE

Salinas River Groundwater Basin Investigation

TITLE

Pressure 180-Foot and East Side Shallow/Both Aquifer 500 mg/L Chloride Contours - 2013

Brown AND Caldwell

DATE 01/16/15

PROJECT 146430

Figure ES-6

B

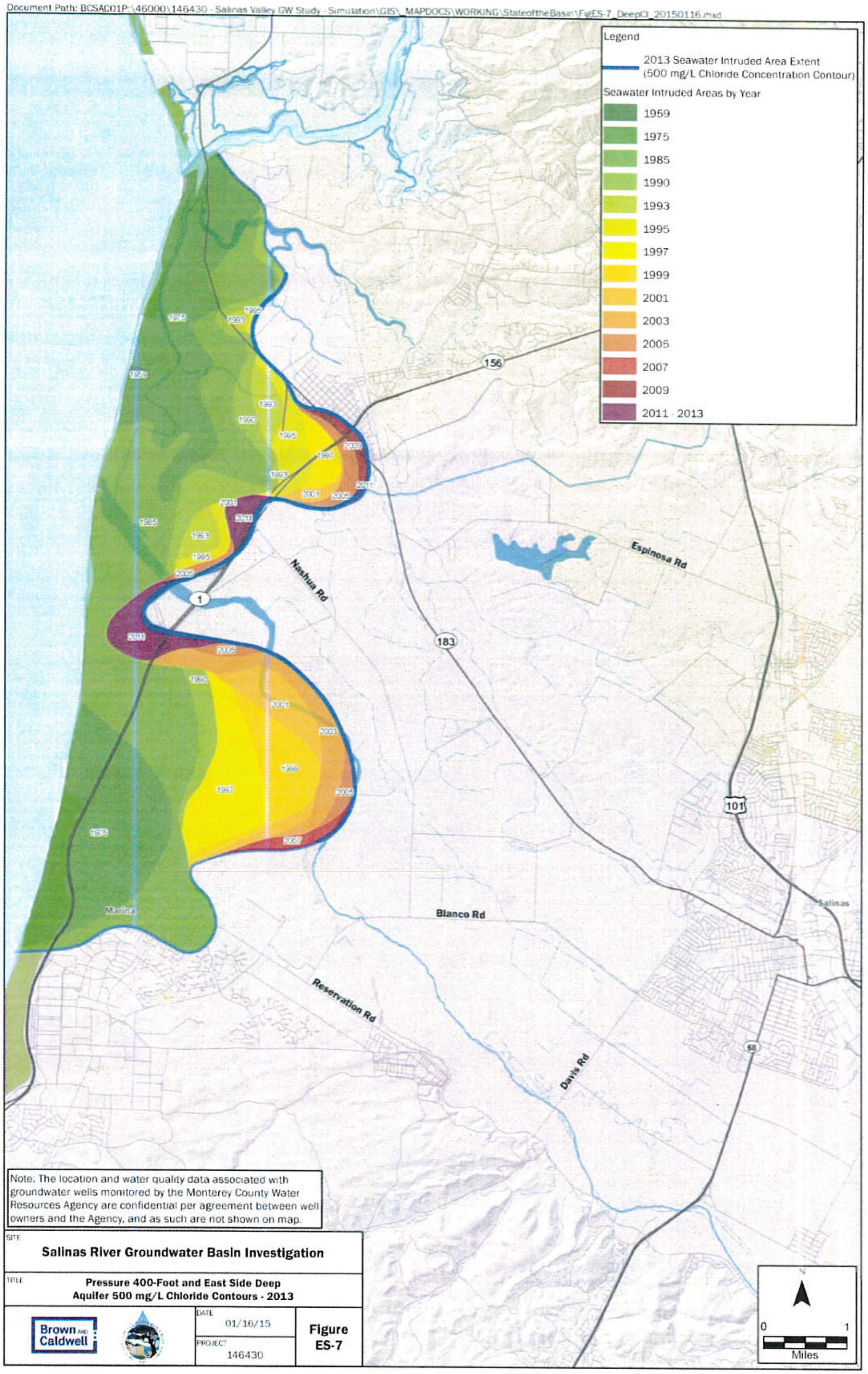

Figure 10. – Map showing the extent of seawater intrusion in the aquifers within the Salinas Valley (Baillie and others, 2015b) for (A) Pressure 180-Foot and East Side Shallow/Both Aquifer 500 mg/L Chloride Contours 1944–2013, and (B) Pressure 400-Foot and East Side Deep Aquifer 500 mg/L Chloride Contours 1959–2013.