FINAL REPORT | APRIL 2025

Salinas Valley
Historical Benefits Analysis Update

PREPARED FOR

Monterey County Water Resources Agency

PREPARED BY

WEST YOST
Water. Engineered.

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Monterey County Water Resources Agency

Project No. 867-60-23-02

Technical Lead: Matt Baillie, PG, CHg	May 30, 2024 Date
Project Manager: Les Chau, BCES	May 30, 2024 Date
QA/QC Review: Samantha Adams	May 30, 2024 Date

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LIST OF ACRONYMS AND ABBREVIATIONS

AEP	Annual Exceedance Probability
af	Acre-Feet
afy	Acre-Feet Per Year
Basin	Salinas River Groundwater Basin
CDF	Cumulative Distribution Function
cfs	Cubic Feet Per Second
CSIP	Castroville Seawater Intrusion Project
DP	Deep Percolation
DWR	Department of Water Resources
ESU	Economic Study Unit
FMP	Farm Process
fps	Feet Per Second
GWP	Groundwater Pumping
HBA	Historical Benefits Analysis
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center's River Analysis System
IGSM	Integrated Groundwater-Surface Water Model
IWFM	Integrated Water Flow Model
MCWRA	Monterey County Water Resources Agency
msl	Mean Sea Level

MW	Montgomery Watson
NWP	Nacimiento Water Project
OWHM	One Water Hydrologic Model
SFR	Stream Flow Routing
SR	Stream Recharge
SRDF	Salinas River Diversion Facility
SVIGSM	Salinas Valley Integrated Ground and Surface Water Model
SVIHM	Salinas Valley Integrated Hydrologic Model
SVWM	Salinas Valley Watershed Model
SVWP	Salinas Valley Water Project
USGS	U.S. Geological Survey
West Yost	West Yost Associates
WY	Water Year

Executive Summary

In 1998, Montgomery Watson (MW) prepared the Salinas Valley Historical Benefits Analysis (HBA; MW, 1998) for the Monterey County Water Resources Agency (MCWRA). This was the first time the benefits received by stakeholders in the Salinas Valley from the Nacimiento and San Antonio Reservoirs had been quantified. Since the original publication 25 years ago, MCWRA has constructed new water projects, additional data have been gathered, the understanding of the groundwater and surface water systems has evolved, and new tools for evaluating conditions in the Salinas Valley have been developed.

This HBA Update leverages these improvements to re-evaluate the water resources benefits provided by the Nacimiento and San Antonio Reservoirs to the Salinas River Groundwater Basin (Basin). It also incorporates projects implemented since Water Year (WY) 1994, which is the last WY covered by the 1998 HBA, including the Castroville Seawater Intrusion Project (CSIP), part of the Monterey County Water Recycling Projects, and the Salinas Valley Water Project (SVWP), which includes the Salinas River Diversion Facility (SRDF). These projects have been implemented to address the issues of seawater intrusion and groundwater overdraft observed in the study area since at least the late 1930s (DWR, 1946).

1998 HISTORICAL BENEFITS ANALYSIS

The 1998 HBA quantified the effects that the Nacimiento and San Antonio Reservoirs have had on the integrated groundwater-surface water system of the Salinas Valley. The analysis was completed using the Salinas Valley Integrated Ground and Surface Water Model (SVIGSM), a numerical model of the hydrologic system. The SVIGSM simulated conditions in the Basin from WY 1949 to 1994, both with and without the reservoirs. The difference between the two scenarios was considered to represent the benefits provided by the reservoirs to users in the Salinas Valley. The effects of flood events were simulated using a separate hydraulic model of the Salinas River and its floodplain, as the SVIGSM was not designed to simulate floodplain inundation.

The reservoirs store streamflow during wet periods and allow for release during drier periods. This has led to a reduction in the frequency and severity of flood events and an increase in groundwater storage, thereby retaining more water within the Basin. As stated in the 1998 HBA, the reservoirs have reduced the estimated magnitude of the 100-year flood in the Salinas River at Bradley from about 167,000 cubic feet per second (cfs) to 87,000 cfs. They have also increased the recharge to the groundwater system from the Salinas River and its tributaries by an average of 30,000 acre-feet per year (afy), and reduced seawater intrusion from about 18,000 afy to about 11,000 afy.

According to the 1998 HBA, the increased groundwater storage led to cost savings by reducing pumping costs, preventing the need for replacement or modification of pumping wells, and slowing the rate of seawater intrusion. This saved stakeholders in the Basin about $1.8 million per year. Additionally, the reduction in flooding prevented damage to buildings, structures, agricultural crops, and soil, saving stakeholders an additional $10.0 million per year. The total estimated benefit received from the reservoirs over the period of analysis was about $11.8 million per year.

PURPOSE AND APPROACH

This report updates the 1998 HBA using information and tools developed over the past 25 years. It also incorporates into the analysis projects that were implemented during that period (CSIP and SVWP, including SRDF). Nacimiento Reservoir, San Antonio Reservoir, CSIP, and SVWP (collectively, the Projects, which are shown in Figure ES-1) operate in tandem, so this analysis presents the benefits of the Projects as a whole. Benefits fall into three major categories:

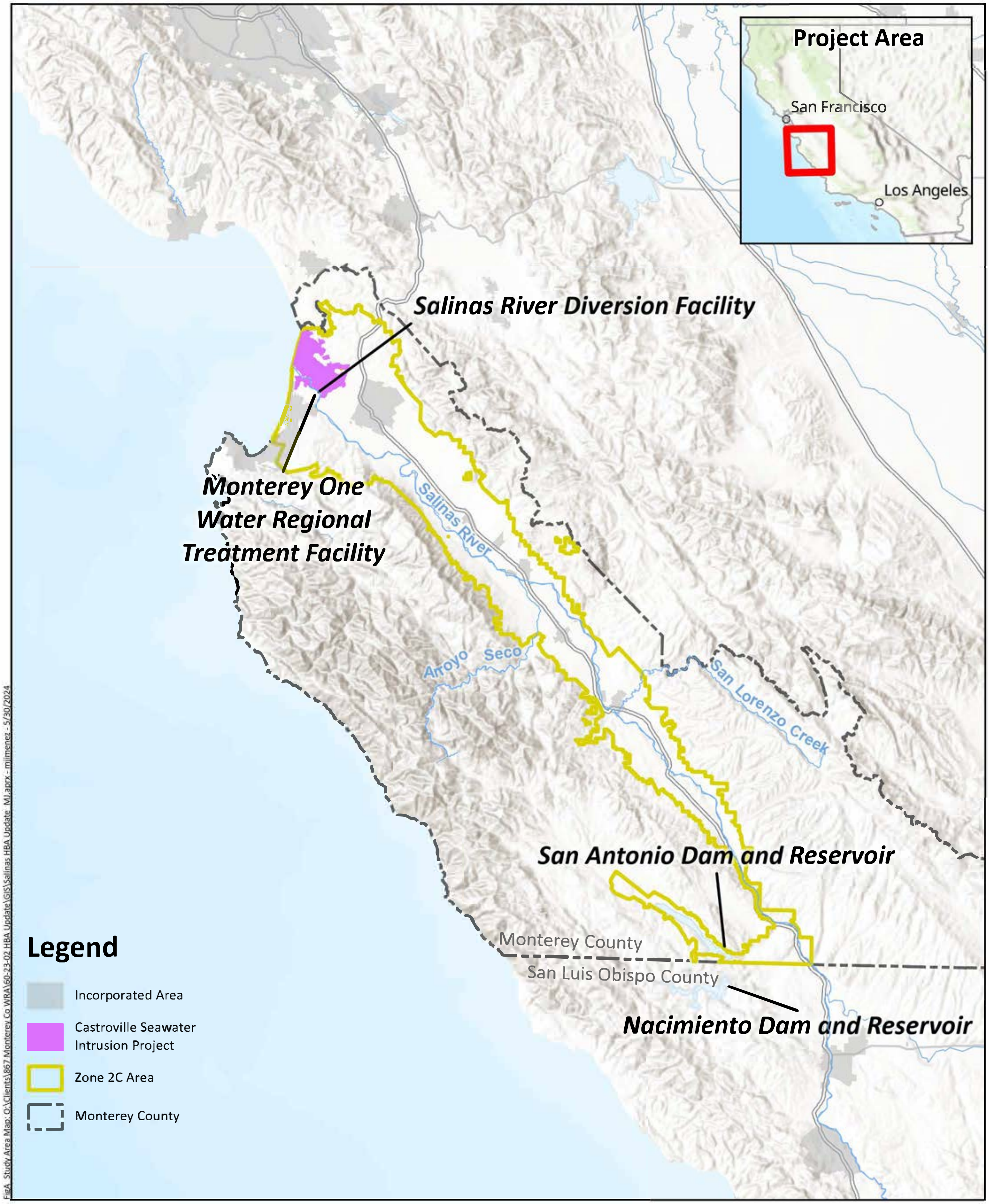
1. Hydrologic Benefits: those relating to groundwater levels and groundwater pumping
2. Flood Control Benefits: those relating to the frequency and severity of flood events
3. Economic Benefits: the monetary benefit realized by stakeholders stemming from the Hydrologic and Flood Control Benefits

For this HBA Update, the quantification of economic benefit is being prepared separately and is not included in this report.

The technical approach for quantifying the hydrologic and flood control benefits of the HBA Update follows that of the 1998 HBA wherever possible. It relies on the Salinas Valley Integrated Hydrologic Model (SVIHM), a numerical groundwater-surface water model developed by the U.S. Geological Survey (USGS). The model simulates conditions in the Basin both with and without the Projects from October 1967 to September 2018. The results from the SVIHM feed into a statistical analysis of annual peak flows for the Salinas River at Bradley. Selected peak flows are then used as inputs to a hydraulic model of the Salinas River and its floodplain. The study area for the HBA Update is MCWRA's Zone 2C, as shown in Figure ES-1. The differences between the SVIHM simulations with the Projects (Historical Scenario) and without the Projects (No Projects Scenario) represents the effects of the Projects.

The SVIHM is currently under development by the USGS and has not been released to the public, nor has its documentation report been published. Any presentation of results from the SVIHM prior to its release must be accompanied by the following disclaimer:

> *Historical SVIHM Model: Unoffical* [sic] *Collaborator Development Version of Preliminary Model. Access to this repository and use of its data is limited to those who are collaborating on the model development. Once the model is published and recieved* [sic] *full USGS approval it will be archived and released to the public. This preliminary data (model and/or model results) are preliminary or provisional and are subject to revision. This model and model results are being provided specifically to collaborate with agencies who are contributing to the model development and meet the need for timely best science. The model has not received final approval by the U.S. Geological Survey (USGS). No warranty, expressed or implied, is made by the USGS or the U.S. Government as to the functionality of the model and related material nor shall the fact of release constitute any such warranty. The model is provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the model.*



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Salinas Valley HBA Update
Study Area

Figure ES-1

STUDY SETTING

The distribution of the effects of the Projects within the Basin is influenced by the hydrogeologic context and developmental history of the Projects. Both factors are crucial for understanding the distribution of historical benefits.

The Basin sediments form aquifers, used for groundwater production, and aquitards, which restrict groundwater movement. The distribution of these aquifers and aquitards is a result of the Basin's complex depositional history. South of Greenfield, the Basin is filled with relatively coarse-grained alluvial and fluvial sediments without extensive fine-grained materials, forming a single aquifer without aquitards.

North of Greenfield, periodic marine transgressions deposited fine-grained materials alternately with terrestrial alluvial and fluvial sediments deposited during periods of lower sea level. In the Pressure Subarea, the sediments are divided into aquifers and aquitards based on the sequence of relatively coarse-grained and fine-grained materials. From the ground surface down, the named aquifers are the Shallow Aquifer, 180-Foot Aquifer, 400-Foot Aquifer, and Deep Aquifer. The 180-Foot and 400-Foot Aquifers have been the most heavily relied upon for groundwater production within the Basin. Further east, in the East Side Subarea, the aquifers and aquitards are less clearly defined. The sediments are typically divided into an East Side Shallow Aquifer and an East Side Deep Aquifer, with the degree of confinement increasing downward. The aquitards separating the aquifers are not continuous throughout the area north of Greenfield, with gaps in the aquitards representing areas where vertical groundwater movement between the aquifers can occur relatively easily.

In the Pressure Subarea, the shallowest aquitard, the Salinas Valley Aquitard, separates the Shallow Aquifer from the 180-Foot Aquifer. It generally restricts direct recharge from the Salinas River and its tributaries into the Basin aquifers. For groundwater to reach the main production aquifers of the northern part of the Basin, it must pass vertically through the aquitards or horizontally from areas further south.

Groundwater overdraft and seawater intrusion were recognized in the Basin during the first half of the 20th century. The California Department of Water Resources (DWR) conducted a detailed hydrogeologic study of the Basin (published as DWR Bulletin 52; DWR, 1946), which recommended storage and conveyance of surface water as a partial solution to the water issues facing the Basin. MCWRA built and operates the Nacimiento and San Antonio Reservoirs as a partial solution to address the issues of seawater intrusion and groundwater overdraft that have been affecting the Basin for decades. Construction of Nacimiento Dam was completed in 1957 and it began operating in WY 1958. Construction of San Antonio Dam was completed in 1967 and it began operating in WY 1968. MCWRA manages both reservoirs jointly for the purposes of flood control, water conservation, support of fish and wildlife habitat, dam safety, and recreation.

Since the construction of the reservoirs, two additional important projects, CSIP and SVWP, have been developed to help address groundwater overdraft and seawater intrusion. CSIP delivers alternative water sources to coastal growers affected by seawater intrusion, replacing locally pumped groundwater. CSIP consists of a conveyance pipeline network constructed beginning in 1995 that started delivering recycled water supplied by the Salinas Valley Reclamation Project at the Monterey One Water Regional Treatment Plant in 1998. SVWP included an increase in the spillway elevation at Nacimiento Dam (increasing the storage capacity of Nacimiento Reservoir) and the construction of the Salinas River Diversion Facility (SRDF), which rediverts stored reservoir water into the CSIP network, and resulted in re-operation of the reservoirs. The spillway raise was completed in 2009, and SRDF was completed in 2010.

HYDROLOGIC BENEFITS ANALYSIS

The Projects have effectively retained more water within the Basin through increased groundwater recharge from the Salinas River and its tributaries, and reduced groundwater demand. As a result, groundwater levels (or hydraulic heads) are higher, representing an increase in the amount of groundwater stored within the Basin. These higher groundwater levels have reduced the rate of seawater intrusion into the Basin's aquifers and decreased the pumping lift required to extract groundwater from wells. This demonstrates the significant effect the Projects have had on the Basin's water resources.

GROUNDWATER LEVELS

Over the analysis period for this HBA update (WY 1968 to 2018), groundwater levels have declined in much of the study area, particularly in the Pressure, East Side, and Arroyo Seco Subareas. Declines have averaged up to 3.0 feet per year in the area between Castroville and Salinas. Groundwater levels in the Forebay and Upper Valley Subareas have largely remained unchanged or have risen in some areas, increasing by as much as 0.5 feet per year along the Salinas River downstream of its confluence with Arroyo Seco. Figure ES-2 (the left side panel on Figure ES-2) shows the average annual simulated groundwater level change in the study area over the model period under the Historical Scenario with the projects in operation. Areas where groundwater levels increased are shown in shades of pink and areas where groundwater levels decreased are shown in shades of blue.

Without the Projects, the decline in groundwater levels would have been more severe and widespread. Figure ES-2b shows the average annual simulated groundwater level change in the study area over the model period under the No Projects Scenario. Figure ES-3 shows the difference in the average annual head change between the Historical and No Projects Scenarios, illustrating that across most of the study area, groundwater levels were higher with the projects. Thus, the Projects have mitigated the degree and extent of the observed groundwater level declines, especially in the northern part of the Basin, by as much as 0.9 feet per year (Figure ES-3a). As shown in Figure ES-3b, by the end of the model period (September 2018), the Projects had resulted in groundwater levels being as much as 67 feet higher than they would have been without the.

The average annual groundwater level changes described above were used to partition the Basin into thirteen Economic Study Units (ESUs). Each ESU includes an area that has experienced similar benefits from the Projects. The ESUs, delineated on Figure ES-3b, follow the established boundaries of the MCWRA Zone 2C subareas, with subdivisions based on the Projects' effects on groundwater levels as depicted in Figure ES-2a. Table ES-1 presents the average annual groundwater level change for each ESU with and without the Projects, as well as the difference between the with- and without-Project conditions. The largest annual differences in groundwater level change occur in ESUs 2 and 3 (0.14 and 0.21 feet per year), located in the East Side and Pressure Subareas, respectively, in the area between Castroville and Salinas.

Time series of average groundwater levels in individual ESUs show that the benefits of the Projects manifest differently in different parts of the Basin (see Figures 3-20a through 3-20m of the report for a time series of groundwater level in each ESU) and in relation to the start of operations of CSIP and the SRDF. Figure ES-4a shows the time series for ESUs 3 and 11 as examples. ESUs in the northwest part of the Basin (ESUs 1 through 4) experienced little effect from the Projects until 1998 when CSIP started operating. For instance, in ESU-3, the Projects resulted in less than a foot of groundwater level increase by the end of WY 1997, with substantial impact starting in WY 1998 when CSIP came online. By the end of the model period (WY 2018), the average groundwater level in ESU-3 was about 11 feet higher with the

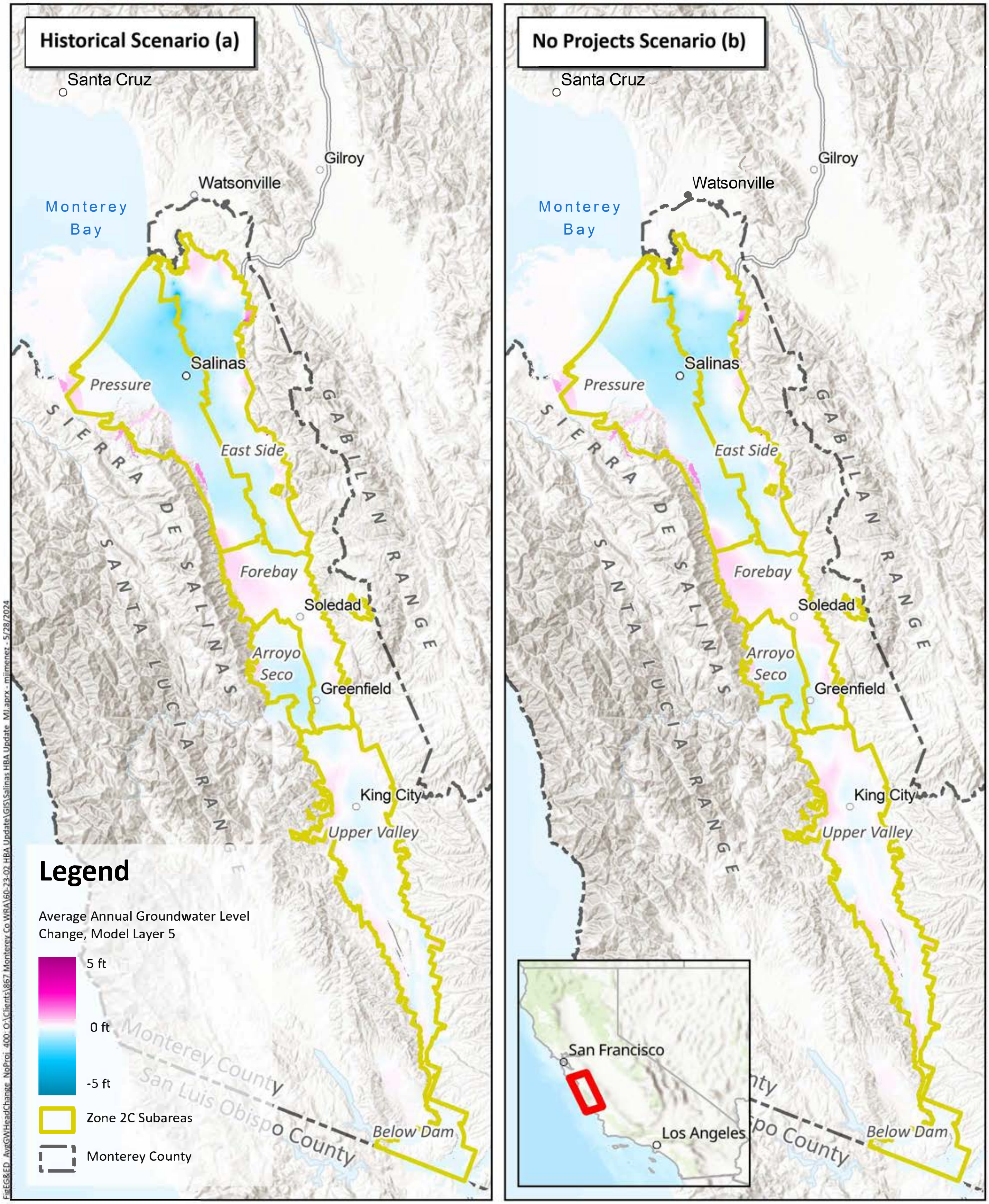
Projects than without. In other parts of the Basin (ESUs 5 through 13), the effects of the Projects are distributed more evenly over time, with fluctuations generally following climatic patterns. The effects of the Projects are felt most strongly during periods when groundwater levels decline because of dry conditions. ESU-11, which covers the northern portion of the Upper Valley Subarea, illustrates this behavior.

Table ES-1. Average Annual Groundwater Level Change (in ft) by ESU, Historical and No Projects Scenarios

ESU	Historical Scenario	No Projects Scenario	Difference Between Scenarios
1	0.08	0.08	0.00
2	-0.54	-0.68	0.14
3	-0.56	-0.78	0.21
4	-0.03	-0.05	0.02
5	-0.21	-0.23	0.02
6	-0.28	-0.31	0.03
7	-0.26	-0.30	0.04
8	0.13	0.09	0.04
9	-0.07	-0.14	0.06
10	-0.26	-0.29	0.03
11	-0.02	-0.10	0.08
12	0.00	-0.07	0.06
13	-0.17	-0.19	0.03

Notes:

Simulated groundwater level changes in this table are for Model Layer 3, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer elsewhere.



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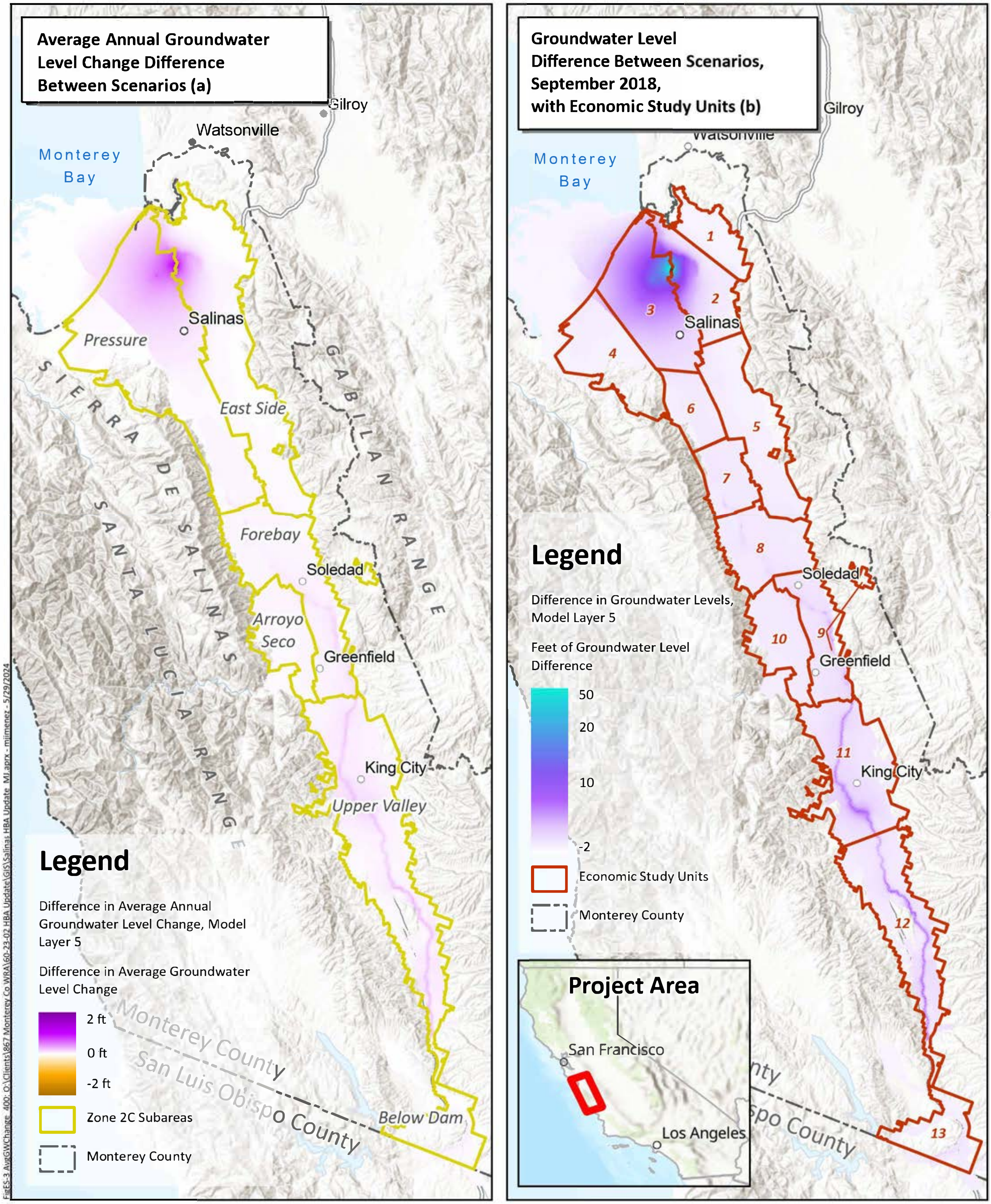
Average Annual Groundwater Level Change
400-Foot Aquifer & Equivalent

Figure ES-2



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Groundwater Level Change (a) and Groundwater Level (b) Differences Between Scenarios
400-Foot Aquifer & Equivalent

Figure ES-3

These results demonstrate that the reservoirs have provided substantial benefits to the portions of the Basin where the Salinas River is directly connected to the Basin aquifers (especially ESUs 6 through 12), while having more limited effect in the ESUs where confining layers limit the river-aquifer connection or where the Salinas River does not run through the ESU (especially ESUs 1 through 4). CSIP, through its delivery of recycled water from the Monterey One Water Regional Treatment Plant and diverted surface water from the SRDF, has provided major benefits to groundwater levels in the coastal portion of the Basin (especially ESUs 2 and 3).

Time series of average groundwater levels in individual ESUs show that the benefit of the Projects manifests differently in the different parts of the Basin (see Figures 3-20a through 3-20m in the main report for a time series of groundwater level in each ESU). ESUs in the northwest part of the Basin (ESUs 1 through 4) experienced little effect from the Projects until 1998 when CSIP came online. For instance, in ESU-3, the Projects resulted in less than a foot of groundwater level increase by the end of WY 1997, with substantial impact starting in WY 1998 when CSIP came online (Figure ES-4a). By the end of the model (WY 2018), the average groundwater level in ESU-3 was about 11 feet higher with the Projects than without.

In other parts of the Basin (ESUs 5 through 13), the effects of the Projects are distributed more evenly over time, with fluctuations generally following climatic patterns. The effects of the Projects are felt most strongly during periods when groundwater levels fall because of dry conditions. ESU-11, which covers the northern portion of the Upper Valley Subarea, illustrates this behavior (Figure ES-4b).

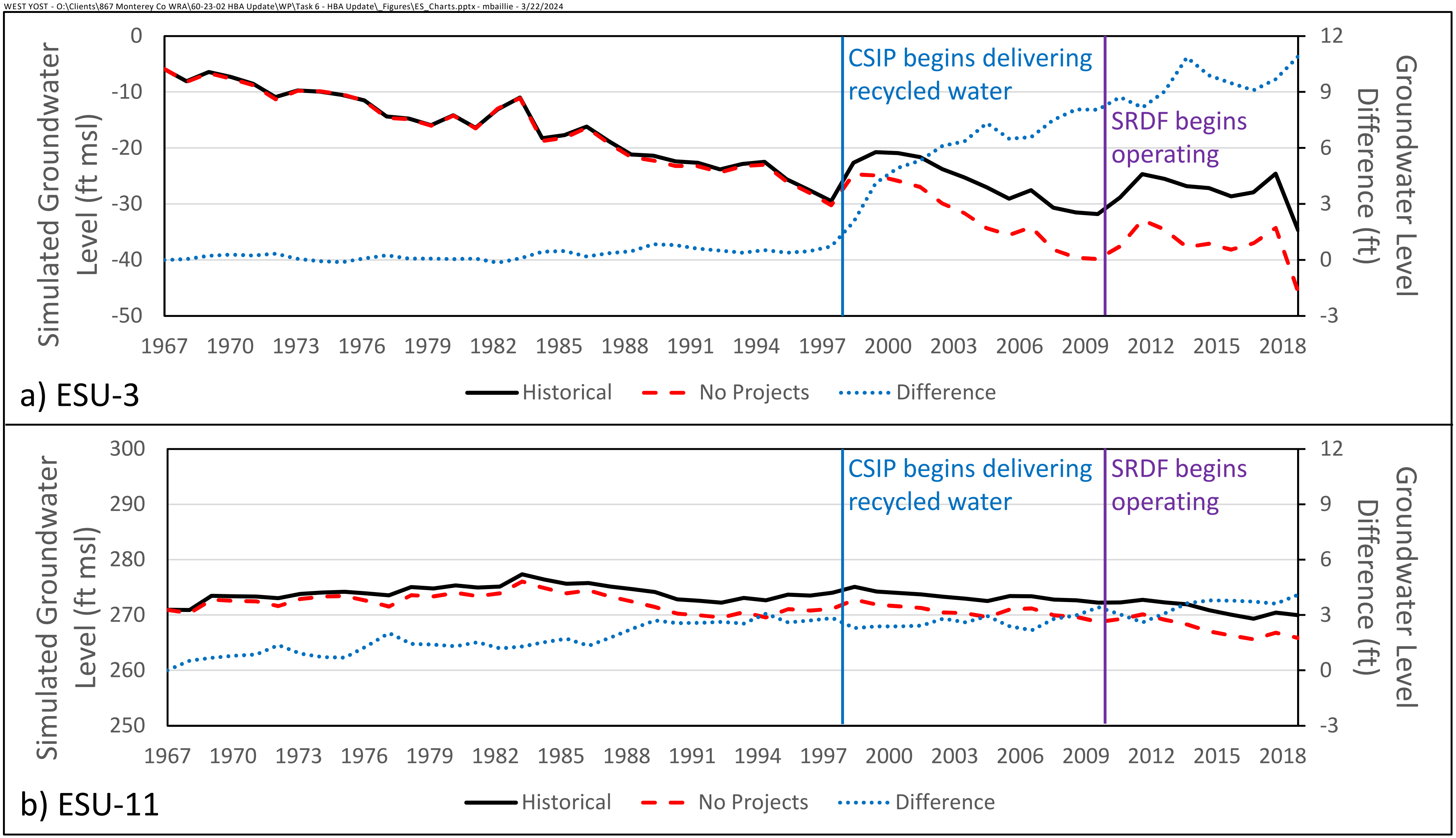


Figure ES-4

Average End-of-Year Groundwater Level in ESUs 3 and 11, Historical and No Projects Scenarios

These results demonstrate that the reservoirs have provided substantial benefits since their construction to those portions of the Basin where the Salinas River is directly connected to the Basin aquifers (especially ESUs 6 through 12), while having more limited effect in the ESUs where confining layers limit the river-aquifer connection (especially ESUs 1 through 4). CSIP, through its delivery of recycled water from the Monterey One Water Regional Treatment Plant and diverted Salinas River water from the SRDF, has provided major benefits to groundwater levels in the coastal portion of the Basin that has not been felt elsewhere.

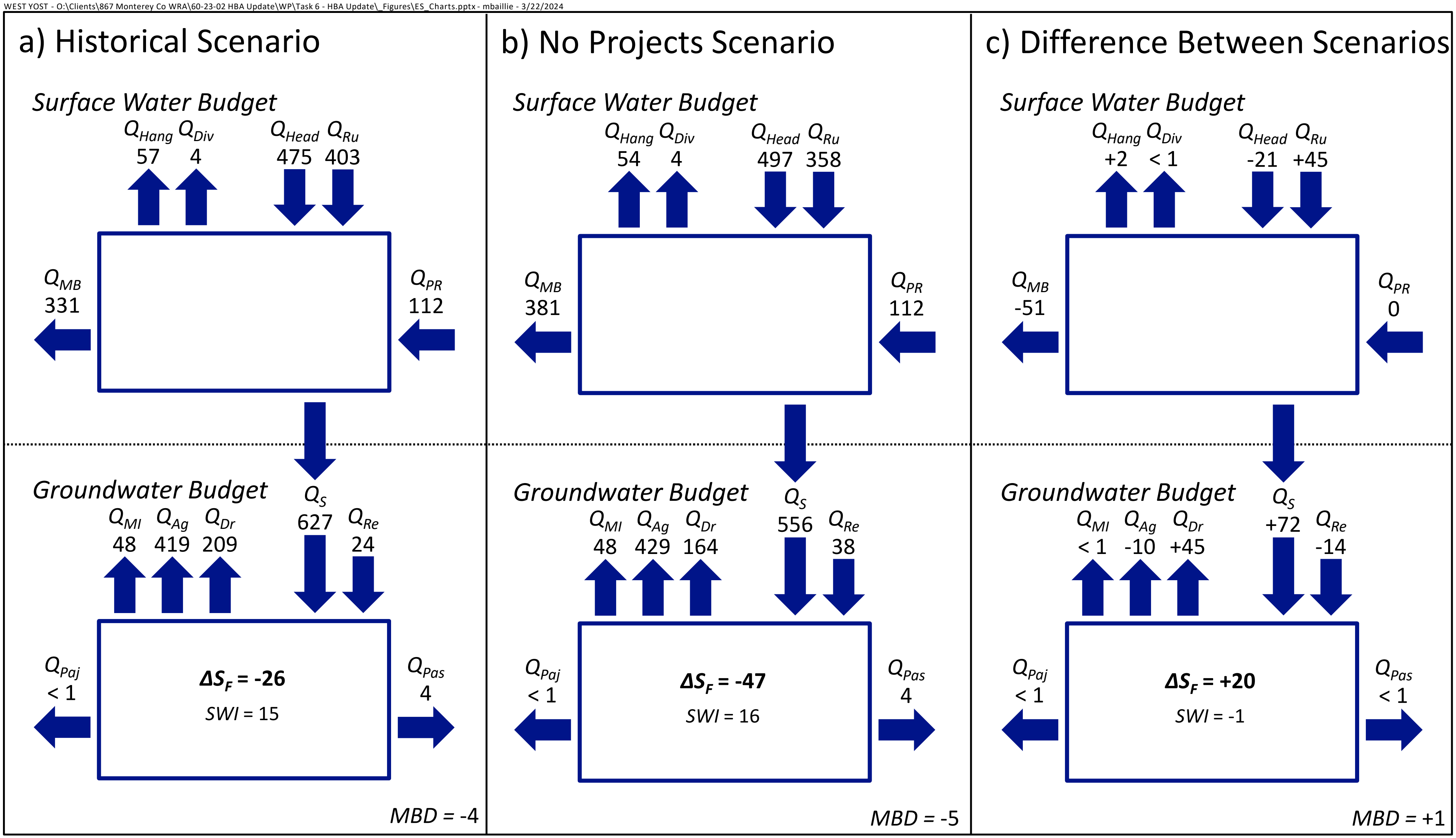
GROUNDWATER AND SURFACE WATER BUDGETS

The benefits of groundwater level rise attributed to the Projects reflect changes to the amount and timing of water moving through the groundwater-surface water system of the Basin. These effects can be represented as changes to groundwater and surface water budgets of the Basin. A water budget quantifies the volume of water entering or exiting a system and is a crucial means for understanding water movement and storage. A water budget can include any number of different components depending on the system being studied and the purpose for which the budget is prepared. The difference between inflow and outflow components of a water budget typically signifies the change in storage within the system.

For this HBA Update, water budgets were prepared for both the groundwater system and the stream network. The groundwater-surface water exchange is the major hydrologic connection between groundwater and the stream network. The average annual water budgets for the Historical and No Project Scenarios are graphically depicted in Figure ES-5. For each scenario, the budget depicts the annual average volume of each inflow and outflow to the surface water and groundwater systems (in thousands of afy). Figure ES-5 also shows the water budget differences between the scenarios.

The average annual groundwater budget for the Historical Scenario is represented in the lower half of Figure ES-5a. The largest component of the simulated groundwater budget over the historical period is recharge to the aquifers from the stream network (Q_S), averaging about 627,000 afy. Other significant inflows to the groundwater system are net recharge[1] (Q_{Re}, 24,000 afy) and seawater intrusion (SWI,15,000 afy). Most of the inflow is balanced by the two largest outflow components: agricultural pumping (Q_{Ag}, 419,000 afy) and discharge from shallow groundwater to agricultural drains (Q_{Dr}, 209,000 afy). Other outflow components include municipal and industrial pumping (Q_{MI}, 48,000 afy) and groundwater outflow to the neighboring Pajaro and Paso Robles Basins (combined, less than 5,000 afy). The total of all outflow components is greater than the total of all inflow components, indicating a loss of fresh groundwater in storage (ΔS_F), averaging about 26,000 afy. The same information for the No Projects scenario is illustrated in Figure ES-5b.

[1] Net recharge is the sum of deep percolation of water past the root zone (positive "recharge") and evapotranspiration of shallow groundwater within the root zone (negative "recharge").



Abbreviations:

Q_S = Groundwater-Surface Water Exchange
Q_{MI} = Municipal & Industrial Pumping
Q_{Ag} = Agricultural Pumping
Q_{Dr} = Discharge to Drains
Q_{Re} = Net Recharge
Q_{Pas} = Groundwater Exchange with Paso Robles Basin
Q_{Paj} = Groundwater Exchange with Pajaro Basin
ΔS_F = Change in Fresh Groundwater Storage
SWI = Seawater Intrusion
MBD = Mass Balance Difference
Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:

1. All components are displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of flow.
3. Difference between scenarios is Historical Scenario minus No Projects Scenario

Figure ES-5

Average Annual Groundwater and Surface Water Budgets, Historical and No Projects Scenarios and Difference Between Scenarios

Monterey County Water Resources Agency

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WELL IMPACTS

As described in the 1998 HBA, changes in groundwater levels can affect the operation of pumping wells. This can occur when the groundwater level in a well drops to within the perforated interval of the well or below the pump intake, potentially necessitating the modification or replacement of the well. For this HBA Update, an analysis was conducted on 292 pumping wells for which construction information was available. The aim was to determine the extent to which the Projects have prevented negative impacts to pumping wells in the Basin. The analysis found that only two of the pumping wells analyzed (one in ESU 3 and one in ESU 11) would have been impacted had the Projects not been implemented.

As stated in the discussion about groundwater budgets, the Projects have reduced the amount of agricultural pumping by about 10,000 afy, totaling about 500,000 af over the model duration. Figure ES-6 illustrates the cumulative difference in agricultural pumping between the Historical and No Projects conditions (by aquifer area) over the simulation period, demonstrating the effect of the Projects. About 60% of the decrease in pumping occurred in the Pressure Subarea, 21% in the Upper Valley Subarea, 15% in the Forebay Subarea, 2% in the Arroyo Seco Subarea, 1% in the East Side Subarea, and less than 1% in areas of the model domain outside Zone 2C.

The decrease in agricultural pumping in the Pressure Subarea has largely occurred since CSIP came online in 1998. The provision of recycled and surface water to the CSIP network has reduced the need for agricultural pumping in this area to satisfy crop demand. The decrease in other subareas has been relatively uniform over the model duration, likely due to the generally higher groundwater levels resulting from the Projects. During the portion of the model period with CSIP operating (WY 1998 to 2018), the Projects reduced pumping by about 19,000 afy over the entire study area.

SEAWATER INTRUSION

Seawater intrusion is a key issue in the Basin. It results from depressed groundwater levels within Basin aquifers that are directly connected to the Pacific Ocean, or vertical leakage from an overlying intruded aquifer. Explicitly simulating seawater intrusion into freshwater aquifers requires accounting for the movement and mixing of waters of two different densities (i.e., seawater and freshwater) within a porous medium. The SVIHM does not employ such an approach to simulating seawater intrusion; where the Basin’s freshwater aquifers intersect Monterey Bay, groundwater levels represent observed sea level values multiplied by a factor accounting for the higher density of seawater. As currently configured, the SVIHM can only simulate seawater intrusion as a flux across the location of the coast and cannot predict the extent of onshore seawater intrusion.

As stated in the groundwater budget discussion, simulated seawater intrusion was about 15,000 afy with the Projects and about 16,000 afy without, indicating that the Projects (mostly CSIP) have prevented about 1,000 afy of seawater intrusion. Figure ES-7 presents the time series of average annual seawater intrusion flux entering the Basin under the Historical and No Projects Scenarios, along with the difference between them. Very little difference in seawater intrusion existed until 1998 when CSIP came online, indicating that the recycled and surface water delivery has significantly and positively influenced the occurrence of seawater intrusion into the Basin.

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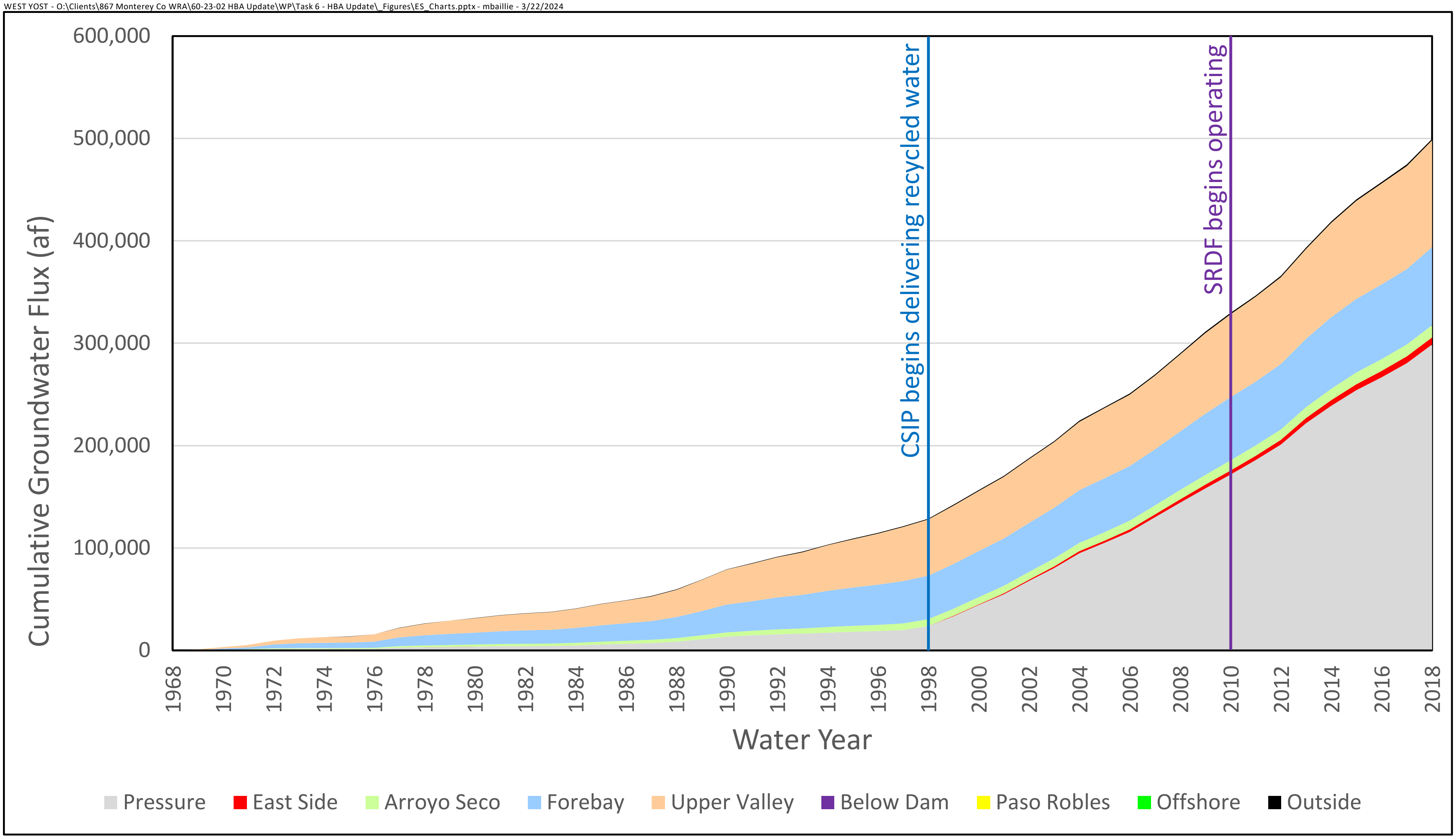

Figure ES-6

Cumulative Difference in Agricultural Pumping by Subarea

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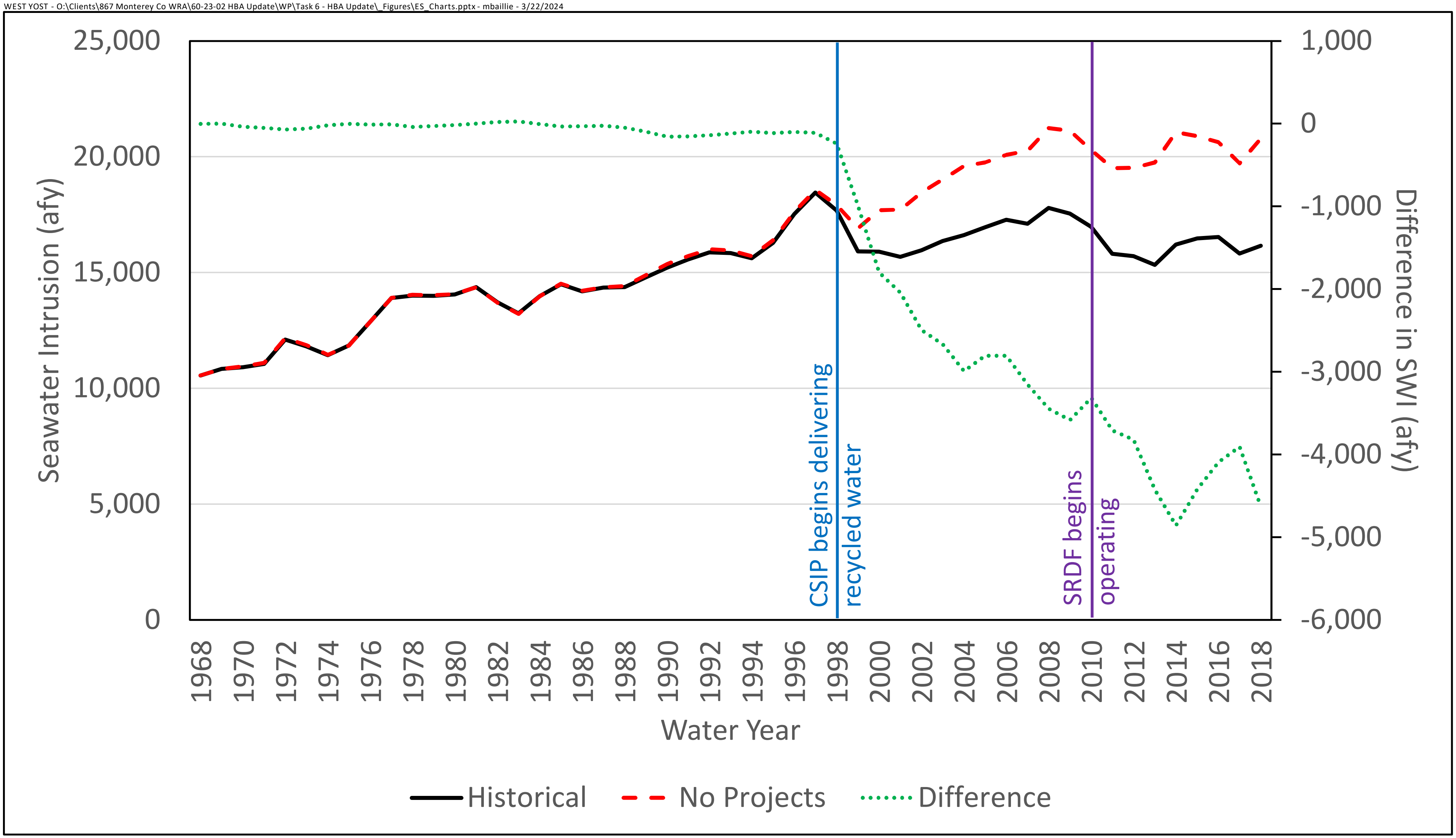

Figure ES-7

Annual Seawater Intrusion into Study Area

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Over the period of the analysis, the Projects have reduced the amount of seawater intrusion in the Basin by about 68,000 af. Most of this reduction occurred in the 180-Foot Aquifer (35%) and the 400-Foot Aquifer (56%). The remaining difference occurred in the Shallow and Deep Aquifers; however, this does not imply that seawater intrusion is directly occurring in the Deep Aquifer, as the nature of the connection between the Deep Aquifer and the Pacific Ocean is currently unknown.

FLOOD CONTROL BENEFITS ANALYSIS

Another major benefit provided by the Projects has been a reduction in the frequency and magnitude of peak flows in the system. This is achieved through the storage in the reservoirs of peak flows generated within the watersheds upstream of the Nacimiento and San Antonio Reservoirs. This attenuates the peak flows, thereby reducing their effect on streamflow in the Salinas River.

For this HBA Update, streamflow data were used to develop a statistical distribution of peak annual streamflow in the Salinas River at Bradley with and without the Projects. The effects of selected peak flows in the Salinas River and its floodplain were then simulated using a 2-dimensional hydraulic model. This provides a quantitative demonstration of the effect the Projects have had on flood risk in the Basin.

FLOOD FLOW FREQUENCIES

For this HBA Update, flood flow magnitudes in the Salinas River at Bradley were estimated using 1) the results of the Historical and No Projects Scenarios, 2) measured streamflow data, 3) measured releases from and estimated inflow to Nacimiento and San Antonio Reservoirs, and 4) simulated streamflow in the Salinas River upstream of the reservoirs. The difference in flood flow magnitudes between the Historical and No Projects conditions represents the effect of the Projects.

Table ES-2 summarizes the peak flow magnitudes for selected annual exceedance probabilities (e.g. a 10-year flood). With the Projects, the 100-year flood at Bradley was estimated to be about 114,600 cfs, which is close to the largest actual observed streamflow at Bradley of 120,000 cfs (on March 11th, 1995). Without the Projects, the 100-year flood would have been about 159,000 cfs. This means that the Projects have reduced the 100-year flood magnitude by about 44,000 cfs, a 28% decrease. Without the Projects, the model suggests that the with-Projects 100-year flood magnitude of about 114,600 cfs would have occurred on average once every 34 years, which is about three times as frequently.

The Projects have had a proportionately larger impact on floods with more frequent recurrence intervals, such as the 25-year flood, which was decreased by 47%. This demonstrates that the reservoirs are more likely to have sufficient storage capacity to absorb the entirety of smaller peak flows generated in the reservoirs' watersheds.

Table ES-2. Peak Flow Magnitudes for Selected Return Probabilities, Observed and Estimated Streamflow Datasets			
Return Period (Years)	10	25	100
Annual Exceedance Probability	0.1	0.04	0.01
Observed Streamflow (WY 1968-2018)	35,700	65,900	132,900
Historical Scenario	28,500	53,400	114,600
No Projects Scenario	67,600	100,900	158,700
Difference Between Scenarios	+39,100	+47,500	+44,100
Percent Decrease Due to Projects	58%	47%	28%

Notes:

All peak flows are in cubic feet per second (cfs)

Difference between scenarios is calculated as No Projects Scenario peak flow minus Historical Scenario peak flow; this is the opposite of the calculation used in Hydrologic Benefits Analysis, and is used here to avoid plotting negative differences on logarithmic charts.

PEAK FLOW INUNDATION

Selected peak flows were used as input to a hydraulic model of the Salinas River and its floodplain to simulate the extent of inundation under the influence of the peak flow at Bradley. Simulations were conducted for 5-, 10-, 25-, and 100-year flows, with and without the Projects. Table ES-3 summarizes the flood inundated area (in acres) for selected return periods. Figures ES-8 and ES-9 shows the inundation areas and depth for the Historical and No Projects Scenarios, respectively, for the 100-year flood. Figure ES-10 shows the difference in the inundation depth between scenarios. The simulation results indicate that the Projects have effectively reduced the extent of inundation during flood events. For instance, the 100-year flood with the Projects resulted in about 60,000 acres of inundation, compared to about 65,000 acres without the Projects. This suggests that the Projects have decreased the 100-year flood inundation by about 5,000 acres.

Table ES-3. Inundated Area (in acres) for Selected Return Periods, Historical and No Projects Scenarios			
Return Period (Years)	10	25	100
Historical Scenario	31,700	45,400	60,000
No Projects Scenario	48,100	56,500	65,000
Difference Between Scenarios	-16,500	-11,100	-4,900

Notes:

Areas are rounded to the nearest 100 acres; totals may not sum due to rounding

Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario.

Just as for the peak flow magnitudes, the Projects have decreased the extent of inundation resulting from more frequent flood events (e.g., the 25-year flood) to a greater degree than less frequent events (e.g., the 100-year flood;). For example, the 25-year flood inundated about 45,000 acres in the Historical Scenario, while the No Projects Scenario inundated about 57,000 acres. This difference equates to about 17 fewer square miles of floodplain inundated.

As shown in Figure ES-10, the Projects have also reduced the depth of flooding during peak flow events. Inundation under the 100-year flood was simulated to be as much as 10 feet lower with the Projects than without, and much of the floodplain experienced several feet less inundation depth due to the Projects.

Lastly, along with the decreased magnitude of peak flows and extent of flooding, the Projects have also reduced the velocity of flows within the inundated area, mitigating the risk of agricultural soil erosion and damage to structures in the floodplain. The linear flow velocity of water within the inundated area for the 100-year floods with and without the Projects is shown in Figure ES-11. The flow velocity with the Projects is mostly about 5 feet per second (fps) or less, with lower velocities in the northern part of the Basin and higher velocities in the southern part, where the floodplain is more constrained laterally. Without the Projects, the flow velocities would have been higher, between 5 and 10 fps across much of the floodplain.

These results demonstrate that the Projects have prevented the inundation of thousands of acres of land by decreasing peak flow magnitudes over the period since the reservoirs began operating.

Just as the Projects have reduced the magnitude of more frequent flood events (e.g., the 25-year flood) to a greater degree than the 100-year flood, the extent of inundation for these more frequent events is decreased more due to the Projects (Table ES-3). For example, the with-Projects 25-year flood inundated about 45,000 acres, while the without-Projects 25-year flood inundated about 57,000 acres.

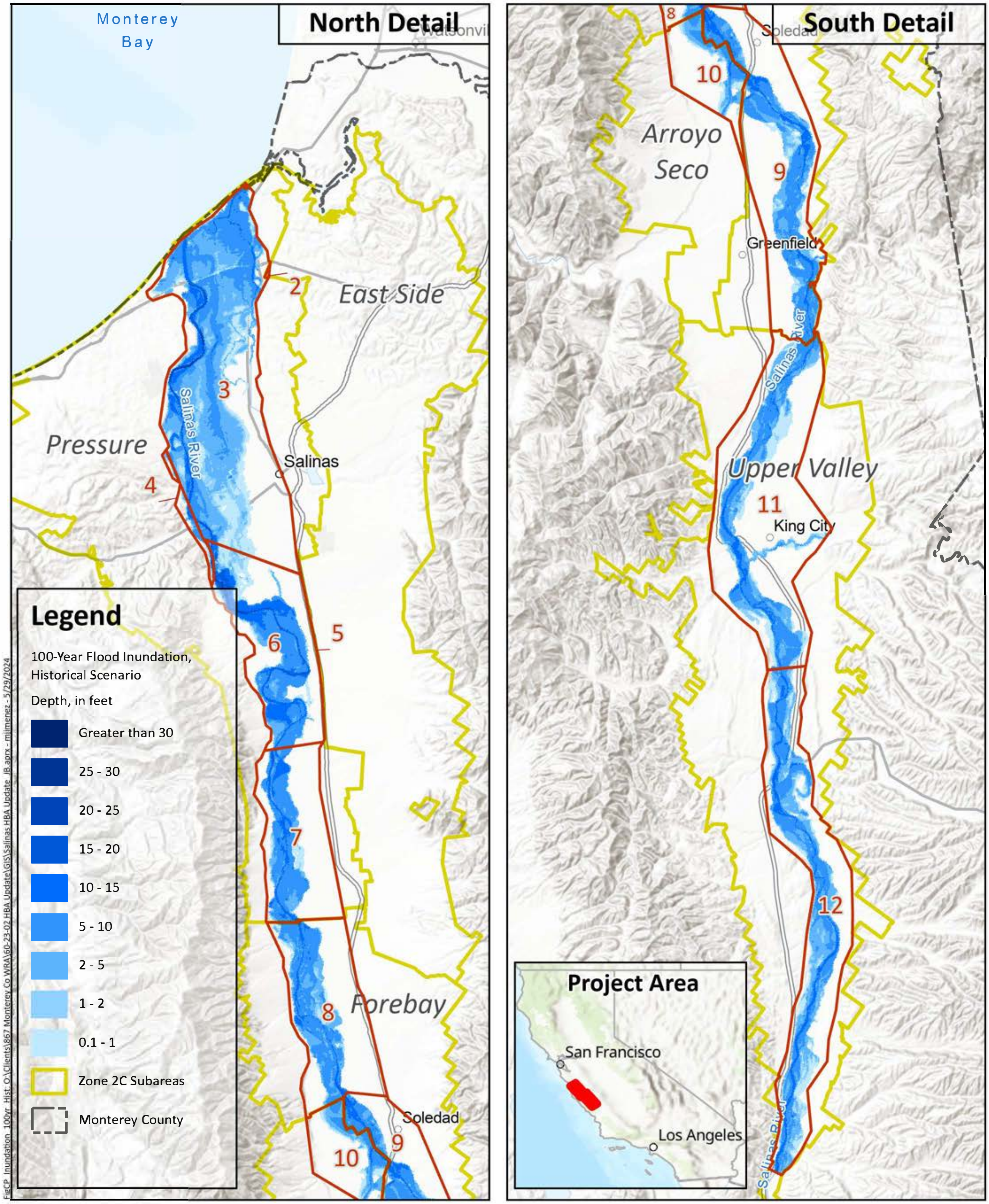
The Projects have also reduced the depth of flooding during peak flow events (compare Figures ES-8 and ES-9). Inundation under the 100-year flood was simulated to be as much as 10 feet lower with the Projects than without, and much of the floodplain experienced several feet less inundation depth due to the Projects.

Along with the decreased magnitude of peak flows and extent of flooding, the Projects have also reduced the velocity of flows within the inundated area. Figure ES-10 shows the linear flow velocity of water within the inundated area for the 100-year floods with and without the Projects. The flow velocity with the Projects is mostly about 5 feet per second (fps) or less, with lower velocities in the northern part of the Basin and higher velocities in the southern part, where the floodplain is more constrained laterally. Without the Projects, the flow velocities would have been higher, between 5 and 10 fps across much of the floodplain.

These results demonstrate that the Projects have prevented the inundation of thousands of acres of land by decreasing peak flow magnitudes over the period since the reservoirs began operating.

SOIL EROSION SUSCEPTIBILITY

The susceptibility of agricultural soils to erosion during inundation is a significant concern. The 1998 HBA categorized inundated soils into high, medium, or low susceptibility to erosion based on the flow velocity of the floodwater and the erodibility of the soil. This HBA Update follows the same approach to determine the Erosion Potential Index (EPI) throughout the inundated area. Table ES-4 summarizes the area, in acres, classified as low, medium, and high EPI for each scenario under selected return periods. The Projects have resulted in about 6,000 fewer acres being classified as high EPI for the 100-year flood event. This reduction in high EPI areas indicates that the Projects have substantially reduced the susceptibility of soil to erosion during flood events.



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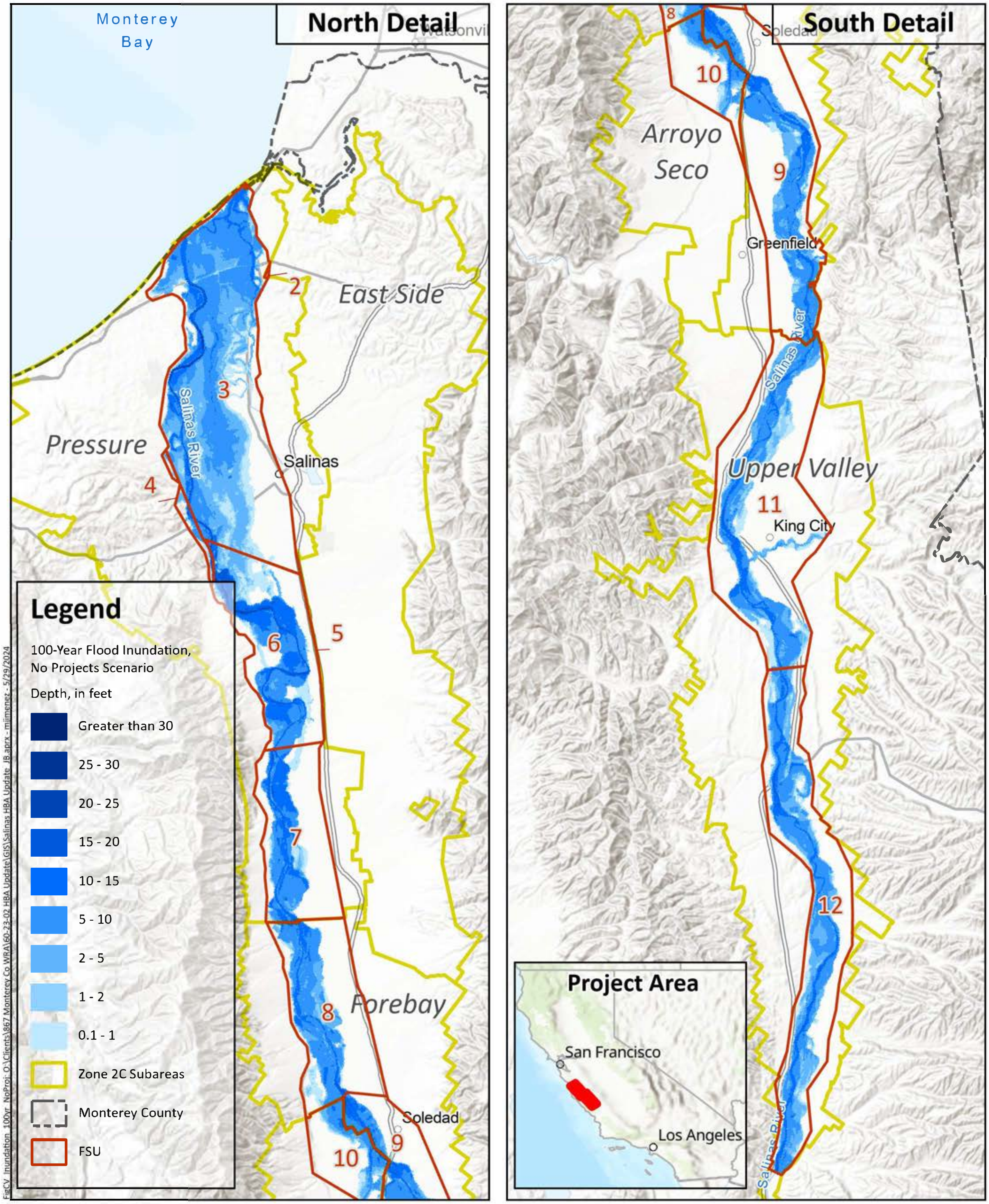
Salinas Valley HBA Update
April 2025

Inundation Area and Depth for 100-Year Flood
Historical Scenario

Figure ES-8



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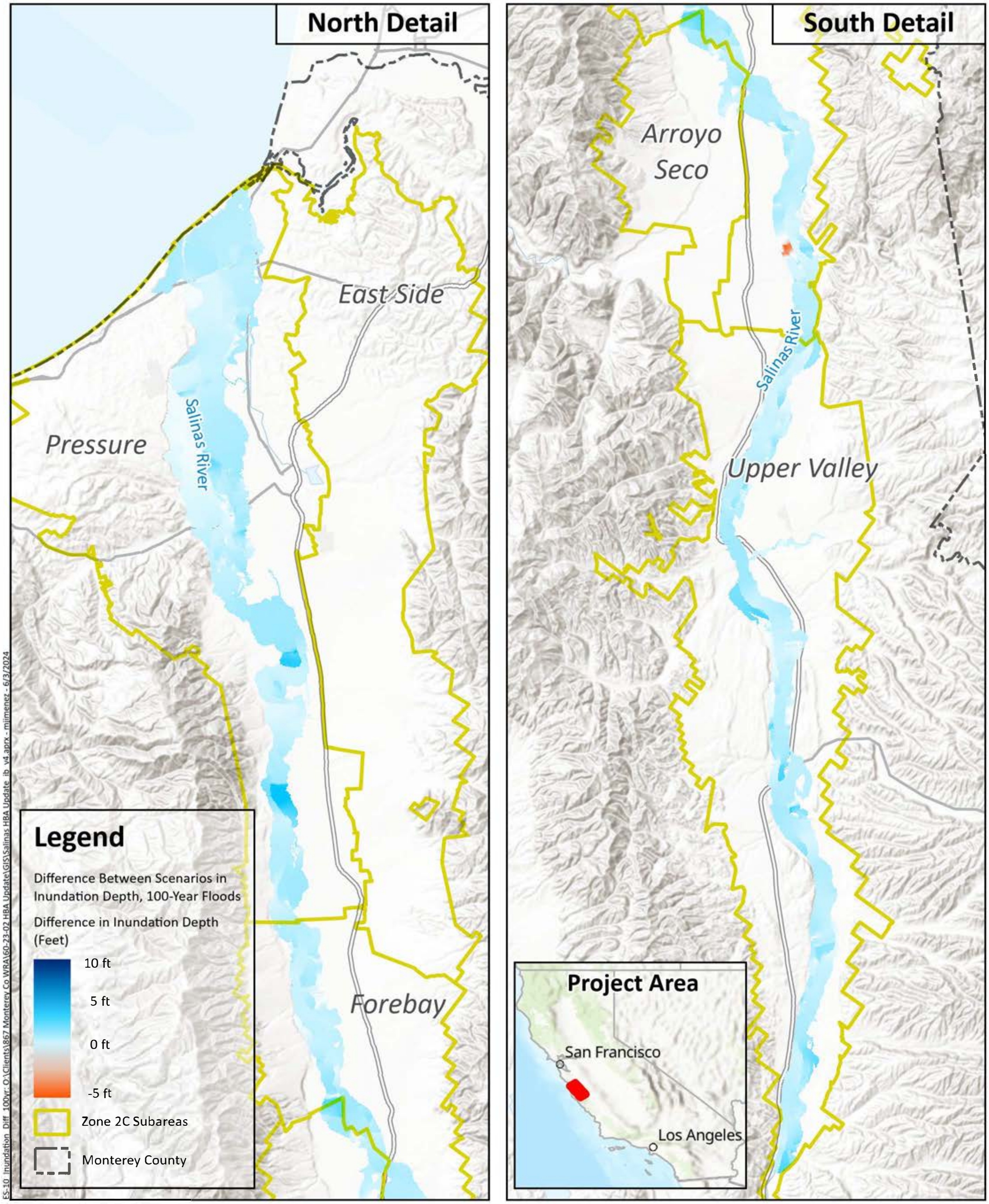
April 2025

Inundation Area and Depth for 100-Year Flood
No Projects Scenario

Figure ES-9



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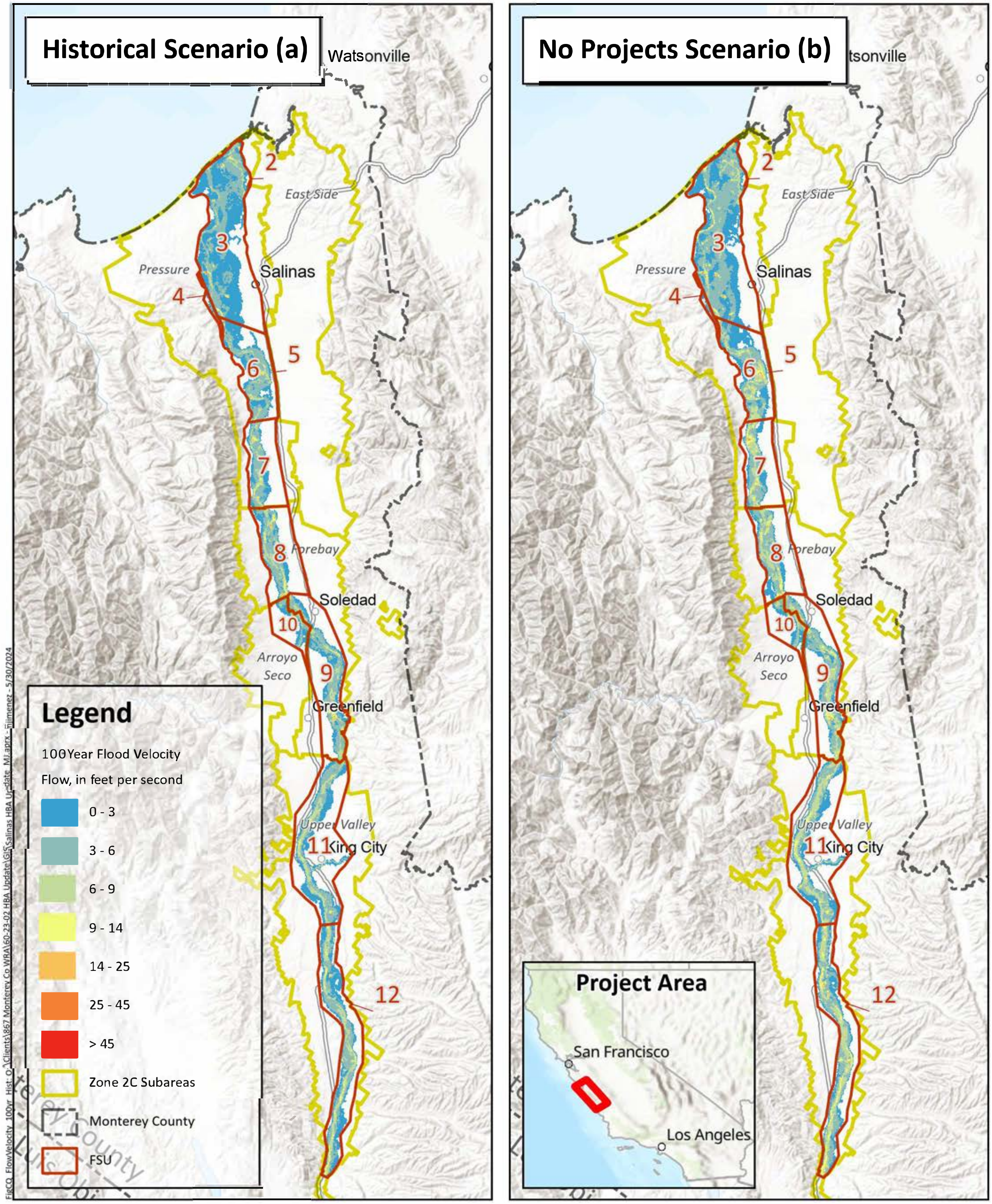
Difference Between Scenarios in Inundation Depth for 100-Year Flood

Figure ES-10



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Flow Velocity for 100-Year Flood

Figure ES-11

Table ES-4. Area in Each Erosion Potential Index Category for 100-Year Event in the Historical and No Projects Scenarios, in acres			
Erosion Potential Index Category	Low	Medium	High
Historical Scenario	22,300	23,200	11,000
No Projects Scenario	17,800	30,100	16,900
Difference Between Scenarios	+4,500	-6,900	-5,900

ECONOMIC BENEFITS ANALYSIS

The 1998 HBA provided an economic estimate of the benefit that stakeholders in the Basin have received from the reservoirs since their construction For this HBA Update, the quantification of economic benefit is being prepared separately and is not included in this report (One Water Econ, In Preparation).

OTHER BENEFITS

The Projects provide a range of benefits beyond the hydrologic and flood control benefits. While these additional benefits are not quantified, they are important. The Projects, particularly the reservoirs, have supported recreation and tourism, including camping, hiking, and fishing. Recreational benefits are evaluated and quantified in further detail in the Economic Benefits Analysis prepared by One Water Econ.

The Projects have contributed environmental benefits by supporting fish and wildlife habitat and the migration of endangered Steelhead trout between the Pacific Ocean and their spawning grounds in the Salinas River and its tributaries. The Projects provide peace of mind to Basin stakeholders by enhancing the predictability of streamflow in the Salinas River through peak flow magnitude reduction and the occurrence of years with little streamflow. Finally, the Projects serve as a safeguard against increased uncertainty in future conditions; with climate change potentially leading to greater climatic variability, the importance of the Projects' ability to store and redistribute flow captured during wet periods is likely to increase.

SUMMARY AND CONCLUSIONS

The Projects provide a range of benefits beyond the hydrologic and flood control benefits. While these additional benefits are not quantified, they are important. The Projects, particularly the reservoirs, have supported recreation and tourism, including camping, hiking, and fishing. Recreational benefits are evaluated and quantified in further detail in the Economic Benefits Analysis prepared by One Water Econ (One Water Econ, In Preparation).

The Projects have also contributed environmental benefits by supporting fish and wildlife habitat below the dams and the migration of endangered Steelhead trout between the Pacific Ocean and their spawning grounds in the Salinas River and its tributaries. The provision of recycled water to the CSIP area has also provided environmental benefits by reducing the discharge of treated wastewater into the Monterey Bay National Marine Sanctuary.

Finally, the Projects serve as a safeguard against increased uncertainty in future conditions; with climate change potentially leading to greater climatic variability, the importance of the Projects' ability to store and redistribute flow captured during wet periods is likely to increase. The Projects provide peace of mind to Basin stakeholders by enhancing the predictability of streamflow in the Salinas River through reduction in both peak flow magnitudes and the occurrence of years with little streamflow.

REFERENCES

California Department of Water Resources (DWR). 1946. Salinas Basin Investigation Summary Report. Bulletin 52-B. 68p.

Montgomery Watson (MW). 1998. Salinas Valley Historical Benefits Analysis (HBA). Prepared for Monterey County Water Resources Agency in association with CH2MHILL and Schaaf and Wheeler Associates. 297p. April 1998.

One Water Econ. In Preparation. Economic Benefits of MCWRA's Investments in Water Infrastructure Projects for Salinas Valley. Prepared for Monterey County Water Resources Agency.

CHAPTER 1
Introduction and Background

This report represents an update to the existing Salinas Valley Historical Benefits Analysis (HBA) prepared by Montgomery Watson (MW) in 1998, which quantified the benefits that the Salinas River Groundwater Basin (Basin) has accrued due to the construction of the Nacimiento and San Antonio Reservoirs. The goal of the work presented in this report is to update the analyses presented in the 1998 HBA to take advantage of an improved understanding of the Basin, improved tools, and additional data collection, and to address important changes in the approach to water resources management in the Basin since 1998. These changes include: production of recycled water at the Salinas Valley Reclamation Plant and distribution of that water for irrigation through the Castroville Seawater Intrusion Project (CSIP) system; development of the Salinas Valley Water Project (SVWP) and construction of the Salinas River Diversion Facility (SRDF); implementation of the Flow Prescription for setting streamflow targets to aid migration of Steelhead trout; construction of the Nacimiento Water Project (NWP); and additional changes to the operation of the Nacimiento and San Antonio Reservoirs. This report presents quantified benefits that have accrued to the Basin stakeholders over the 51-year period from Water Year (WY) 1968 to 2018 due to the presence of the Nacimiento and San Antonio Reservoirs and related projects and programs (referred to collectively in this report as "the Projects"). This quantification of benefit is used by the Monterey County Water Resources Agency (MCWRA) to demonstrate the continued effects these projects and programs have on the system and as part of the determination of assessments on stakeholders in the Basin.

This HBA Update was completed in fulfillment of the scope of services submitted by West Yost to the MCWRA on April 7, 2023. The scope of services was approved by the MCWRA Board of Directors on April 17, 2023 by Board Order No. 23-32.

1.1 ORGANIZATION OF REPORT

This HBA Update is organized into chapters that broadly follow the structure of the 1998 HBA. The nine chapters are:

- Chapter 1. Introduction and Background
- Chapter 2. Tools and Approach
- Chapter 3. Hydrologic Benefits Analysis
- Chapter 4. Flood Control Benefits Analysis
- Chapter 5. Economic Benefits Analysis
- Chapter 6. Other Benefits
- Chapter 7. Discussion of Uncertainty
- Chapter 8. Summary and Conclusions
- Chapter 9. References

1.2 STUDY AREA

The study area for this HBA Update is equivalent to the MCWRA assessment Zone 2C (Zone 2C), which falls within the Salinas Valley in coastal central California between the San Joaquin Valley and the Pacific Ocean, as shown on Figure 1-1. This section describes the context of water resources in the study area, including the hydrogeologic setting in which the study area resides, the history of water resources development in the study area, and the particular water-related issues that are of greatest concern.

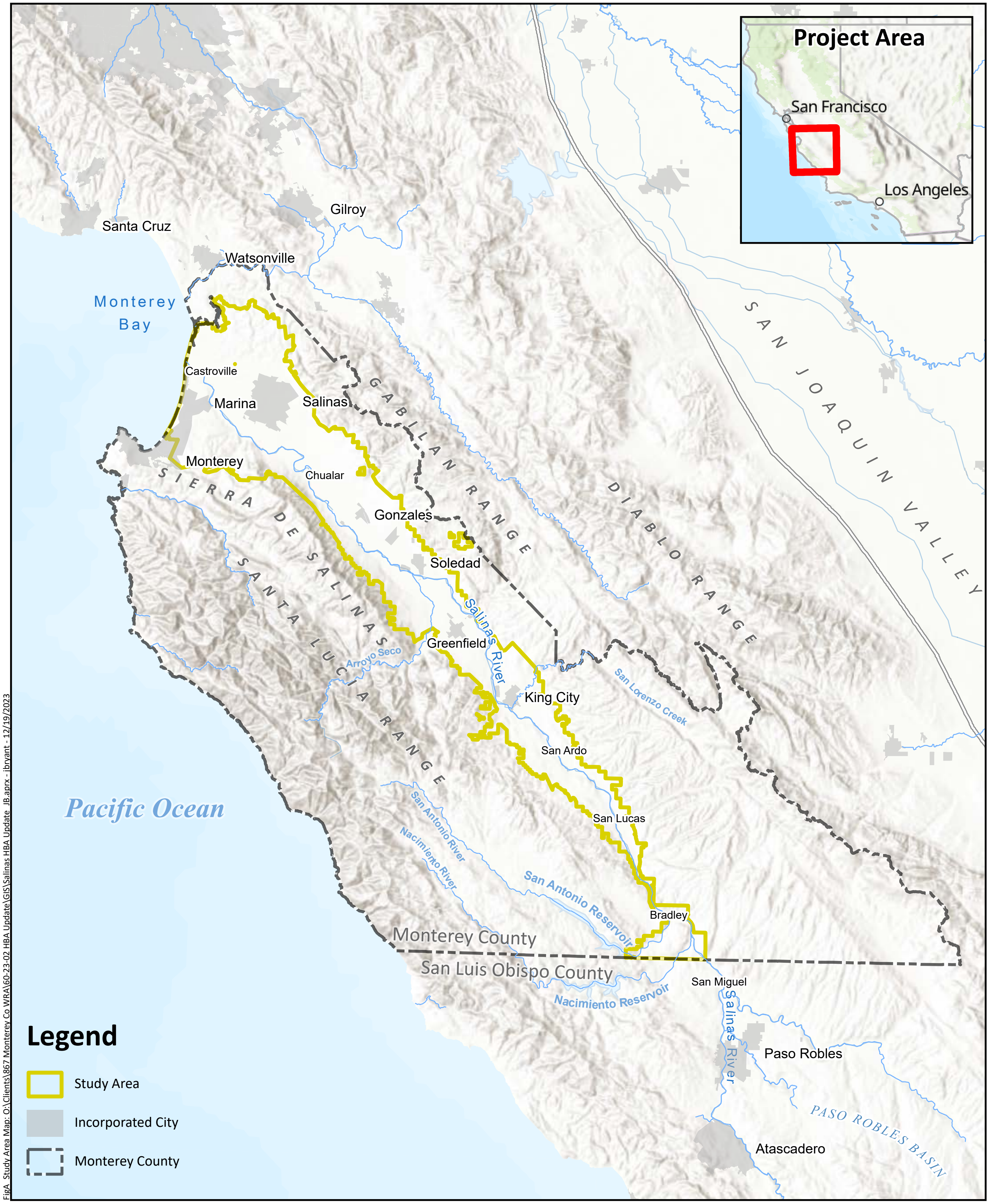
1.2.1 Study Area Overview

The Salinas Valley stretches along the Salinas River from its headwaters in San Luis Obispo County about 170 miles north to its outlet to the Pacific Ocean at Monterey Bay. The Salinas River watershed covers an area of more than 4,000 square miles, or more than 2.5 million acres. This study concentrates on the portion of the Salinas River watershed north of San Miguel, where the Salinas Valley narrows after passing through the Paso Robles Basin. Major tributaries to the Salinas River within the study area include the Nacimiento River (on which Nacimiento Reservoir lies), the San Antonio River (on which San Antonio Reservoir lies), San Lorenzo Creek, Arroyo Seco, Alisal Creek, and El Toro Creek. The study area also includes some areas outside of the Salinas River watershed that are tributary to Elkhorn Slough and Monterey Bay.

The study area is bounded on the east and west by mountain ranges. The eastern boundary comprises the Gabilan and Diablo Ranges, while the western boundary comprises the Sierra de Salinas and the Santa Lucia Range. The northern boundary lies along Elkhorn Slough and the hills to its east. The southern extent of the study area is defined based on a lateral constriction of the alluvial valley as the eastern and western bounding ranges approach the Salinas River.

The Salinas Valley is bounded on either side by normal faults that accommodate the uplift of the bounding mountain ranges. The geologic history and current geologic context of the Salinas Valley are described in detail in Rosenberg (2001); this history has resulted in low-permeability bedrock mountain ranges bounding an alluvial basin in which the sediment thickness is as great as 12,000 feet. The depositional environment has varied from fluvial to marine over time, depending on the location, tectonic history, and sea level fluctuations (Kennedy/Jenks, 2004). The structural and depositional history of the Basin have resulted in a deep, productive alluvial basin that can be broadly broken into two regions: a southern region where groundwater is unconfined and resides in undifferentiated aquifers made up of largely fluvial and alluvial sediments, and a northern region where groundwater is contained in a series of confined to semi-confined aquifers made up of fluvial, alluvial, and marine sediments, including extensive but discontinuous fine-grained confining layers. This hydrostratigraphic context has been critical to the past and present of water resources development in the Basin.

The study area land use is heavily agricultural, but also includes a number of urban areas and rural, unincorporated communities. The total value of agricultural production in Monterey County in 2021 was over $4 billion from about 300,000 irrigated acres (County of Monterey Agricultural Commissioner, 2022), most of it within the Salinas Valley. Cities and unincorporated communities within the study area include Bradley, Castroville, Chualar, Gonzales, Greenfield, King City, Marina, Salinas, San Ardo, San Lucas, and Soledad. Both the agricultural users and the population place heavy demands on groundwater in the Basin, which represents by far the largest source of water to users. Of this, agricultural use is by far the dominant use of groundwater in the Basin, representing about 90 percent of total metered pumping (e.g., Brown and Caldwell, 2015a).



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WEST YOST

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Salinas Valley HBA Update
April 2025

Salinas Valley
HBA Update
Study Area

Figure 1-1

1.2.2 Relevant Research

Since the 1998 HBA was prepared, numerous studies have contributed to advancing the understanding of the geology and hydrology of the study area. Some of these studies are listed below:

- Seafloor Rocks and Sediments of the Continental Shelf from Monterey Bay to Point Sur, California (Eittreim et al., 2000)
- Hydrogeologic Investigation of the Salinas Valley Basin in the Vicinity of Fort Ord and Marina (Harding ESE, 2001)
- Geologic Resources and Constraints, Monterey County, California (Rosenberg, 2001)
- Geohydrology of a Deep-Aquifer System Monitoring-Well Site at Marina, Monterey County, California (Hanson et al., 2002)
- North Monterey County Comprehensive Water Resources Management Plan (MCWRA and EDAW, 2002)
- Deep Aquifer Investigation – Hydrogeologic Data Inventory, Review, Interpretation and Implications (Feeney and Rosenberg, 2003)
- Geohydrologic Framework of Recharge and Seawater Intrusion in the Pajaro Valley, Santa Cruz and Monterey Counties, California (Hanson, 2003)
- Hydrostratigraphic Analysis of the Northern Salinas Valley (Kennedy/Jenks, 2004)
- Installation of Deep Aquifer Monitoring Wells – DMW-2 (MACTEC, 2005)
- Seaside Groundwater Basin Watermaster Seawater Sentinel Wells Project Summary of Operations (Feeney, 2007)
- El Toro Groundwater Study (Geosyntec, 2007)
- Protective Elevations to Control Sea Water Intrusion in the Salinas Valley (Geoscience, 2013)
- State of the Salinas River Groundwater Basin (Brown and Caldwell, 2015a)
- Recommendations to Address the Expansion of Seawater Intrusion in the Salinas Valley Groundwater Basin (MCWRA, 2017)
- Recommendations to Address the Expansion of Seawater Intrusion in the Salinas Valley Groundwater Basin – 2020 Update (MCWRA, 2020)
- California’s Groundwater – Update 2020 (DWR, 2021)
- Eastside Aquifer Subbasin Groundwater Sustainability Plan (SVBGSA, 2022a)
- Forebay Aquifer Subbasin Groundwater Sustainability Plan (SVBGSA, 2022b)
- Langley Area Subbasin Groundwater Sustainability Plan (SVBGSA, 2022c)
- Upper Valley Aquifer Subbasin Groundwater Sustainability Plan (SVBGSA, 2022d)
- 180/400-Foot Aquifer Subbasin Groundwater Sustainability Plan 2022 Update (SVBGSA, 2022e)
- Groundwater Sustainability Plan, Monterey Subbasin (MCWDGSA and SVBGSA, 2022)

These studies have contributed to an increased understanding of Basin characteristics, and their results have been used to develop the tools and analyses that allow for in-depth, holistic representation of the

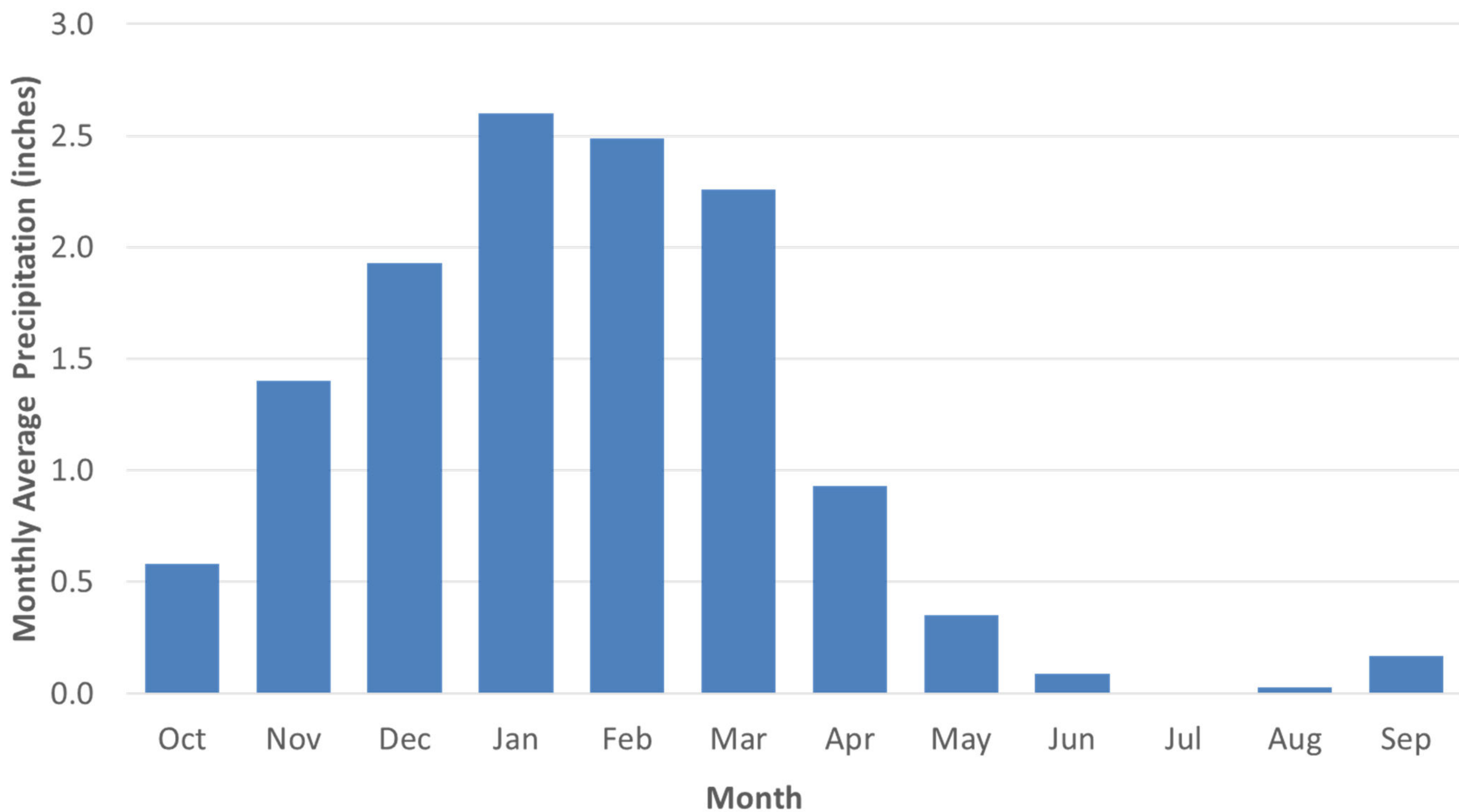
Basin. Of particular importance are the models under development by the U.S. Geological Survey (USGS) that were used to assist with preparation of this report (as described in Chapter 2 of this report).

1.2.3 Hydrologic Setting

The study area lies within coastal Central California, an area with a Mediterranean climate typified by mild, dry summers and cool, wet winters. As shown on Figure 1-2, about 90 percent of the annual rainfall occurs during the period from November to April. The seasonal rainfall pattern results in highly seasonal natural streamflow distribution in the study area. Figure 1-3 shows the monthly average streamflow at the USGS Arroyo Seco near Soledad stream gauge (#11152000), which was chosen because it represents a location of relatively high, unregulated streamflow in the study area. Figure 1-4 illustrates the spatial distribution of rainfall in the study area, which is highly impacted by topography, with the highest average annual rainfall occurring on the mountain ranges that bound the study area, especially on the coastal Santa Lucia Range to the west.

As a result of its complex depositional history, the Basin contains a heterogeneous mix of alluvial, fluvial, and marine sediments. For analytical and documentational purposes, this complexity has been simplified into a hydrostratigraphy with defined aquifers and aquitards in parts of the Basin, based on the presence of extensive connected sediments that respond in similar ways to regional stresses, as detailed in hydrogeologic cross-sections present in Kennedy/Jenks, 2004 and Brown and Caldwell, 2015a. As noted above, the Basin can generally be divided into two broad hydrostratigraphic regions, with the northern region hosting a series of confined to semi-confined aquifers interspersed with aquitards, and the southern region hosting a generally continuous sequence of unconfined fluvial and alluvial sediments (e.g., Kennedy/Jenks, 2004).

The sediments of the basin are generally interconnected in various ways, although hydrostratigraphic units (such as aquifers and aquitards) have been defined based on the long experience of hydrogeologists and groundwater users. Although there are no structural barriers within the Basin that compartmentalize groundwater in the system, differences in the generalized hydrostratigraphic context in different parts of the Basin have led to its division into subbasins. Figure 1-5 shows groundwater subbasins that make up the study area as defined by the California Department of Water Resources (DWR). The study area includes part or all of the 180/400 Foot Aquifer (DWR basin 3-004.01), East Side Aquifer (3-004.02), Forebay Aquifer (3-004.04), Upper Valley Aquifer (3-004.05), Seaside (3-004.08), Langley Area (3-004.09), and Monterey (3-004.10) Subbasins. MCWRA subdivides the Basin somewhat differently. Figure 1-6 shows the MCWRA-defined groundwater subareas that make up Zone 2C; this approach divides the study area into the Pressure, East Side, Forebay, Arroyo Seco, Upper Valley, and Below Dam Subareas. This HBA Update presents results based on the Zone 2C Subarea definitions.



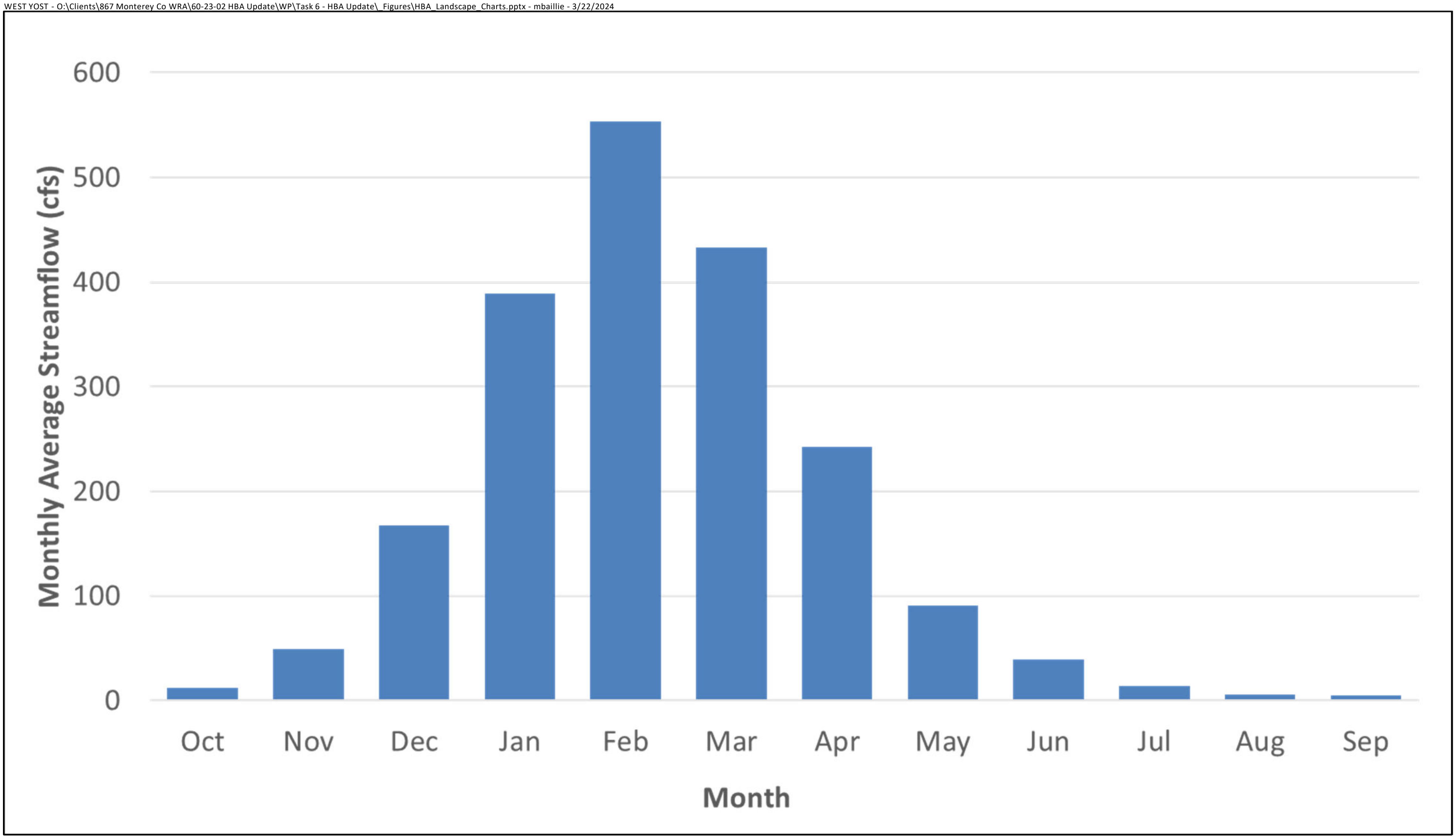
Notes:

1. Source: PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, data created 12 Sep 2013, accessed 20 Aug 2015.
2. Data represent monthly average rainfall values over period from Water Years 1981 to 2010

Figure 1-2

Monthly Average Rainfall, Salinas Municipal Airport

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025



Notes:
1. Source: USGS
2. Average monthly streamflows for the period from Oct 1901 to Sep 2022

Figure 1-3

Monthly Average Streamflow, Arroyo Seco near Soledad Gauge

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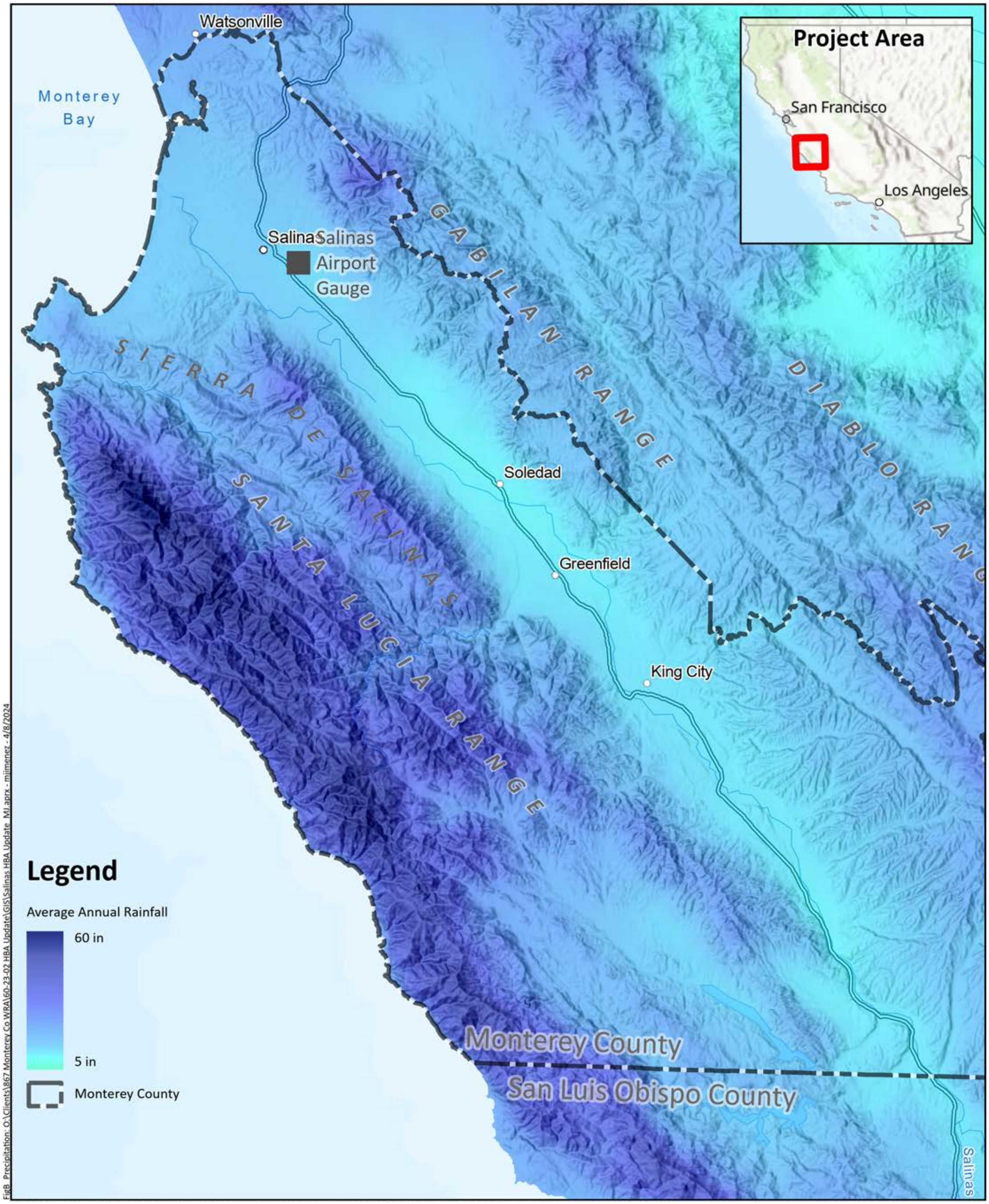
Historical Benefits Analysis Update
April 2025



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Source: PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, data created 12 Sep 2013, accessed 20 Aug 2015. Data represent monthly average rainfall values over the period from Water Year 1981 to 2010.

Prepared by:

WEST YOST

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Salinas Valley HBA Update
May 2024

Regional Distribution of Annual Rainfall

Figure 1-4

Source: DWR, 2021

Prepared by:

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April 2025

DWR-Defined Groundwater Subbasins

Figure 1-5

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Source: MCWRA

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MCWRA Zone 2C Subareas

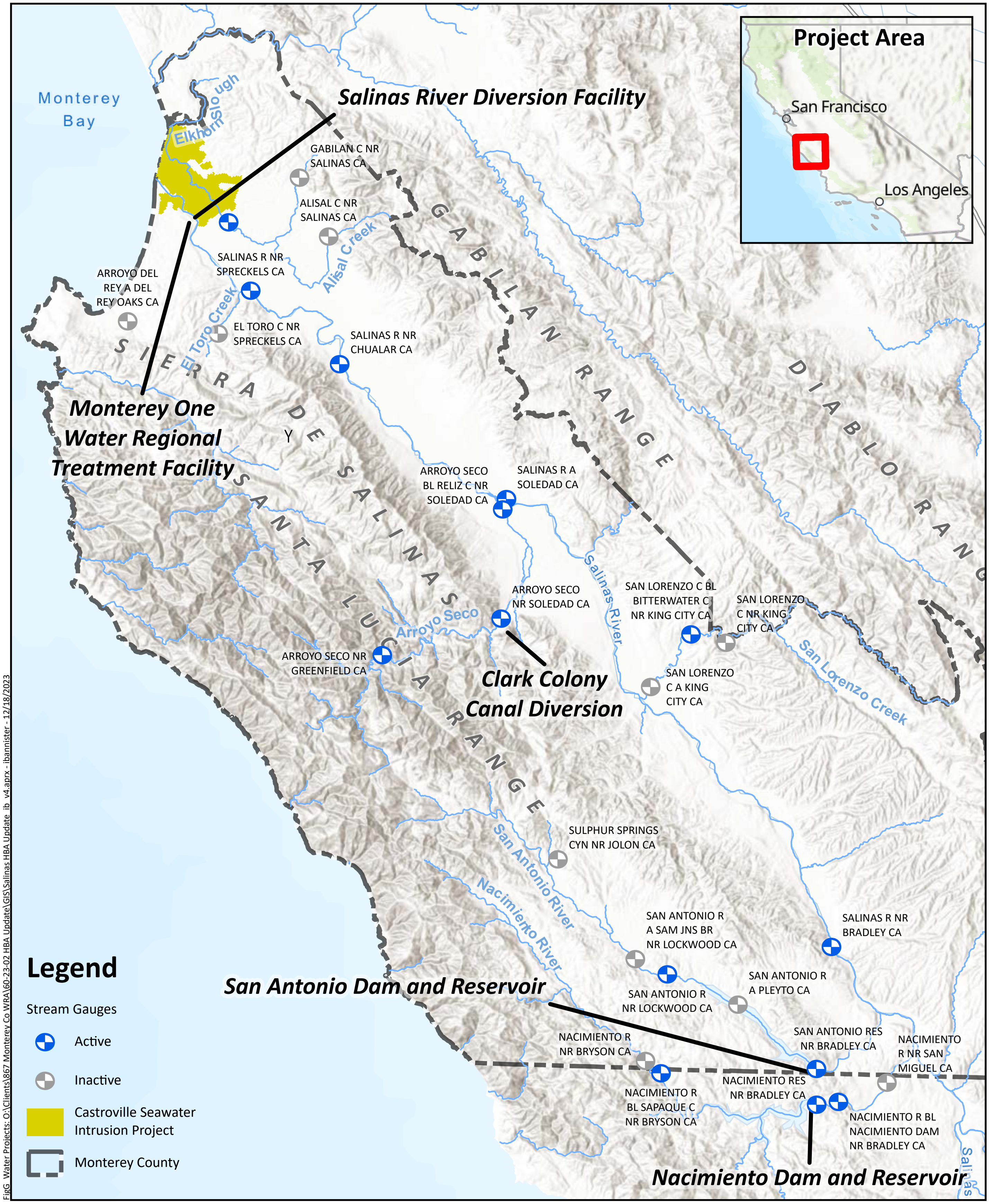
Figure 1-6

Detailed hydrogeologic studies have revealed that the aquifers and aquitards of the northern region are discontinuous, particularly approaching the foothills of the Gabilan Range. The coastal area contains three major freshwater supply aquifers – termed the 180-Foot, 400-Foot, and Deep Aquifers – separated from each other by aquitards made up of fine-grained sediments. There is also a thin aquifer made up of surficial sediments overlying the uppermost aquitard, but it is not generally used for water supply. On the eastern side of the northern region, the defined layering present in the coastal area breaks down into a sequence of thin, discontinuous coarse- and fine-grained layers in which groundwater exists in semi-confined conditions; in this area, the sediments are typically broken into a Shallow Aquifer and a Deep Aquifer, generally mapped (e.g., by MCWRA) as hydrologically equivalent of the 180-Foot and 400-Foot Aquifers, respectively. A transition zone lies between the confined and semi-confined portions of the northern region (Kennedy/Jenks, 2004). The aquitards present in the northern region pinch out to the south around Chualar; south of this point, the aquifers are in an unconfined state (Brown and Caldwell, 2015a).

The Salinas River is the dominant hydrologic feature in the study area, running from south to north through the Salinas Valley and gathering tributary flow from the watersheds that drain the surrounding mountain ranges (Figure 1-7). The Salinas River enters the study area from the Paso Robles Basin to the south, ultimately discharging into Monterey Bay near the town of Marina. Beyond about San Ardo, the Salinas River is a low-gradient, meandering river that runs more or less down the center of the Salinas Valley except where major tributaries, such as Arroyo Seco, have delivered sediments that have pushed the course of the Salinas River to one side or the other of the Valley.

In general, the Salinas River loses water to the Basin aquifers throughout the study area. Communication between the river and the aquifers is limited where fine-grained sediments underlie the river, acting as a barrier to exchange between the groundwater and surface water systems. As described above, extensive, continuous fine-grained sediments are present in the northern region of the Basin, especially the coastal area. The uppermost aquitard, the Salinas Valley Aquitard, limits the amount of recharge that the Salinas River is able to provide to the freshwater aquifers.

There are a few significant manmade structures and projects that impact groundwater and surface water flow in the study area (Figure 1-7) and discussed in more detail in Section 1.2.4. The two large surface water reservoirs present at the southern end of the study area, the Nacimiento and San Antonio Reservoirs, store streamflow generated in the watersheds of the Nacimiento and San Antonio Rivers, which are tributary to the Salinas River. These reservoirs are owned and operated by MCWRA for the purposes of flood control, water conservation, support of fish migration and fish and wildlife habitat, and recreation. Two diversions exist to provide surface water to agricultural users in the study area. The Clark Colony Canal diverts water from Arroyo Seco and delivers it to users in an area to the southwest of Greenfield. The SRDF diverts water from the Salinas River and delivers it to agricultural users in the CSIP area near Castroville. Finally, the Monterey One Water Recycled Water Facility treats wastewater generated in the northern region of the study area and delivers it to agricultural uses in the CSIP area.



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April 2025

Salinas Valley Surface Water Network and Water Projects

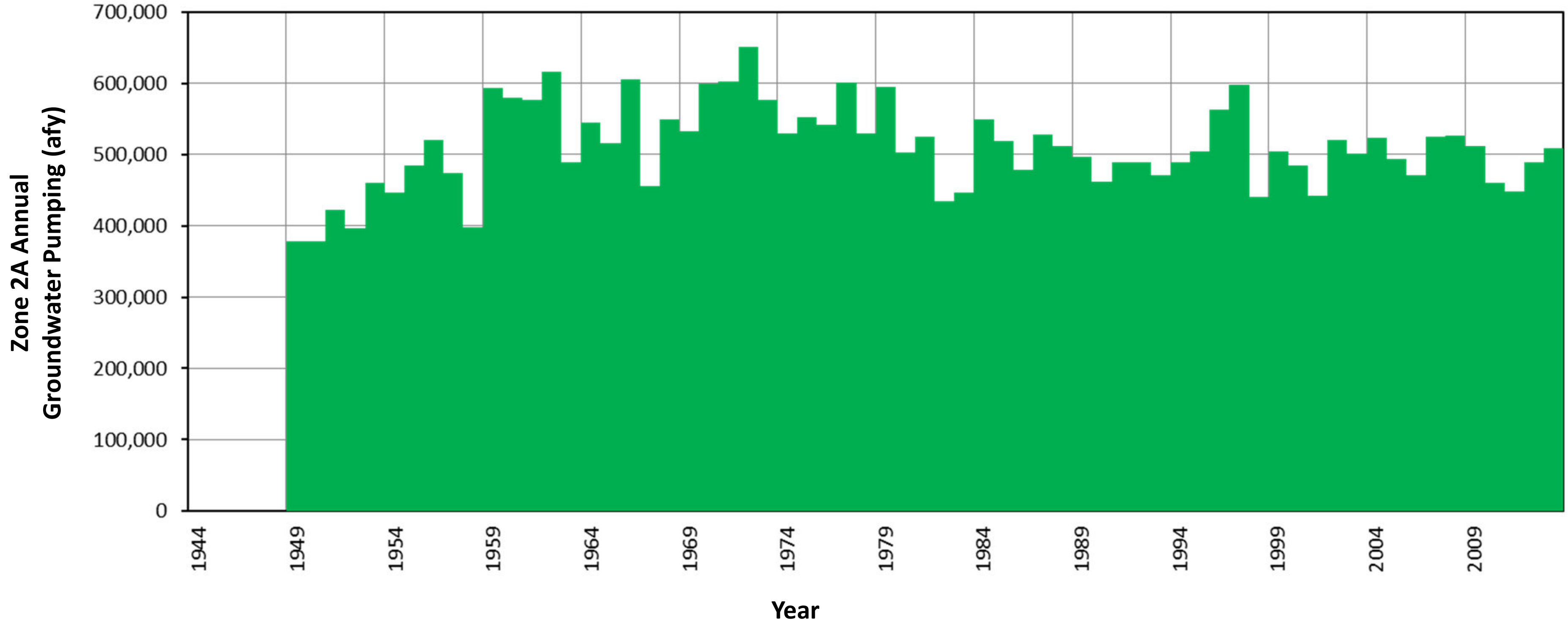
Figure 1-7

1.2.4 Water Resources Development in the Basin

Groundwater resources of the study area have been utilized to supply agricultural users since the late 19th century (DWR, 1946). The development of water resources in the Basin has been driven largely by agricultural demand, which grew over the course of the 20th century as the amount of irrigated acreage increased (MW, 1998). Total groundwater pumping reported to MCWRA for Zone 2A (which is a slightly smaller area than Zone 2C) increased from about 400,000 acre-feet per year (afy) in 1949 to about 600,000 afy by 1959, and has decreased slightly since then, generally falling between 400,000 and 500,000 afy over the past several decades (Figure 1-8).

Declining groundwater head in the middle part of the 20th century, especially in the northern part of the Basin, demonstrated that groundwater pumping was increasing beyond the capability of the natural system to replenish the aquifers. The projects and programs that have been constructed in the study area have sought to address this imbalance. Nacimiento Reservoir became operational in WY 1958, followed by San Antonio Reservoir in WY 1968. The reservoirs retain more water within the Basin by holding high flows back behind the dams in the winter when they would otherwise largely flow out to the ocean and releasing them in the summertime when the recharge potential along the Salinas River is at its highest. The presence of the reservoirs reversed groundwater storage losses in the southern region of the study area (the Forebay and Upper Valley Subareas; Brown and Caldwell, 2015a), but not in the northern region (the Pressure and East Side Subareas). This result can be attributed to the spatial variability in the connection between the Salinas River and the underlying aquifers described in Section 1.2.1; increasing recharge through the Salinas River has the most direct impact on aquifers that are hydraulically connected to the river.

To help address seawater intrusion in the 180- and 400-Foot Aquifers, MCWRA constructed the CSIP, a pipeline system that distributes recycled wastewater from the Monterey One Water Regional Treatment Plant to agricultural users in the area around the town of Castroville (Figure 1-7). The intention of the CSIP is to reduce pumping in the coastal areas of the main production aquifers by providing an alternative supply, increasing freshwater storage through in-lieu recharge, and slowing the occurrence of seawater intrusion in this area. Construction of CSIP started in 1995 and recycled water deliveries started in 1998.



Notes:
1. Source: Brown and Caldwell, 2015a

Figure 1-8

Annual Zone 2A Groundwater Pumping

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025

To help provide additional flexibility and introduce more tools to manage seawater intrusion, MCWRA developed the SVWP, which consists of two major components: modification of the spillway at Nacimiento Dam to increase the reservoir storage capacity; and construction of the SRDF near Blanco (Figure 1-7). The spillway modification, completed in 2009, consisted of the installation of an Obermeyer gate on top of the existing Nacimiento Dam spillway, which increases the spillway crest elevation. The gate allows Nacimiento Reservoir to store additional water, especially during the winter wet season, which allows for the reservoir stage to increase while retaining the ability to pass the Probable Maximum Flood. The SRDF, completed in 2010, consists of an inflatable rubber dam that stretches across the Salinas River, impounding streamflow in the Salinas River, diverting and treating it at the Salinas Valley Reclamation Plant, and delivering it to the CSIP distribution pipeline system.

As conditions and infrastructure in the basin have changed, the approach to operating the Nacimiento and San Antonio Reservoirs has been modified. A detailed discussion of the current and prior operational approaches for the reservoirs is beyond the scope of this report. Important alterations have resulted from the infrastructure projects described above and the development of the Flow Prescription that focused on modifying operations to support the migration of endangered Steelhead trout in the Salinas River and its tributaries, and critical fish and wildlife habitat below the Nacimiento and San Antonio Dams (MCWRA, 2005). MCWRA has published documentation of their current operational approach for Nacimiento Reservoir (MCWRA, 2018). Wood (2023) provides a discussion of the current operational approach as it was implemented in the groundwater-surface water modeling performed to support the Environmental Impact Report for the proposed Nacimiento-San Antonio Interlake Tunnel and Spillway Modification Project.

1.2.5 Groundwater Issues in the Basin

The Basin has been in an overall condition of overdraft for decades due to its long history of intense irrigated agriculture, a near-total reliance on groundwater, and its complex hydrogeology. This overdraft has resulted in reductions in groundwater in storage, depressed groundwater head in all major water supply aquifers, and seawater intrusion into the Basin. The severity of these issues led to all of the non-adjudicated portions of the Basin being categorized as Medium or High Priority by DWR, and the Pressure Subbasin categorized as critically overdrafted (DWR, 2021). Manifestations of these issues occur most prominently in the northern part of the Basin, specifically the Pressure and East Side Subareas, where fine-grained units prevent substantial replenishment of depleted aquifers from the Salinas River.

MCWRA has monitored groundwater head conditions throughout the Basin since the 1940s, and has prepared annual to biannual groundwater head maps since 1994 (available on https://www.co.monterey.ca.us/government/government-links/water-resources-agency/documents/groundwater-elevation-contours, accessed September 15, 2023). These maps demonstrate the groundwater head decline that has continued since at least the 1980s, with the lowest observed groundwater heads occurring in the East Side subarea and seasonal lows occurring near the end of the summer irrigation season. Figure 1-9 shows contours of groundwater elevation (referred to throughout this report as groundwater head) in the 180-Foot Aquifer, East Side Shallow, Forebay, and Upper Valley Aquifers in Fall 2022 (i.e., after the irrigation season and before seasonal rainfall). Figure 1-10 shows groundwater head contours in the 400-Foot Aquifer and East Side Deep Aquifers in Fall 2022. Figure 1-11 shows groundwater head contours in the 180-Foot and East Side Shallow Aquifers in August 2022 (i.e., near the end of the irrigation season). Figure 1-12 shows groundwater head contours in the 400-Foot and East Side Deep Aquifers in August 2022. These maps show groundwater heads well below sea level in much of the northern part of the Basin, both during and after the main part of the irrigation season. Near the end of the irrigation season, in August 2022, groundwater head was as much as 130 feet below sea level in the East Side Deep Aquifer (Figure 1-12).

Depressed groundwater heads equate to a loss of total storage in the aquifers of the Basin. The 2015 State of the Basin Report (Brown and Caldwell, 2015a) presented an analysis of storage changes by subarea since the mid-1940s, based on annual subarea-average groundwater head changes provided by MCWRA (Figure 1-13). This analysis showed that groundwater storage in the Basin decreased by nearly 800,000 acre-feet (af) by the peak of the mid-1990s drought, rebounding to a decrease of around 500,000 af by 2014. The largest proportion of the storage loss happened in the East Side Subarea (about 300,000 af by 2014). The Pressure Subarea also saw substantial declines in storage (about 100,000 af by 2014) that resisted replenishment during wet periods. The Forebay and Upper Valley Subareas have also experienced extensive declines in storage during very dry periods, but these tended to recover during wet periods. The completion of the Nacimiento and San Antonio Reservoirs in 1957 and 1967, respectively, led to a reversal of the storage loss in the Forebay and Upper Valley Subareas (except during extended dry periods), but not in the Pressure and East Side Subareas.

Seawater intrusion was recognized in the Basin as early as the 1930s (DWR, 1946). MCWRA has monitored chloride levels in the northern part of the Basin since then, and sporadically publishes updated maps of the extent of seawater intrusion in the 180-Foot and 400-Foot Aquifers in the Pressure Subarea – these maps have been reproduced as Figures 1-14 and 1-15, respectively. The extent of seawater intrusion has continued to migrate inland over the past 80 years, progressing to the outskirts of Salinas in recent years, about 8 miles from the coast. The extent of seawater intrusion in the 400-Foot Aquifer (Figure 1-15) shows the importance of cross-aquifer communication (through wells screened across both aquifers, poorly constructed wells, or discontinuities in the aquitard separating them), with a large area experiencing elevated chloride concentrations well east of the main body of the seawater intrusion front.

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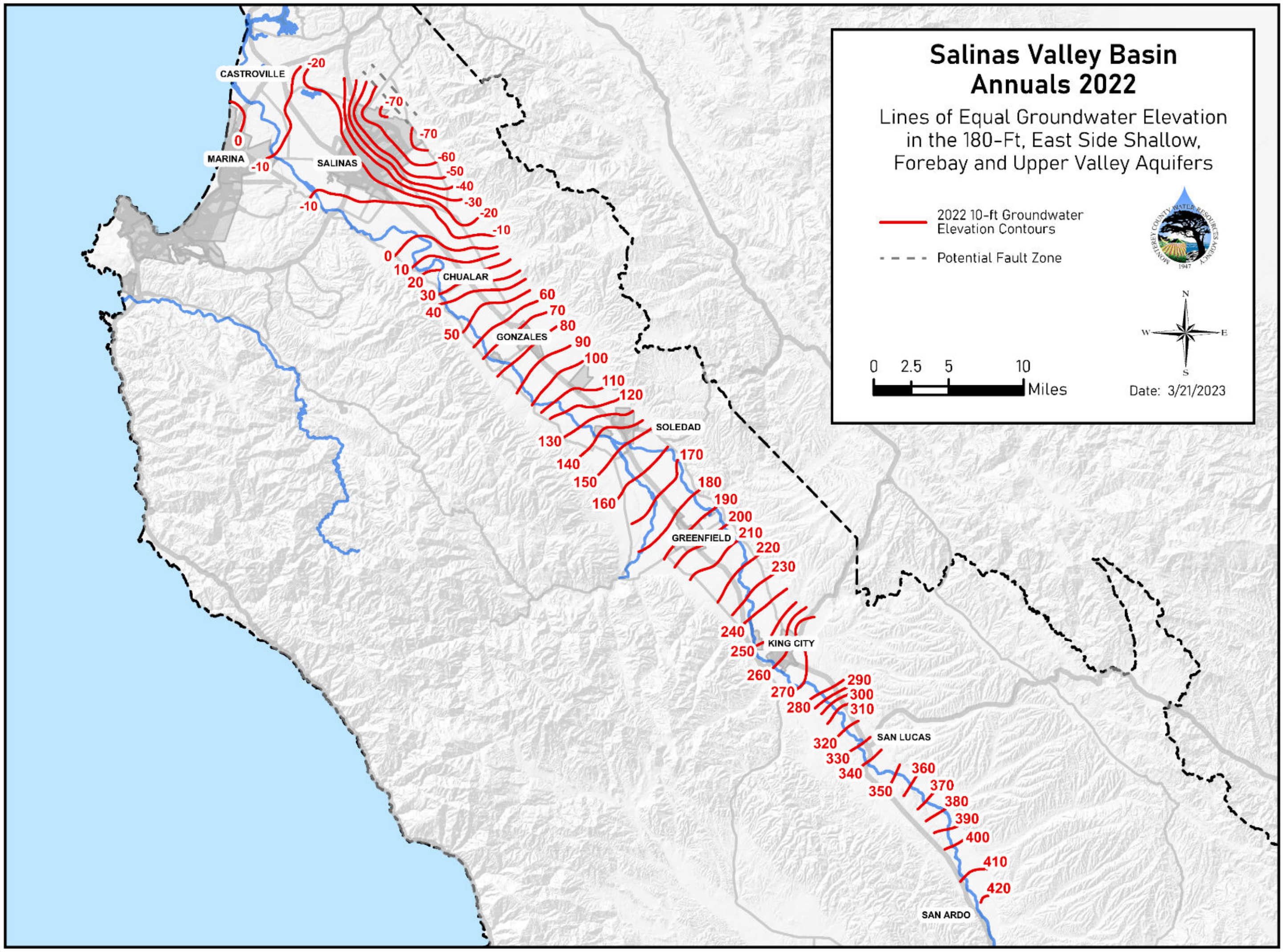
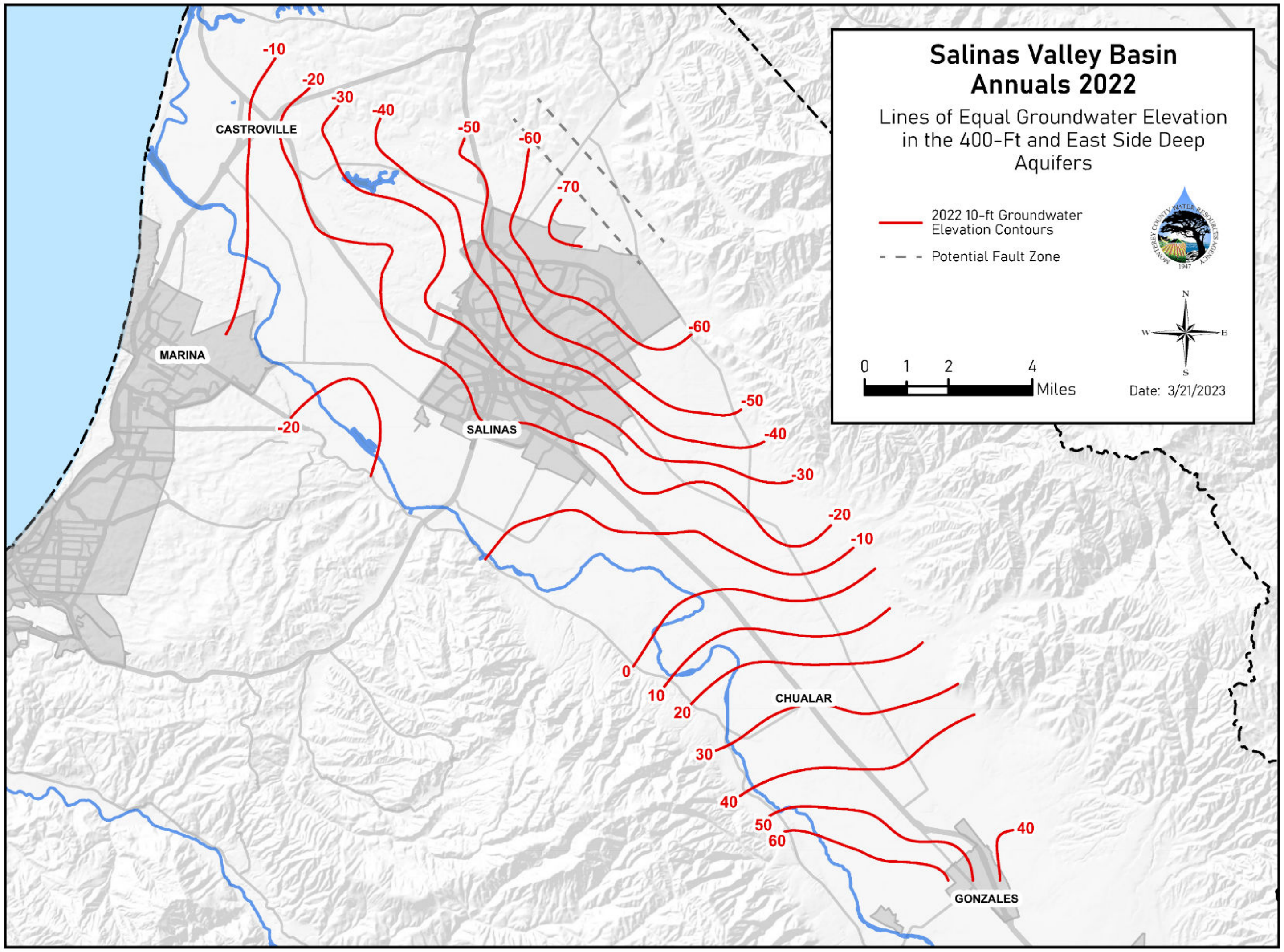


Notes:
1. Source: MCWRA

Figure 1-9

Groundwater Head in 180-Foot Aquifer (and Equivalent), Fall 2022

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025



Notes:

1. Source: MCWRA

Figure 1-10

Groundwater Head in 400-Foot Aquifer (and Equivalent), Fall 2022

Monterey County Water Resources Agency

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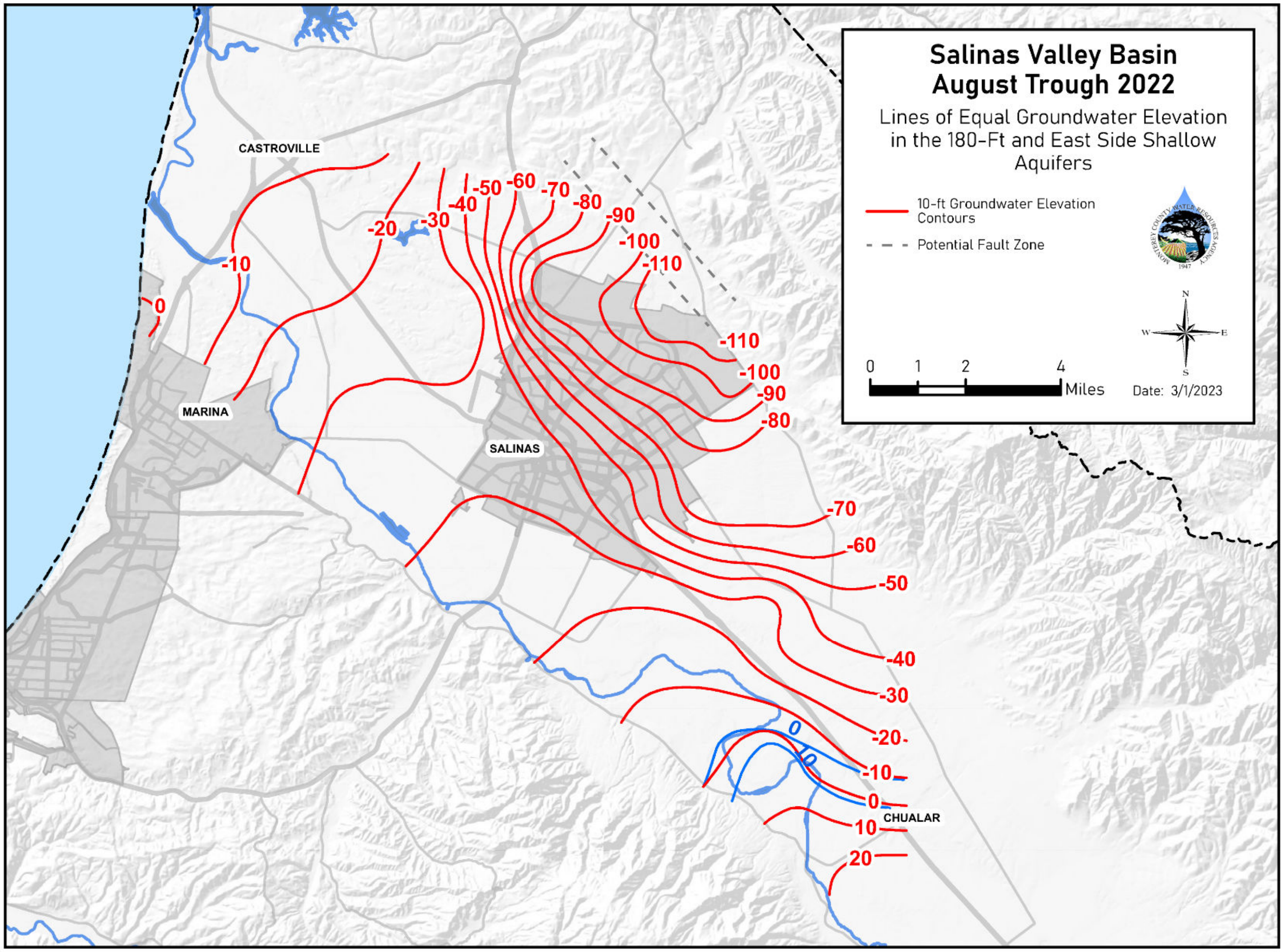

Notes:
1. Source: MCWRA

Figure 1-11

Groundwater Head in 180-Foot Aquifer (and Equivalent), August 2022

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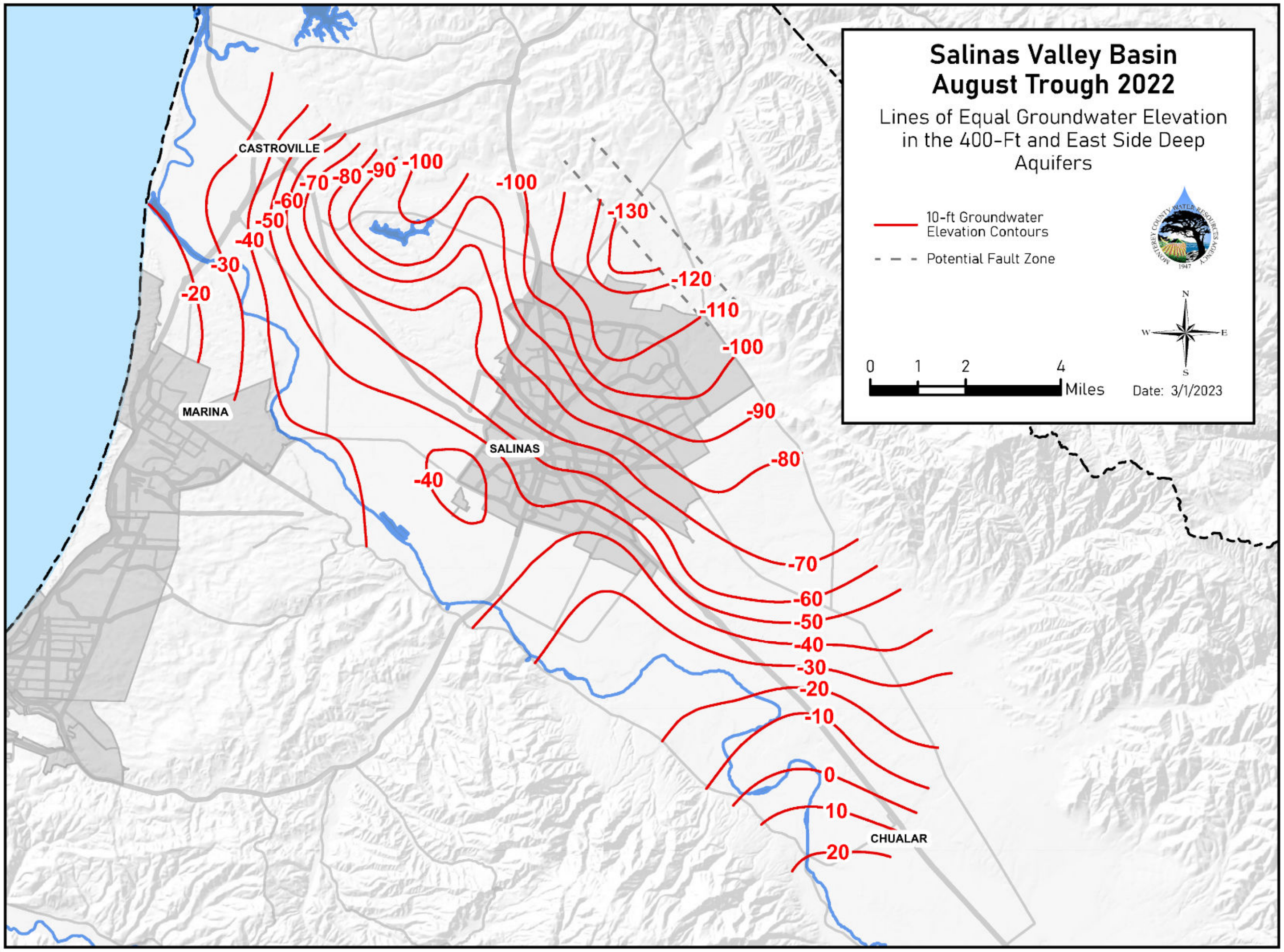

Notes:
1. Source: MCWRA

Figure 1-12

Groundwater Head in 400-Foot Aquifer (and Equivalent), August 2022

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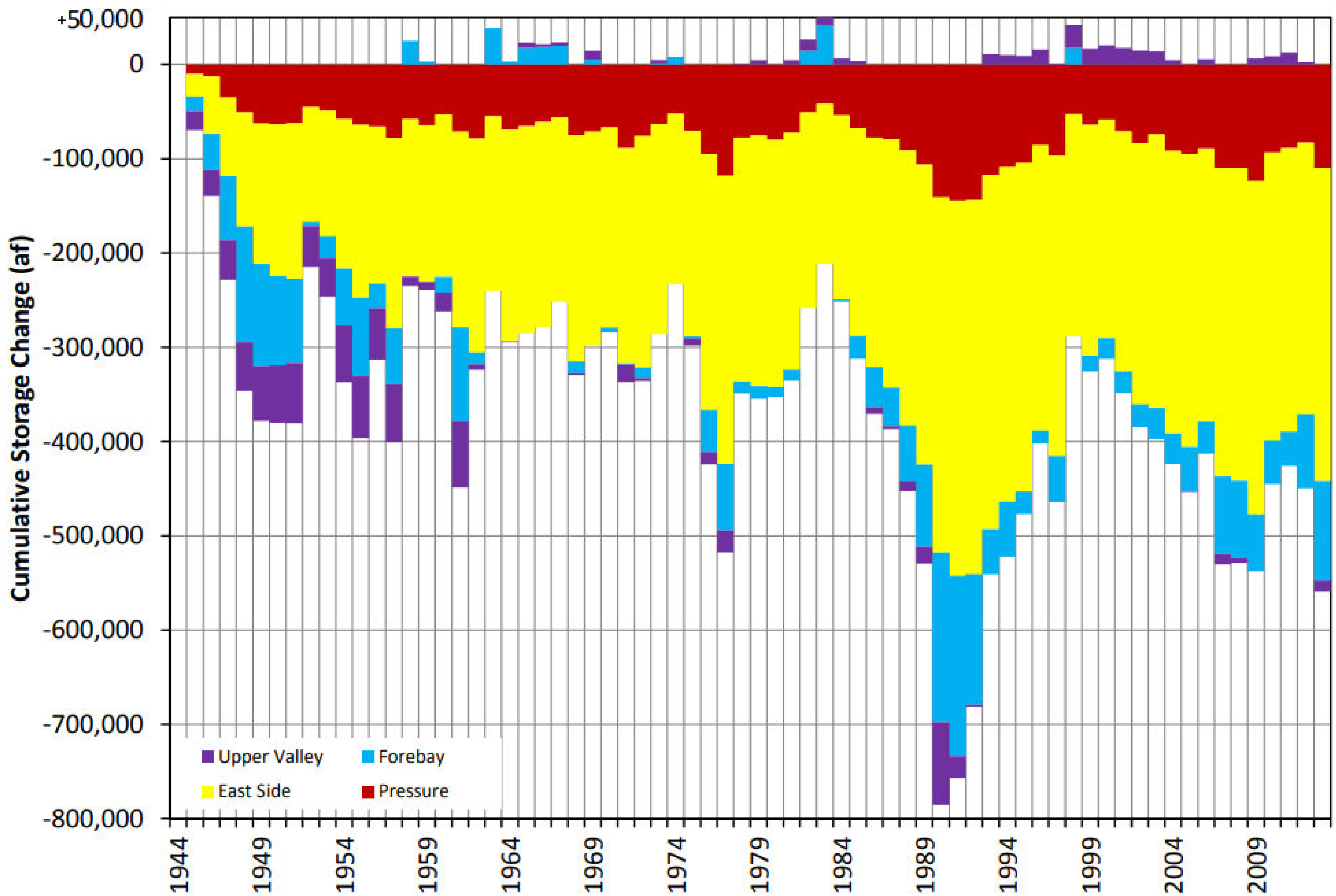
Historical Benefits Analysis Update
April 2025



Notes:
1. Source: Brown and Caldwell, 2015a

Figure 1-13

Cumulative Storage Change by Zone 2C Subarea

Monterey County Water Resources Agency
Historical Benefits Analysis Update
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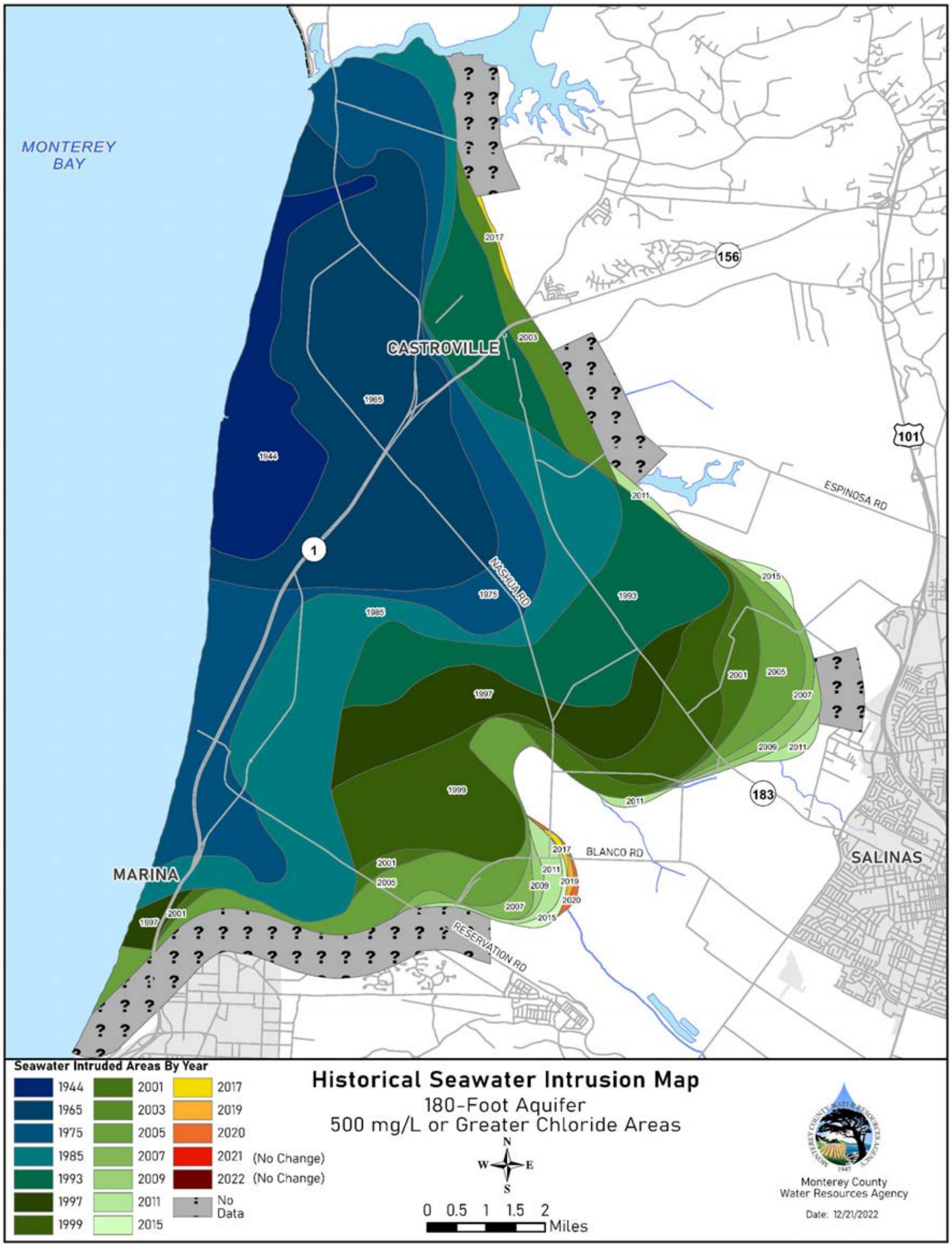
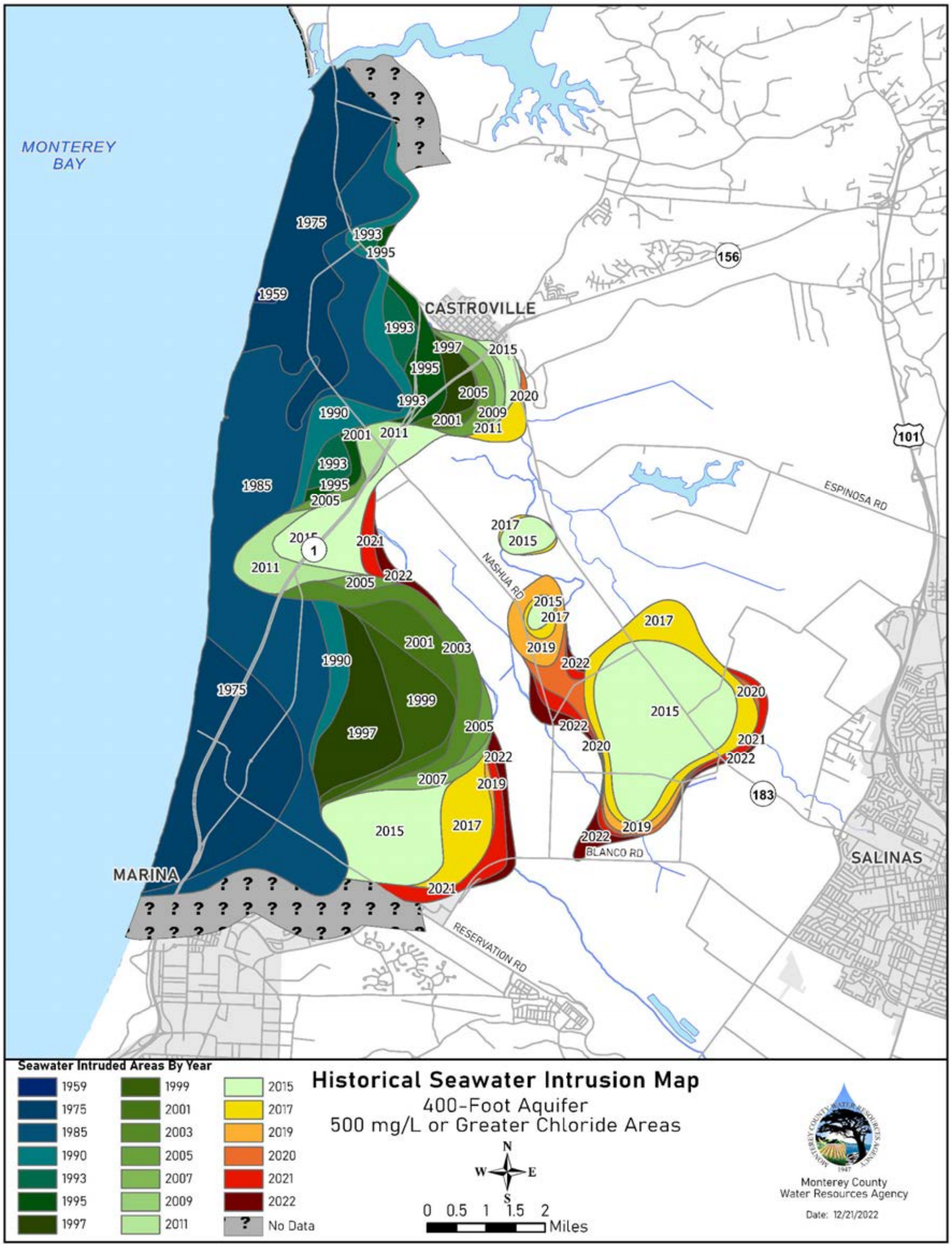


Notes:
1. Source: MCWRA

Figure 1-14

Seawater Intrusion Extent in 180-Foot Aquifer, 2022



Notes:
1. Source: MCWRA

Figure 1-15

Seawater Intrusion Extent in 400-Foot Aquifer, 2022

Monterey County Water Resources Agency

Historical Benefits Analysis Update

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1.3 1998 HBA

The 1998 HBA investigated the benefits to the Basin stakeholders from the construction and operation of Nacimiento and San Antonio Reservoirs over the period since Nacimiento Reservoir was completed in 1957. The quantification of benefits was achieved by simulation of conditions in the Basin with and without the reservoirs using then-current tools, with the difference between the with- and without-reservoir conditions representing the influence of the reservoirs. The 1998 HBA used economic analyses to express the benefits in monetary terms to illustrate the value that the Basin stakeholders have received from the presence of the reservoirs.

In general, the quantified benefits of the reservoirs have resulted from their ability to impound water during the winter wet period and release it during drier periods. The existence of the reservoirs has resulted in more water being kept within the Basin, increased groundwater recharge, more water in groundwater storage, higher groundwater heads, reduced seawater intrusion, and reduced flooding.

1.3.1 Hydrologic Benefits

According to the 1998 HBA, from 1958 to 1994 the reservoirs resulted in an average of 30,000 afy of additional fresh groundwater entering storage in the Basin. This led to a decrease of seawater intrusion of about 7,000 afy. The higher groundwater heads resulting from the increased freshwater storage have also lessened the need for the replacement or modification (e.g., deepening) of extraction wells in the Basin, particularly in the Upper Valley Subarea. The decreased extent of seawater intrusion has prevented the salinization of dozens of extraction wells in the coastal area, which otherwise would likely have needed to be replaced with wells pumping from the Deep Aquifers.

1.3.2 Flood Control Benefits

The 1998 HBA analysis of flooding quantified the degree by which flood flows in the Salinas River have been reduced as a result of the effective management of the reservoirs. The 100-year flood in the Salinas River at Bradley was estimated to be about 87,000 cubic feet per second (cfs) with the reservoirs in place, as compared to an about 167,000 cfs without the reservoirs. This resulted in substantially reduced inundation of the Salinas River floodplain and the land and structures found there. In the Salinas River at Spreckels, the 100-year flood with the reservoirs was estimated to be about 86,000 cfs, and about 149,000 cfs without the reservoirs. The analysis also found that the with-reservoir 100-year flow of 87,000 afy at Bradley would have occurred about once every 8 years without the reservoirs, while the with-reservoir 100-year flow of 86,000 cfs at Spreckels would have occurred about once every 22 years without the reservoirs.

1.3.3 Economic Benefits

The 1998 HBA estimated the monetary benefits that the Basin has realized because of the increased storage, reduced seawater intrusion, and reduced frequency and extent of inundation. Overall, the reservoirs resulted in about $1.5 million per year in reduced pumping costs, $89,000 per year in reduced well costs (deepening and other modifications to wells), and $241,000 per year in avoided costs to replace wells impacted by seawater intrusion (totaling just over $1.8 million per year in benefit due to the increased fresh groundwater in storage). In addition, the reduced frequency and extent of inundation caused by the presence of the reservoirs has increased crop income, reduced repair costs, and reduced damage to structures and buildings in the floodplain. The 1998 HBA estimated that the reservoirs resulted in about $5.5 million per year of increased crop income and reduced repair costs, and about $4.5 million per year of reduced damage to structures and buildings in the floodplain. In total, the 1998 HBA estimated that the reservoirs resulted in $11.8 million per year of benefit to the stakeholders in the Basin.

1.3.4 Other Benefits

The 1998 HBA listed a number of other benefits that stakeholders in the Basin have received from the reservoirs that cannot necessarily be quantified. These benefits included groundwater quality improvements outside of the area of seawater intrusion, the future utility of fresh groundwater currently in storage, avoided costs for developing a surface water distribution system for addressing seawater intrusion, reduction of risk due to rainfall variation, recreational and environmental benefits, and other indirect benefits such as employment and tourism. The 1998 HBA did not quantify these other benefits because they would occur outside the period of the analysis, or the uncertainties in accounting were too high, or their quantification would result in the double counting of benefit.

1.3.5 Need for an Updated HBA

The 1998 HBA covered the 46-year period from 1949 to 1994 using the Salinas Valley Integrated Ground and Surface Water Model (SVIGSM), which was developed for MCWRA over the previous several years and was updated for the 1998 HBA. Since the publication of the 1998 HBA, 25 years have passed that have seen substantial improvements in the understanding of the Basin, collection of additional data, changes to how MCWRA operates the reservoirs, and improvements to the computational tools suited to the kind of analysis undertaken for the 1998 HBA. These factors all justify an update to the 1998 HBA. Accordingly, this HBA Update relies on the improvements of knowledge and tools over the past 25 years to provide a revised characterization of the benefit accrued by stakeholders in the Basin from the presence of the Nacimiento and San Antonio Reservoirs.

CHAPTER 2
Tools and Approach

This chapter describes the tools and approaches used to perform the analyses presented in this HBA Update. This study relies on various numerical, analytical, and qualitative assessments of conditions in the Basin to arrive at a characterization of the effect of the Projects on the groundwater-surface water system.

2.1 1998 HBA APPROACH

The 1998 HBA used then-current tools to estimate the benefit accrued to the Basin stakeholders from the existence of the Nacimiento and San Antonio Reservoirs. The 1998 HBA largely relied on model simulations using the SVIGSM, which was built using the finite element Integrated Groundwater-Surface Water Model (IGSM) software, the development of which was later taken over by DWR and transitioned into the Integrated Water Flow Model (IWFM), which is currently in use for studies in many basins throughout California.

IGSM was designed to simulate groundwater and surface water conditions, groundwater-surface water interaction, and agricultural supply and demand processes, with the goal of investigating basin-wide conditions in heavily agricultural settings such as the Salinas Valley. The SVIGSM relied on some important customizations to simulate reservoir operations and seawater intrusion, both critical to the understanding of the Basin. The SVIGSM was developed by MW in the mid-1990s based on earlier models (MW, 1997) and used to prepare the 1998 HBA. The SVIGSM was used to simulate groundwater head, groundwater flow, streamflow, groundwater-surface water interaction, land surface processes, agricultural demand, groundwater extraction, reservoir operations, and seawater intrusion. It was calibrated to measured groundwater head at wells, streamflow at gauging stations on the Salinas River, mapped extents of seawater intrusion, and trends in groundwater chloride concentrations over time. For the 1998 HBA, the SVIGSM simulation covered WY 1949 to 1994, a period which included years prior to and after the construction of the reservoirs.

The estimated effect of the reservoirs over the historical period was assessed by simulating two configurations of the Basin with the SVIGSM: a historical simulation and a “without reservoirs” simulation (MW, 1998). The historical simulation represented the calibrated historical scenario developed by MW, the intention of which was to match as closely as possible the historical observations of Basin conditions included in the calibration dataset. The “without reservoirs” simulation was similarly configured to the historical simulation, but without the reservoirs present, i.e., the Nacimiento and San Antonio Rivers were allowed to flow uncontrolled. The difference between the historical and “without reservoirs” simulations represented the effect of the reservoirs.

The SVIGSM was not well-suited to simulating certain aspects of the effect of the reservoirs, particularly the Flood Control and Economic Benefits Analyses. For the Flood Control Benefits Analysis, the SVIGSM results were supplemented by an analytical approach to quantifying the magnitude of peak flow events (flood frequency analysis) based on simulated streamflows. The effect of these peak flows on the extent and depth of inundation, streamflow velocities, and soil erosion were investigated using a separate Hydrologic Engineering Center (HEC) model known as HEC-2.

The Economic Benefits Analysis relied on the results of the Hydrologic and Flood Control Benefits Analyses, equating the differences between the historical and “without reservoirs” simulations to monetary benefits using estimates of well construction costs, power costs, flood damage to structures, and other factors. These calculations were based on calculations of economic benefits (such as the difference in groundwater head at a pumping well multiplied by cost per foot of pumping lift equaling the additional cost of power to extract groundwater). Altogether, the 1998 HBA estimated that the reservoirs resulted in a total benefit of about $11.8 million per year over the historical period, as discussed in Chapter 1 of this report.

2.2 HBA UPDATE MODELING TOOLS

This section briefly describes the tools that were utilized to prepare this HBA Update. This discussion does not provide an exhaustive explanation of these modeling tools, but instead provides a brief overview and references to documentation for the individual models and modeling software. The Salinas Valley Integrated Hydrologic Model (SVIHM) is a preliminary product that is currently under review by the USGS, and no documentation of this tool is available at the time of publication of this report.

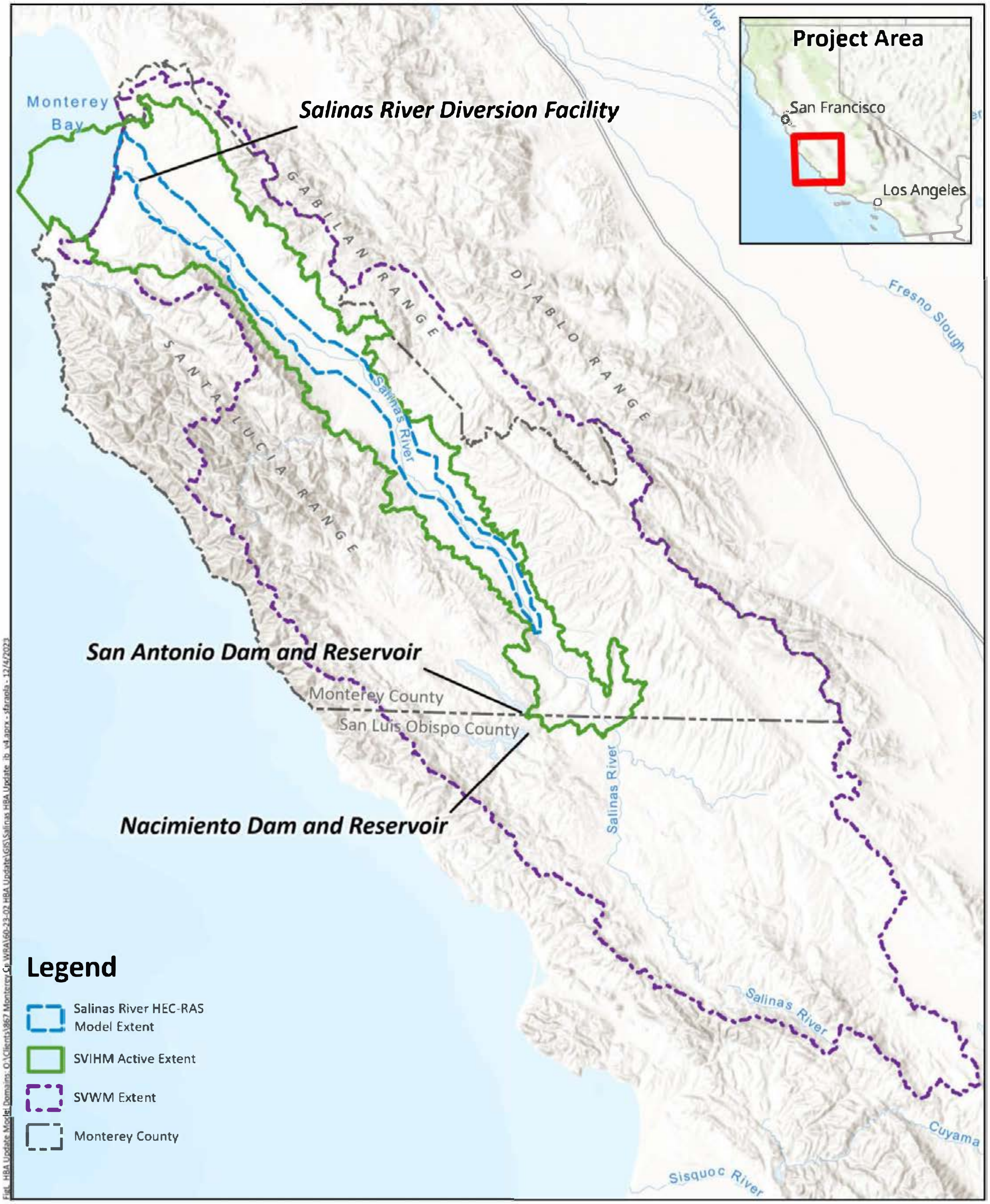
2.2.1 Salinas Valley Integrated Hydrologic Model

The SVIHM is a complex, three-dimensional groundwater and surface water flow model of the Salinas Basin developed by the USGS. This model is built using the MODFLOW One Water Hydrologic Model (OWHM) code, which is focused on coupled groundwater-surface water systems in which agricultural supply and demand are key components of the overall water budget (Boyce et al., 2020). OWHM simulates three-dimensional groundwater flow, streamflow routing, land surface processes, water demand based on crop type, and other processes impacting the groundwater and surface water systems.

The SVIHM is designed to simulate groundwater and surface water flow over the historical period from October 1967 to September 2018. The model is discretized into 612 monthly stress periods[1]. The model domain consists of 976 rows, 272 columns, and 9 layers. The horizontal spacing is 529 feet by 529 feet; layer thicknesses vary throughout the model domain to represent the hydrostratigraphy described in Chapter 1 of this report. The active model domain is shown on Figure 2-1. The Salinas Valley Watershed Model (SVWM), a USGS rainfall-runoff routing model, provides streamflow inputs along the edges of the SVIHM. The domain of the SVWM and the Salinas River HEC River Analysis System (HEC-RAS) model are also shown in Figure 2-1.

The SVIHM includes capabilities for simulating: groundwater flow through the permeable aquifers of the Basin; streamflow routing through the defined stream system; groundwater-surface water interaction; groundwater exchange with adjacent basins and the ocean; estimation of crop water demand; satisfaction of crop water demand by precipitation, surface water deliveries, and groundwater pumping; the diversion and delivery of surface water; municipal and industrial well pumping; agricultural drains; and internal structural barriers (e.g., faults). The SVIHM incorporates historical estimates of climate variables (precipitation and potential evapotranspiration), land use data, sea level variation, groundwater heads in adjacent basins, reservoir releases, stream flow inputs, and recycled and surface water deliveries to the CSIP area. The model receives along its edges streamflow inputs simulated by the SVWM.

[1] The stress period is the basic unit of time discretization in a MODFLOW model and represents a period of the model during which all stresses on the model (e.g., groundwater pumping) are uniform. Each stress period can be divided into multiple timesteps.



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Prepared for:
Monterey County Water Resources Agency
Salinas Valley HBA Update
April 2025

HBA Update Model Domains

Figure 2-1

The USGS has calibrated the SVIHM to long-term records of groundwater, surface water, and agricultural pumping data. Because of the preliminary nature of the SVIHM, details on the calibration are not currently available. Accordingly, the USGS requires that any presentation of results from the SVIHM before it is published publicly must be accompanied by the following disclaimer:

> *Historical SVIHM Model: Unoffical* [sic] *Collaborator Development Version of Preliminary Model. Access to this repository and use of its data is limited to those who are collaborating on the model development. Once the model is published and recieved* [sic] *full USGS approval it will be archived and released to the public. This preliminary data (model and/or model results) are preliminary or provisional and are subject to revision. This model and model results are being provided specifically to collaborate with agencies who are contributing to the model development and meet the need for timely best science. The model has not received final approval by the U.S. Geological Survey (USGS). No warranty, expressed or implied, is made by the USGS or the U.S. Government as to the functionality of the model and related material nor shall the fact of release constitute any such warranty. The model is provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the model.*

2.2.2 Salinas River HEC-RAS Model

A streamflow model for the Salinas River was developed by FlowWest based on earlier models by Newfields and others (FlowWest, 2015) using the HEC-RAS 2D software. The model simulates two-dimensional flow in the Salinas River and its floodplain from about Bradley to the mouth of the river at Monterey Bay (Figure 2-1). In addition to inflow at the south end of the system, the Salinas River is fed by tributary inflow from Arroyo Seco and San Lorenzo Creek. HEC-RAS 2D is not capable of simulating groundwater-surface water interaction, which is an important process in the study area.

The Salinas River HEC-RAS model has been used in previous studies to investigate the impacts of various projects and management actions on 5- and 10-year peak flow events in the system, focusing on the extent and depth of flooding and the velocity of flow (FlowWest, 2015). It has been used to study the effect of peak streamflows on the system in a quasi-steady state mode, with input flow in the Salinas River consisting of a ramp-up period followed by an extended period of the peak flow rate. The simulations do not include any subsequent ramp-down period, and the model does not simulate the movement of a realistic hydrograph through the system.

2.2.3 Differences from 1998 HBA Modeling Approach

The most fundamental difference between the 1998 HBA and this HBA Update is that this update addresses the effects of key water projects that have been implemented or changed operationally since 1994; these effects were not captured in the 1998 HBA. This HBA Update covers most of the intervening period, with the analysis ending with WY 2018 (the end of the period simulated by the SVIHM). The SVIGSM used to prepare the 1998 HBA covered the period of WY 1949 through WY 1994, a 46-year period, including nine years before either reservoir became operational (WY 1949 to 1957), 10 years between Nacimiento Reservoir beginning operations and San Antonio Reservoir beginning operations (WY 1958 to 1967), and 27 years with both reservoirs operational (WY 1968 to 1994). The first 9 years of the SVIGSM modeling period were not included in the analysis of benefit, such that the benefit analysis covered the 37-year period from WY 1958 to 1994.

The SVIHM covers the period from WY 1968 (when San Antonio Reservoir came online) to WY 2018. Because the SVIHM is a preliminary model, it cannot be modified to cover the earlier period included in the 1998 HBA analysis (WY 1958 to 1967), when only Nacimiento Reservoir was operational, or the years before that (WY 1949 to 1957) simulated by the SVIGSM.

One consequence of extending the analytical period to WY 2018 is that the SVIHM simulates projects and programs in the Basin that were not included in the SVIGSM. These include the recycled water and treated Salinas River water deliveries to the CSIP area and the increased spillway elevation at Nacimiento Dam (see Chapter 1). The latter is implemented within the historical record of Nacimiento Reservoir releases, which is used as the upstream boundary condition for the Nacimiento River. Deliveries to the CSIP area are included as non-routed deliveries (for the recycled water) and semi-routed deliveries (for the Salinas River water) supplied to agricultural users in the CSIP area using historical records provided to the USGS. It would be extremely difficult to determine the benefit of each aspect of the Projects individually (e.g., the benefit of just the SRDF), since it would require estimating historical reservoir releases in its absence, which would be highly speculative. Therefore, this HBA Update analyzes the benefit of the various Projects collectively.

Based on the analyses presented in the 1998 HBA, the SVIGSM did not simulate the effect of reductions in groundwater head on the ability of pumping wells to supply the demands placed on them. The model showed no difference in the average annual pumping between the historical and "without reservoir" conditions, despite substantial differences in the fresh groundwater storage. Impacts of the removal of the reservoirs on pumping wells was quantified based on the simulated head at each well, known details of the well construction, and assumptions about how a reduction in groundwater head would necessitate changes to the well design or replacement of the well. In contrast, the SVIHM may modify pumping due to differences in the availability of other water sources to satisfy crop demand. Therefore, for the HBA Update, well impacts are considered in terms of changes both to groundwater head and groundwater pumping between scenarios.

The SVIHM does not currently include the capability to directly simulate the intrusion of seawater into freshwater aquifers. While the model does simulate the flux of water across the interfaces between the aquifer units and the ocean (where they outcrop on the floor of Monterey Bay), it uses an approximation to convert the head along those outcrops from a depth below sea level to an equivalent freshwater head. Characterization of groundwater within the model does not account for the differences in density between seawater and freshwater that drive seawater intrusion or the mixing of seawater and fresh groundwater. There are packages available for MODFLOW that can approximate the amount and extent of seawater intrusion in a more sophisticated way (e.g., SWI2; Bakker et al., 2013), but they have not been utilized in the SVIHM to date. The rate of seawater intrusion can be quantified using the SVIHM from the rate of groundwater flow across the coast, but it ignores the impact of density differences between seawater and freshwater. The SVIHM, as configured, cannot therefore be used to simulate the extent of seawater intrusion or how it changes over time.

Other than the above differences, the approach used in this HBA Update to quantifying benefits largely follows that of the 1998 HBA in order to allow for a direct comparison to the extent possible. There are additional differences between the SVIGSM and SVIHM that result from differences in the hydrologic conceptual models and the software tools being used. These differences are assumed to be of relatively low significance compared to those discussed above and are not considered in detail here. Comparisons between the capabilities of the SVIGSM and MODFLOW-OWHM were discussed in Brown and Caldwell (2015b).

2.3 BENEFITS QUANTIFICATION APPROACH

As noted above, the benefits quantification approach follows that of the 1998 HBA as closely as possible considering the differences between the modeling tools used. This section briefly describes how the analysis of model results was translated into a quantified benefit provided by the reservoirs. The benefits are categorized into hydrologic (groundwater head and storage and impacts on wells), flood control (frequency and severity of flood events), economic (monetary equivalent of the hydrologic and flood control benefits), and other benefits.

2.3.1 Hydrologic Benefits Analysis

The 1998 HBA included a Hydrologic Benefits Analysis based on an evaluation of the reservoirs' effects on groundwater levels, seawater intrusion, well construction and/or rehabilitation, and regional groundwater quality. For this HBA Update, the Hydrologic Benefits Analysis (Chapter 3 of this report) similarly assesses the benefits that the Projects have supplied to the groundwater system, with a focus on groundwater quantity and quality.

Changes in groundwater head, and therefore the amount of groundwater storage, represent the fundamental manifestation of impacts on the groundwater system. Changes to groundwater head and storage are tracked throughout the model and are presented in this report as: maps of groundwater head (and groundwater head differences between scenarios); storage change as a component of groundwater budgets (including differences between scenarios); and groundwater head changes aggregated into spatial subdivisions of the Basin, following the concept of Economic Study Units (ESUs) in the 1998 HBA.

Seawater intrusion was quantified in the 1998 HBA as a flux of groundwater across the coast, as well as delineation of the onshore area underlain by aquifers intruded by seawater (i.e., the extent of the seawater intrusion front). As noted above, the SVIHM does not have the capability to directly simulate the intrusion of seawater into a groundwater system, or to track its movement within the aquifers. Instead, the volume of seawater crossing the coast can be calculated from the simulated groundwater flux from the model.

Changes to groundwater head and storage have the potential to have negative effects on the ability of groundwater wells to operate. In the 1998 HBA, impacts on wells were approached either by evaluating increases to pumping lift necessitated by lower groundwater heads at well locations, or by identifying wells needing modifications or replacement to operate under depleted aquifer conditions. For this HBA Update, the well impacts analysis includes: estimates of increased pumping lift due to reduced groundwater head at wells; simulated reductions in pumping due to reduced groundwater head at wells; and the proportion of wells requiring modification or replacement as suggested by the model results. As noted in the 1998 HBA, well replacement can be assumed to involve installation of wells in deeper aquifers than those in which the existing well is already screened, especially the Deep Aquifers; however, the effect of this replacement is not simulated in the model. The connection between the Deep Aquifers and the ocean remains poorly understood, so the long-term effect on seawater intrusion of shifting pumping downward into the Deep Aquifers remains difficult to assess.

The analysis of regional groundwater quality impacts in the 1998 HBA was somewhat qualitative, and considered whether the reservoirs would be likely to lead to impacts on groundwater quality. That analysis concluded that the reservoirs could be expected to have positive effects on groundwater quality in the Basin, due to the increased recharge that takes place in the riparian area. This HBA Update does not include a discussion of impacts on regional groundwater quality.

2.3.2 Flood Control Benefits Analysis

The Flood Control Benefits Analysis in the 1998 HBA focused on the impacts of flooding in the system by quantifying benefits from reductions in frequency of flooding, severity of flooding, impacts to agricultural soil, and impacts to buildings and structures in the floodplain. That analysis estimated the magnitude of flood events of different return intervals (e.g., the 100-year flood) with and without the reservoirs, then simulated the propagation of inundation under the calculated peak flows using a separate HEC-2 model. The results of those simulations were used to estimate the impact of the reservoirs on agriculture and structures in the floodplain.

For this HBA Update, the impacts of the Projects on the system follows much the same approach. The results of the SVIHM are used to develop time series of peak annual streamflow with and without the Projects. These time series are then converted into a statistical distribution of peak flows for different return periods using a Flood Frequency Analysis. These statistical distributions provide information on both the magnitude of peak flows and the frequency of significant flood events.

Selected peak flow events from the Flood Frequency Analysis are simulated using the Salinas River HEC-RAS Model to demonstrate the extent and depth of inundation and the flow velocity under each event. The model results are then combined with published information on the spatial distribution of soil types to understand the potential for flood events to cause agricultural soil erosion. The effect on buildings and structures is assessed as part of the Economic Benefits Analysis discussed in the next section.

2.3.3 Economic Benefits Analysis

The Economic Benefits Analysis in the 1998 HBA translated the impacts quantified under the Hydrologic and Flood Control Benefits Analyses into monetary benefits to the stakeholders of the Basin due to the effects that the reservoirs have had on the groundwater and surface water systems. These benefits were expressed in numerous ways, including reduced power costs to pump groundwater, reduced well maintenance and replacement costs, reduced crop damage due to flooding, and reduced damage to buildings and structures in the floodplain.

For the HBA Update, the Economic Benefits Analysis is currently being performed by One Water Econ. Their analysis is based on the results of the Hydrologic and Flood Control Benefits Analyses presented in this report. The methodology and results of the Economic Benefits Analysis will be presented in a separate report.

2.3.4 Other Benefits

The 1998 HBA included a brief discussion of other benefits that have been derived from the reservoirs over time, including: improved groundwater quality outside of the area of seawater intrusion; storage of high-quality groundwater for future use; preservation of freshwater storage for future use; reduced risk from rainfall variability; and increased land values, employment opportunities, and tourism.

This HBA Update similarly discusses in a qualitative manner other benefits that the Projects have provided to the stakeholders of the Basin. Like the 1998 HBA, no attempt is made in this analysis to quantify these benefits.

2.4 MODEL SCENARIOS

The analyses supporting this HBA Update rely on two model scenarios run using the SVIHM: a Historical Scenario and a No Projects Scenario. The key model outputs of note include groundwater head (h) and water flux (Q). The latter may refer to groundwater/surface water interaction across the streambed, groundwater pumping, recharge , and other such processes. The difference between the two scenarios is used to demonstrate the benefits accrued from the Projects over the course of the model simulation period, and is based on the following calculations:

$$h_{diff} = h_{hist} - h_{noproj} \quad (1)$$

$$Q_{diff} = Q_{hist} - Q_{noproj} \quad (2)$$

where h_{diff} is the head difference between the scenarios, h_{hist} is a groundwater head under the Historical Scenario, h_{noproj} is the head at the same location and time under the No Projects Scenario, Q_{diff} is the water flux difference between the scenarios, Q_{hist} is a water flux under the Historical Scenario, and Q_{noproj} is the water flux at the same location and time under the No Projects Scenario. Values of h_{diff} and Q_{diff} are assumed to represent the effects of the Projects. This approach follows that of the 1998 HBA. Unless stated otherwise, the difference between the scenarios is expressed as the Historical Scenario minus the No Projects Scenario.

2.4.1 Historical Scenario

The Historical Scenario (analogous to the historical case of the 1998 HBA) simulates historical conditions within the Salinas Valley over the period from October 1967 to September 2018 (i.e., WY 1968 to 2018). It was designed by the USGS to reproduce, as closely as possible, observed conditions in the study area over the historical period.

The spatial extent of the SVIHM does not include Nacimiento and San Antonio Reservoirs (Figure 2-1). The effect of the reservoirs on the system is simulated using the historical measurements of reservoir releases from each reservoir, which are provided as streamflow inputs to the Nacimiento and San Antonio Reservoirs. The Nacimiento River enters the SVIHM about 5 miles below the outlet of the Nacimiento Dam; the USGS assumes no groundwater-surface water interaction or surface runoff occurs above this point in the Nacimiento River.

The Historical Scenario incorporates projects and programs related to the reservoirs (as described in Chapter 1) during the period of their operation. Both reservoirs are present throughout the time period simulated by the model. The effect of raising of the Nacimiento Dam spillway elevation is included in the time series of reservoir releases beginning in 2009 when the spillway modifications were completed. Recycled water deliveries from the Monterey One Water Regional Treatment Plant begin in 1998, while SRDF deliveries of Salinas River water begin in 2010.

2.4.2 No Projects Scenario

The No Projects Scenario fulfills the same purpose for the HBA Update as did the “without reservoirs” case used for the 1998 HBA analysis. It is similar to the Historical Scenario except that it removes the Projects by making the following modifications to the Historical Scenario:

- **Removal of the reservoirs:** The Historical Scenario uses historical reservoir releases (as reported by MCWRA) as the streamflow inputs for the Nacimiento and San Antonio Rivers. For the No Projects Scenario, the streamflow inputs at these locations are replaced by estimated historical reservoir inflows provided by MCWRA. The use of the reservoir inflow ignores any potential interaction with the surrounding environment that would have occurred between where MCWRA estimates reservoir inflow and where each stream intersects the active domain of the SVIHM. Because the stream inflow into the SVIHM represents a monthly average, this study assumes that the travel time between the reservoir inflow and the SVIHM boundary is negligible.
- **Raising of Nacimiento Dam spillway elevation (part of SVWP):** The modification of the Nacimiento Dam spillway was completed in 2009. The impact of raising the spillway crest elevation is incorporated into the reservoir release time series for the Historical Scenario input. The use of reservoir inflows as the stream inflow inputs to the SVIHM in the No Projects Scenario removes the effect of the spillway raise.
- **Removal of recycled water deliveries to CSIP area:** The Monterey One Water Regional Treatment Plant began delivering recycled water to growers in the CSIP area via a pipeline network in 1998, as described in Chapter 1. The SVIHM simulates recycled water deliveries to the CSIP area as non-routed deliveries (meaning that they do not move through the stream network) available to satisfy crop demands in the area. The volume of delivery is based on historical records provided by MCWRA. The No Projects Scenario sets these deliveries to zero.
- **Removal of Salinas River diversions to CSIP area (part of SVWP):** The SRDF began diverting water from the Salinas River to deliver to growers in the CSIP area in 2010. As with the recycled water deliveries, the SVIHM makes diverted water available to satisfy crop demands in the CSIP area; SRDF diversions are delivered to CSIP as semi-routed deliveries (meaning that they move through the stream network prior to delivery). The volume of delivery is based on historical records provided by MCWRA. The No Projects Scenario sets these deliveries to zero.

As noted in Section 2.3, the difference between the Historical and No Projects Scenarios is taken to represent the effect (benefits) on the study area of the construction and operation of the Projects. Throughout this report (unless stated otherwise), the difference represents the Historical Scenario minus the No Projects Scenario; for example, if head is higher under the Historical Scenario than the No Projects Scenario, the head difference is reported as positive.

CHAPTER 3
Hydrologic Benefits Analysis

This chapter describes the effects that the Nacimiento and San Antonio Reservoirs, and related projects and programs, have had on groundwater conditions in the study area. The storage of flows in the Nacimiento and San Antonio River watersheds during the wet winter season, and subsequent release during dry parts of the year (and in dry years) has resulted in the retention of more water in the Basin through recharge of reservoir releases. This increased recharge has resulted in higher groundwater heads in the Basin.

The spatial distribution of these effects must take place in context of the hydrogeologic conceptual model described in Chapter 1. The connection between the surface water and groundwater systems is strongest in the Upper Valley and Forebay Subareas and in the southern part of the Pressure and East Side Subareas, where no extensive confining units exist to separate the Salinas River from important water supply aquifers. Further north, through the majority of the Pressure and East Side Subareas, the Salinas Valley Aquitard largely separates the Salinas River from the major production aquifers.

3.1 BENEFIT QUANTIFICATION APPROACH

The Hydrologic Benefits of the Projects were determined by quantifying the differences between the Historical (with projects) and No Projects Scenarios (see Chapter 2). The effects on the groundwater system manifest as regional groundwater head differences, changes to groundwater-surface water flux, changes to well pumping, and seawater intrusion rates. In each case, the sections below quantify the head and water flux values under each scenario, as well as the difference between them.

To the extent possible, differences in the simulated state of the system between the Historical and No Projects Scenarios are ascribed to one or more of the projects and programs simulated under the Historical Scenario but removed for the No Projects Scenario, based on understanding of the hydrogeologic conceptual model and the timing and location of the projects and programs.

3.2 GROUNDWATER HEAD

The groundwater level at a given location is defined in terms of piezometric head (or simply head), which is a measurement of the pressure that the water stored in an aquifer is under, referenced to a vertical datum. It is commonly thought of as the elevation to which water would rise in a well or piezometer installed in an aquifer. MODFLOW calculates the head in each active model cell for each model timestep, producing a three-dimensional distribution of head within the Basin.

Changes in groundwater head are a proxy for changes in aquifer storage. As storage in aquifers declines, groundwater head declines, while increasing groundwater storage is represented by an increase in groundwater head. Accordingly, the groundwater head results in the model can be used to understand how aquifer storage changes over time.

As described in Chapter 1, decades of overdraft in the Basin have resulted in decreased groundwater heads, largely in the northern part of the Basin, where aquitards restrict the downward movement of water (including from the Salinas River) to recharge the main production aquifers. This situation has resulted in groundwater heads that are below sea level through much of the Pressure and East Side Subareas (as shown in Figures 1-9 through 1-12). This section describes the effects that the Projects have had on simulated groundwater head through the historical period from WY 1968 to 2018. These effects were quantified as the difference between the Historical and No Projects Scenarios, as described in Chapter 2.

This discussion focuses on differences between scenarios in Model Layer 3 (representing the 180-Foot Aquifer, East Side Shallow Aquifer, and undifferentiated aquifers of the other Subareas), Model Layer 5 (representing the 400-Foot Aquifer, East Side Deep Aquifer, and undifferentiated aquifers of the other Subareas), and Model Layer 7 (taken to represent the Deep Aquifer in the Pressure Subarea). Outside of the Pressure Subarea, where extensive aquitards separate the sediments into relatively well-defined aquifers, and the East Side Subarea, where groundwater exists in a semi-confined to confined state (with confinement increasing with depth) due to many fine-grained interbeds within the aquifer sediments, the sediments in the study area are not separable into different aquifer units, and groundwater head varies little from layer to layer.

3.2.1 September 2018 Simulated Groundwater Head

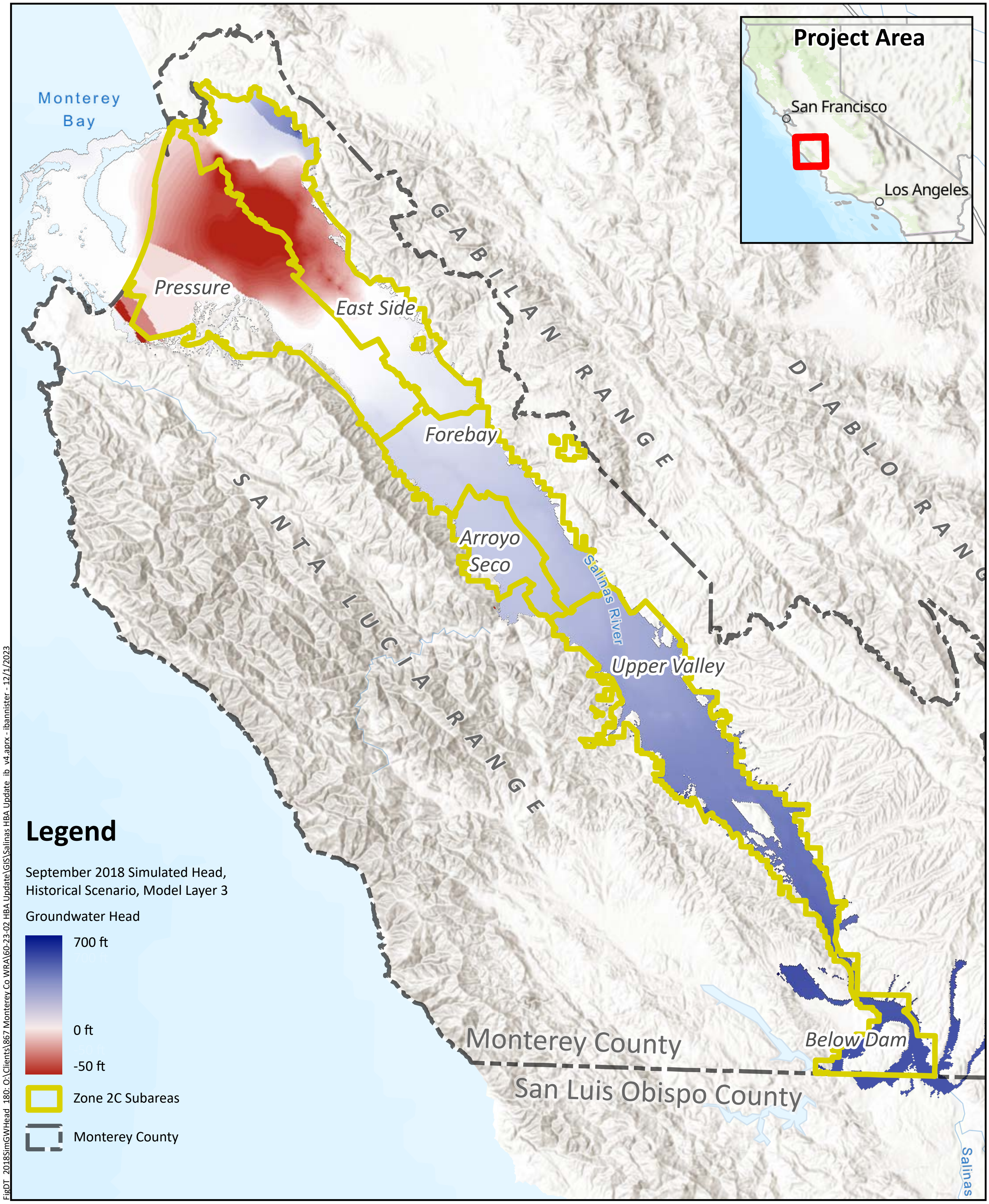
Modeled groundwater head values at the end of the model simulation period (i.e., September 2018) aggregate the effects of the Projects on the groundwater head conditions in the Basin. Figures 3-1 through 3-3 provide the groundwater head values simulated for September 2018 under the Historical Scenario for Model Layers 3, 5, and 7. Figures 3-4 through 3-6 show the groundwater head values simulated for September 2018 under the No Projects Scenario for the same model layers. Figures 3-7 through 3-9 show the differences between the Historical and No Projects Scenarios simulated for September 2018 for the same model layers.

Figures 3-1 through 3-6 show the expected decline in head from the higher-elevation parts of the Basin at its southern end to the coastal area to the north. On these figures, blue colors represent groundwater head values above mean sea level (msl) and red colors represent groundwater head values below msl. The large area of groundwater heads below sea level in the Pressure and East Side Subareas is notable on these figures.

Figure 3-7 shows the head difference in Model Layer 3 between the Historical and No Projects Scenarios simulated for the end of the model, September 2018. The head difference is largest in two areas: along the Salinas River from about Bradley to about Gonzales, and in the area between Castroville and Salinas (see Figure 1-1 for referenced locations). The head difference along the Salinas River is up to about 15 feet, with the largest differences occurring upstream of King City. Most differences along the River are about 10 feet or less. The difference vanishes around Gonzales. In the area between Castroville and Salinas, the difference is as much as about 48 feet between scenarios.

Figure 3-8 shows the head difference in Model Layer 5 between the Historical and No Projects Scenarios simulated for the end of the model, September 2018. The pattern of the head differences is very similar to that of Model Layer 3. Head differences along the Salinas River in Model Layer 5 are very similar in magnitude to those of Model Layer 3 up to about Greenfield, and then are smaller north of this point. Head differences in the area between Castroville and Salinas are slightly larger in Model Layer 5, reaching as much as about 67 feet.

Figure 3-9 shows the head difference in Model Layer 7 between the Historical and No Projects Scenarios simulated for the end of the model simulation period in September 2018. The overall pattern of head differences is similar to those of Model Layers 3 and 5. Head differences along the Salinas River are generally similar in magnitude, reaching up to about 15 feet south of King City. Head differences in the area between Castroville and Salinas are smaller compared to those in Model Layers 3 and 5, reaching a maximum of about 12 feet.



Prepared by:

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Prepared for:
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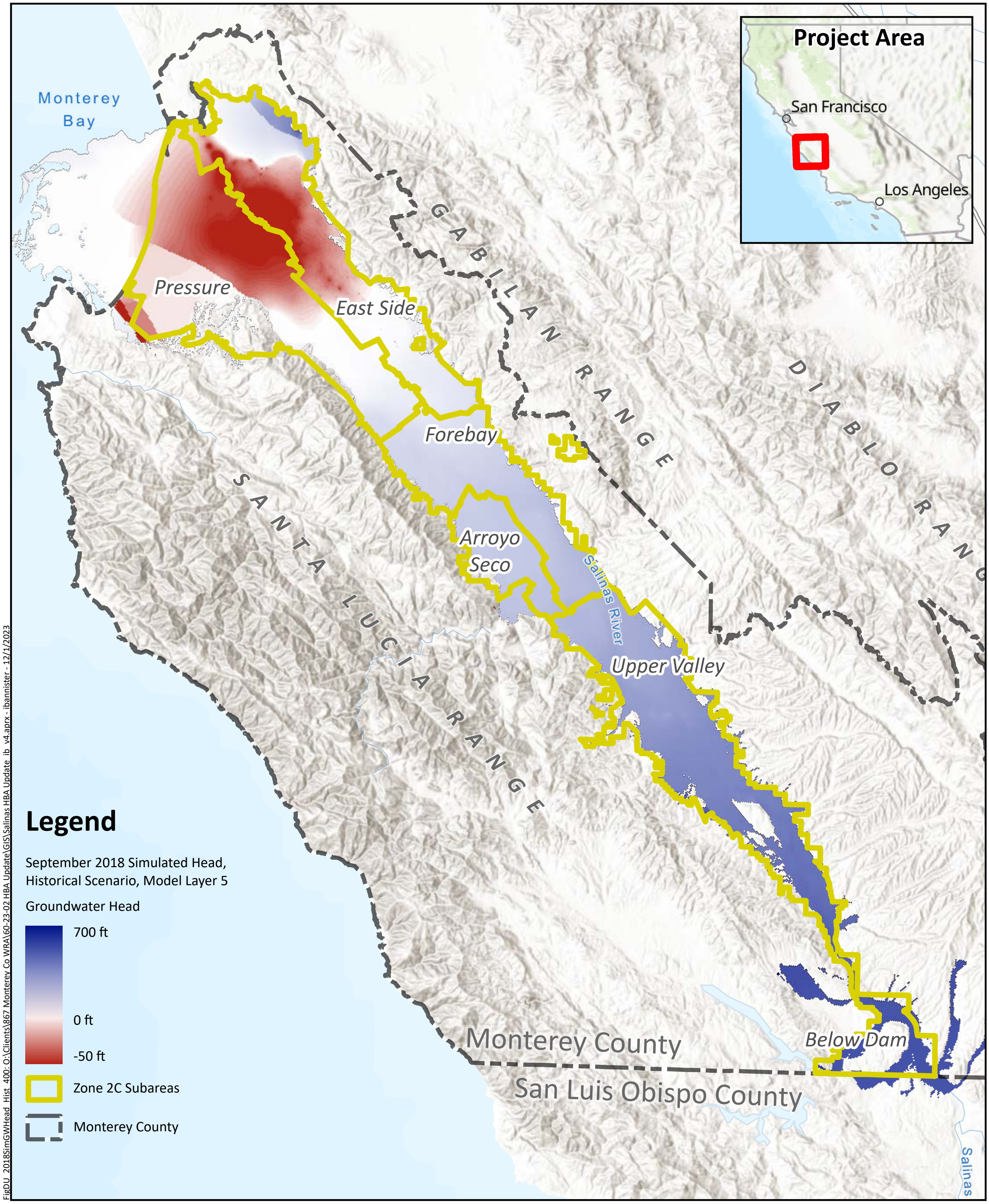
Salinas Valley HBA Update
April 2025

September 2018
Simulated Groundwater Head
Historical Scenario
180-Foot Aquifer & Equivalent

Figure 3-1



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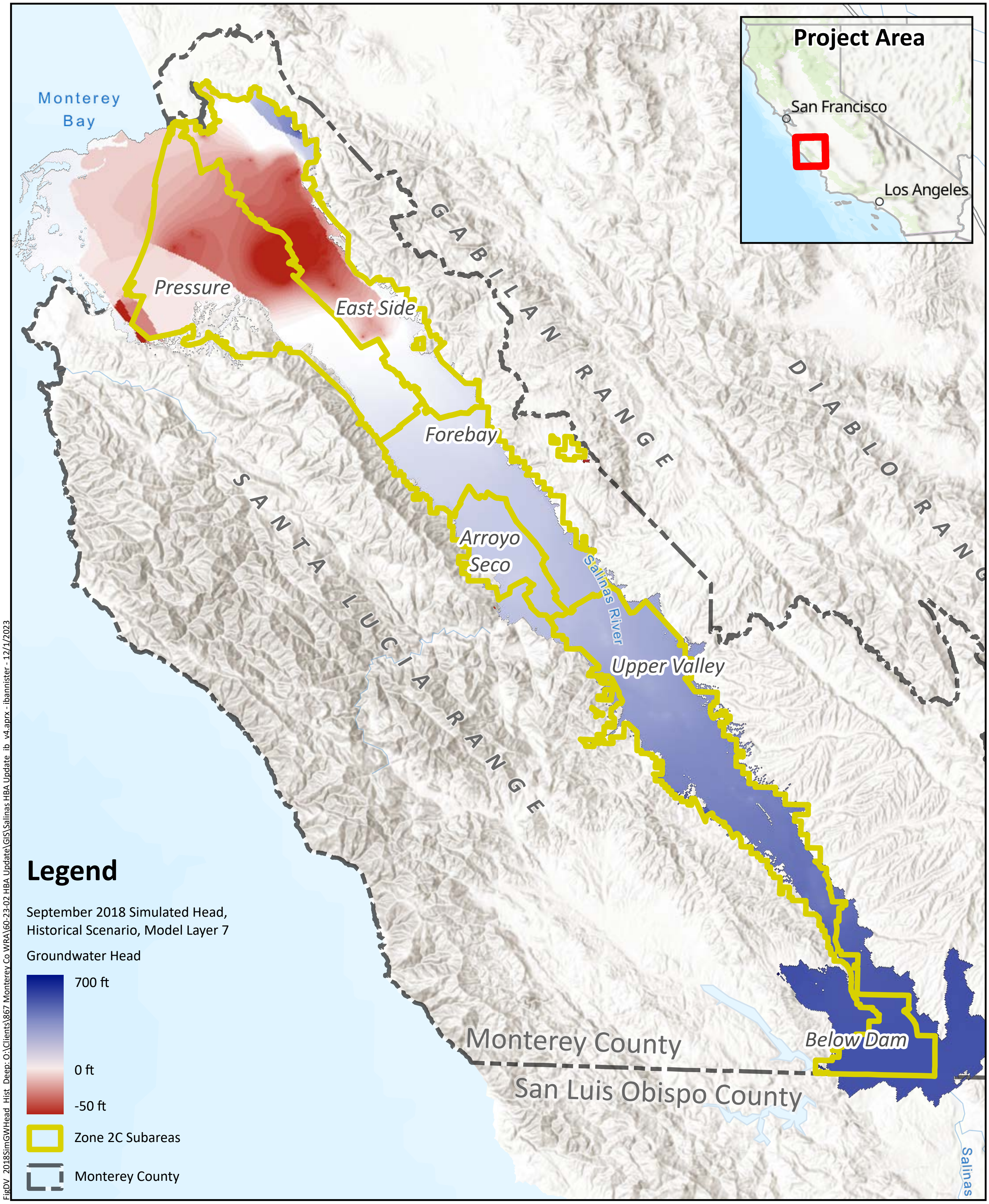
September 2018
Simulated Groundwater Head
Historical Scenario
400-Foot Aquifer & Equivalent

Figure 3-2



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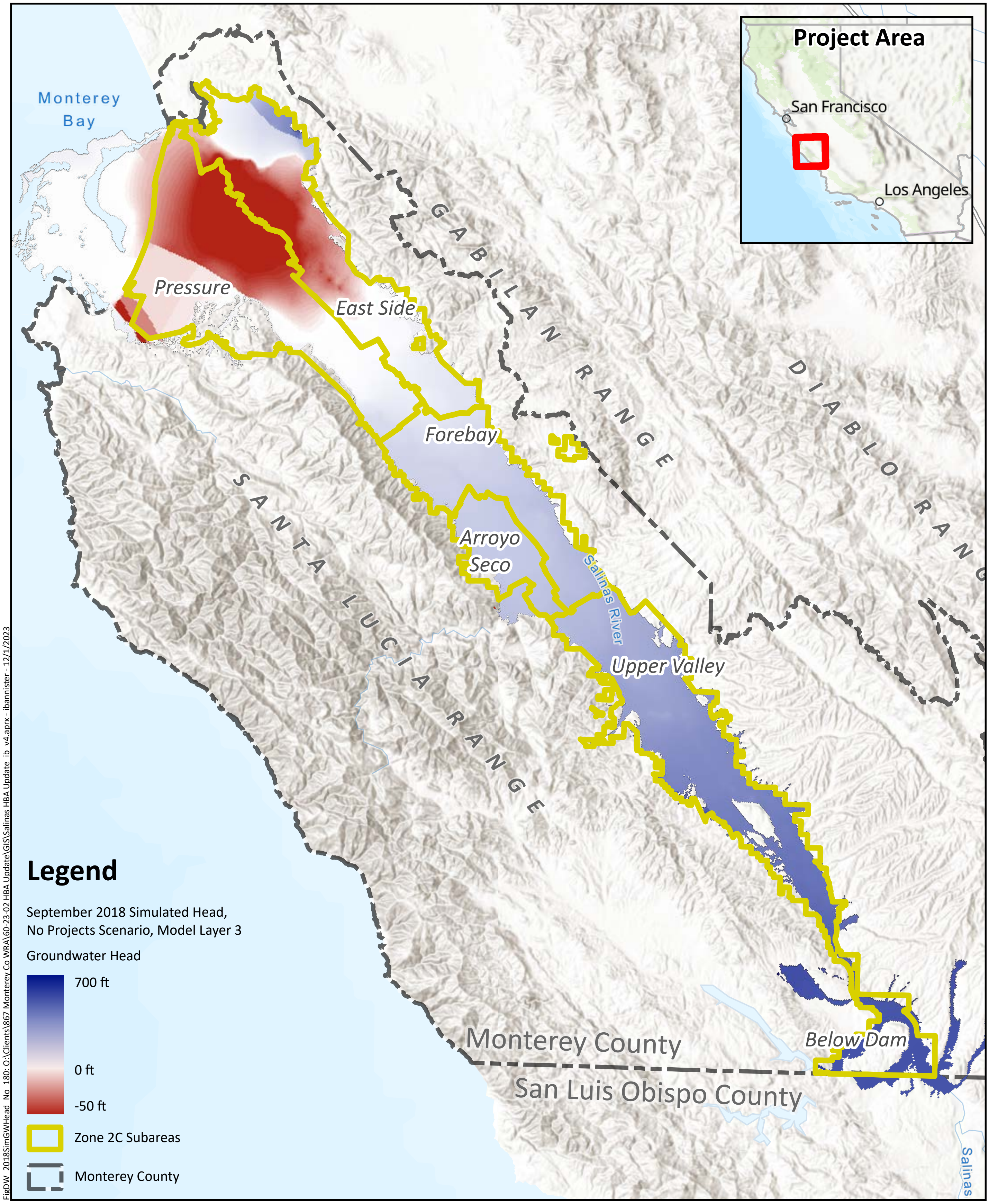
September 2018
Simulated Groundwater Head
Historical Scenario
Deep Aquifer

Figure 3-3



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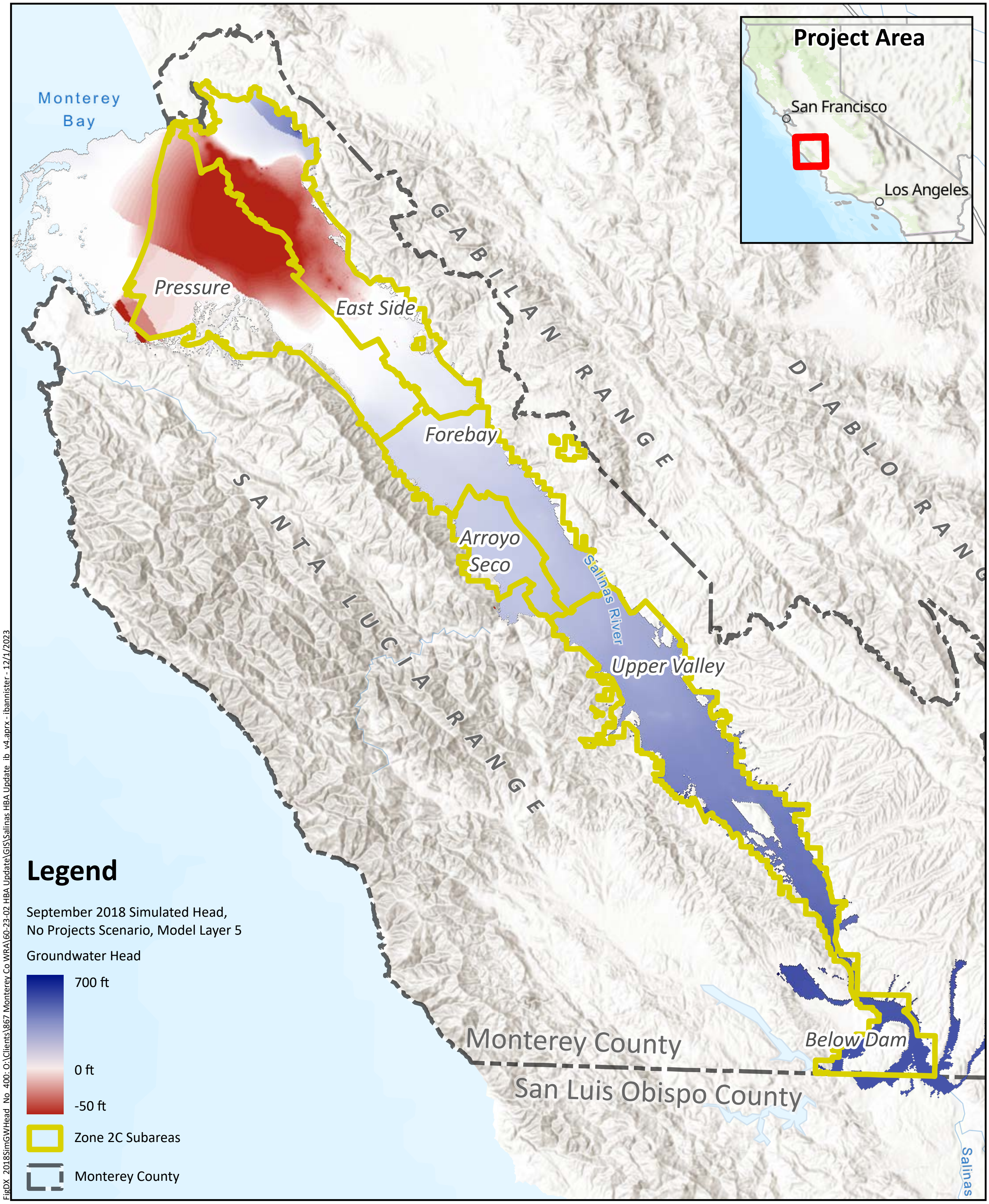
September 2018
Simulated Groundwater Head
No Projects Scenario
180-Foot Aquifer & Equivalent

Figure 3-4



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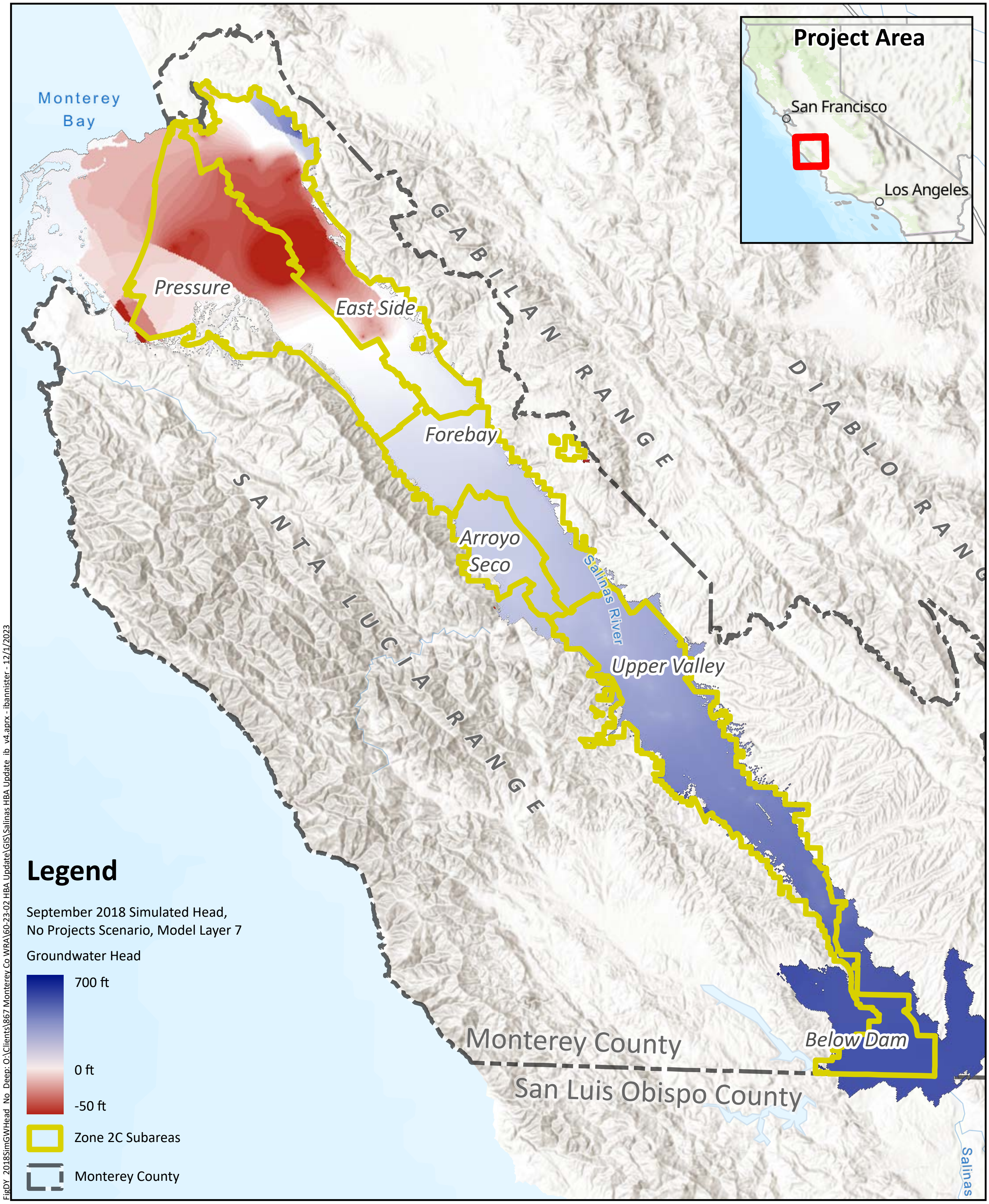
September 2018
Simulated Groundwater Head
No Projects Scenario
400-Foot Aquifer & Equivalent

Figure 3-5



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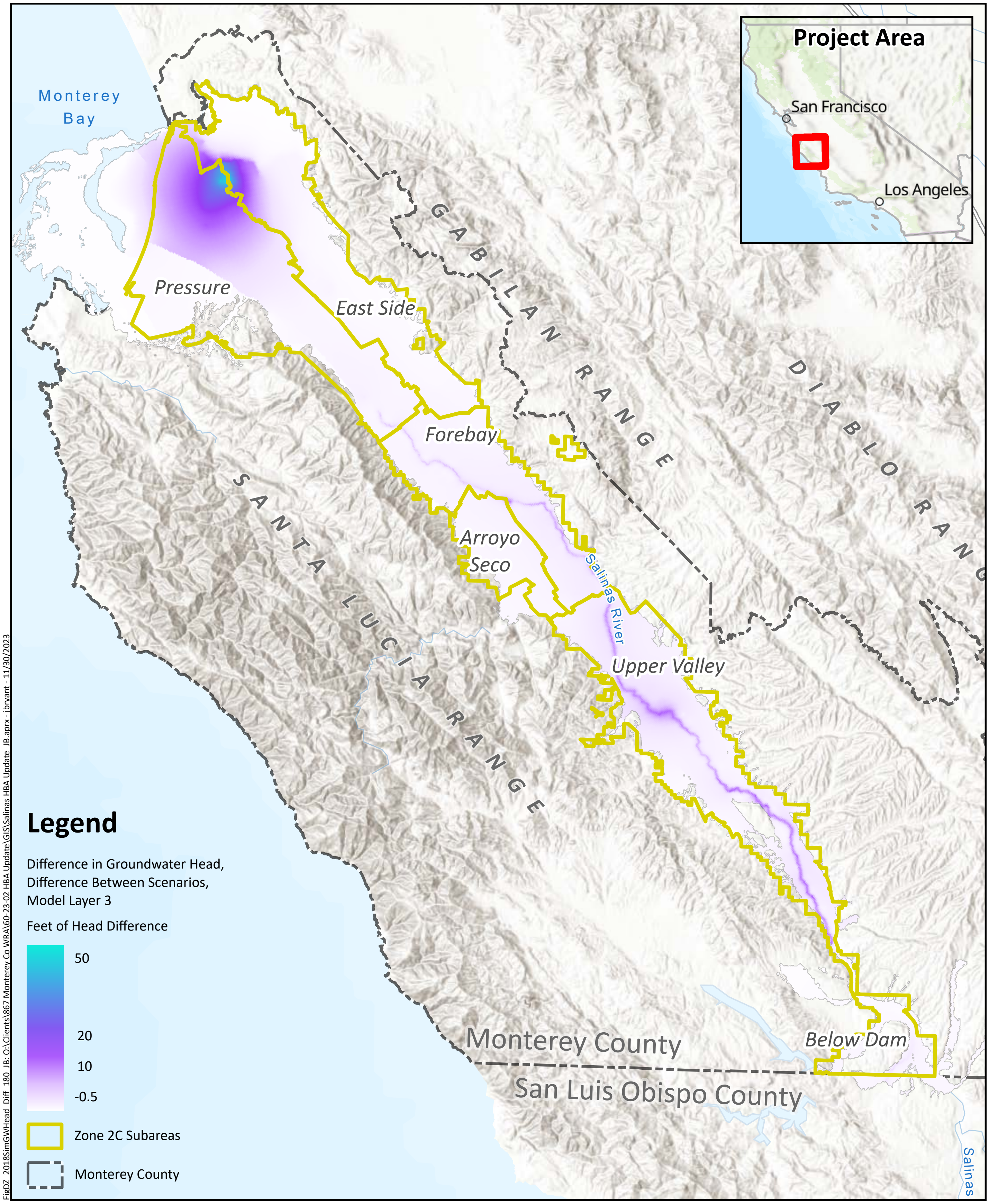
September 2018
Simulated Groundwater Head
No Projects Scenario
Deep Aquifer

Figure 3-6



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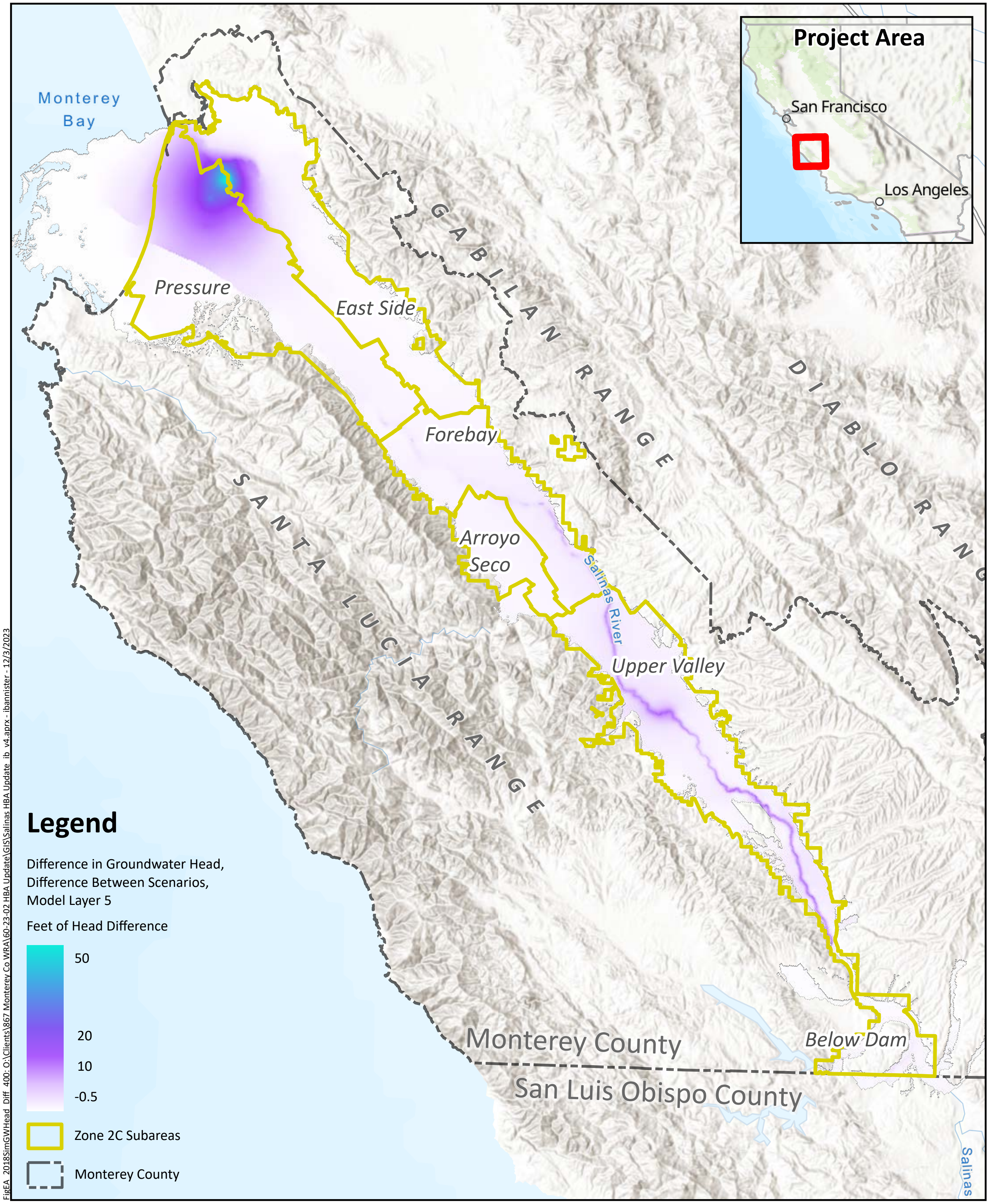
September 2018
Simulated Groundwater Head Difference Between Scenarios
180-Foot Aquifer & Equivalent

Figure 3-7



September 2018
Simulated Groundwater Head
Difference Between Scenarios
400-Foot Aquifer & Equivalent

Figure 3-8

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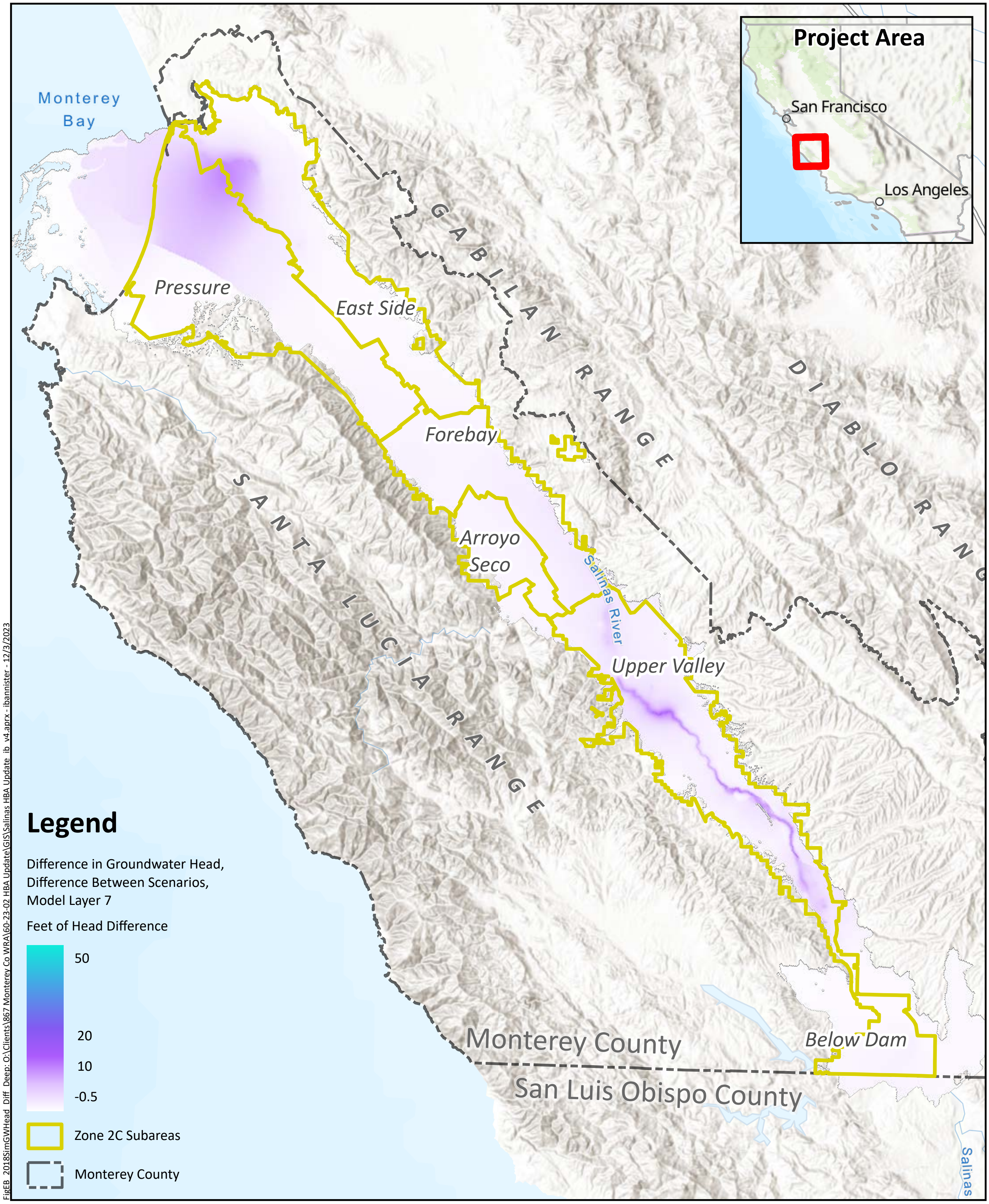

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September 2018
Simulated Groundwater Head Difference Between Scenarios
Deep Aquifer

Figure 3-9

The head differences that occur along the Salinas River can be understood to result from the operations of the reservoirs, which store high flows during wet periods for later release during drier periods. This results in increased recharge along the Salinas River, maintaining higher groundwater head values in the riparian area and adjacent aquifers. Head differences between Castroville and Salinas can likely be ascribed to the operation of CSIP, which delivers recycled and surface water to agricultural users in the coastal area to reduce agricultural demand on the main production aquifers in the Pressure Subarea (the 180-Foot and 400-Foot Aquifers). The head difference is much smaller in the Deep Aquifers of the Pressure Subarea because the effects of the CSIP are more significant in the shallower aquifers.

3.2.2 Average Annual Groundwater Head Change

Another approach to understanding the effects of the Projects on groundwater head is to analyze the head change that occurs over the course of each year (annual groundwater head change). This is done by calculating the simple difference between the end-of-water-year head and the head simulated for the end of the previous water year.

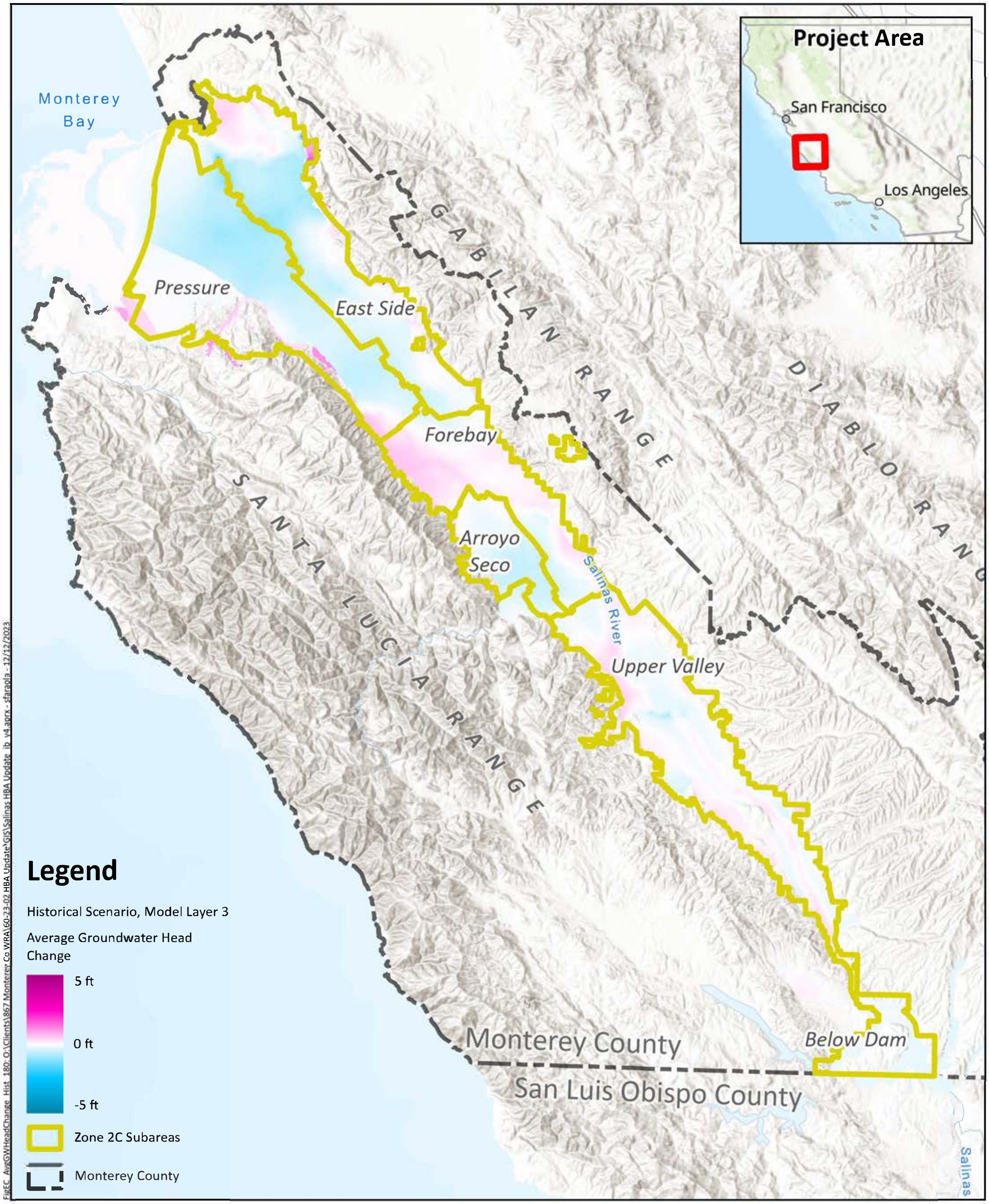
Figures 3-10 through 3-12 present the average annual groundwater head change under the Historical Scenario for Model Layers 3, 5, and 7. Figures 3-13 through 3-15 show the average annual groundwater head change under the No Projects Scenario for the same model layers. Figures 3-16 through 3-18 present the differences in the average annual groundwater head change between the two scenarios for the same model layers.

On average, head in Model Layer 3 simulated under the Historical Scenario (Figure 3-10) declined by about half a foot to a foot per year in much of the northern part of the study area, from about Gonzales north; the largest decline in head in this area was about 1.5 feet per year in the area between Castroville and Salinas (see Figure 1-1 for locations). Head also declined by up to about half a foot per year in the Arroyo Seco area, and by up to about 0.2 feet per year in the area between the dams and Bradley. Increases in head were mostly limited to the vicinity of the Salinas River (up to around Gonzales), reaching as much as about 0.5 feet per year downstream of the confluence with Arroyo Seco.

Average annual head change in Model Layer 5 under the Historical Scenario (Figure 3-11) followed the same pattern as in Model Layer 3, but with a slightly larger average annual head decrease in the northern part of the study area, reaching a maximum of about 3 feet per year in the area between Castroville and Salinas.

Average annual head change in Model Layer 7 under the Historical Scenario (Figure 3-12) followed the same general pattern as in Model Layers 3 and 5. South of about Gonzales, the aquifers are generally undifferentiated, so head changes in this area would be expected to be very similar between model layers. Model Layer 7 average annual head change in the northern part of the study area was around 1 foot per year through much of the area, reaching up to about 2 feet per year in the northeastern corner of the model domain.

The overall pattern of average annual head change in Model Layer 3 simulated under the No Projects Scenario (Figure 3-13) is similar to that for the Historical Scenario (Figure 3-10), except that the average annual head change was generally more negative, with larger head declines in the northern part of the study area (large area of at least 0.7 feet per year, with a maximum head decline of about 2.2 feet per year). Head increases along the Salinas River are mostly limited to the area downstream of Soledad, the area around King City, and the area downstream of San Ardo.



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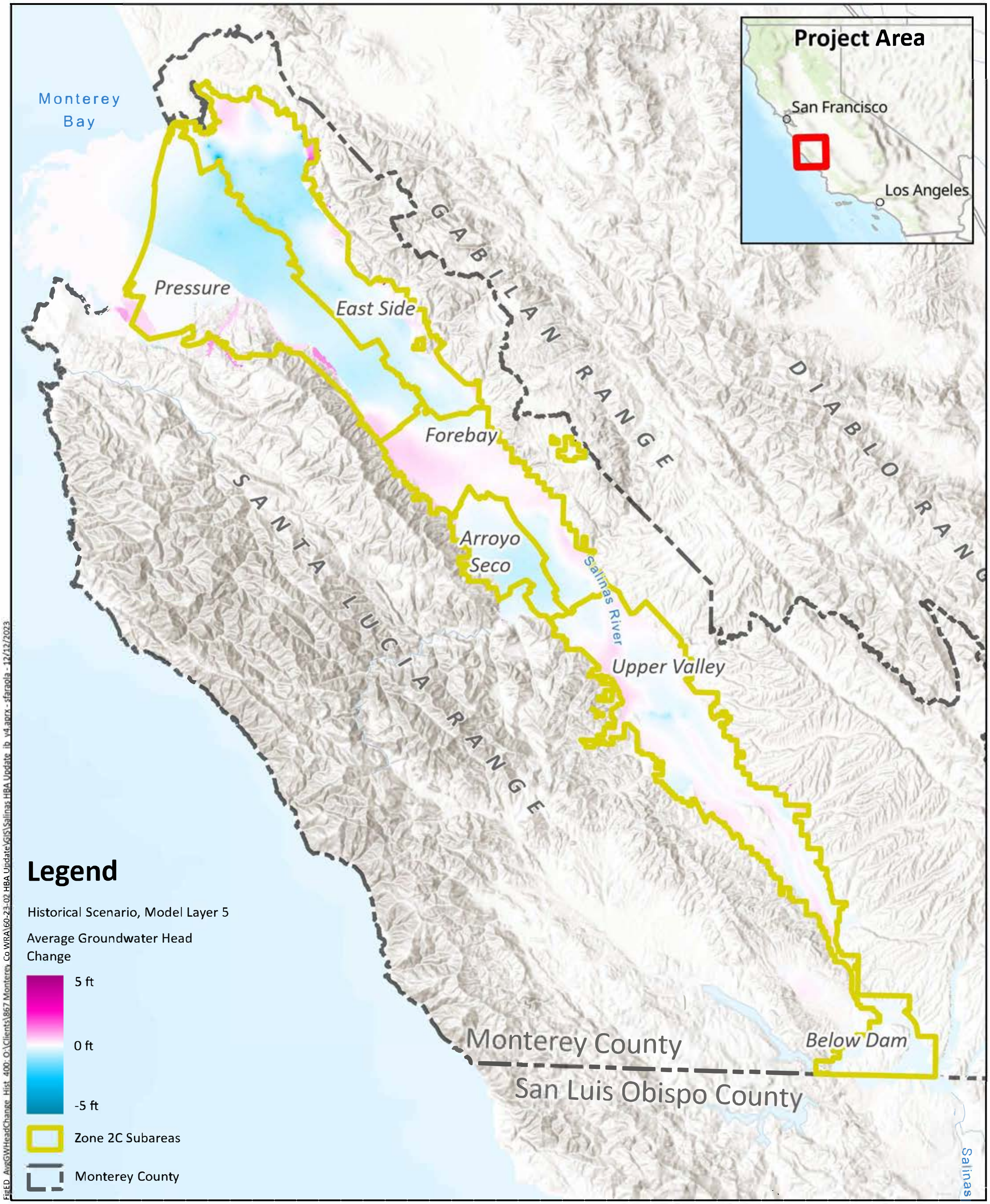
Average Annual Groundwater Head Change, Historical Scenario
180-Foot Aquifer & Equivalent

Figure 3-10



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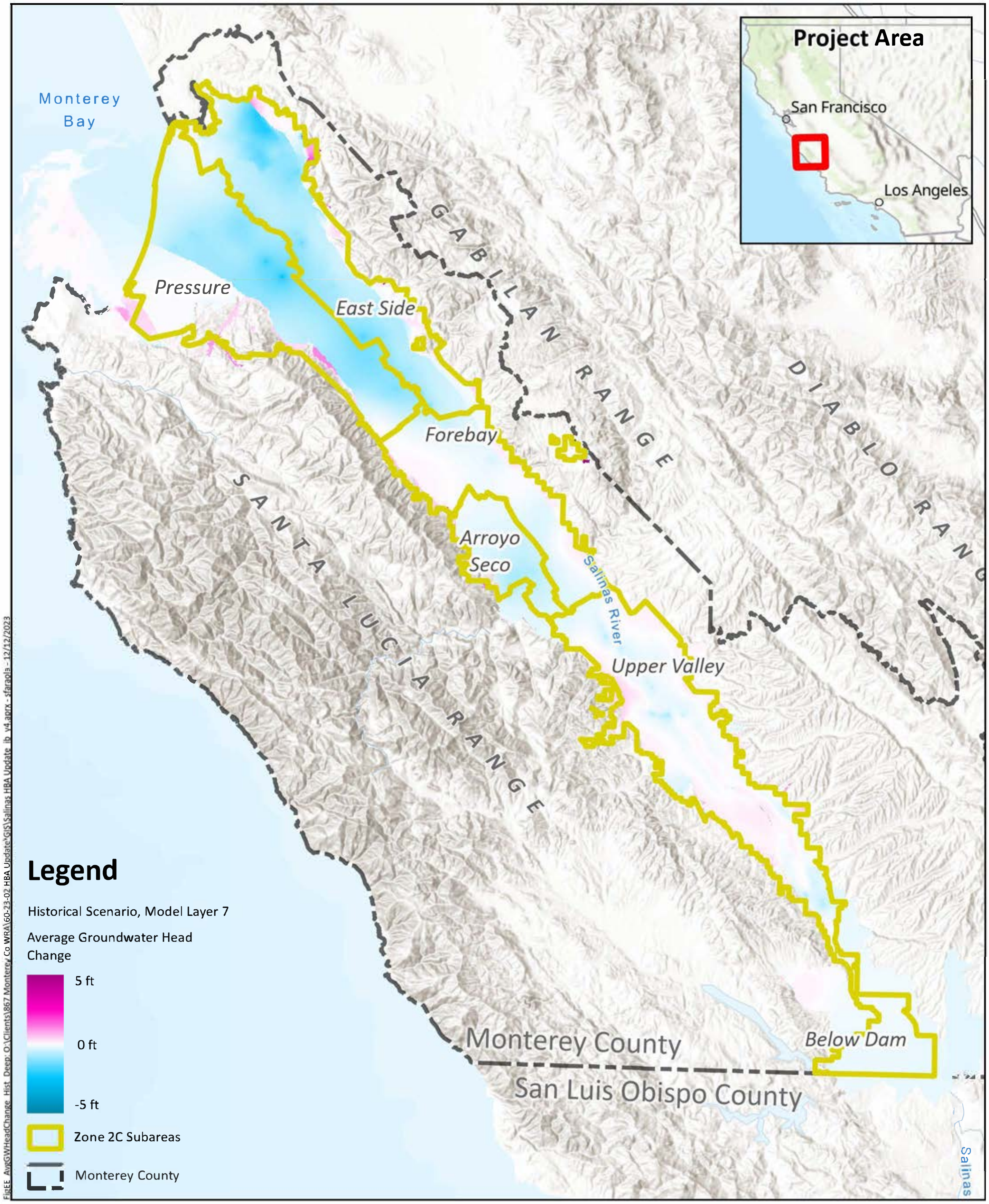
Average Annual Groundwater Head Change, Historical Scenario
400-Foot Aquifer & Equivalent

Figure 3-11



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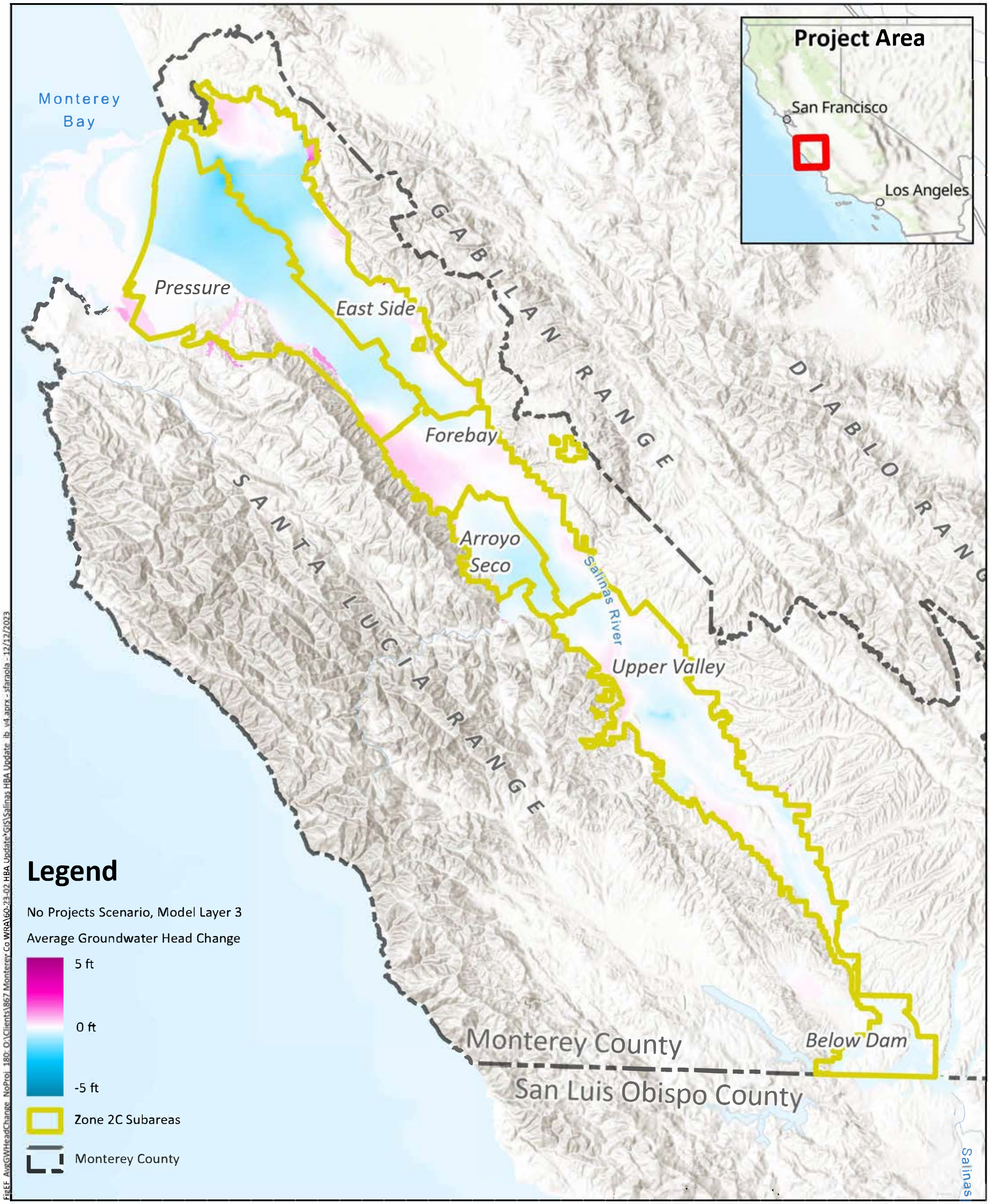
Average Annual Groundwater Head Change, Historical Scenario
Deep Aquifer

Figure 3-12



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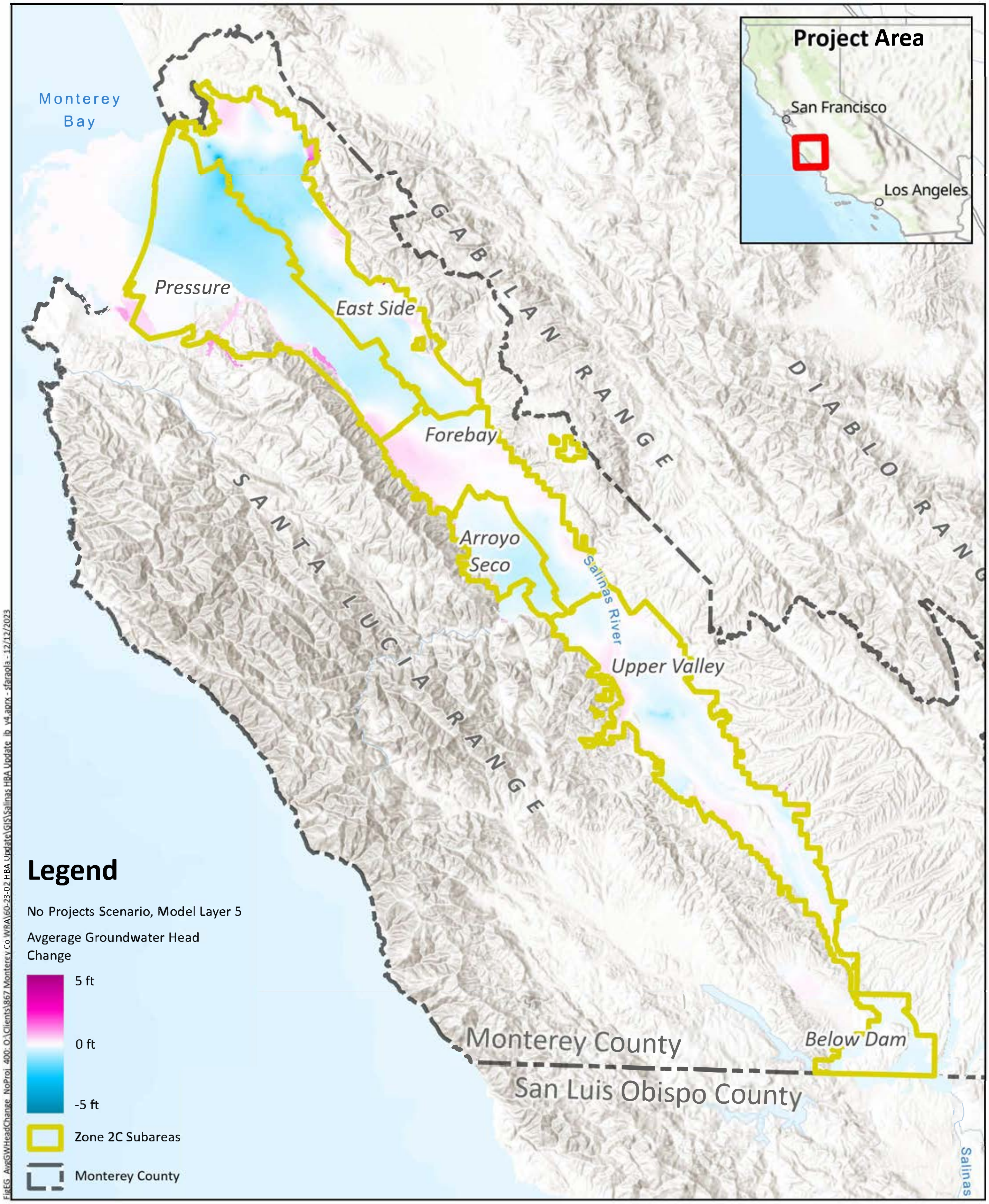
Average Annual Groundwater Head Change, No Projects Scenario
180-Foot Aquifer & Equivalent

Figure 3-13



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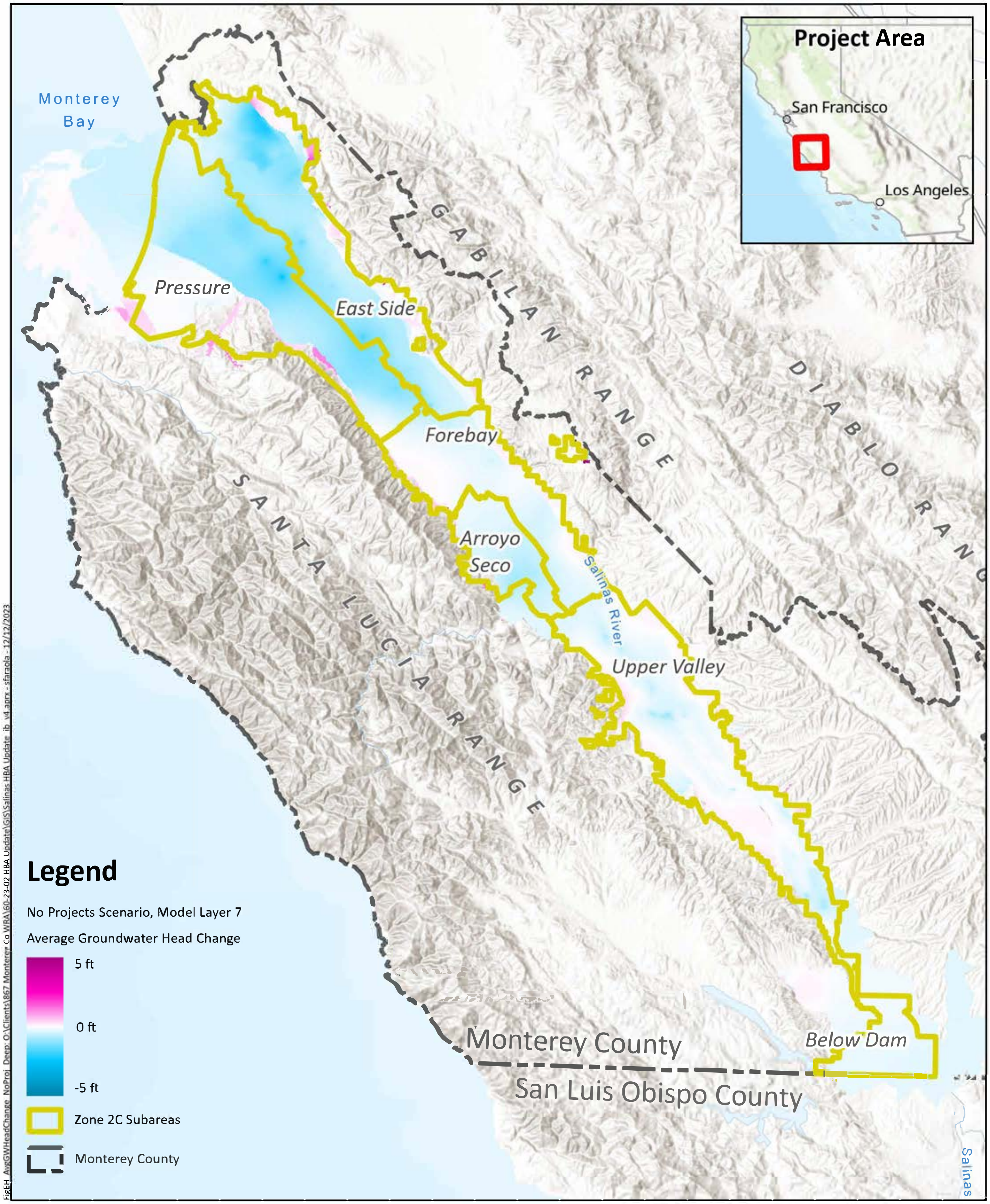
Average Annual Groundwater Head Change, No Projects Scenario
400-Foot Aquifer & Equivalent

Figure 3-14



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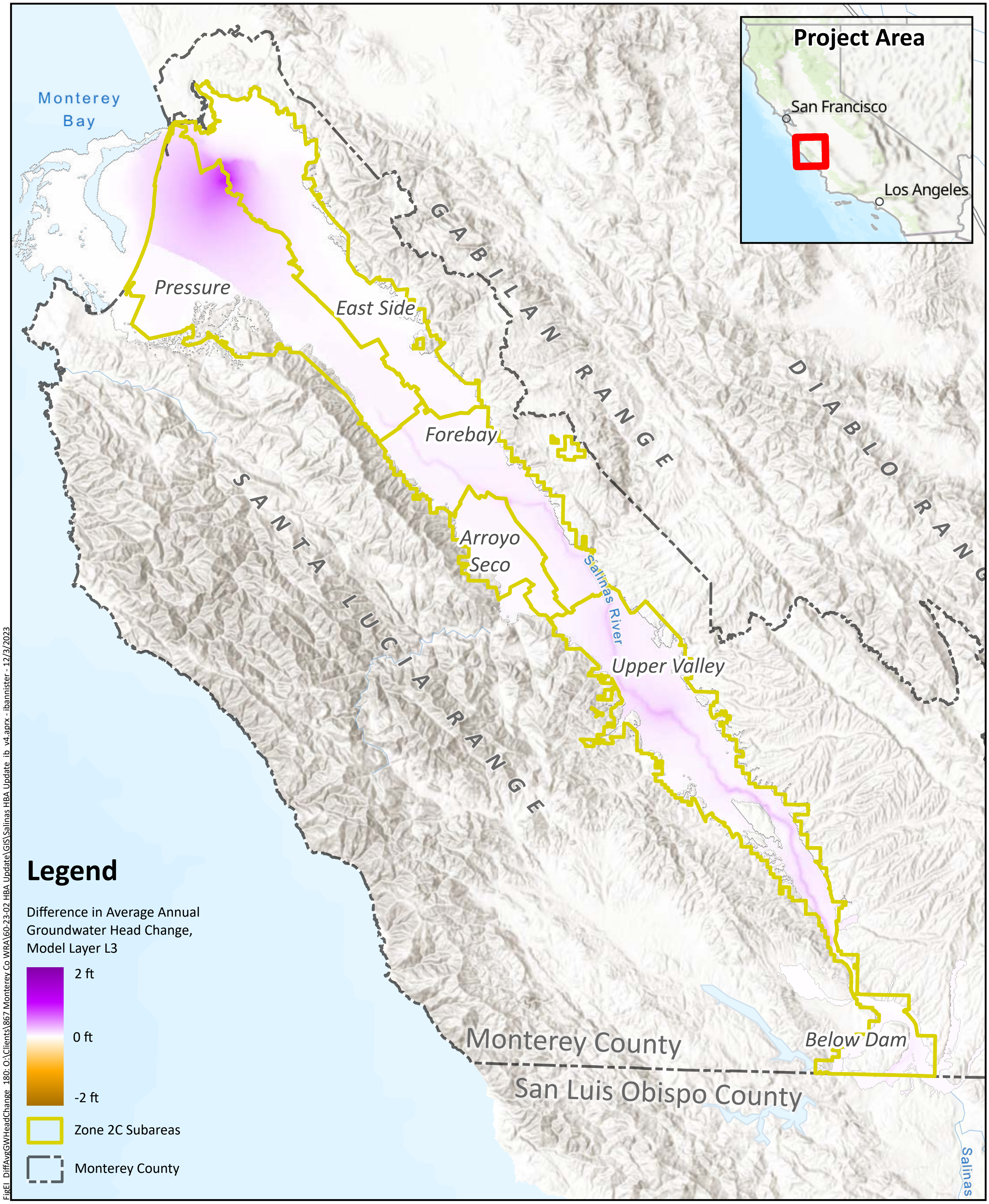
Average Annual Groundwater Head Change, No Projects Scenario
Deep Aquifer

Figure 3-15



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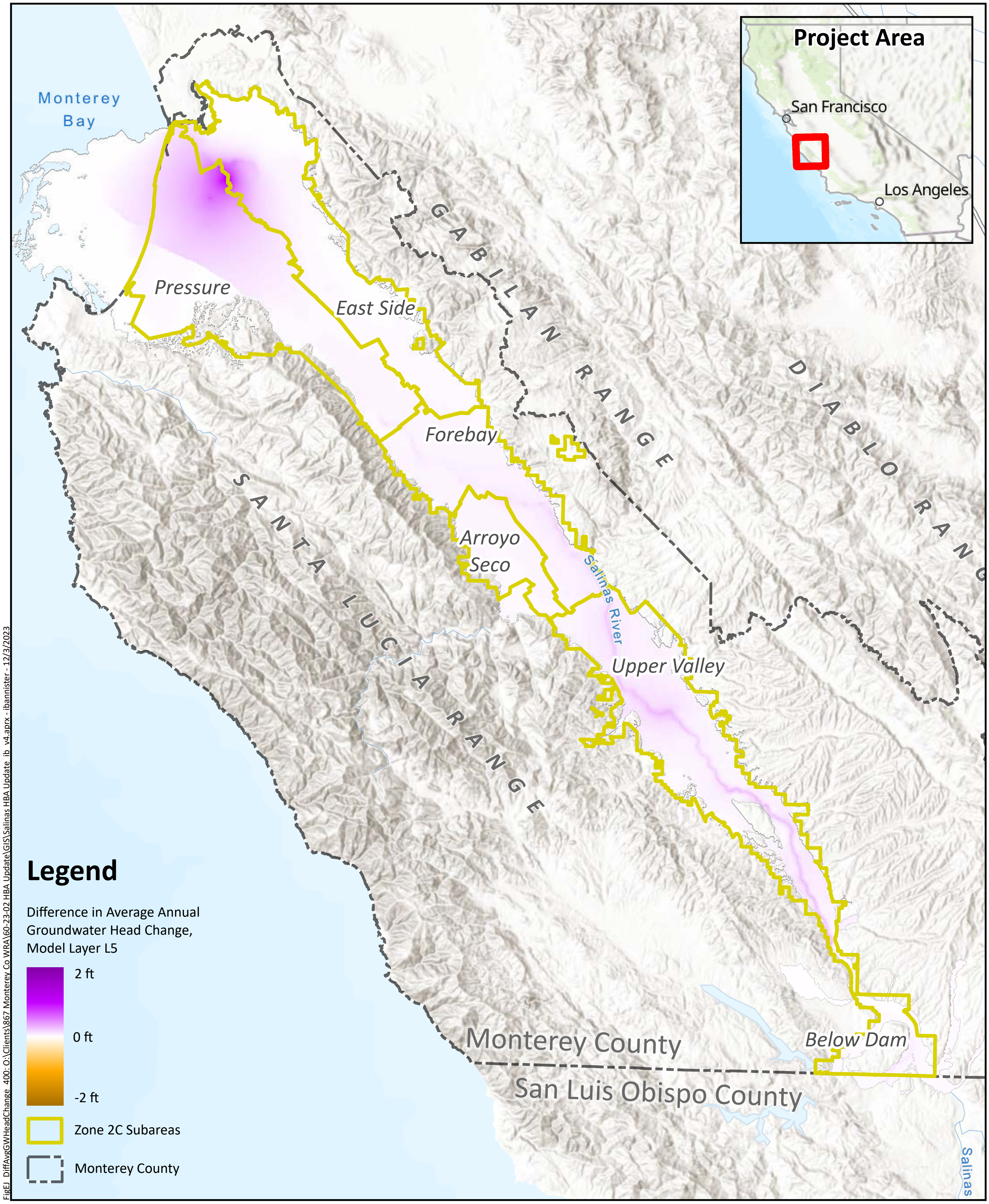
Difference in Average Annual Groundwater Head Change
180-Foot Aquifer & Equivalent

Figure 3-16



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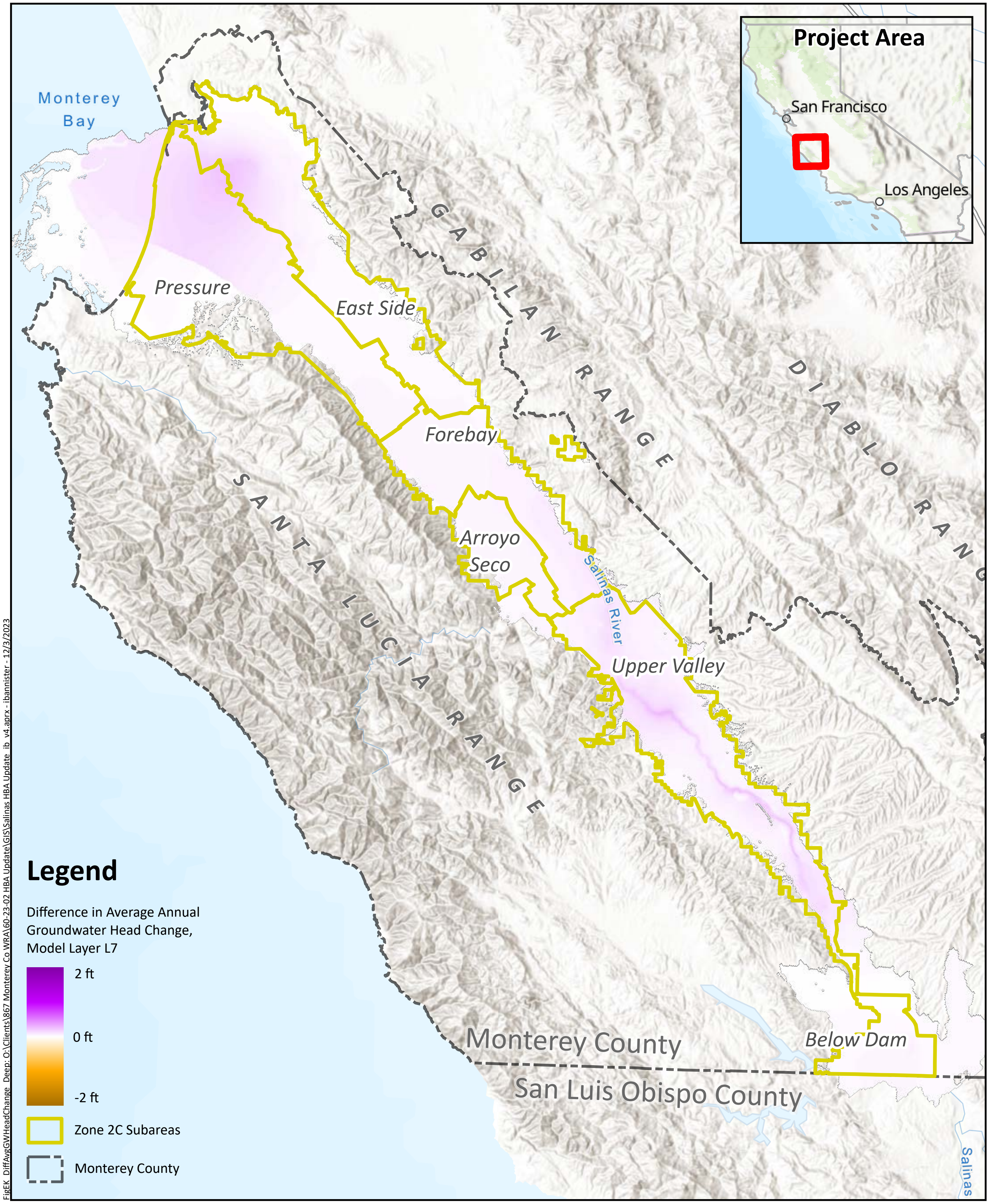
Difference in Average Annual Groundwater Head Change
400-Foot Aquifer & Equivalent

Figure 3-17



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April 2025

Difference in Average Annual Groundwater Head Change

Deep Aquifer

Figure 3-18

Similarly, the overall pattern of average annual groundwater head change in Model Layer 5 for the No Projects Scenario (Figure 3-14) is similar to that for the Historical Scenario (Figure 3-11), except that head changes are generally more negative along the Salinas River and in the area between Castroville and Salinas. In the northern part of the study area, groundwater head declined by more than a foot per year in much of the area between Castroville and Salinas, with a maximum decline of about 3.3 feet per year.

The average annual head change pattern in Model Layer 7 under the No Projects Scenario (Figure 3-15) looks similar to that for the Historical Scenario (Figure 3-12). In the northern part of the study area, where the Deep Aquifer is a separate defined unit, head declined by about a foot to 1.2 feet per year in much of the area between Castroville and Salinas.

The differences between scenarios are illustrated on Figures 3-16 to 3-18, which show the difference in the Historical Scenario and No Projects Scenario average annual head changes. As noted in previous sections, these differences are calculated as the Historical Scenario results minus the No Projects Scenario results; a positive number indicates higher head conditions simulated for the Historical Scenario. Figure 3-16 shows the difference between the scenarios in Model Layer 3. Notable differences between scenarios were largely in the vicinity of the Salinas River south of about Gonzales, and the region between Castroville and Salinas. The average annual head change was about 0.1 to 0.3 feet per year more positive in the vicinity of the Salinas River under the Historical Scenario. In the northern part of the study area, the average annual head change was up to about 0.9 feet per year less negative under the Historical Scenario.

The difference in average annual head change in Model Layer 5 (Figure 3-17) looks very similar to the differences simulated in Model Layer 3. The head change in the area between Castroville and Salinas was as much as about 1.3 feet per year less negative under the Historical Scenario compared to the No Projects Scenario.

The differences in average annual head change in Model Layer 7 (Figure 3-18) are smaller than those simulated in Model Layers 3 and 5. The average annual head change in the area between Castroville and Salinas was up to about 0.2 feet per year less negative under the Historical Scenario than under the No Projects Scenario.

The average annual head change maps presented in this section provide another indication of the effect of the Projects. As described in Section 3.2.1 above, the most significant effects occur in the vicinity of the Salinas River and in the area between Castroville and Salinas. Along the Salinas River, the average annual head change was positive along much of the Salinas River south of Gonzales under the Historical Scenario, whereas the No Projects Scenario simulated positive head changes over a much more constrained portion of the riparian area. This difference can be ascribed to the presence and operation of the Nacimiento and San Antonio Reservoirs. The average annual head change was also less negative in the area between Castroville and Salinas under the Historical Scenario compared to the No Projects Scenario. Differences in this area indicate the effect of the presence and operation of the CSIP system.

Further understanding of the effect of the Projects can be gained by considering the average annual head change maps for wet, normal, and dry years. The maps representing average annual head changes for both scenarios by water year type for Model Layers 3, 5, and 7 are presented in Appendix A. The difference between scenarios is largely insensitive to year type in the northern part of the study area, where the differences are likely to be largely due to the operation of the CSIP system, which can provide water to agricultural users during any year type.

Along the Salinas River, the reservoirs (and related projects and programs) result in smaller average annual head increases during wet years compared to the No Projects Scenario because the storage of high winter wet flows within the reservoirs results in less streamflow and less recharge during the winters of wet years. During normal and dry years, the average annual head change along the Salinas River is less negative under the Historical Scenario than the No Projects Scenario, reflecting the effect of the reservoirs releasing water during dry years. The overall effect of the reservoirs on the area around the Salinas River is to provide additional recharge during normal and dry years at the expense of recharge during wet years. Sections 3.3 and 3.4 below describe the differences in the fluxes entering and leaving the groundwater system, including recharge along the Salinas River.

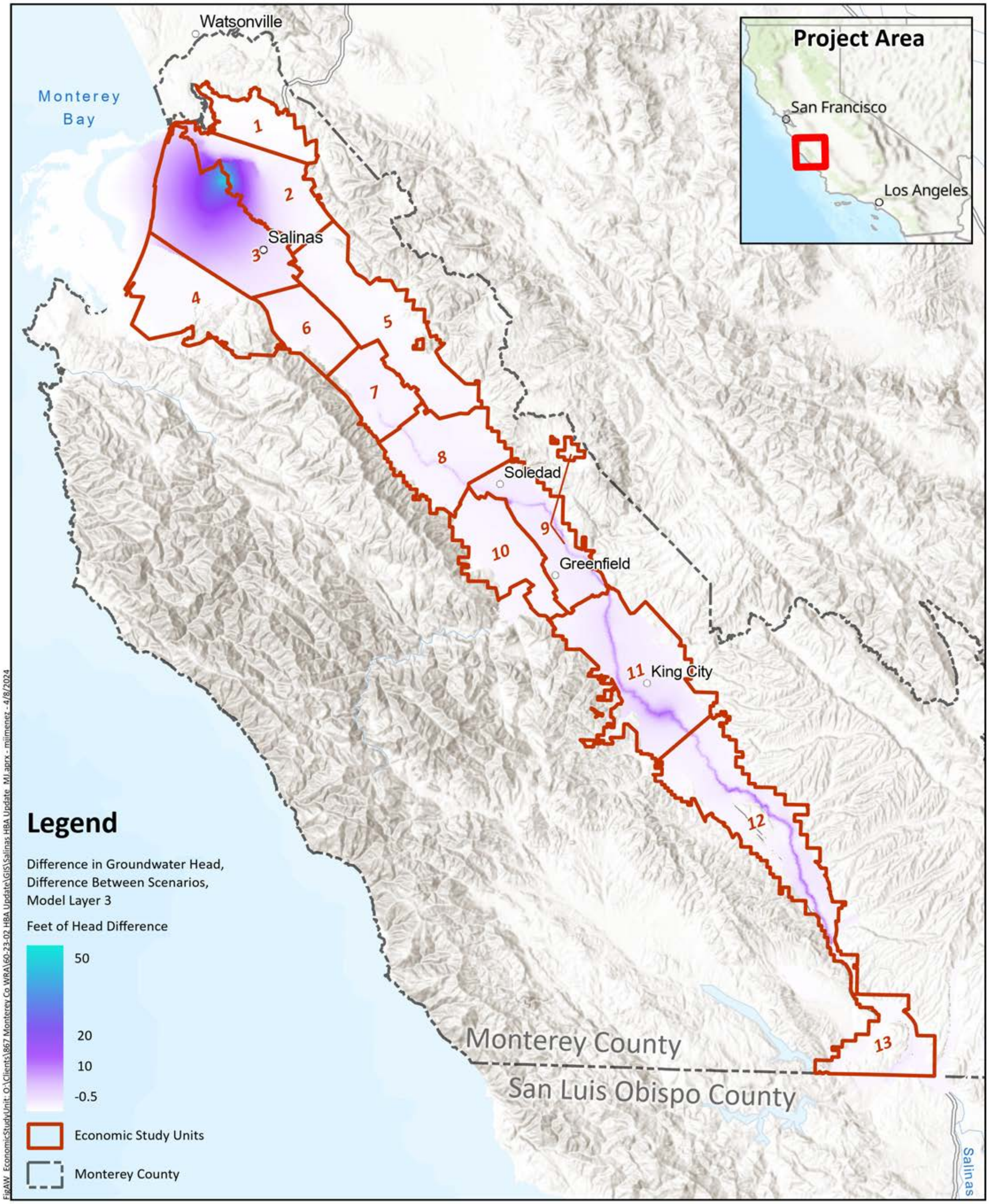
3.2.3 Economic Study Unit Delineation

The 1998 HBA summarized the benefits provided by the Nacimiento and San Antonio Reservoirs on a spatial basis using subdivisions of the model domain referred to as Economic Study Units (ESUs). These units provided a way to group together portions of the study area that experienced similar benefits (as quantified by the average annual groundwater head change). The 1998 HBA divided the SVIGSM model domain into 12 ESUs, two of which were not included in the benefit quantification.

Because this HBA Update utilizes a different set of tools for the quantification of the benefits of the Projects, a new ESU map is used to group portions of the study area together. As with the 1998 HBA, the ESU map is based on the groundwater head difference between the Historical and No Projects Scenarios, in this case demonstrated using the September 2018 model results (shown previously on Figure 3-7). The September 2018 results represent the cumulative difference between scenarios over the entirety of the 51-year simulation period, providing the most detailed understanding of the spatial variation in the benefit of the Projects.

Figure 3-19 shows the ESUs used for this study, along with the September 2018 head difference. This study uses 13 ESUs covering all of Zone 2C. The ESUs follow the Zone 2C Subarea boundaries (see Figure 1-6), with subareas subdivided into multiple ESUs as dictated by the head differences between scenarios. The East Side Subarea is divided into 3 ESUs (1, 2, and 5); the Pressure Subarea is divided into 4 ESUs (3, 4, 6, and 7); the Forebay Subarea is divided into 2 ESUs (8 and 9); the Arroyo Seco Subarea is a single ESU (10); the Upper Valley Subarea is divided into 2 ESUs (11 and 12); and the Below Dam Subarea is a single ESU (13). Other areas within the model domain but outside of Zone 2C are not included in any ESU, including the portion of the model domain within San Luis Obispo County.

The 1998 HBA presented (as Figures 1-14 through 1-23) time series of average annual groundwater head for the individual ESUs. The averaging relied on a temporal and spatial weighting approach that emphasized the times and places of the greatest magnitude of pumping. For this HBA Update, heads were not weighted either spatially or temporally. Instead, the analysis of head values by ESU concentrates on the end-of-water-year (i.e., end of September) simulated groundwater heads output by the SVIHM, averaged across each ESU. Figure 3-20 presents the average end-of-water-year groundwater heads for ESUs 1 through 13, showing the results for the Historical and No Projects Scenarios as well as the difference between the two (note that the scale of the left-hand vertical axis is the same on each of these figures, but the upper and lower bounds change to suit the results for each ESU). Table 3-1 provides the average annual head change averaged across each ESU for the Historical and No Projects Scenarios.



Prepared by:

WEST YOST

Prepared for:
Monterey County Water Resources Agency
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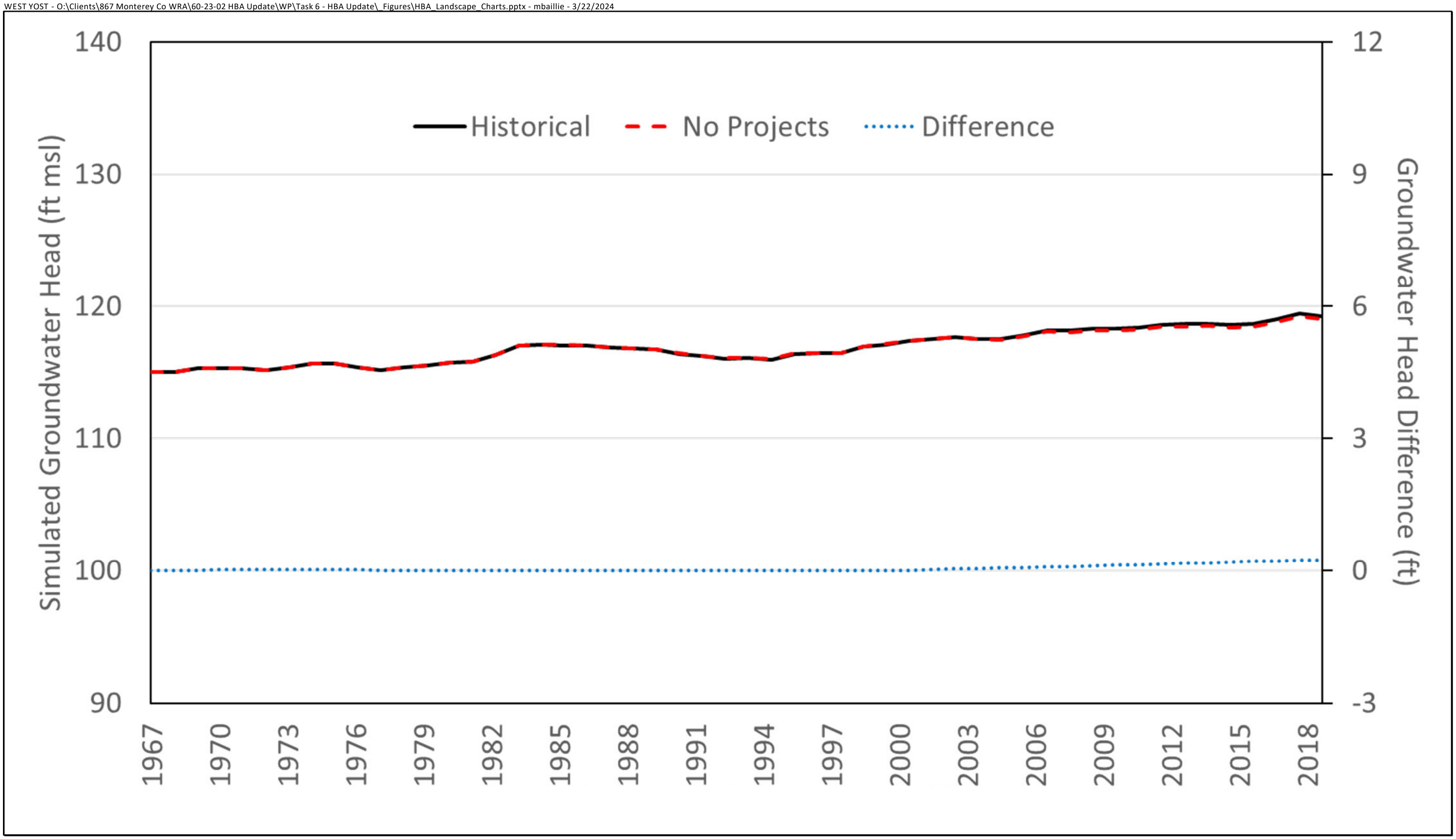
Economic Study Units

Figure 3-19

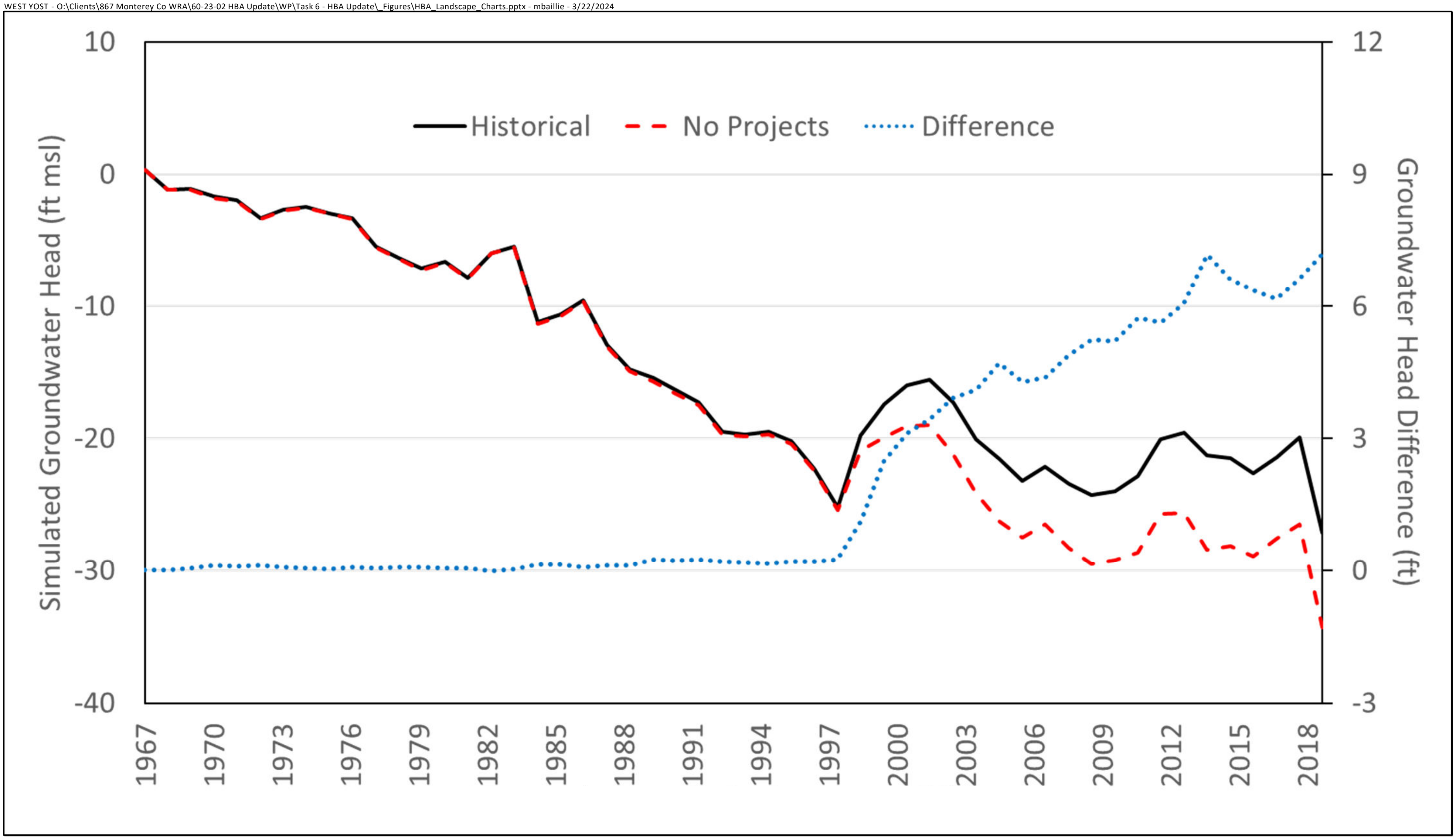


Notes:

1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20a

Average End-of-Year Groundwater Head in ESU-1, Historical and No Projects Scenarios



Notes:

1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20b

Average End-of-Year Groundwater Head in ESU-2, Historical and No Projects Scenarios

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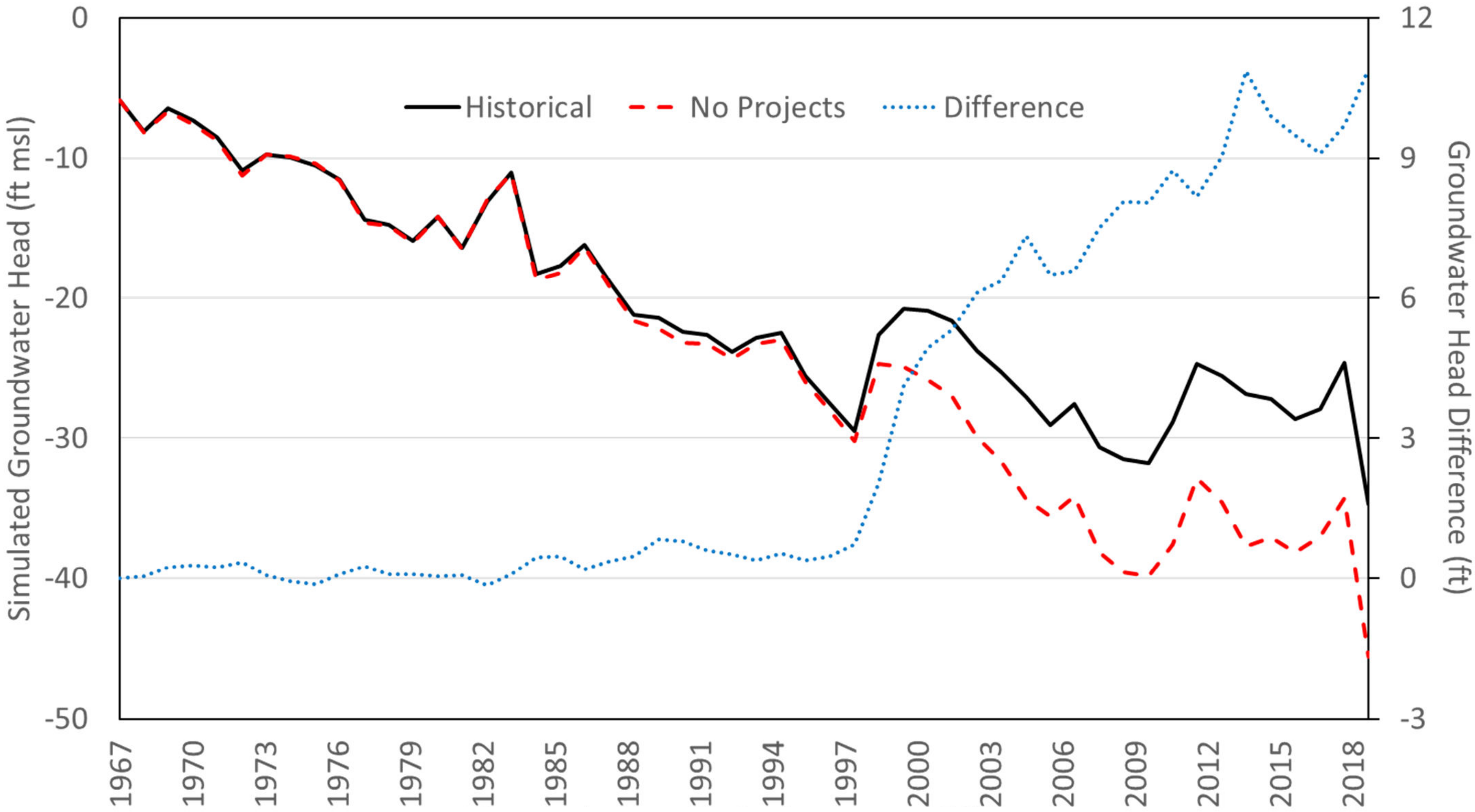

Notes:
1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20c

Average End-of-Year Groundwater Head in ESU-3, Historical and No Projects Scenarios

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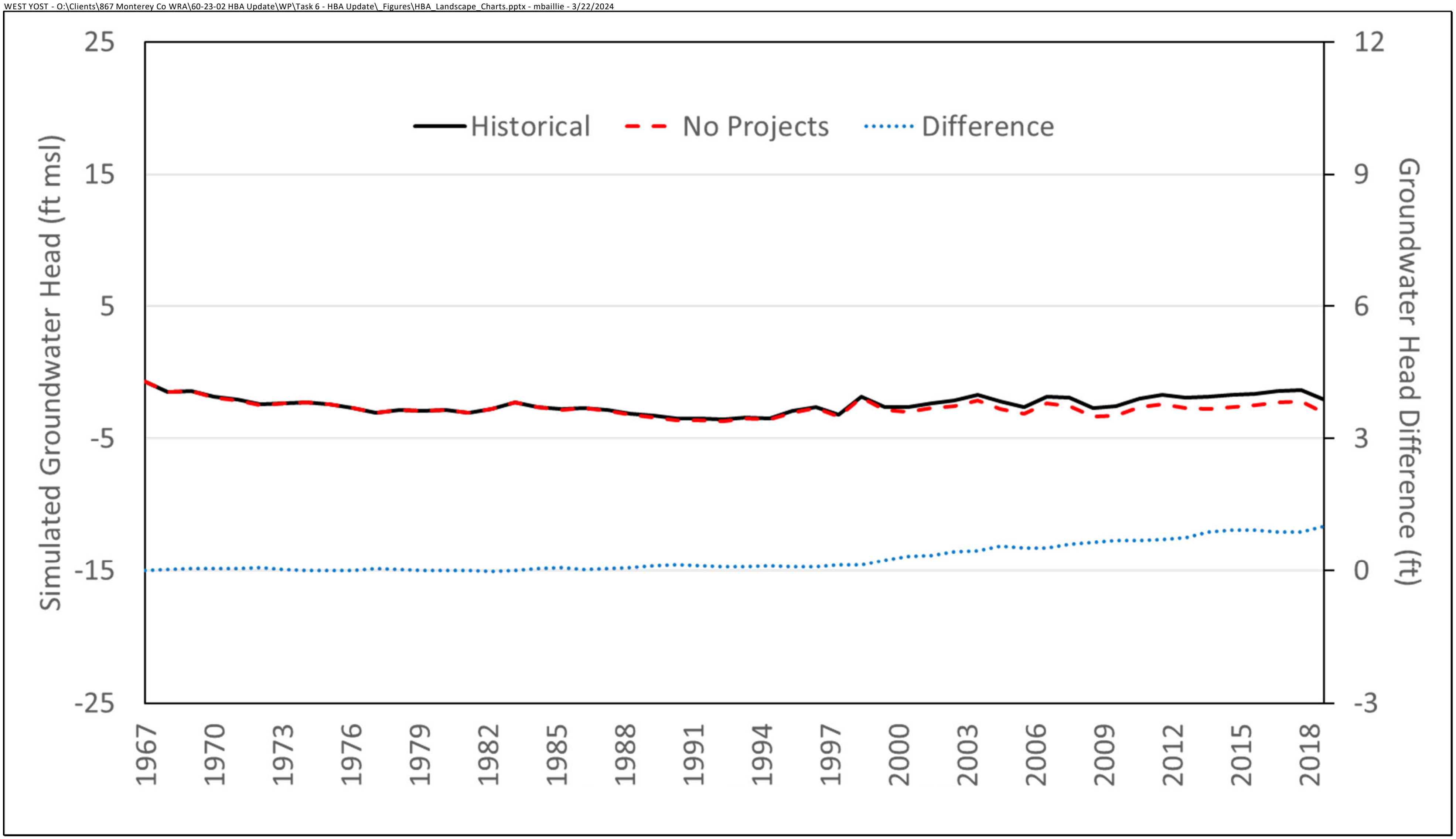

Notes:

1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20d

Average End-of-Year Groundwater Head in ESU-4, Historical and No Projects Scenarios

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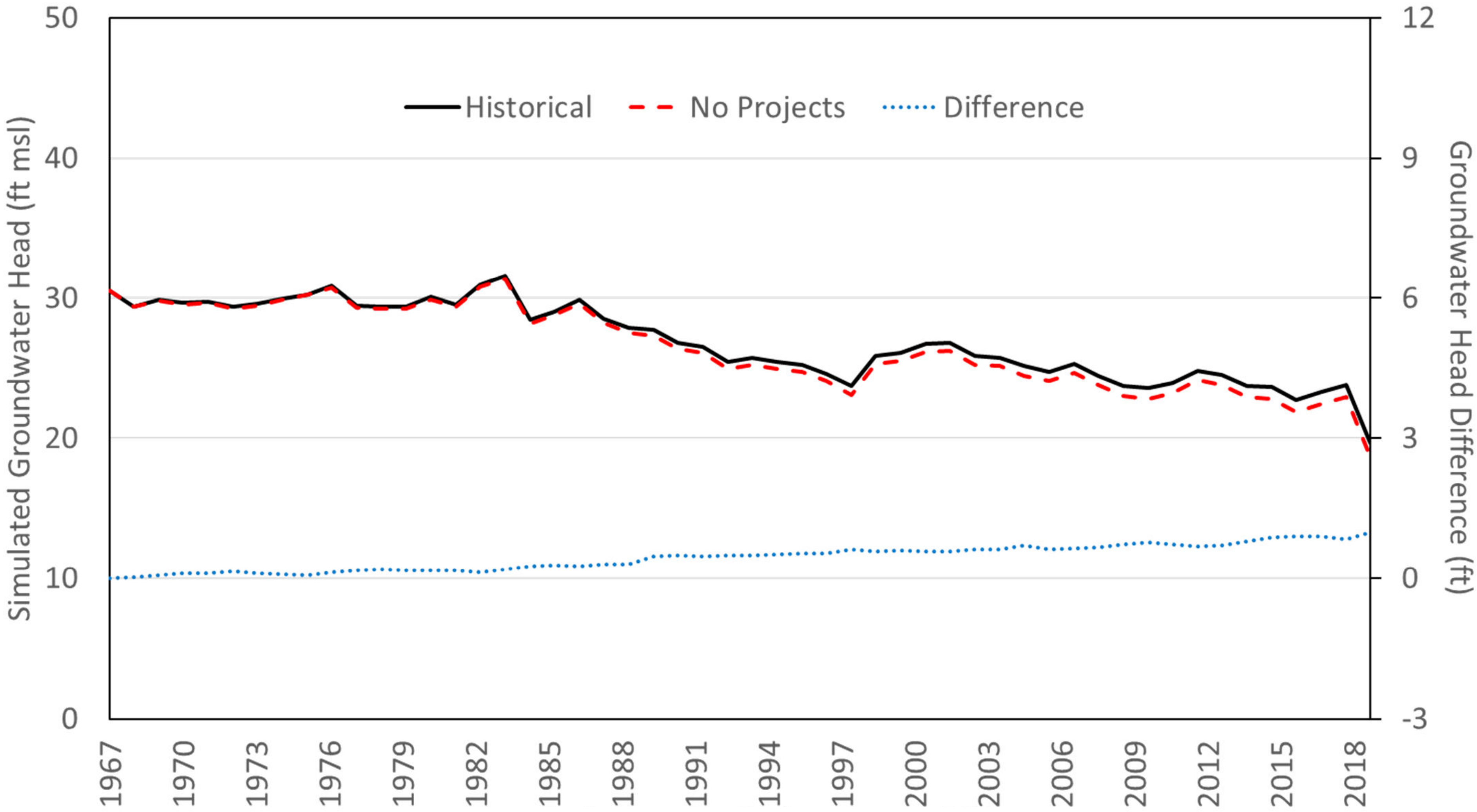

Notes:

1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20e

Average End-of-Year Groundwater Head in ESU-5, Historical and No Projects Scenarios

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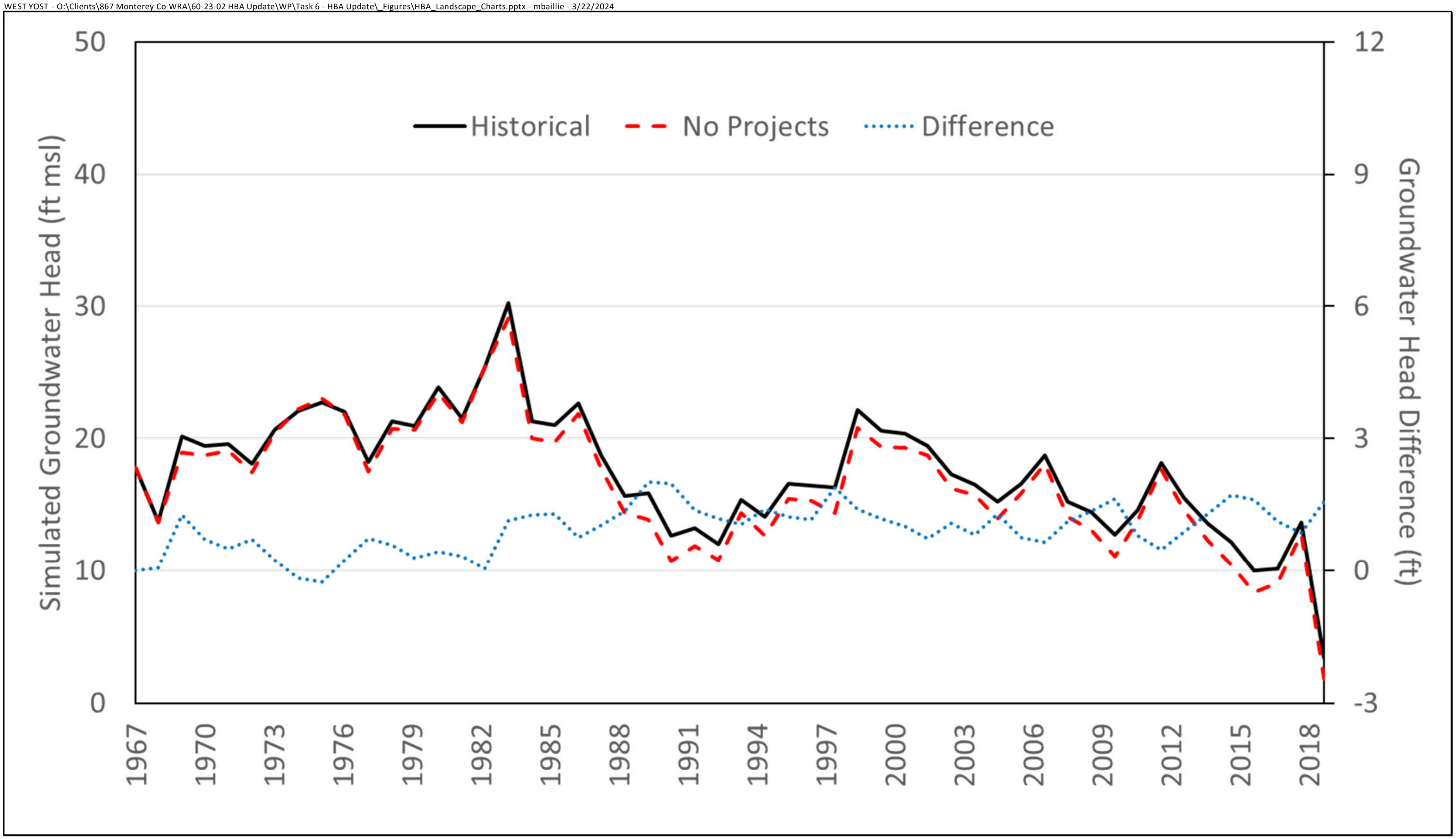

Notes:

1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20f

Average End-of-Year Groundwater Head in ESU-6, Historical and No Projects Scenarios

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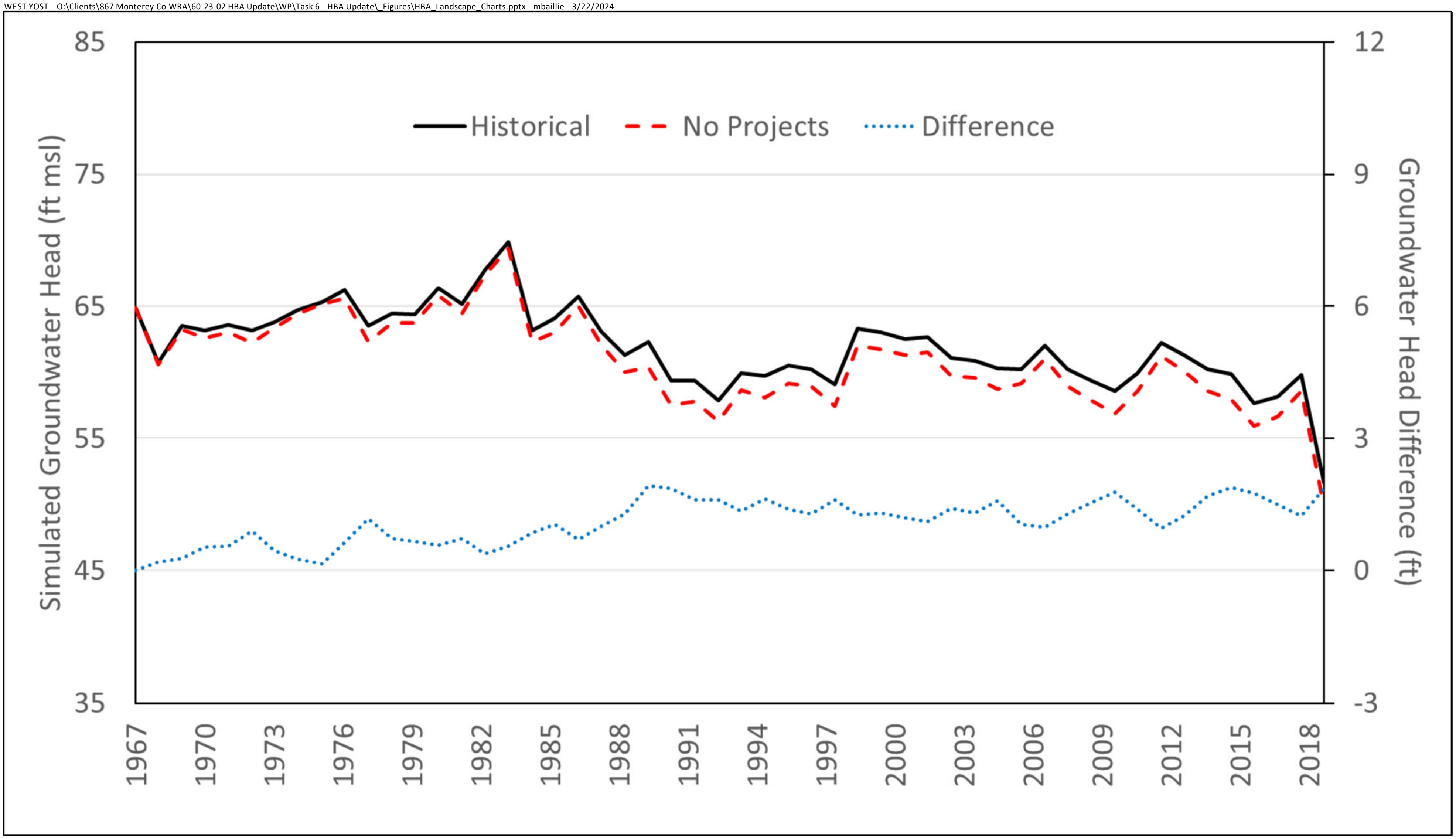

Notes:

1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20g

Average End-of-Year Groundwater Head in ESU-7, Historical and No Projects Scenarios

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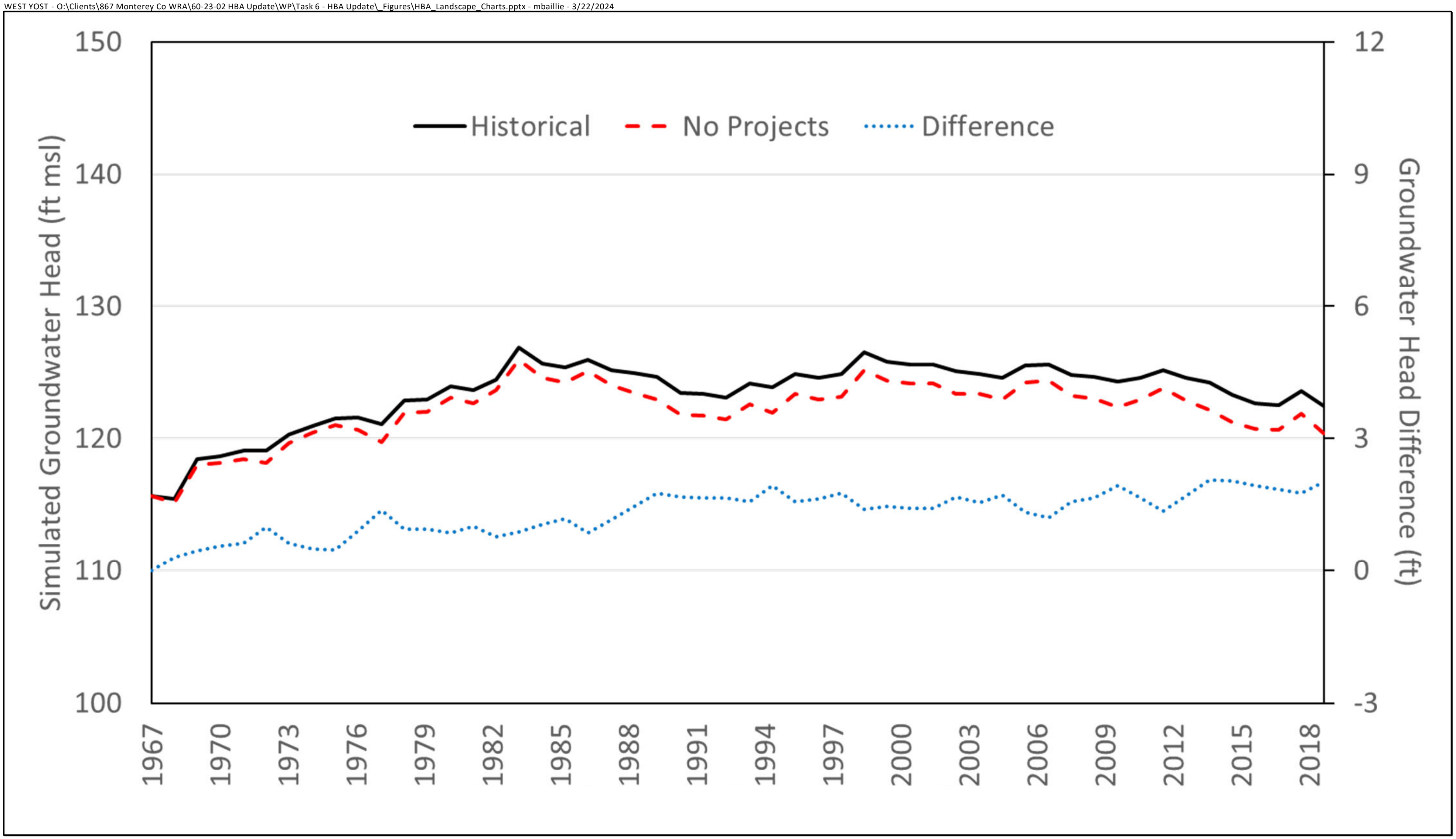

Notes:

1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20h

Average End-of-Year Groundwater Head in ESU-8, Historical and No Projects Scenarios

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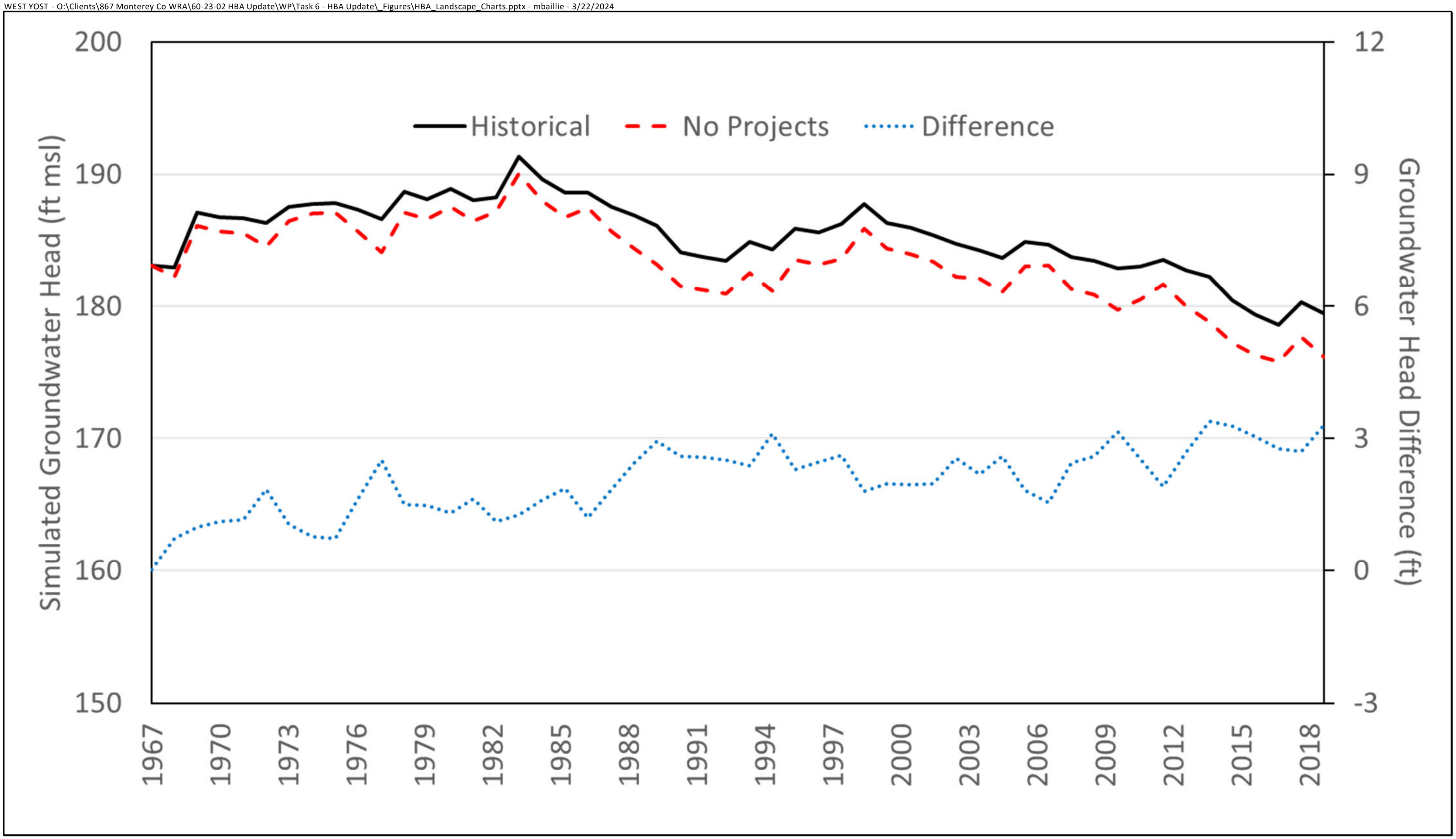

Notes:

1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20i

Average End-of-Year Groundwater Head in ESU-9, Historical and No Projects Scenarios

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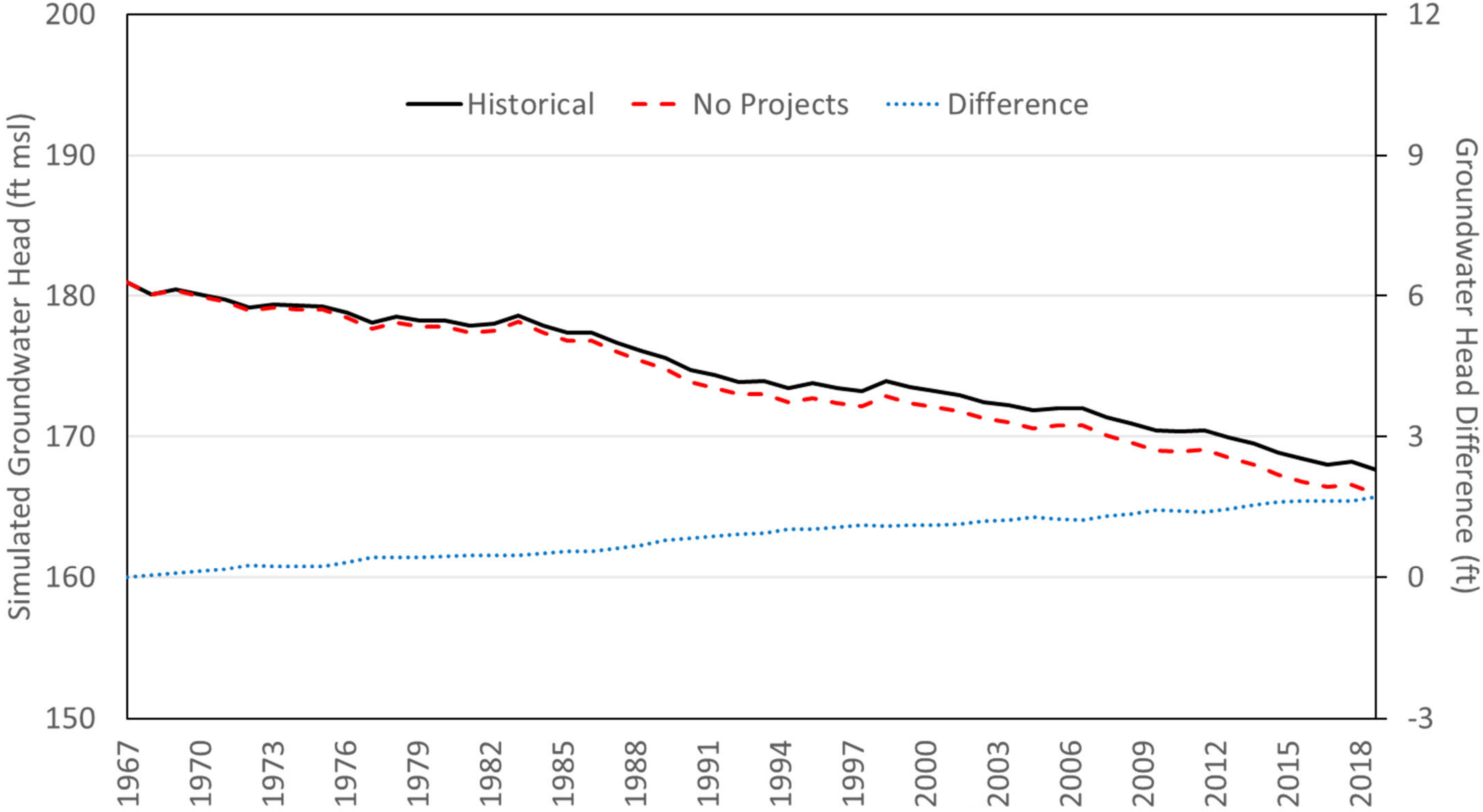

Notes:
1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20j

Average End-of-Year Groundwater Head in ESU-10, Historical and No Projects Scenarios

Monterey County Water Resources Agency
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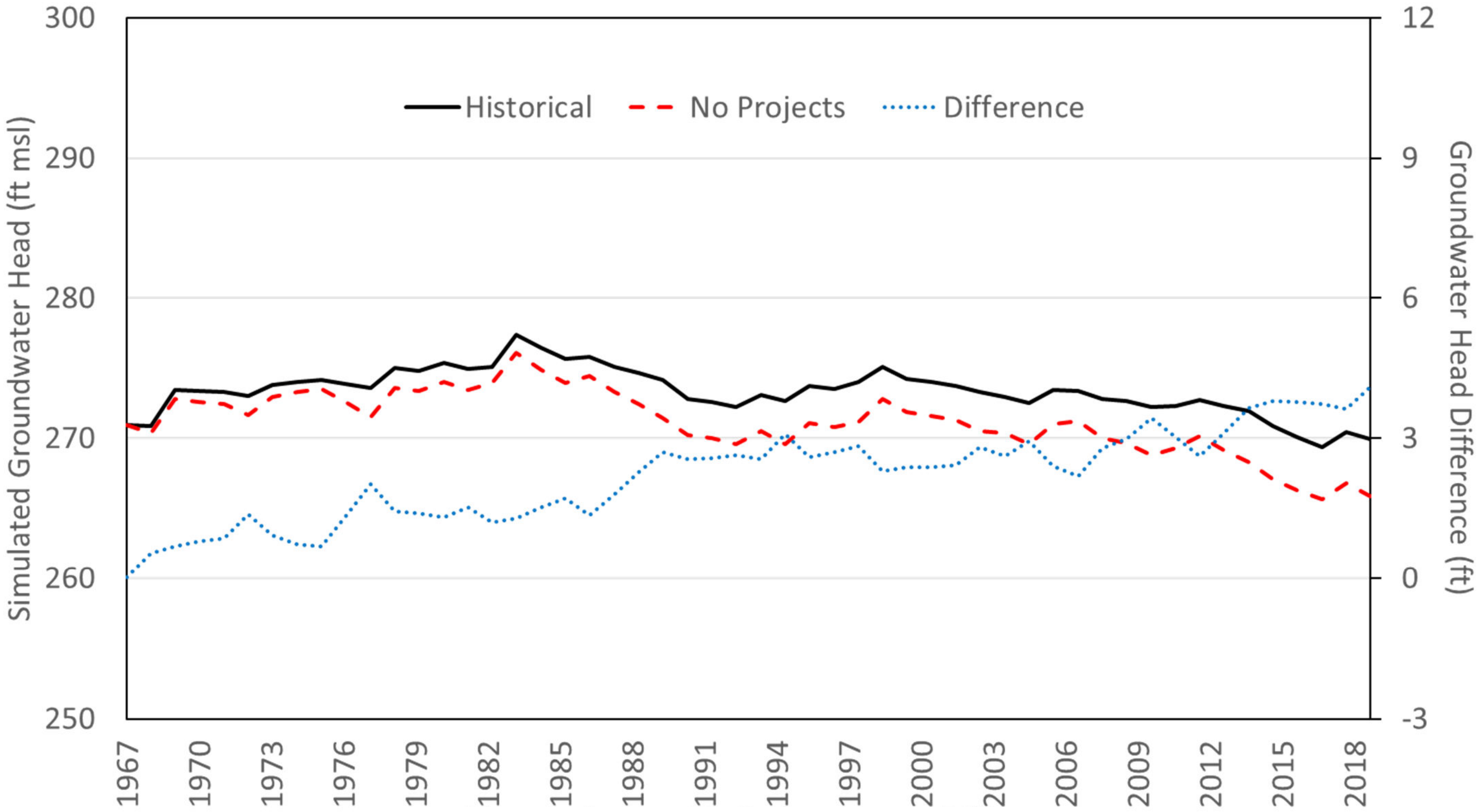

Notes:
1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20k

Average End-of-Year Groundwater Head in ESU-11, Historical and No Projects Scenarios

Monterey County Water Resources Agency
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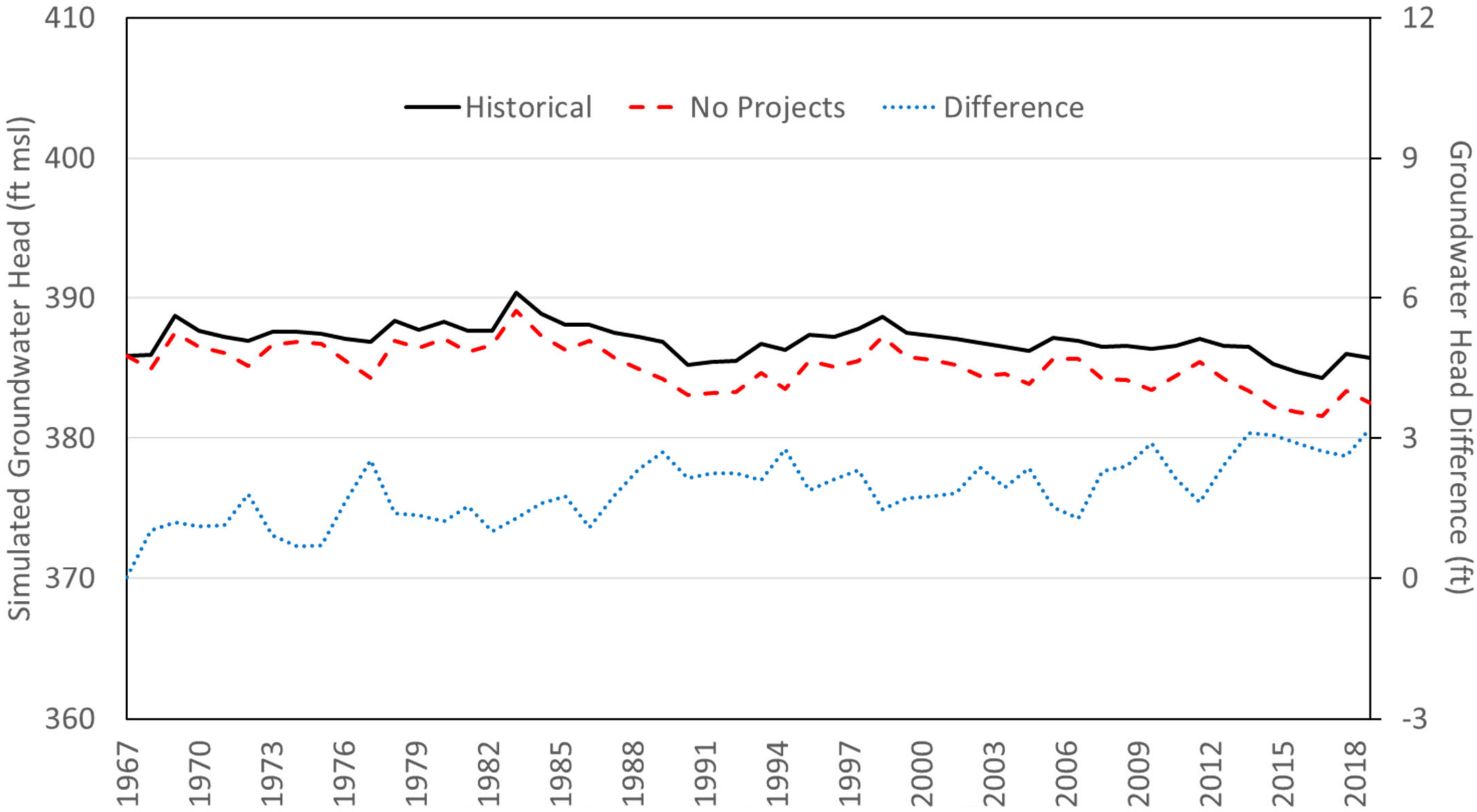

Notes:
1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20l

Average End-of-Year Groundwater Head in ESU-12, Historical and No Projects Scenarios

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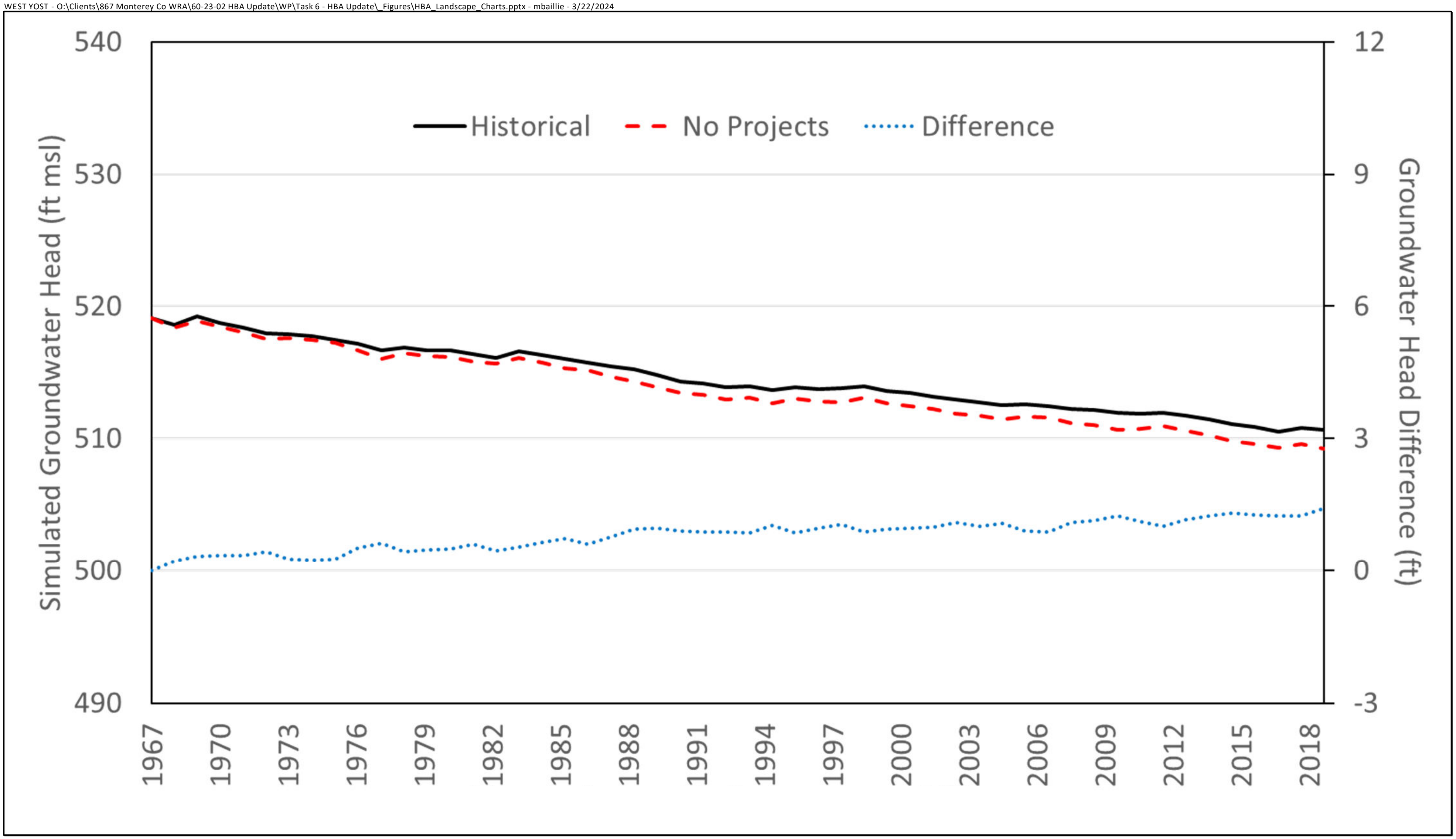

Notes:
1. Average annual head changes are presented for Model Layer 3 only, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer in other Subareas
2. ft = feet; ft msl = feet above mean sea level

Figure 3-20m

Average End-of-Year Groundwater Head in ESU-13, Historical and No Projects Scenarios

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Table 3-1. Annual Average Head Change (in ft) by ESU, Historical and No Projects Scenarios												
	Historical Scenario				No Projects Scenario				Difference Between Scenarios			
ESU	All Years	Wet Years	Normal Years	Dry Years	All Years	Wet Years	Normal Years	Dry Years	All Years	Wet Years	Normal Years	Dry Years
1	+0.08	+0.25	+0.08	-0.05	+0.08	+0.25	+0.08	-0.06	0.00	0.00	+0.01	+0.01
2	-0.54	+0.44	-0.66	-1.17	-0.68	+0.38	-0.90	-1.24	+0.14	+0.07	+0.24	+0.07
3	-0.56	+1.21	-0.84	-1.63	-0.78	+1.19	-1.18	-1.82	+0.21	+0.02	+0.34	+0.19
4	-0.03	+0.23	-0.06	-0.20	-0.05	+0.24	-0.08	-0.22	+0.02	-0.01	+0.03	+0.03
5	-0.21	+0.38	-0.23	-0.68	-0.23	+0.38	-0.24	-0.72	+0.02	0.00	+0.02	+0.04
6	-0.28	+3.08	-0.76	-2.36	-0.31	+3.12	-0.67	-2.60	+0.03	-0.03	-0.09	+0.25
7	-0.26	+1.52	-0.39	-1.52	-0.30	+1.74	-0.44	-1.75	+0.04	-0.22	+0.04	+0.23
8	+0.13	+1.21	-0.11	-0.40	+0.09	+1.41	-0.17	-0.62	+0.04	-0.20	+0.06	+0.21
9	-0.07	+1.40	-0.48	-0.71	-0.14	+1.85	-0.58	-1.14	+0.06	-0.45	+0.10	+0.43
10	-0.26	+0.19	-0.33	-0.54	-0.29	+0.19	-0.36	-0.60	+0.03	0.00	+0.03	+0.06
11	-0.02	+0.97	-0.28	-0.46	-0.10	+1.25	-0.37	-0.82	+0.08	-0.28	+0.09	+0.36
12	0.00	+1.05	-0.36	-0.36	-0.07	+1.52	-0.47	-0.81	+0.06	-0.47	+0.10	+0.44
13	-0.17	+0.12	-0.24	-0.29	-0.19	+0.19	-0.27	-0.39	+0.03	-0.07	+0.03	+0.10

Note:

- Simulated head changes in this table are for Model Layer 3, which represents the 180-Foot Aquifer in the Pressure Subarea, the East Side Shallow Aquifer in the East Side Subarea, and the undifferentiated aquifer elsewhere.

These figures show the effect of the Projects on groundwater head in the different parts of the study area. For all 13 ESUs, the Projects result in higher head throughout the model duration, with the largest head differences mostly occurring at the end of the modeling period. (Negative head differences, indicating higher head without the Projects, are present, but they are small in magnitude and very isolated in time.) In general, the ESUs can be grouped into broad categories based on their responses to the Projects. The northernmost ESUs (1 through 4) show little to no response to the Projects until the CSIP system comes online in 1998, then a steady increase in the head difference between scenarios is seen over the remainder of the model period. By the end of the simulation period, this area shows the largest overall difference between the Scenarios, with an average difference of about 11 feet in ESU 3. The response in the remaining ESUs (5 through 13) is largely governed by conditions in the Salinas River. The difference between the scenarios is smaller in these ESUs (about 4 feet or less) compared to the northernmost ESUs, and increases over the entire model duration, indicating that the reservoirs are most important to head conditions in these ESUs.

3.3 GROUNDWATER BUDGETS

The groundwater budget is the basic accounting tool for the movement of water into and out of a groundwater basin. It quantifies groundwater inflows and outflows and changes in groundwater storage. This section discusses groundwater budgets for the study area, detailing various portions of it for the Historical and No Projects Scenarios, as well as the difference between the scenarios. This discussion focuses on changes in storage, recharge, streamflow losses, and seawater intrusion.

3.3.1 Development of Groundwater Budget Equation

A groundwater budget can be formulated in various ways, depending on the goal of the analysis and the data available. A very basic groundwater budget may be written as:

$$\Delta S = Q_{in} - Q_{out} \tag{3}$$

where ΔS is the change in groundwater storage, Q_{in} is the sum of all inflow components, and Q_{out} is the sum of all outflow components. If the various inflow and outflow components can be quantified separately, the groundwater budget equation can be expanded. For example:

$$\Delta S = Q_{in1} + Q_{in2} + Q_{in3} - Q_{out1} - Q_{out2} - Q_{out3} \tag{4}$$

where Q_{in1}, Q_{in2}, Q_{in3}, Q_{out1}, Q_{out2}, and Q_{out3} are various different inflow and outflow components. The detail included in a groundwater budget is a function of the amount of data available and the goal of the analysis.

The 1998 HBA categorized groundwater budget inflows and outflows as follows. Groundwater inflows were deep percolation of recharge (*DP*), stream recharge (*SR*), and groundwater inflow from adjacent basins (*BF*). The sole groundwater outflow was groundwater pumping (*GWP*). Groundwater exchange with adjacent parts of the model domain (*SF*) if a groundwater budget applied for a portion of the model (e.g., a subarea) could be either an inflow or an outflow. The 1998 HBA groundwater budget equation was represented as:

$$DFGW = DP + SR + BF \pm SF - GWP \tag{5}$$

where *DFGW* is the change in fresh groundwater storage. Seawater intrusion was not included in this equation because the equation only deals with fresh groundwater inflows and outflows, not the aquifer as a whole. A calculation of total storage change would need to incorporate the amount of seawater intrusion.

For this HBA Update, we follow the approach of the 1998 HBA, but with an increased number of groundwater budget components. The groundwater budget equation for the HBA Update is represented as:

$$\Delta S_F = Q_R + Q_S - Q_{MI} - Q_{Ag} - Q_{Dr} + Q_{Pas} + Q_{Paj} \tag{6}$$

where ΔS_F is the change in fresh groundwater storage, Q_R is net recharge, Q_S is net groundwater-surface water flux, Q_{MI} is municipal and industrial groundwater pumping, Q_{Ag} is agricultural pumping, Q_{Dr} is net discharge to drains, Q_{Pas} is net groundwater inflow from the Paso Robles Basin, and Q_{Paj} is net groundwater inflow from the Pajaro Basin. As with the groundwater budget formulation used in the 1998 HBA, this equation implicitly incorporates the effect of seawater intrusion. To explicitly incorporate seawater intrusion, the above equation can be modified as follows:

$$\Delta S = Q_R + Q_S - Q_{MI} - Q_{Ag} - Q_{Dr} + Q_{Pas} + Q_{Paj} + SWI \tag{7}$$

where ΔS is the change in overall groundwater storage and SWI is seawater intrusion. Combining these two equations:

$$\Delta S_F = \Delta S - SWI \tag{8}$$

ΔS can be thought of as the change in overall groundwater storage that is reflected by changes to groundwater head. In settings where seawater intrusion is a concern, seawater entering freshwater aquifers maintains higher head values in the aquifer as compared to a situation where the coast is a no-flow boundary. *SWI* then represents a loss of fresh groundwater storage (hence minus *SWI* in Equation 8) because it replaces fresh groundwater in storage with seawater. Therefore, the change in fresh groundwater is equal to the change in storage reflected in changes to groundwater head plus the amount of seawater intrusion.

The groundwater budgets presented in this report are derived from the results of a MODFLOW-OWHM model. The general MODFLOW approach for reporting groundwater budget results groups all of the inflows together and all outflows together; any given groundwater budget component (e.g., well pumping) can have both inflow and outflow. The default groundwater budget is reported by MODFLOW as a mass balance check to demonstrate the model is conserving mass. This approach to the groundwater budget equation can be depicted as:

$$MBD = \sum Q_{in} - \sum Q_{out} \tag{9}$$

where $\sum Q_{in}$ is the sum of all groundwater inflow components, $\sum Q_{out}$ is the sum of all groundwater outflow components, and *MBD* is the mass balance difference (i.e., a quantification of the degree to which mass is conserved in the model). In this equation, the change in storage is incorporated into the sums of groundwater inflows and outflows. This means that, contrary to general hydrogeologic convention, a loss in storage is represented in the model groundwater budget as a positive number (a net inflow *from* storage). This is because the MODFLOW groundwater budget is calculated from the perspective of the groundwater flow system, and groundwater in storage is considered separate from the flow system; water entering storage is considered to be leaving the groundwater flow system and is therefore expressed as an outflow.

Expressed in the same terms as Equation 7 above, the MODFLOW groundwater budget can be expanded to:

$$MBD = Q_R + Q_S - Q_{MI} - Q_{Ag} - Q_{Dr} + Q_{Pas} + Q_{Paj} + SWI - \Delta S \qquad (10)$$

In terms of the change in fresh groundwater storage,

$$\Delta S_F = Q_R + Q_S - Q_{MI} - Q_{Ag} - Q_{Dr} + Q_{Pas} + Q_{Paj} - MBD \qquad (11)$$

This groundwater budget equation is the basis for discussions of groundwater inflows, outflows, and changes in storage in this report.

One other important matter to understand regarding the groundwater budgets presented in this report is the expression of recharge. MODFLOW-OWHM relies on a specialized module for MODFLOW called the Farm Process (FMP). FMP simulates dynamic crop demand based on climate data inputs, and the satisfaction of that demand by various sources of available water (Schmid et al., 2006). One source is groundwater in situations where the crop root zone intersects the water table. This use of groundwater by crops is quantified in the water budget as *negative recharge*. If this use is larger than the flux of groundwater downward past the root zone, the net recharge can be less than zero. This situation is not the norm throughout the Basin, but can occur in certain places at certain times.

3.3.2 Model Domain Groundwater Budget

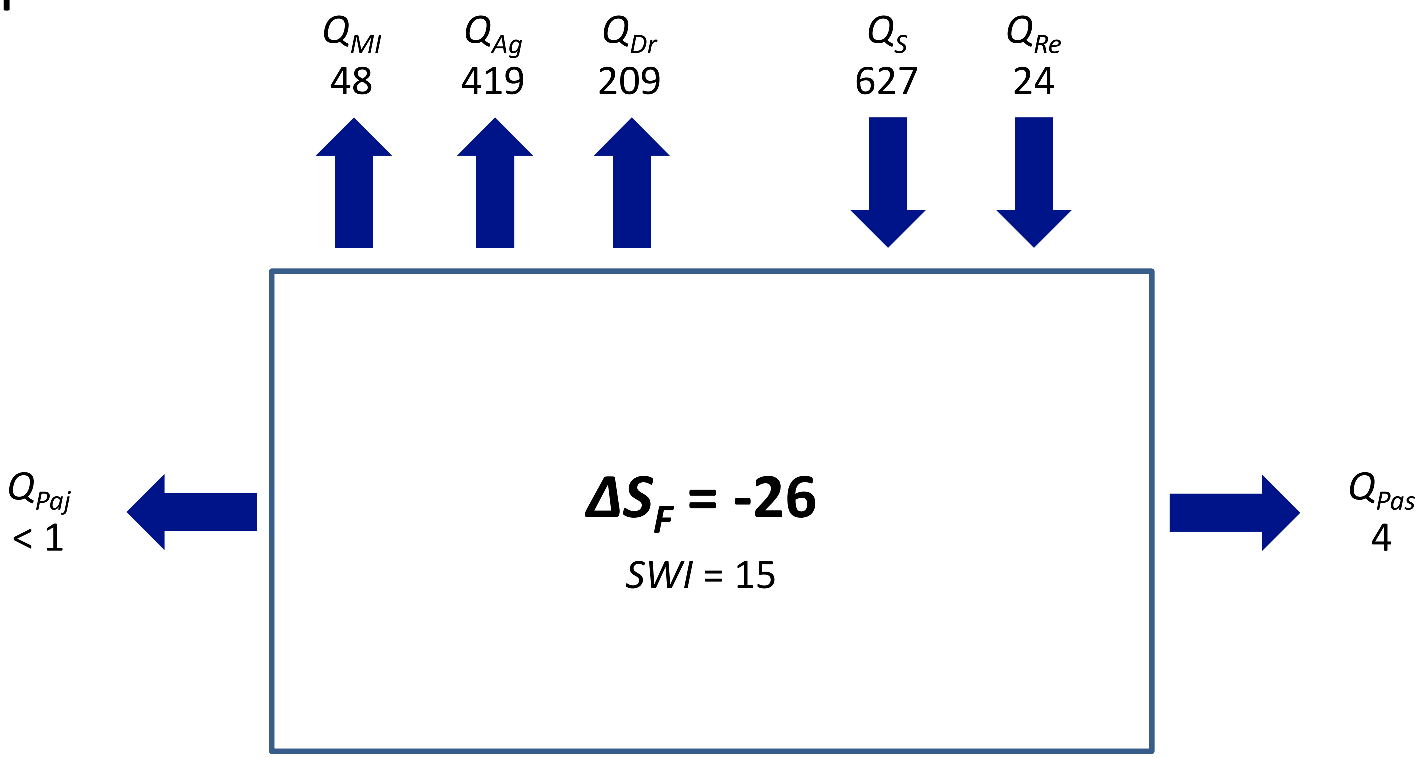
The average annual groundwater budget for the entire model domain for the Historical Scenario is shown as Figure 3-21; the budget for the No Projects Scenario is shown as Figure 3-22. The difference in groundwater budget components is shown as Figure 3-23. The tabulated groundwater budget is presented in Table 3- 2. Groundwater budget components depicted in these and other figures are rounded to the nearest 1,000 afy; depicted averages may not sum exactly due to this rounding. As noted in Chapter 2, the difference shown is equal to the Historical Scenario groundwater budget component minus the No Projects Scenario groundwater budget component. A positive difference indicates that the magnitude of the groundwater flux was greater under the Historical Scenario.

The model results indicate that the Basin experienced under the Historical Scenario (as compared to the No Projects Scenario) about 72,000 afy more groundwater-surface flux, about 45,000 afy more discharge to drains, about 14,000 afy less net recharge, about 10,000 afy less agricultural pumping, and about 20,000 afy less storage loss. Seawater intrusion is simulated to be about 1,000 afy less (seawater intrusion is discussed in more detail in Section 3.6). Changes to other groundwater budget components are not significant in magnitude.

Historical Scenario

Area: **Entire Model Domain**

Year Type: **All**



MBD = -4

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- SWI = Seawater Intrusion
- MBD = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.

Figure 3-21

Average Annual Groundwater Budget, Historical Scenario

Monterey County Water Resources Agency

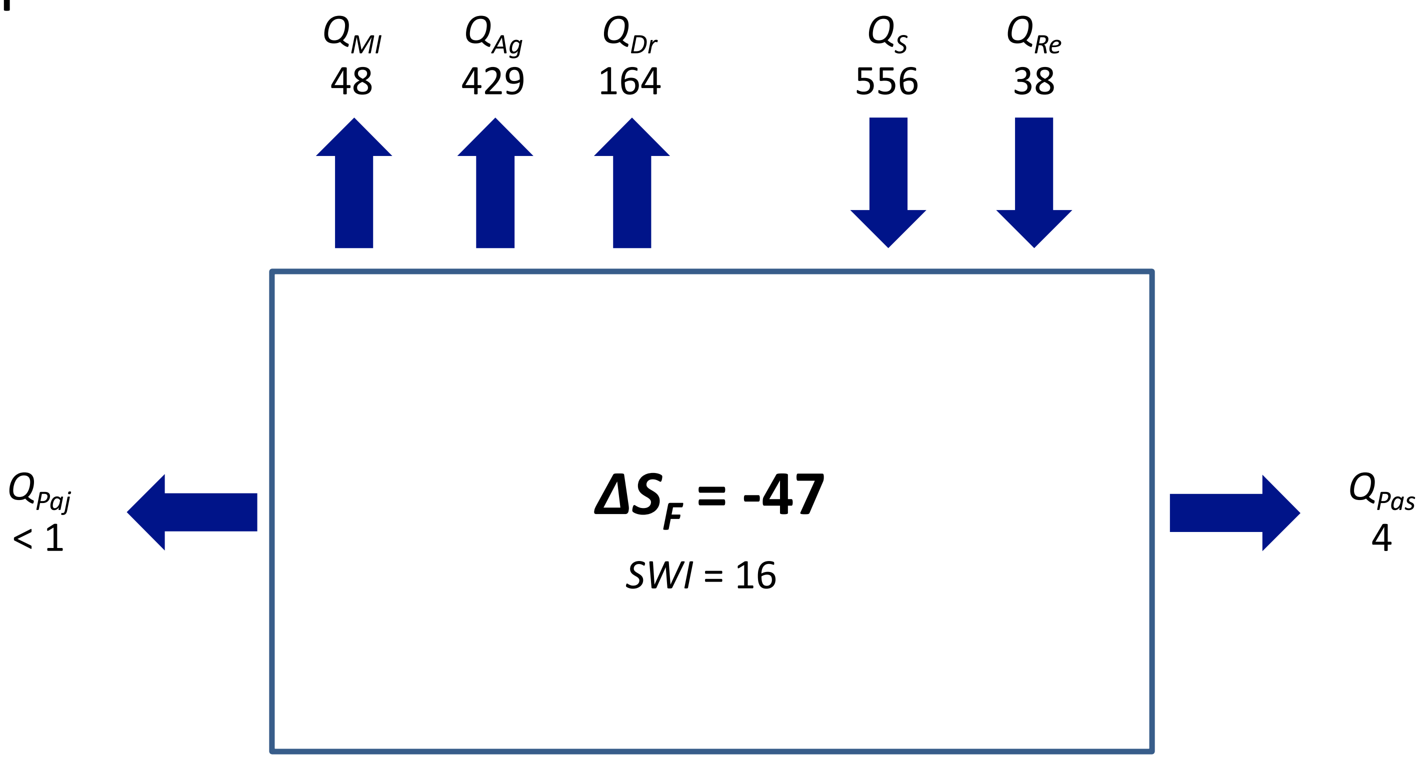
Historical Benefits Analysis Update

April 2025

No Projects Scenario

Area: **Entire Model Domain**

Year Type: **All**



MBD = -5

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- *SWI* = Seawater Intrusion
- *MBD* = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.

Figure 3-22

Average Annual Groundwater Budget, No Projects Scenario

Monterey County Water Resources Agency

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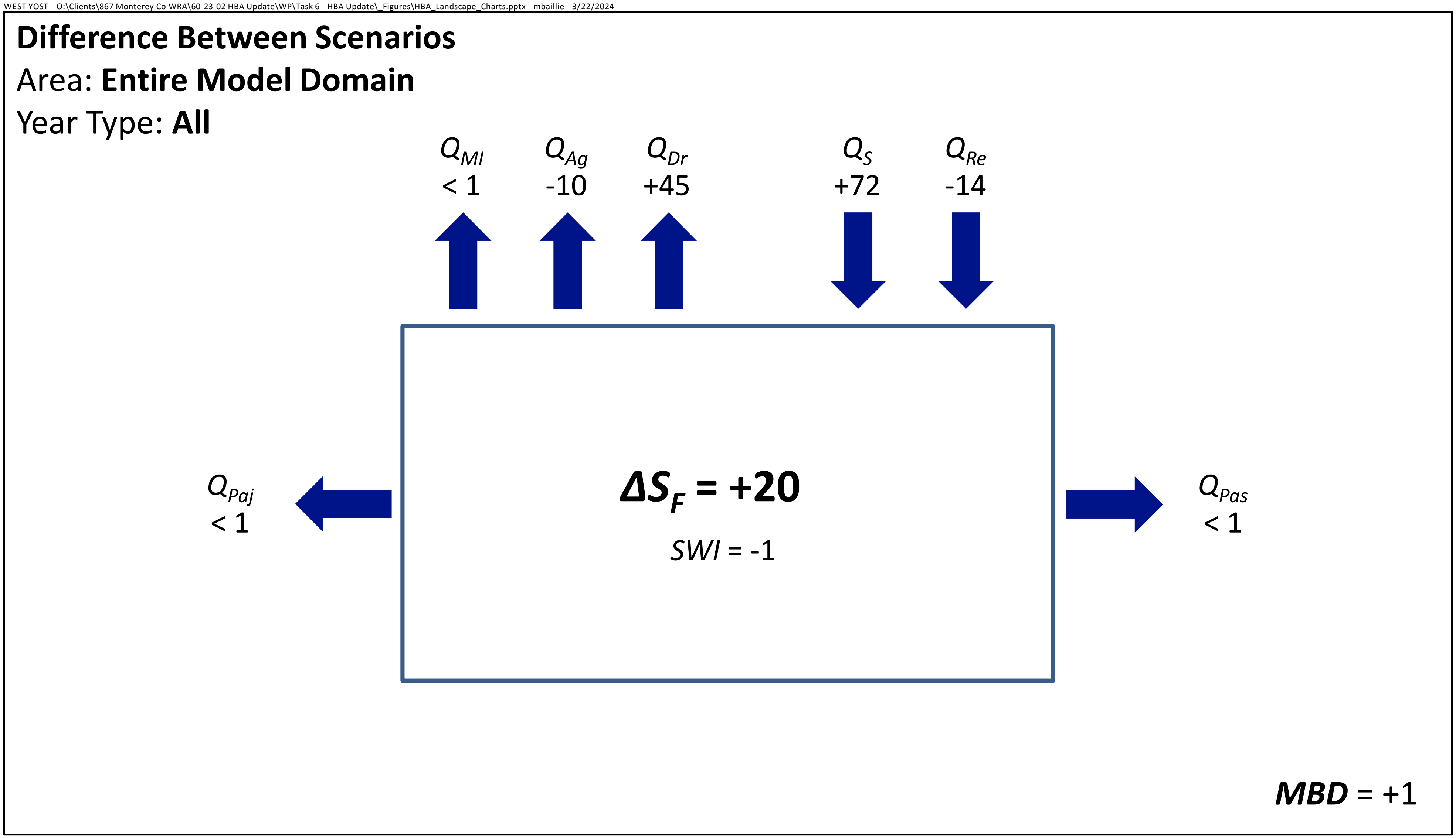

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- *SWI* = Seawater Intrusion
- *MBD* = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-23

Average Annual Groundwater Budget, Difference Between Scenarios

Monterey County Water Resources Agency
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Table 3-2. Average Annual Groundwater Budget for Historical and No Projects Scenario, and Difference Between Scenarios (in afy)

Groundwater Budget Component		Historical Scenario	No Projects Scenario	Difference
Inflows	Net Recharge	24,000	38,000	-14,000
	GW/SW Flux	627,000	556,000	+72,000
	GW Exchange with Ocean	15,000	16,000	-1,000
	Total In	**666,000**	**610,000**	**+56,000**
Outflows	M&I Pumping	48,000	48,000	< 1,000
	Ag Pumping	419,000	429,000	-10,000
	Drains	209,000	164,000	+45,000
	GW Exchange with Pajaro Basin	< 1,000	< 1,000	< 1,000
	GW Exchange with Paso Robles Basin	4,000	4,000	< 1,000
	Total Out	**680,000**	**645,000**	**+35,000**
Change in Storage		**-11,000**	**-31,000**	**+20,000**
Mass Balance Difference		**-4,000**	**-5,000**	**+1,000**

Notes:
- Groundwater budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

The increase in groundwater-surface water flux mostly results from increased normal- and dry-year stream losses in the southern portion of the study area. Increased drain discharge and reduced net recharge result from higher groundwater head values in this same southern area. Reduced agricultural pumping occurs in various parts of the study area. The reduced storage loss is also distributed across the study area, although it is most substantial in the south. The reduced seawater intrusion is focused in the coastal area. The spatial and temporal distribution of changes between the scenarios is discussed more fully in Section 3.3.4.

Additional insight can be gained by considering average annual groundwater budgets for different year types. The categorization of year types is discussed briefly in Section 3.2.1; water year type categories used here are wet, normal, and dry.

Figures 3-24, 3-25, and 3-26 provide the average annual wet-year groundwater budgets for the Historical Scenario, No Projects Scenario, and difference between scenarios, respectively. Table 3-3 presents this groundwater budget information in a tabular format. During wet years, substantially more water moves through the system compared to the average for all years. This includes increased streamflow losses, more recharge, and more discharge to drains. Agricultural pumping is smaller in wet years because of increased availability of precipitation to supply crop demands. Overall, the average wet year sees a substantial increase in fresh groundwater storage. The difference between scenarios during the average wet year is generally similar (less net recharge, less agricultural pumping, and more drain discharge under the Historical Scenario compared to the No Projects Scenario), but there is about 37,000 afy less streamflow loss and about 75,000 afy less increase in storage under the Historical Scenario than in the No Projects Scenario. This reflects the fact the reservoirs capture high flows during wet years that otherwise would have flowed down the Salinas River; some amount of this flow would have contributed to recharging the aquifers during wet years.

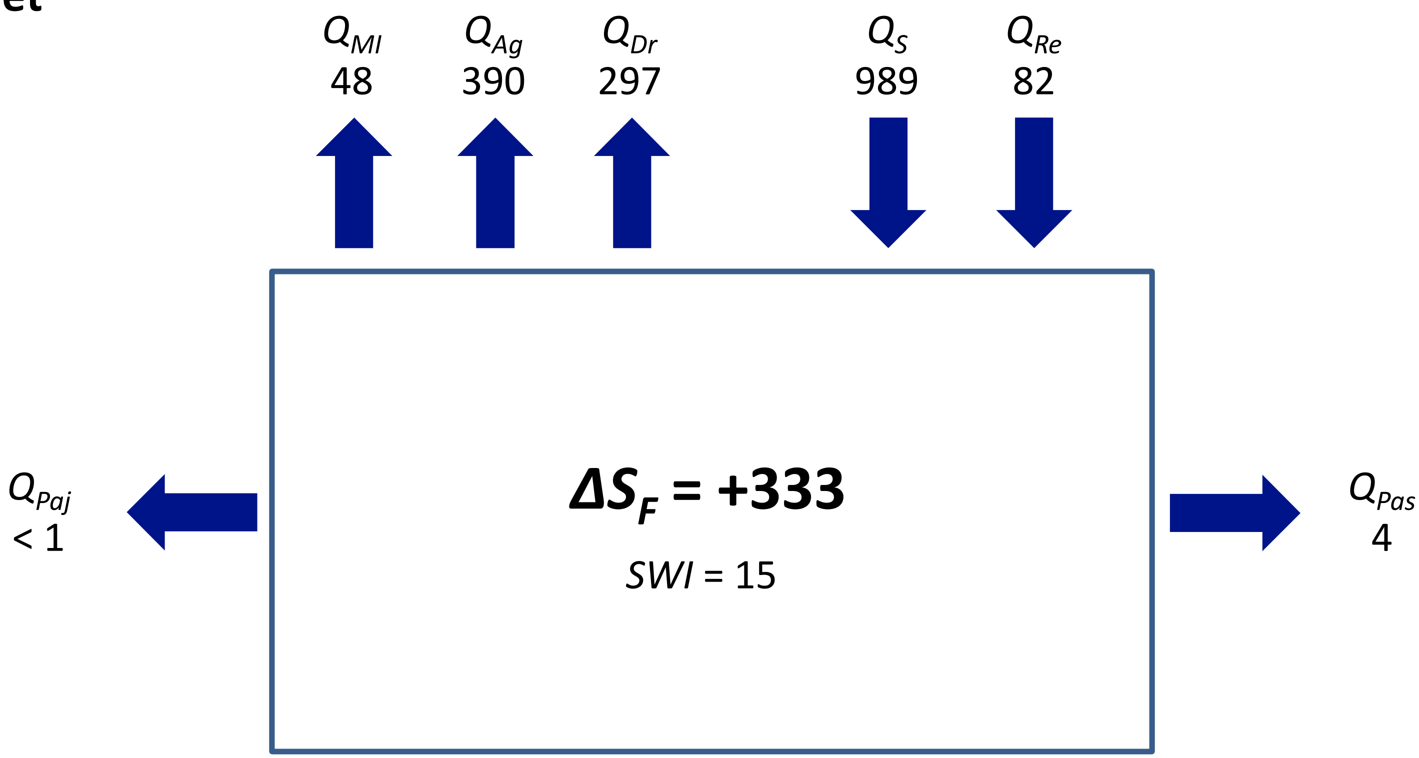
Figures 3-27, 3-28, and 3-29 provide the average annual normal-year groundwater budgets for the Historical Scenario, No Projects Scenario, and difference between scenarios, respectively. Table 3-4 presents this groundwater budget information in a tabular format. Overall, the average normal-year groundwater budget is similar to the average groundwater budget for all years, except that the loss of fresh groundwater storage is much higher. This reflects the fact that the average annual groundwater storage loss for all years is biased by very large storage gains during wet years.

Figures 3-30, 3-31, and 3-32 provide the average annual dry-year groundwater budgets for the Historical Scenario, No Projects Scenario, and difference between scenarios, respectively. Table 3-5 presents this groundwater budget information in a tabular format. During dry years, there is less water moving through the system compared to other year types. Stream loss, recharge, and discharge to drains are all smaller. The differences between the Historical and No Projects Scenarios demonstrate that the effect of the Projects is greatest during dry years. Stream losses are about 159,000 afy higher under the Historical Scenario compared to the No Projects Scenario. Although some amount of this increased stream leakage ends up discharging to drains (about 57,000 afy higher under the Historical Scenario), much of it contributes to replenishment of fresh groundwater storage (about 90,000 afy higher under the Historical Scenario). This demonstrates the ability of the reservoirs to continue supporting flow in the Salinas River and recharge of hydraulicly connected aquifers during dry years.

Historical Scenario

Area: **Entire Model Domain**

Year Type: **Wet**



MBD = -2

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- SWI = Seawater Intrusion
- MBD = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.

Figure 3-24

Average Annual Wet-Year Groundwater Budget, Historical Scenario

Monterey County Water Resources Agency

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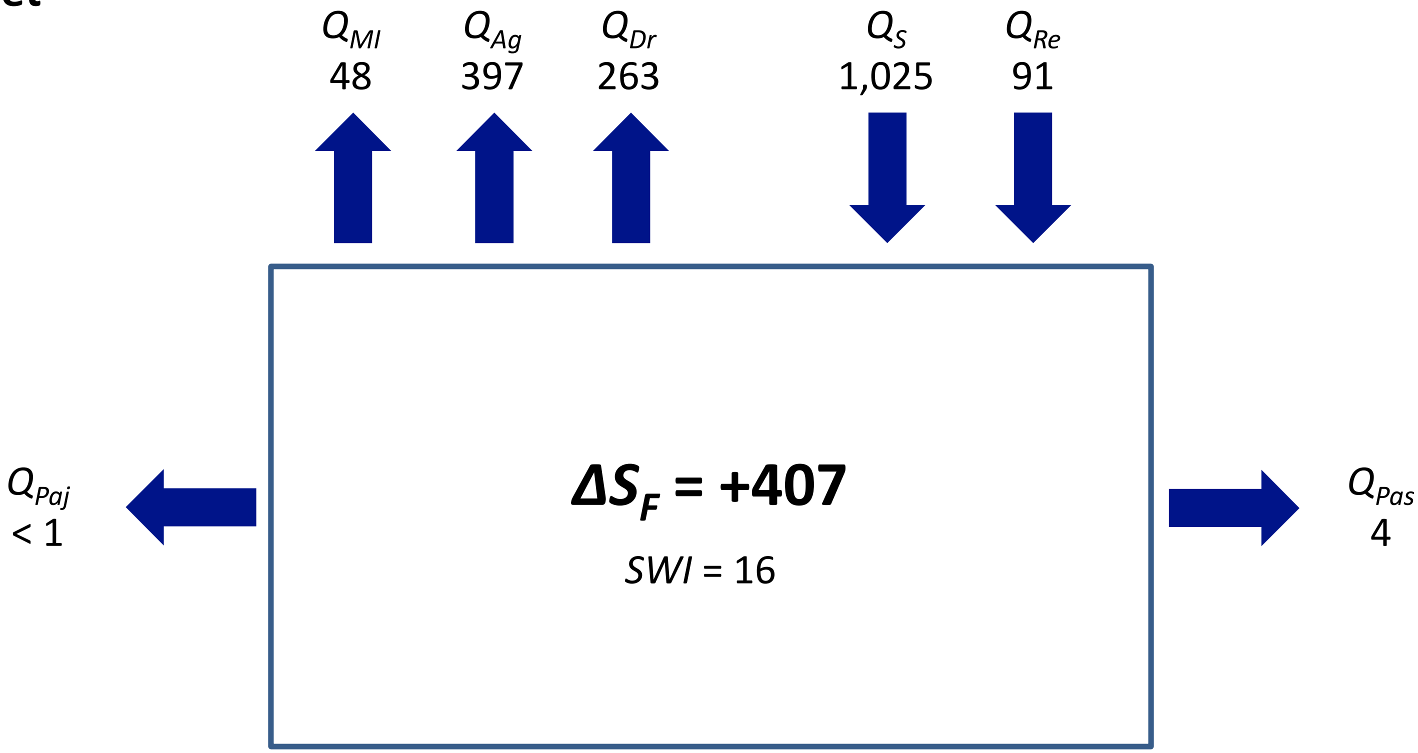
No Projects Scenario

Area: **Entire Model Domain**

Year Type: **Wet**



MBD = -2

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- *SWI* = Seawater Intrusion
- *MBD* = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.

Figure 3-25

Average Annual Wet-Year Groundwater Budget, No Projects Scenario

Monterey County Water Resources Agency

Historical Benefits Analysis Update

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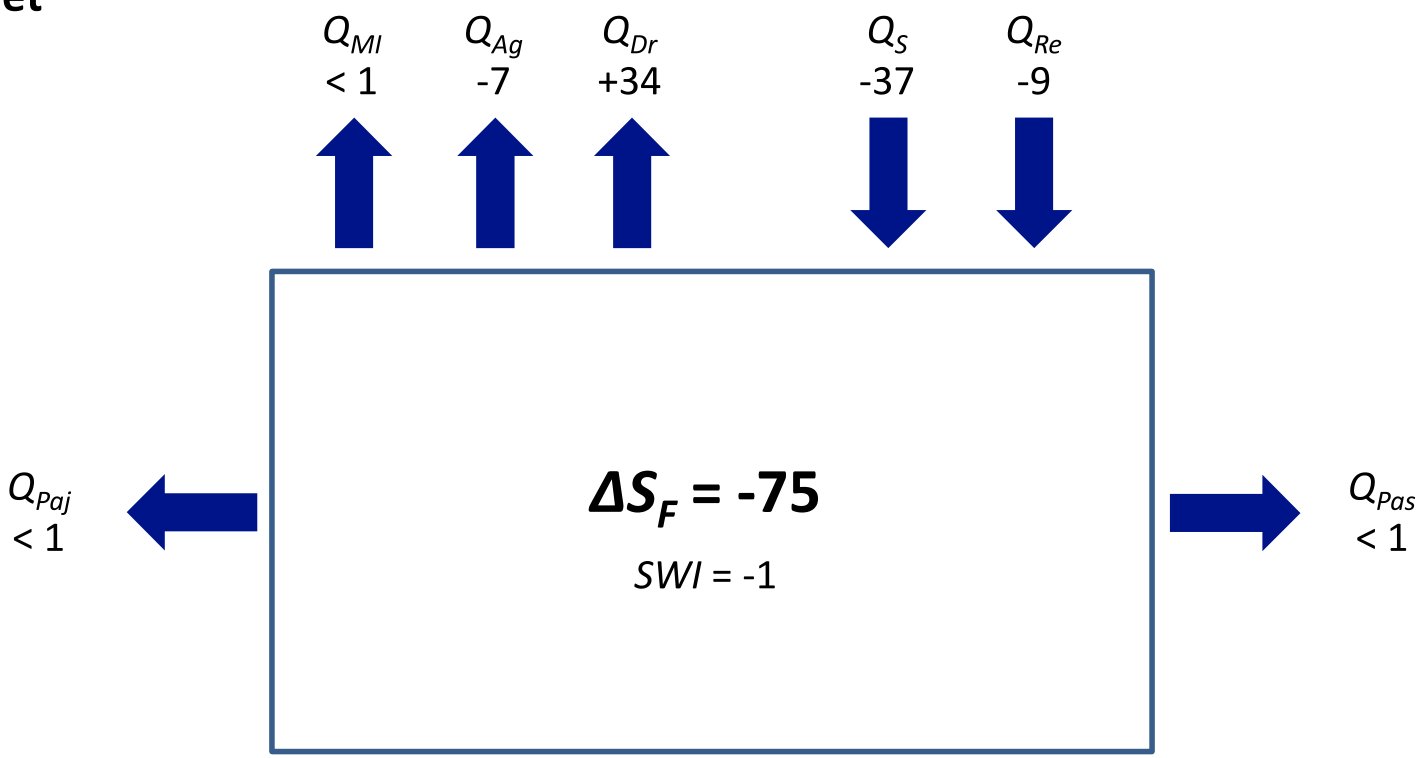
Difference Between Scenarios

Area: **Entire Model Domain**

Year Type: **Wet**



MBD = +1

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- *SWI* = Seawater Intrusion
- *MBD* = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

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Figure 3-26

Average Annual Wet-Year Groundwater Budget, Difference Between Scenarios

Monterey County Water Resources Agency

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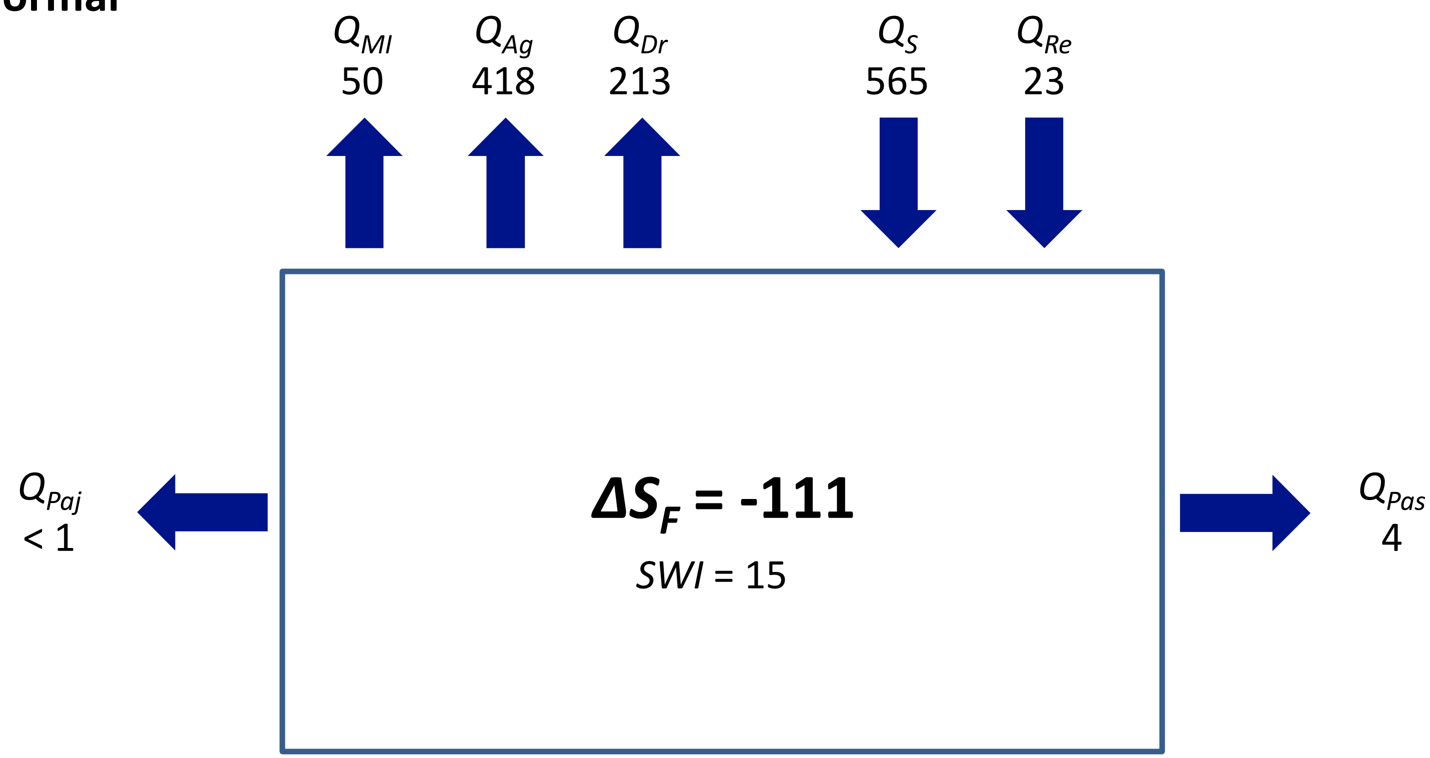
Historical Scenario

Area: **Entire Model Domain**

Year Type: **Normal**



MBD = -4

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- SWI = Seawater Intrusion
- MBD = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.

Figure 3-27

Average Annual Normal-Year Groundwater Budget, Historical Scenario

Monterey County Water Resources Agency

Historical Benefits Analysis Update

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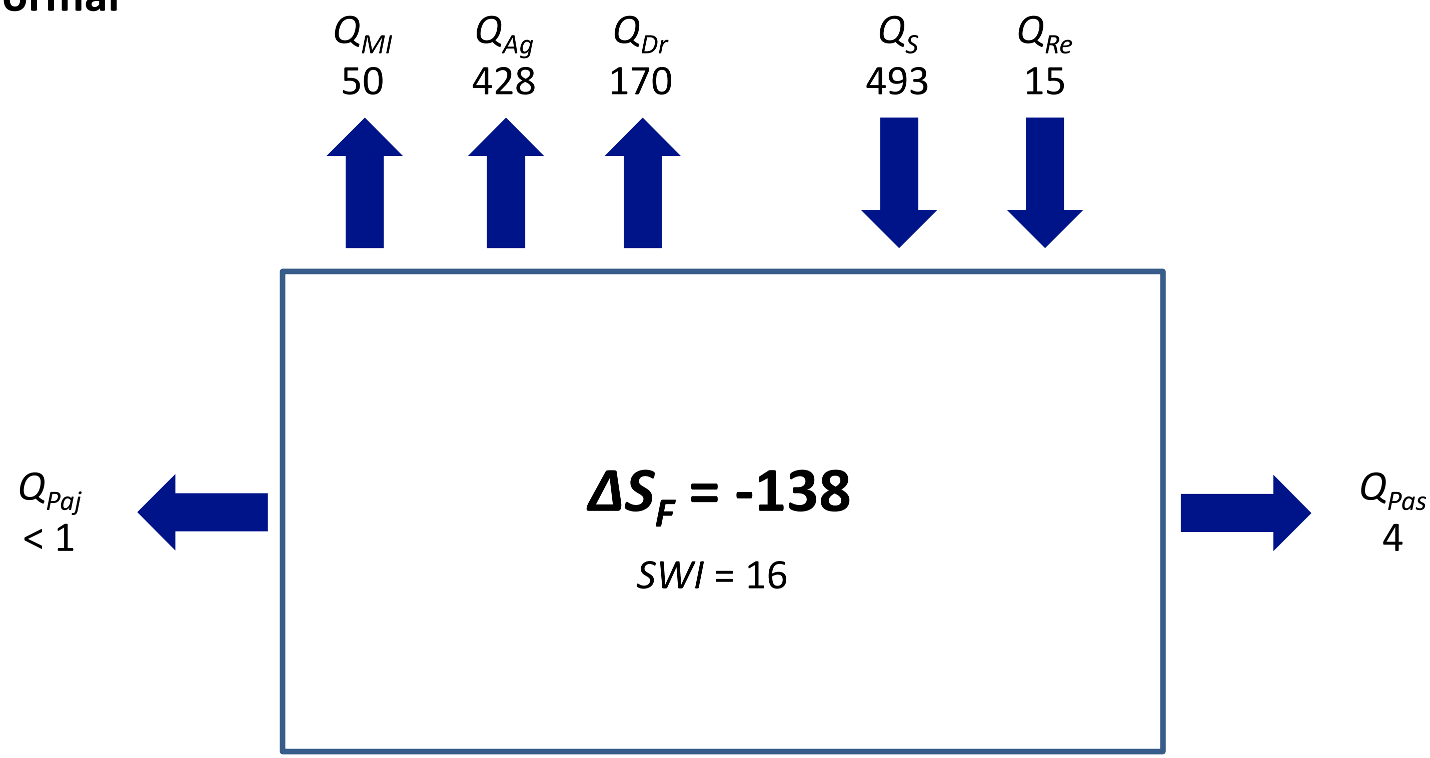
No Projects Scenario

Area: **Entire Model Domain**

Year Type: **Normal**



MBD < 1

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- *SWI* = Seawater Intrusion
- *MBD* = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.

Figure 3-28

Average Annual Normal-Year Groundwater Budget, No Projects Scenario

Monterey County Water Resources Agency

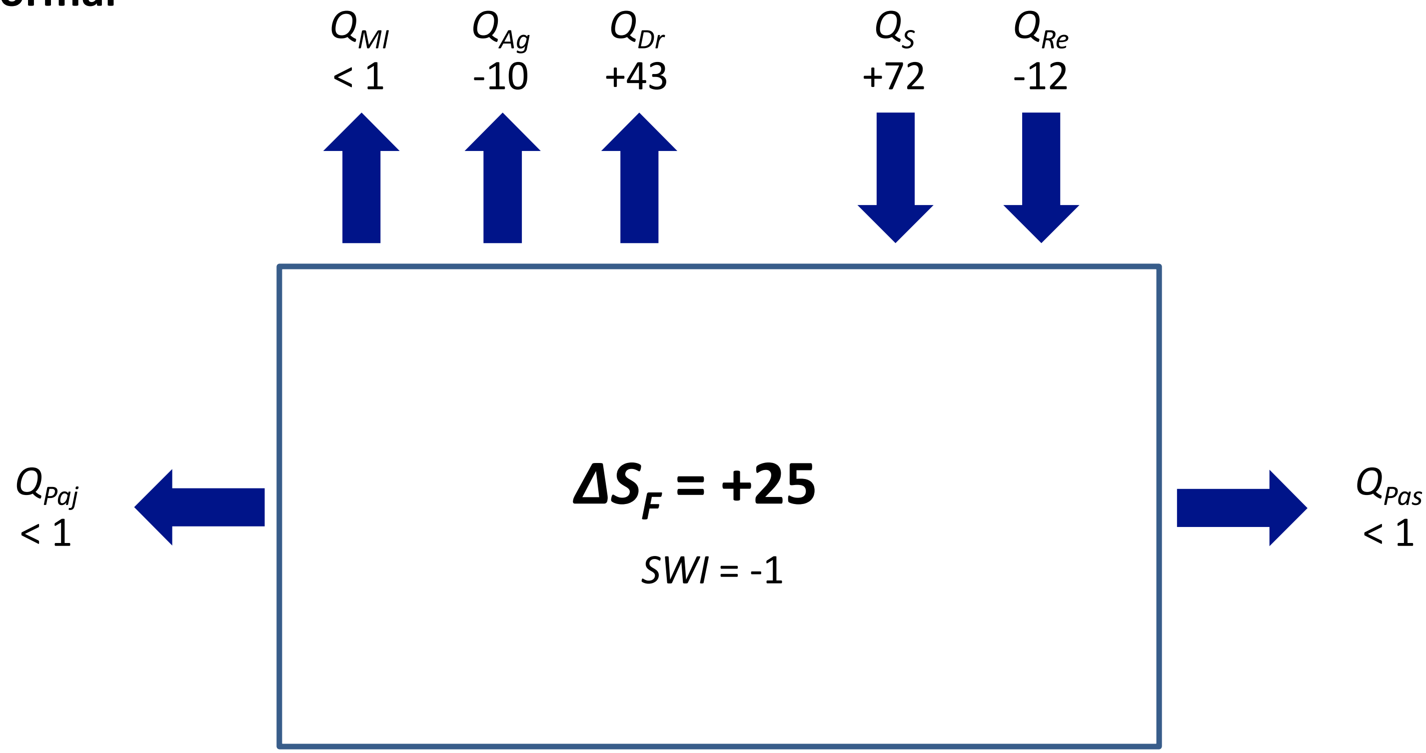
Historical Benefits Analysis Update

April 2025

Difference Between Scenarios

Area: **Entire Model Domain**

Year Type: **Normal**



MBD = +1

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- *SWI* = Seawater Intrusion
- *MBD* = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-29

Average Annual Normal-Year Groundwater Budget, Difference Between Scenarios

Monterey County Water Resources Agency
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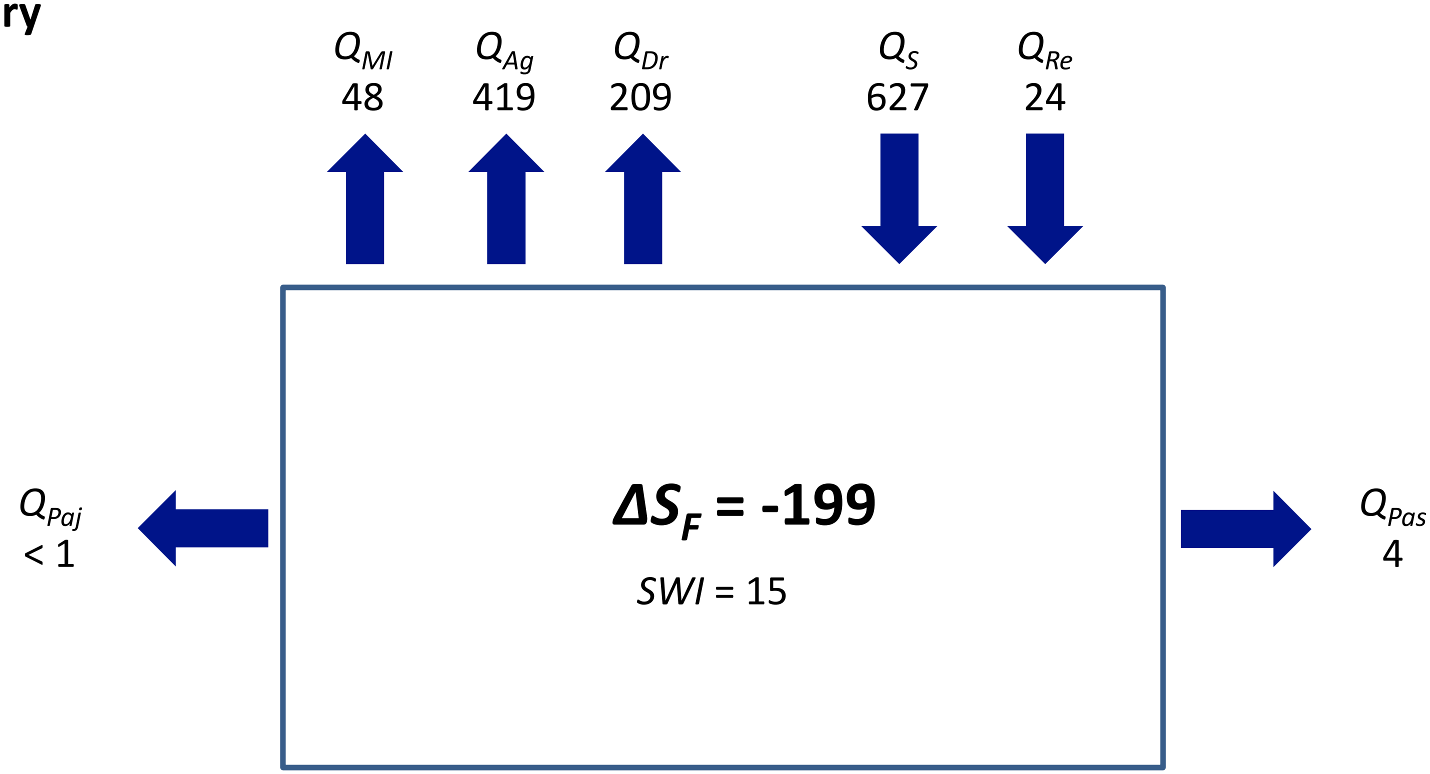
Historical Scenario

Area: **Entire Model Domain**

Year Type: **Dry**



MBD = -6

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- *SWI* = Seawater Intrusion
- *MBD* = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.

Figure 3-30

Average Annual Dry-Year Groundwater Budget, Historical Scenario

Monterey County Water Resources Agency

Historical Benefits Analysis Update

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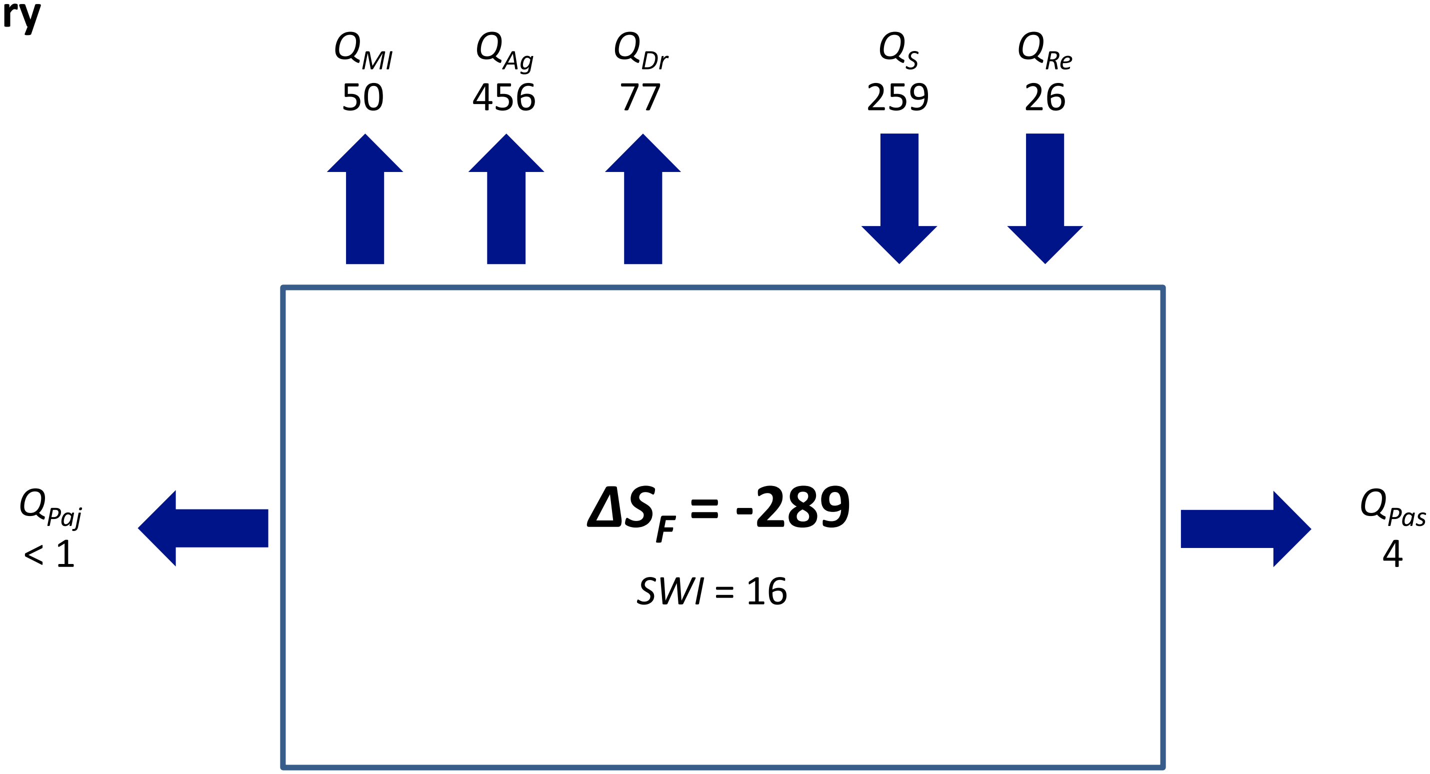
No Projects Scenario

Area: **Entire Model Domain**

Year Type: **Dry**



MBD = -7

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- *SWI* = Seawater Intrusion
- *MBD* = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.

Figure 3-31

Average Annual Dry-Year Groundwater Budget, No Projects Scenario

Monterey County Water Resources Agency

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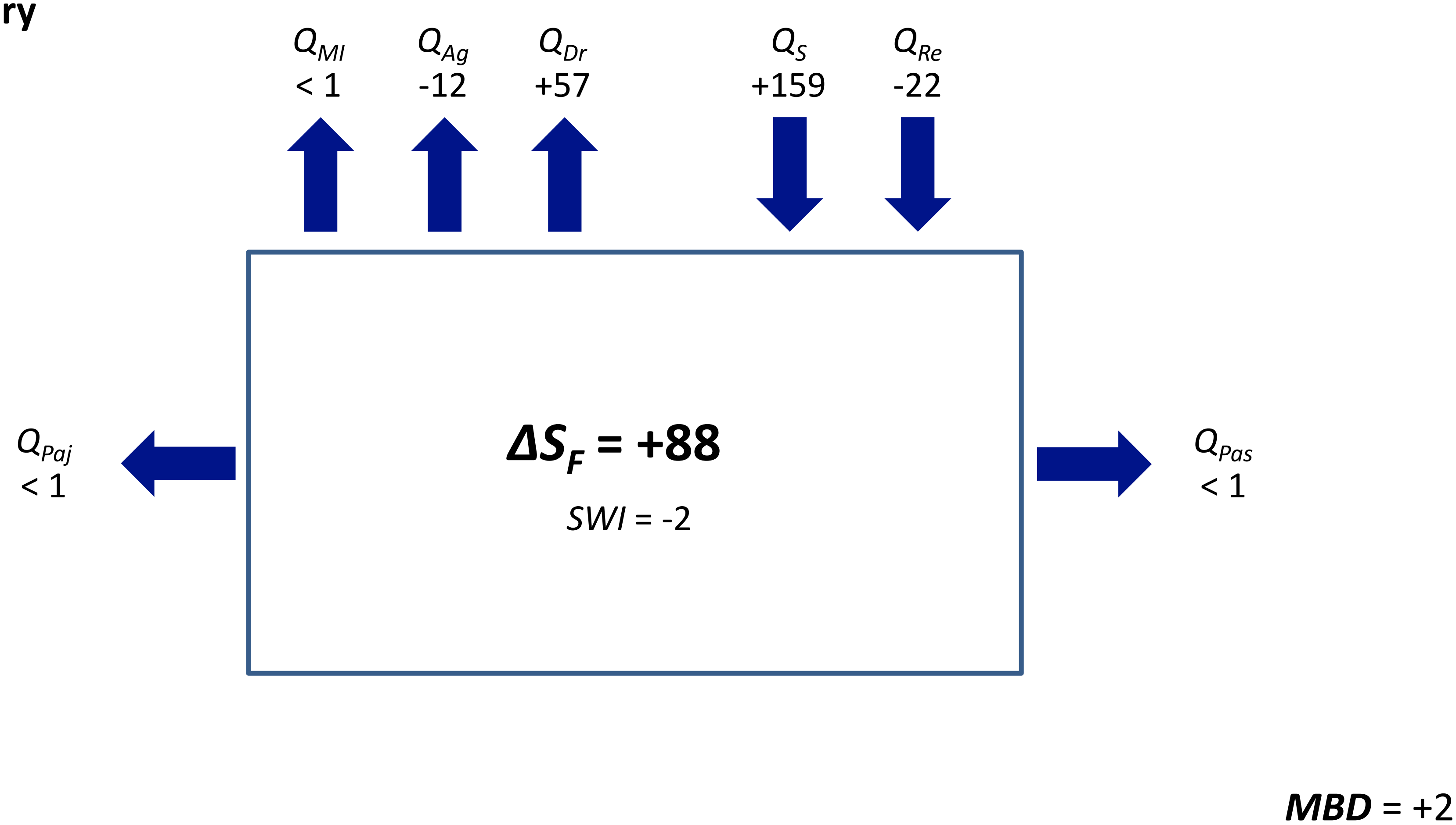
Difference Between Scenarios

Area: **Entire Model Domain**

Year Type: **Dry**



Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- SWI = Seawater Intrusion
- MBD = Mass Balance Difference

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance (denoted by *MBD*).
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-32

Average Annual Dry-Year Groundwater Budget, Difference Between Scenarios

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Table 3-3. Average Annual Wet-Year Groundwater Budget for Historical and No Projects Scenario, and Difference Between Scenarios (in afy)

	Groundwater Budget Component	Historical Scenario	No Projects Scenario	Difference
Inflows	Net Recharge	82,000	91,000	-9,000
	GW/SW Flux	989,000	1,026,000	-37,000
	GW Exchange with Ocean	15,000	16,000	-1,000
	Total In	**1,086,000**	**1,132,000**	**-46,000**
Outflows	M&I Pumping	48,000	48,000	< 1,000
	Ag Pumping	390,000	397,000	-7,000
	Drains	297,000	236,000	+34,000
	GW Exchange with Pajaro Basin	< 1,000	< 1,000	< 1,000
	GW Exchange with Paso Robles Basin	4,000	4,000	< 1,000
	Total Out	**739,000**	**712,000**	**+27,000**
Change in Storage		**348,000**	**423,000**	**-75,000**
Mass Balance Difference		**-1,000**	**-2,000**	**+1,000**

Notes:
- Groundwater budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Table 3-4. Average Annual Normal-Year Groundwater Budget for Historical and No Projects Scenario, and Difference Between Scenarios (in afy)				
Groundwater Budget Component		Historical Scenario	No Projects Scenario	Difference
Inflows	Net Recharge	3,000	15,000	-12,000
	GW/SW Flux	565,000	493,000	+72,000
	GW Exchange with Ocean	15,000	16,000	-1,000
	Total In	**538,000**	**524,000**	**+59,000**
Outflows	M&I Pumping	50,000	50,000	< 1,000
	Ag Pumping	418,000	428,000	-10,000
	Drains	213,000	170,000	+43,000
	GW Exchange with Pajaro Basin	< 1,000	< 1,000	< 1,000
	GW Exchange with Paso Robles Basin	4,000	4,000	< 1,000
	Total Out	**685,000**	**652,000**	**+33,000**
Change in Storage		**-97,000**	**-122,000**	**+25,000**
Mass Balance Difference		**-4,000**	**-5,000**	**+1,000**

Notes:
- Groundwater budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Table 3-5. Average Annual Dry-Year Groundwater Budget for Historical and No Projects Scenario, and Difference Between Scenarios (in afy)				
Groundwater Budget Component		Historical Scenario	No Projects Scenario	Difference
Inflows	Net Recharge	4,000	26,000	-22,000
	GW/SW Flux	418,000	259,000	+159,000
	GW Exchange with Ocean	15,000	16,000	-2,000
	Total In	**437,000**	**302,000**	**+135,000**
Outflows	M&I Pumping	45,000	45,000	< 1,000
	Ag Pumping	444,000	456,000	-12,000
	Drains	134,000	77,000	+57,000
	GW Exchange with Pajaro Basin	< 1,000	< 1,000	< 1,000
	GW Exchange with Paso Robles Basin	4,000	3,000	< 1,000
	Total Out	**627,000**	**582,000**	**+45,000**
Change in Storage		**-184,000**	**-272,000**	**+88,000**
Mass Balance Difference		**-6,000**	**-7,000**	**+2,000**

Notes:

- Groundwater budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

3.3.3 Subarea Groundwater Budgets

Groundwater budgets for individual Zone 2C Subareas (see Figure 1-6 for the Subarea locations) provide a more detailed understanding of the impact of the Projects on groundwater conditions in the Basin. Zone 2C includes the Pressure, East Side, Arroyo Seco, Forebay, Upper Valley, and Below Dam Subareas (the Above Dam Subarea is located outside of the active model domain and is therefore excluded from all groundwater budgets). The portion of the active model domain located south of the Monterey-San Luis Obispo County Line is considered the Paso Robles Basin for these groundwater budgets. The area of the active model domain off the coast is considered the Offshore Area. Areas of the active model domain that do not fall into any of the above categories are listed as Other Non-Zone 2C Areas.

Figure 3-33 and Table 3-6 present the average annual groundwater budget for the Historical Scenario, by Zone 2C Subarea. Figure 3-34 and Table 3-7 present the average annual groundwater budget for the No Projects Scenario, by Subarea. Figure 3-35 and Table 3-8 present the differences between the Subarea groundwater budget results for the two scenarios.

As described in Section 3.3.2, the most significant differences between the Historical and No Projects Scenarios are limited to the groundwater-surface water flux, discharge to drains, net recharge, agricultural pumping, and storage change. Differences in groundwater-surface water flux, amounting to 72,000 afy, are distributed to the Pressure Subarea (about 6,000 afy), Arroyo Seco Subarea (about 1,000 afy), Forebay Subarea (about 20,000 afy), Upper Valley Subarea (about 44,000 afy), and Below Dam Subarea (about 1,000 afy). The majority of the difference being limited to the Forebay and Upper Valley Subareas reflects the strong hydraulic connection between the Salinas River and the aquifers of these Subareas.

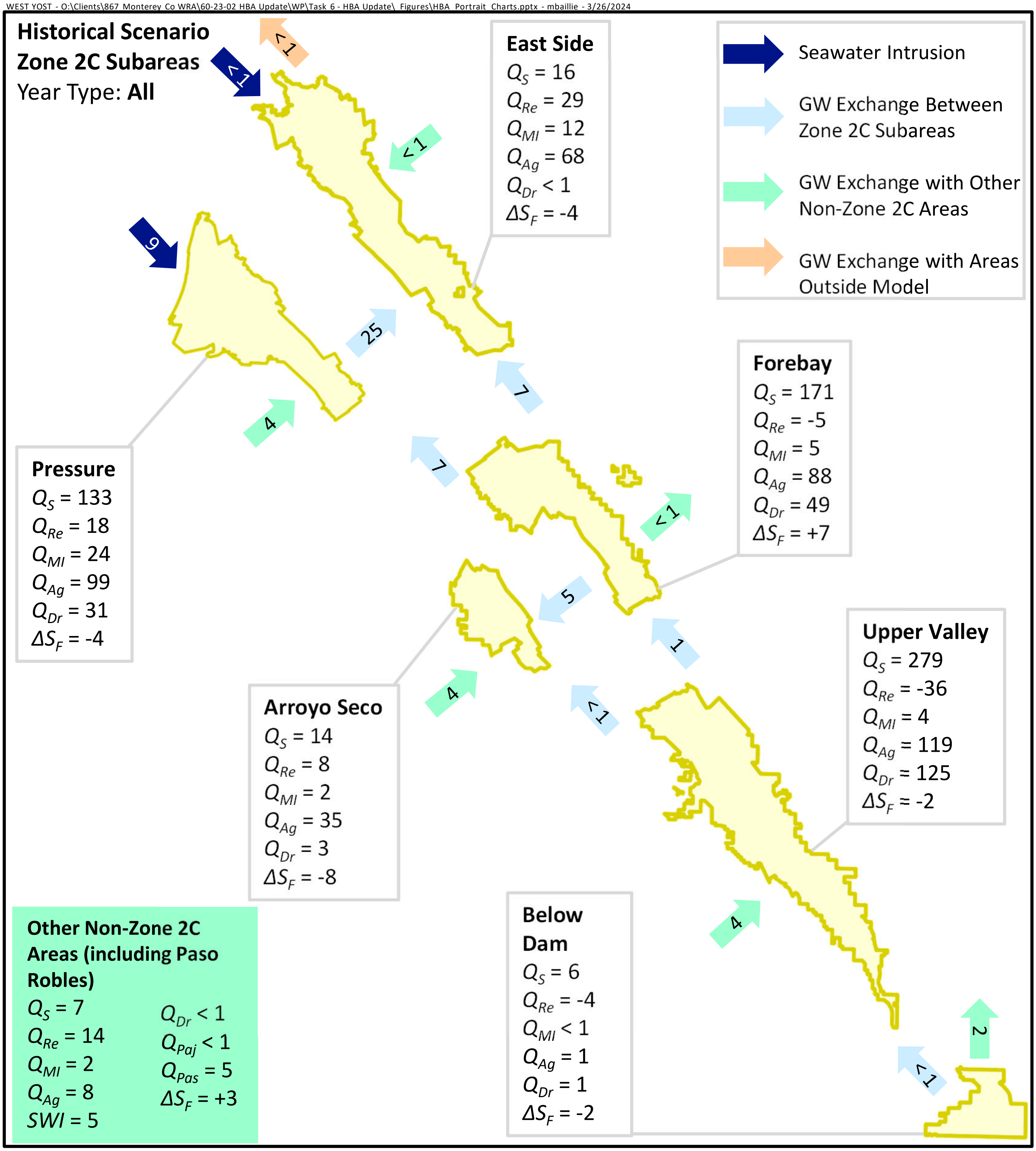
About 45,000 afy more discharge to drains was simulated under the Historical Scenario compared to the No Projects Scenario. The distribution of this difference between subareas strongly follows the difference in groundwater-surface water flux. About 3,000 afy more discharges to drains in the Pressure Subarea, about 1,000 afy more in the Arroyo Seco Subarea, about 11,000 afy more in the Forebay Subarea, and about 29,000 afy more in the Upper Valley Subarea. This indicates that the increase in drain discharge is likely to be driven by the increased groundwater-surface water flux maintaining groundwater heads closer to the elevations of the agricultural drains.

Similarly, the decrease in net recharge of about 14,000 afy under the Historical Scenario compared to the No Projects Scenario is limited to the Pressure Subarea (about 2,000 afy), Forebay Subarea (about 5,000 afy), and Upper Valley Subarea (about 7,000 afy). Average annual net recharge is negative in the Forebay, Upper Valley, and Below Dam Subareas under both scenarios, indicating that groundwater heads are close enough to the land surface in these areas to contribute significantly to the satisfaction of crop water demand.

The reduction in agricultural pumping under the Historical Scenario (about 10,000 afy) occurred in the Pressure Subarea (about 6,000 afy), Forebay Subarea (about 1,000 afy), and Upper Valley Subarea (about 2,000 afy). The SVIHM can simulate a reduction in agricultural pumping either because groundwater head in the pumping wells falls to a level where the well pump can no longer maintain the desired pumping rate, or because the irrigation demand of the crop is smaller (because, for example, the crops have increased access to groundwater within the root zone). In the Forebay and Upper Valley Subareas, the reduction in agricultural pumping is less than the decrease in net recharge (or increase in evapotranspiration of soil zone groundwater, as noted above), so increased head could explain the reduction in agricultural pumping due to reduced irrigation demand. The same is not true in the Pressure Subarea, where the reduction in agricultural pumping was larger than the decrease in net recharge. Figure 3-36 is a time series of cumulative Pressure Subarea agricultural groundwater pumping throughout the entire model duration for the Historical and No Projects Scenarios, as well as the difference between the scenarios. The difference in agricultural pumping in the Pressure Subarea is largely confined to the period from 1998 onward, indicating that the difference is likely due to the provision of recycled water and diverted surface water to the CSIP system reducing the demand for groundwater to be pumped by the agricultural wells.

Under the Historical Scenario, the model domain experiences an average annual reduction in total groundwater storage (ΔS) of about 11,000 afy, which represents the combined effect of about 15,000 afy of seawater intrusion (*SWI*) and a reduction in fresh groundwater storage (ΔS_F) of about 26,000 afy (see Equation 8; Figure 3-21). Under the No Projects Scenario, the average annual reduction in total groundwater storage (ΔS) is about 31,000 afy, which represents the combined effect of about 16,000 afy of seawater intrusion (*SWI*) and a reduction in fresh groundwater storage (ΔS_F) of about 47,000 afy (Figure 3-22); this means that the total groundwater storage loss under the Historical Scenario is about 20,000 afy less than under the No Projects Scenario (Figure 3-23). There is less storage loss (or more storage gain) simulated in every Subarea, as shown in Figure 3-35. The largest storage gain under the Historical Scenario occurs in the Upper Valley Subarea (about 8,000 afy), followed by the Pressure and Forebay Subareas (about 4,000 afy each), the East Side Subarea (about 2,000 afy), the Arroyo Seco Subarea (about 1,000 afy), other Non-Zone 2C Areas (about 1,000 afy), and the Below Dam Subarea, Paso Robles Basin, and offshore area (less than 1,000 afy each).

The reduction of about 1,000 afy of seawater intrusion simulated under the Historical Scenario compared to the No Projects Scenario is confined to the Pressure Subarea.



Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- SWI = Seawater Intrusion

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance.
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.
4. For this figure, the portion of the Paso Robles Basin within the model domain is included in the Other Non-Zone 2C Areas.
5. Net recharge can be negative if transpiration of groundwater exceeds deep percolation.
6. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-33

Average Annual Groundwater Budget by Subarea, Historical Scenario

Monterey County Water Resources Agency
Historical Benefits Analysis Update
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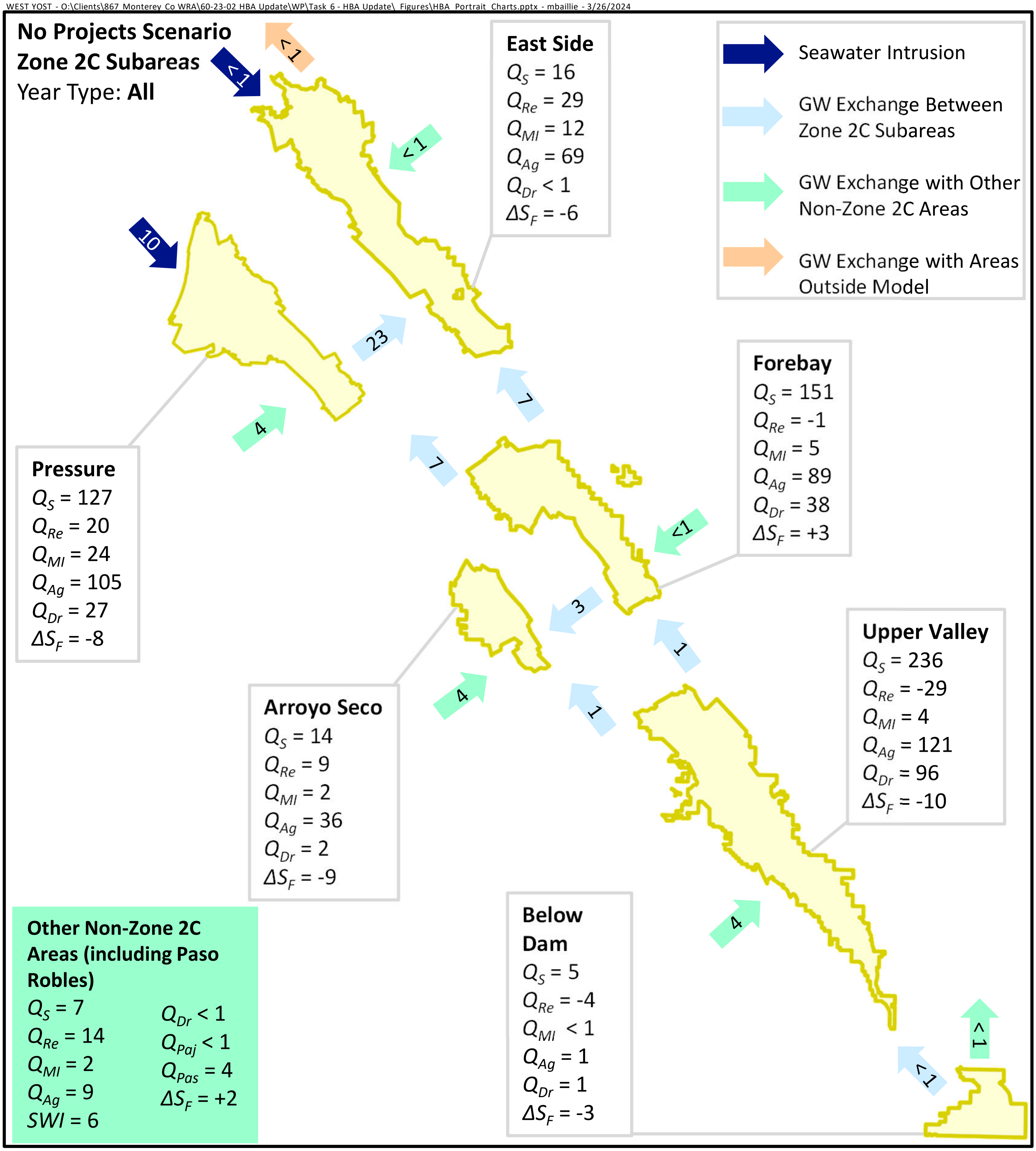

Abbreviations:

- Q_S = Groundwater-Surface Water Exchange
- Q_{MI} = Municipal & Industrial Pumping
- Q_{Ag} = Agricultural Pumping
- Q_{Dr} = Discharge to Drains
- Q_{Re} = Net Recharge
- Q_{Pas} = Groundwater Exchange with Paso Robles Basin
- Q_{Paj} = Groundwater Exchange with Pajaro Basin
- ΔS_F = Change in Fresh Groundwater Storage
- SWI = Seawater Intrusion

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance.
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.
4. For this figure, the portion of the Paso Robles Basin within the model domain is included in the Other Non-Zone 2C Areas.
5. Net recharge can be negative if transpiration of groundwater exceeds deep percolation.
6. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-34

Average Annual Groundwater Budget by Subarea, No Projects Scenario

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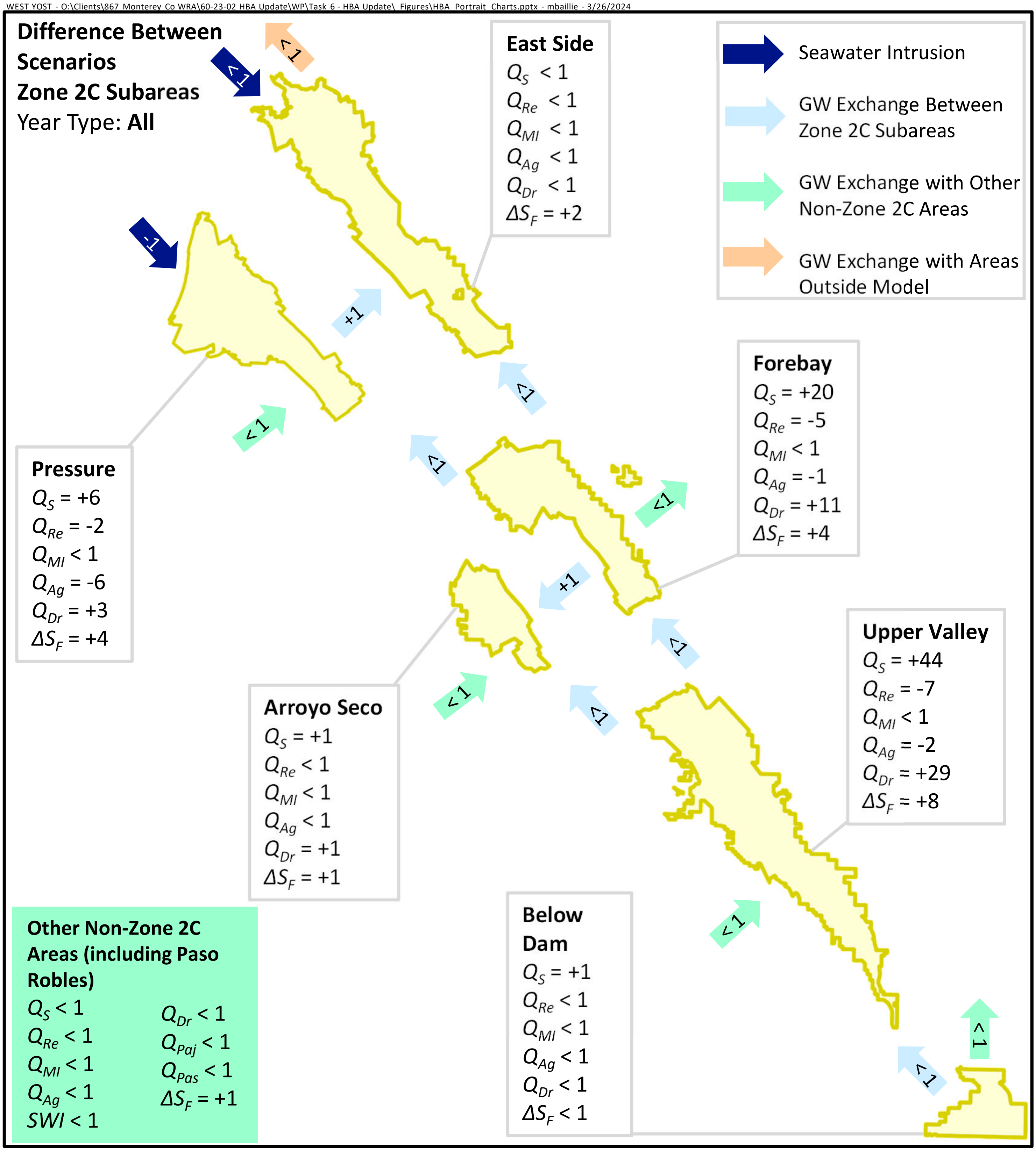

Abbreviations:

Q_S = Groundwater-Surface Water Exchange
Q_{MI} = Municipal & Industrial Pumping
Q_{Ag} = Agricultural Pumping
Q_{Dr} = Discharge to Drains
Q_{Re} = Net Recharge
Q_{Pas} = Groundwater Exchange with Paso Robles Basin
Q_{Paj} = Groundwater Exchange with Pajaro Basin
ΔS_F = Change in Fresh Groundwater Storage
SWI = Seawater Intrusion

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding and imperfect closure of the model mass balance.
2. Arrow orientation denotes direction of groundwater flow. Arrows pointing away from the box show groundwater leaving the aquifer volume under consideration. Arrows pointing toward the box show groundwater entering the aquifer volume.
3. See Section 3.3 of the text for the development of the SVIHM groundwater budget equation.
4. For this figure, the portion of the Paso Robles Basin within the model domain is included in the Other Non-Zone 2C Areas.
5. Net recharge can be negative if transpiration of groundwater exceeds deep percolation.
6. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-35

Average Annual Groundwater Budget by Subarea, Difference Between Scenarios

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025

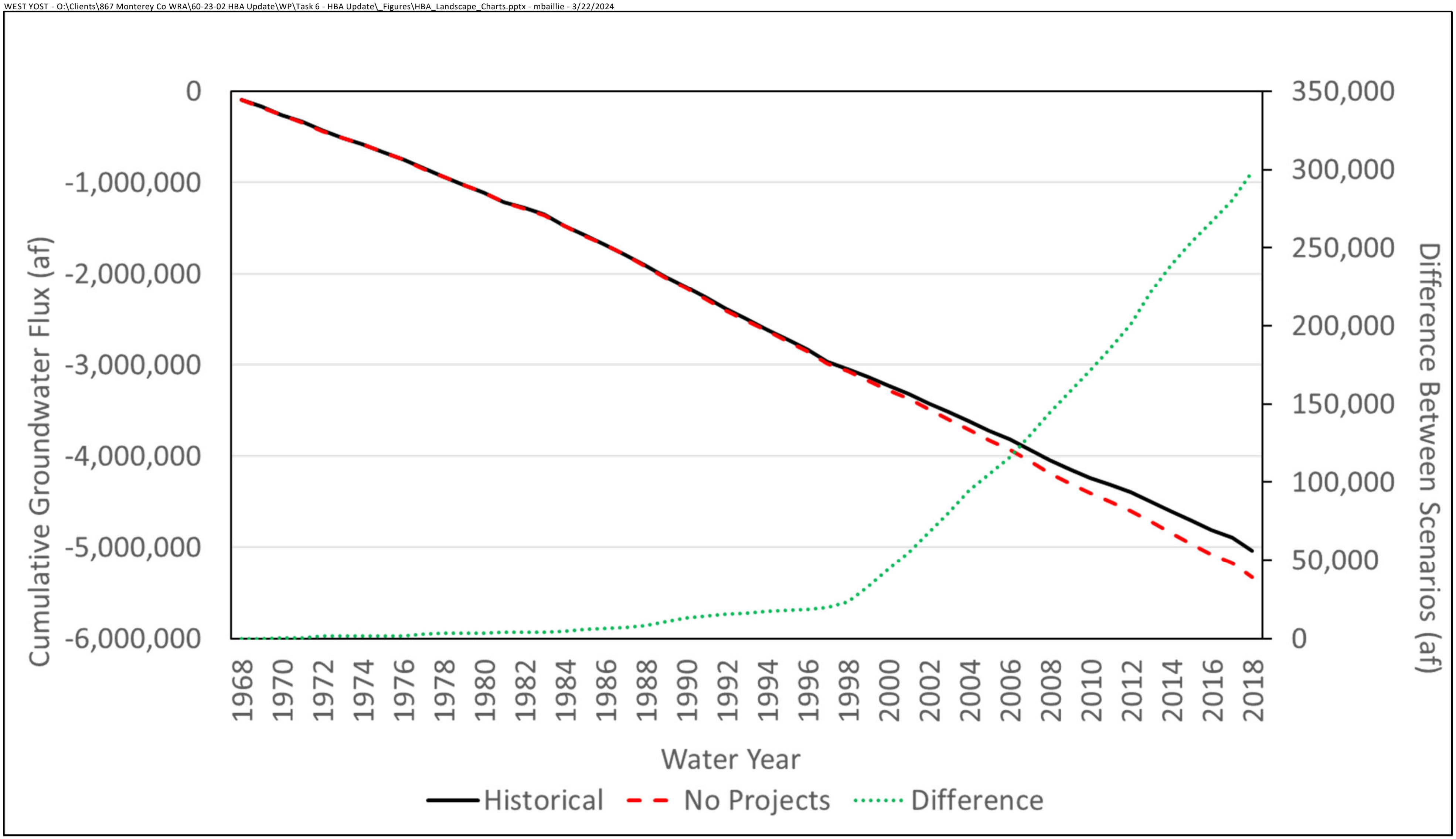

Figure 3-36

Cumulative Simulated Agricultural Pumping, Pressure Subarea

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025

Table 3-6. Average Annual Groundwater Budget by Subarea, Historical Scenario (in afy)										
	Groundwater Budget Component	Pressure	East Side	Arroyo Seco	Forebay	Upper Valley	Below Dam	Paso Robles Basin	Offshore	Other Non-Zone 2C Area
Inflows	Net Recharge	18,000	29,000	8,000	-5,000	-36,000	-4,000	1,000	0	13,000
	GW/SW Flux	133,000	16,000	14,000	171,000	279,000	6,000	1,000	0	7,000
	Seawater Intrusion	9,000	< 1,000	0	0	0	0	0	0	5,000
	GW Inflow from Other Subareas	11,000	32,000	9,000	1,000	4,000	< 1,000	1,000	0	2,000
	GW Inflow from Ocean	0	0	0	0	0	0	0	15,000	0
	Total In	**172,000**	**76,000**	**32,000**	**167,000**	**247,000**	**2,000**	**3,000**	**15,000**	**27,000**
Outflows	M&I Pumping	24,000	12,000	2,000	5,000	4,000	< 1,000	< 1,000	0	2,000
	Ag Pumping	99,000	68,000	35,000	88,000	119,000	1,000	< 1,000	0	8,000
	Drains	31,000	< 1,000	3,000	49,000	125,000	1,000	0	0	< 1,000
	GW Exchange with Pajaro Basin	0	< 1,000	0	0	0	0	0	0	< 1,000
	GW Exchange with Paso Robles Basin	0	0	0	0	0	0	4,000	0	1,000
	GW Outflow to Other Subareas	25,000	0	0	19,000	2,000	2,000	< 1,000	15,000	12,000
	Total Out	**178,000**	**81,000**	**40,000**	**161,000**	**250,000**	**4,000**	**4,000**	**15,000**	**23,000**
Change in Storage		**-4,000**	**-4,000**	**-8,000**	**+7,000**	**-2,000**	**-2,000**	**-1,000**	**< 1,000**	**+4,000**
Mass Balance Difference		**-1,000**	**< 1,000**	**< 1,000**	**-1,000**	**+1,000**	**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**

Notes:
- Groundwater budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding

Table 3-7. Average Annual Groundwater Budget by Subarea, No Project Scenario (in afy)

	Groundwater Budget Component	Pressure	East Side	Arroyo Seco	Forebay	Upper Valley	Below Dam	Paso Robles Basin	Offshore	Other Non-Zone 2C Area
Inflows	Net Recharge	20,000	29,000	9,000	-1,000	-29,000	-4,000	1,000	0	13,000
	GW/SW Flux	127,000	16,000	14,000	151,000	236,000	5,000	1,000	0	7,000
	Seawater Intrusion	10,000	< 1,000	0	0	0	0	0	0	6,000
	GW Inflow from Other Subareas	12,000	30,000	8,000	1,000	4,000	< 1,000	1,000	0	2,000
	GW Inflow from Ocean	0	0	0	0	0	0	0	16,000	0
	Total In	**169,000**	**75,000**	**30,000**	**151,000**	**211,000**	**1,000**	**3,000**	**16,000**	**27,000**
Outflows	M&I Pumping	24,000	12,000	2,000	5,000	4,000	< 1,000	< 1,000	0	2,000
	Ag Pumping	105,000	69,000	36,000	89,000	121,000	1,000	< 1,000	0	8,000
	Drains	27,000	< 1,000	2,000	38,000	96,000	1,000	0	0	< 1,000
	GW Exchange with Pajaro Basin	0	< 1,000	0	0	0	0	0	0	< 1,000
	GW Exchange with Paso Robles Basin	0	0	0	0	0	0	4,000	0	1,000
	GW Outflow to Other Subareas	23,000	0	0	17,000	2,000	2,000	< 1,000	16,000	12,000
	Total Out	**179,000**	**81,000**	**40,000**	**149,000**	**223,000**	**4,000**	**4,000**	**16,000**	**24,000**
Change in Storage		**-8,000**	**-6,000**	**-9,000**	**+3,000**	**-10,000**	**+3,000**	**-1,000**	**< 1,000**	**3,000**
Mass Balance Difference		**-1,000**	**< 1,000**	**< 1,000**	**-1,000**	**+2,000**	**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**

Notes:
- Groundwater budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding

Table 3-8. Average Annual Groundwater Budget by Subarea, Difference Between Scenarios (in afy)										
	Groundwater Budget Component	Pressure	East Side	Arroyo Seco	Forebay	Upper Valley	Below Dam	Paso Robles Basin	Offshore	Other Non-Zone 2C Area
Inflows	Net Recharge	-2,000	< 1,000	< 1,000	-5,000	-7,000	< 1,000	0	0	< 1,000
	GW/SW Flux	+6,000	< 1,000	+1,000	+20,000	+44,000	+1,000	< 1,000	0	< 1,000
	Seawater Intrusion	-1,000	< 1,000	0	0	0	0	0	0	< 1,000
	GW Inflow from Other Subareas	< 1,000	+1,000	+1,000	< 1,000	< 1,000	< 1,000	< 1,000	0	< 1,000
	GW Inflow from Ocean	0	0	0	0	0	0	0	-1,000	0
	Total In	**+3,000**	**+2,000**	**+2,000**	**+15,000**	**+36,000**	**+1,000**	**< 1,000**	**-1,000**	**< 1,000**
Outflows	M&I Pumping	< 1,000	< 1,000	< 1,000	0	0	0	0	0	0
	Ag Pumping	-6,000	< 1,000	< 1,000	-1,000	-2,000	0	0	0	< 1,000
	Drains	+3,000	< 1,000	+1,000	+11,000	+29,000	< 1,000	0	0	< 1,000
	GW Exchange with Pajaro Basin	0	< 1,000	0	0	0	0	0	0	< 1,000
	GW Exchange with Paso Robles Basin	0	0	0	0	0	0	< 1,000	0	< 1,000
	GW Outflow to Other Subareas	+1,000	0	0	+2,000	< 1,000	< 1,000	< 1,000	-1,000	-1,000
	Total Out	**-1,000**	**< 1,000**	**+1,000**	**+11,000**	**+27,000**	**< 1,000**	**< 1,000**	**-1,000**	**-1,000**
Change in Storage		**+4,000**	**+2,000**	**+1,000**	**+4,000**	**+8,000**	**< 1,000**	**< 1,000**	**< 1,000**	**+1,000**
Mass Balance Difference		**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**	**+1,000**	**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**

Notes:
- Groundwater budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

3.3.4 Groundwater Budgets Summary

This section described the results of the effects of the Projects on the simulated fluxes of groundwater into and out of the aquifers of the Basin, as well as changes in the amount of groundwater stored within those aquifers. The groundwater budget analysis shows that the reservoirs (and related projects and programs) have resulted in substantially more groundwater held in storage (about 20,000 afy). Storage increases during wet years were greatly decreased (by about 75,000 afy) under the Historical Scenario compared to the No Projects Scenario but increased during normal (about 25,000 afy) and dry (about 88,000 afy) years. The increased groundwater storage provided by the operation of the Projects is distributed around Zone 2C, but the largest amount occurs in the Upper Valley Subarea (about 8,000 afy), followed by the Pressure and Forebay Subareas (each about 4,000 afy), the East Side Subarea (about 2,000 afy), and the Arroyo Seco Subarea (about 1,000 afy).

Changes to groundwater storage represent differences between the inflows and outflows to the groundwater system; when groundwater outflows are larger than inflows, groundwater storage declines. The groundwater budget component that exhibited the largest differences between scenarios was groundwater-surface water flux. The groundwater system receives streamflow losses throughout most of the study area. The model results indicate that the Projects have resulted in an average of about 72,000 afy more streamflow losses to the groundwater system. During wet years, this flux is smaller (by about 37,000 afy) because the reservoirs store high flows during wet years. Normal years see an increase in groundwater-surface water flux of about 72,000 afy and dry years see an increase of about 159,000 afy. These differences reflect the release of stored water from the reservoirs during drier years. Changes to the groundwater-surface water flux are highest in the Upper Valley Subarea (about 44,000 afy), followed by the Forebay Subarea (about 20,000 afy), the Pressure Subarea (about 6,000 afy), and the Arroyo Seco and Below Dam Subareas (about 1,000 afy each). Other areas experienced insignificant changes to groundwater-surface water flux.

Agricultural pumping was about 10,000 afy less with the Projects than without. This difference was less sensitive to water year type compared to the changes to groundwater storage and groundwater-surface water flux. During wet years, agricultural pumping was about 7,000 afy less, compared to about 10,000 afy for normal years and 12,000 afy for dry years. The reduction in agricultural pumping was largest in the Pressure Subarea (about 6,000 afy), followed by the Upper Valley Subarea (about 2,000 afy) and Forebay Subarea (about 1,000 afy). Differences were minimal in other parts of the study area. In the Pressure Subarea, the reduction in agricultural pumping seems to be due to the operation of the CSIP system, which delivers recycled and surface water to agricultural users and thereby offsets crop groundwater demand. In the Forebay and Upper Valley Subareas, the reduction in agricultural pumping seems to result from increased groundwater head values supplying more groundwater to crop root zones, reducing the need for supplemental groundwater to satisfy crop demands.

Other changes to the groundwater budget between the scenarios were minor, or resulted directly from the changes to groundwater-surface water flux and groundwater storage. For example, drain discharge was about 45,000 afy higher with the Projects than without, due to groundwater heads that were more consistently above the elevations of the drain bottoms. Similarly, net recharge was about 14,000 afy less with the Projects than without, because higher groundwater head resulted in more use of root zone groundwater by crops (reported as negative recharge), and in additional runoff of precipitation due to saturation of the ground.

3.4 SURFACE WATER BUDGETS

This section discusses surface water budgets for the study area, detailing various portions of it for the Historical and No Projects Scenarios, as well as the difference between the scenarios. This discussion focuses on changes in streamflow losses, tributary inflow, and outflow to the Pacific Ocean.

3.4.1 Development of Surface Water Budget Equation

A water budget can be constructed for a surface water body or network in much the same way as described in Section 3.3. for groundwater. A surface water budget equation is nearly identical to the basic groundwater budget equation (Equation 3). For typical stream networks, the water budget could include difference inflow and outflow components, for example:

$$\Delta S = Q_{in} + Q_{trib} + Q_P + Q_R - Q_E - Q_T - Q_{div} - Q_{out} \pm Q_S \tag{12}$$

where Q_{in} is inflow from upstream, Q_{trib} is inflow from tributaries, Q_P is direct precipitation into the stream network, Q_R is land surface runoff, Q_E is open water evaporation from the stream surface, Q_T is transpiration by plants tapping stream water, Q_{div} represents diversions from the stream network, and Q_{out} is outflow to downstream, and Q_S is groundwater-surface water interaction. Additional or fewer components in the surface water budget may be appropriate, depending on the setting.

Before presenting the surface water budget equation for the HBA Update, some relevant aspects of the approach to surface water routing in MODFLOW and in the SVIHM in particular are discussed. The SVIHM uses the MODFLOW Stream Flow Routing (SFR) Package (Prudic et al., 2004) to simulate streamflow routing within the model domain. The SFR Package does not simulate storage in the stream network; conditions within the stream network are not informed by streamflow conditions during the preceding timestep. This means that storage change is not simulated, and the sum of inflows is equal to the sum of outflows:

$$0 = Q_{in} - Q_{out} \tag{13}$$

$$Q_{in} = Q_{out} \tag{14}$$

Although MODFLOW can simulate direct precipitation into stream networks and evapotranspiration from them, the SVIHM does not include these components of the surface water budget. Q_P, Q_E, and Q_T in Equation 12 would all be zero in a surface water budget of the SVIHM stream network.

The SFR Package routes streamflow through a simulated stream network, according to a user-specified scheme. Each stream reach is connected to other stream reaches in the network; a given stream reach can receive water from one or more upstream reaches and can contribute water to a single downstream reach (or a downstream reach and a diversion, as appropriate). If the user does not specify a downstream reach as a destination for water in a stream reach, MODFLOW does not have any mechanism for routing it anywhere. As noted above, there is no simulation of storage in the stream network. This means that streamflow reaching the end of a stream reach with no defined destination effectively leaves the model domain without any further interactions with the groundwater or surface water systems. A water budget of the stream system must account for water lost in this manner to attain mass balance closure. The SVIHM includes a number of streams with no downstream destination defined, representing various ephemeral streams that flow down from the mountain front but disappear on the valley floor without reaching the Salinas River or one of its tributaries. For the purposes of these water budgets, these streams are referred to as “hanging streams.”

Considering all of the above, a surface water budget equation for the SVIHM can be written as:

$$Q_{in} + Q_{trib} + Q_{head} + Q_R = Q_S + Q_{hang} + Q_{div} + Q_{out} \tag{15}$$

where Q_{head} is inflow at stream headwaters within the area of the surface water budget, and Q_{hang} is outflow from hanging streams that end within the area of the surface water budget; all other components are as defined in Equation 12 (as noted above, Q_P, Q_E, and Q_T are zero for the SVIHM and are excluded from Equation 15). Groundwater surface water interaction can result in an outflow from the stream network (i.e., stream loss) or inflow to the stream network (i.e., stream gain). In the Salinas Valley, streams generally lose water to the aquifers, so Equation 15 includes Q_S on the side of the equation with other outflows. This formulation of the surface water budget is used in this report. Generally, the Salinas River is the main surface water body of interest, and Q_{in} and Q_{out} represent the Salinas River inflows to and outflows from the area over which the surface water budget is computed; Q_{trib} represents other inflows generated from outside the surface water budget area that reach the Salinas River.

3.4.2 Model Domain Surface Water Budget

The average annual surface water budget for the entire model domain for the Historical Scenario is shown as Figure 3-37); that for the No Projects Scenario is shown as Figure 3-38. The difference in surface water budget components is shown as Figure 3-39. Tabular surface water budget information is presented in Table 3-9. Surface water budget components depicted in these and other figures are rounded to the nearest 1,000 afy; depicted averages may not sum exactly due to this rounding. As noted in Chapter 2, the difference shown is equal to the Historical Scenario surface water budget component minus the No Projects Scenario surface water budget component. A positive difference indicates that the magnitude of the surface water flux was greater under the Historical Scenario.

The surface water budget information indicates that, under the Historical Scenario, the Basin experienced about 72,000 afy more streamflow loss to groundwater, about 51,000 afy less outflow to Monterey Bay via the Salinas River, about 45,000 afy more land surface runoff, about 21,000 afy less inflow from the Nacimiento and San Antonio Rivers (the difference in headwater inflow on Figure 3-39 and Table 3-9), and about 2,000 afy more loss of streamflow at the ends of hanging streams compared to the No Projects Scenario. Changes to other surface water budget components are not significant in magnitude.

The increase of streamflow loss is discussed in Section 3.3.2, where it is depicted as a gain to groundwater; in general, it results from increased normal- and dry-year streamflow in the Salinas River leading to increased recharge of the aquifers, especially in the southern part of the Basin. The decrease in outflow to Monterey Bay via the Salinas River results from decreased flow during wet years due to storage of wet year flows in the reservoirs, as well as increased recharge to groundwater during normal and dry years capturing more Salinas River flow before it reaches the river mouth. Increased land surface runoff can occur because additional water is reaching the land surface (through increased precipitation or irrigation), or because higher groundwater heads in water table aquifers are resulting in the water table rising to the land surface or runoff of applied water that would otherwise have become recharge; both processes are likely resulting in the increased land surface runoff under the Historical Scenario. The reduction in "headwater" inflow represents a decrease of average annual inflow from the Nacimiento and San Antonio Rivers with the reservoirs. Finally, the Historical Scenario results in slightly more outflow from hanging streams, which may reflect increased groundwater head resulting in less recharge from hanging streams, or increased land surface runoff into them.

Figures 3-40, 3-41, and 3-42 provide the average annual wet-year surface water budgets for the Historical Scenario, No Projects Scenario, and difference between scenarios, respectively. Table 3-10 presents this surface water budget information in a tabular format. During wet years, there is a decrease of about 229,000 afy of inflow from the Nacimiento and San Antonio Rivers due to the presence of the reservoirs; this represents the ability of the reservoirs to store the high flows during wet years. This decrease in inflow results in a decrease (of about 37,000 afy) of streamflow loss to the aquifers and a further decrease of about 161,000 afy of outflow to Monterey Bay; this represents water that is kept within the system during wet years due to the Projects. The presence of the reservoirs results in an increase (of about 34,000 afy) of land surface runoff into the stream network, which, as noted above, likely represents the effect of higher groundwater head conditions reducing the ability for applied water to recharge to the aquifers, instead becoming runoff.

Figures 3-43, 3-44, and 3-45 provide the average annual normal-year surface water budgets for the Historical Scenario, No Projects Scenario, and difference between scenarios, respectively. Table 3-11 presents this surface water budget information in a tabular format. During normal years, there is a slight increase (of about 10,000 afy) of inflow from the Nacimiento and San Antonio Rivers, representing water that is held in the reservoirs and released during the dry summer season of normal years. Normal years also see an increase of about 43,000 afy of land surface runoff. The model simulates about 72,000 afy additional stream loss during normal years with the Projects; this likely results from a combination of factors, especially the modification of the timing of streamflows during normal years (shifting from the winter wet season to the summer dry season). About 22,000 afy less streamflow reaches Monterey Bay during normal years. Finally, the Projects result in an increase of about 2,000 afy lost from the ends of hanging streams, the same as in wet years.

Figures 3-46, 3-47, and 3-48 provide the average annual dry-year surface water budgets for the Historical Scenario, No Projects Scenario, and difference between scenarios, respectively. Table 3-12 presents this surface water budget information in a tabular format. During dry years, both inflows and outflows are substantially larger in magnitude with the Projects than without. In particular, there is an increase of about 104,000 afy of inflow from the Nacimiento and San Antonio Reservoirs due to the storage and release of flows from wetter years. There is about 159,000 afy more streamflow loss to groundwater, representing a substantial increase in recharge to the groundwater system during dry years. Dry years also see an increase of about 57,000 afy of land surface runoff and about 2,000 afy of increased loss via hanging streams. The Historical Scenario simulates about 1,000 afy of SRDF diversion during dry years (averaged over the entire model duration), versus zero under the No Projects Scenario (by definition)[1]. Outflow to Monterey Bay is about 1,000 afy less with the Projects.

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[1] On average, less than 1,000 afy of SRDF diversion was simulated under the Historical Scenario for wet and normal years. The SRDF did not start diverting water from the Salinas River until WY 2010, near the end of the model duration. For the 9 water years during the model after SRDF started operating, the average annual diversion was about 3,000 afy (about 4,000 afy during wet years, 6,000 afy during normal years, and 2,000 afy during dry years.

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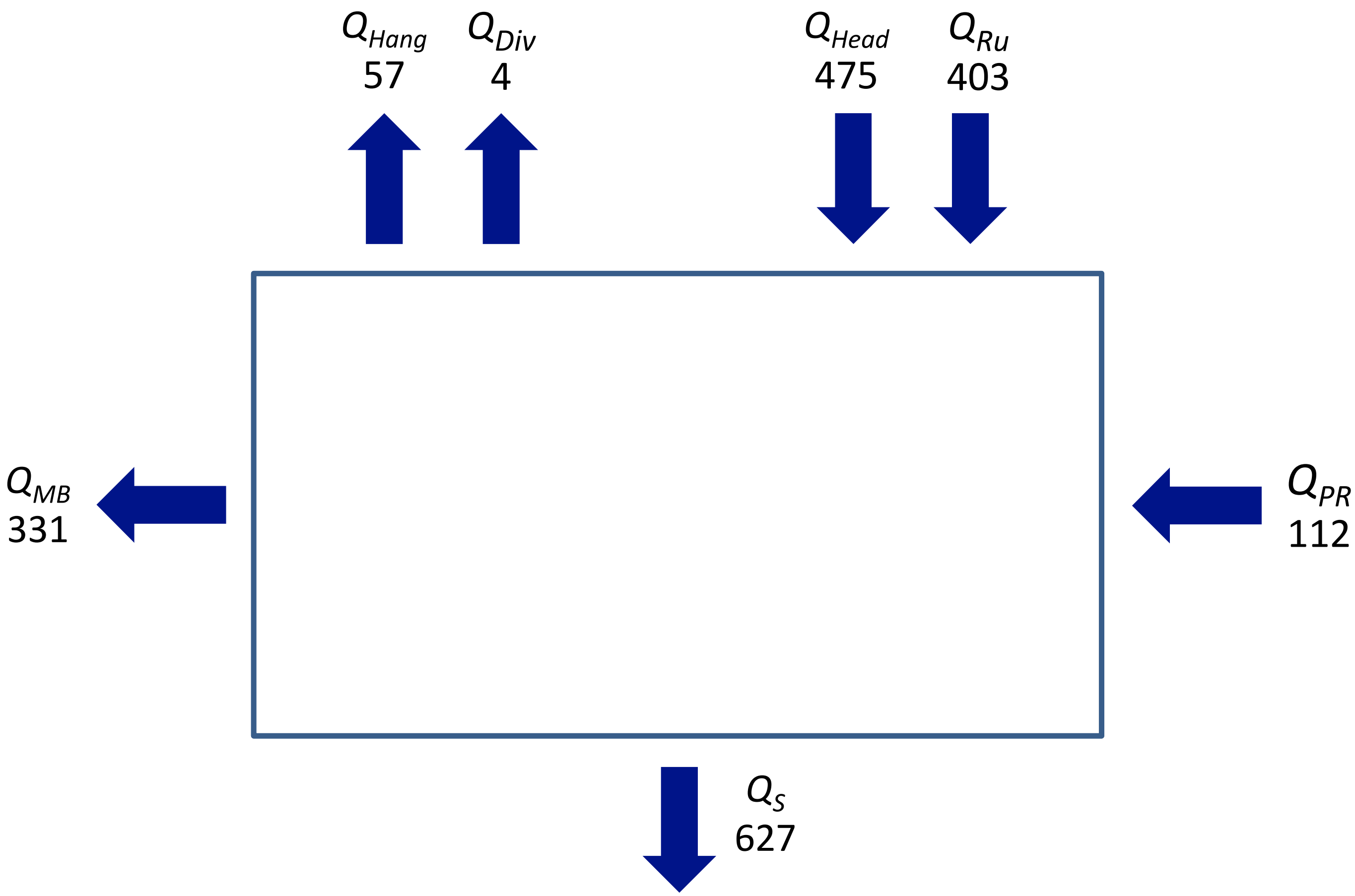
Historical Scenario

Area: **Entire Model Domain**

Year Type: **All**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-37

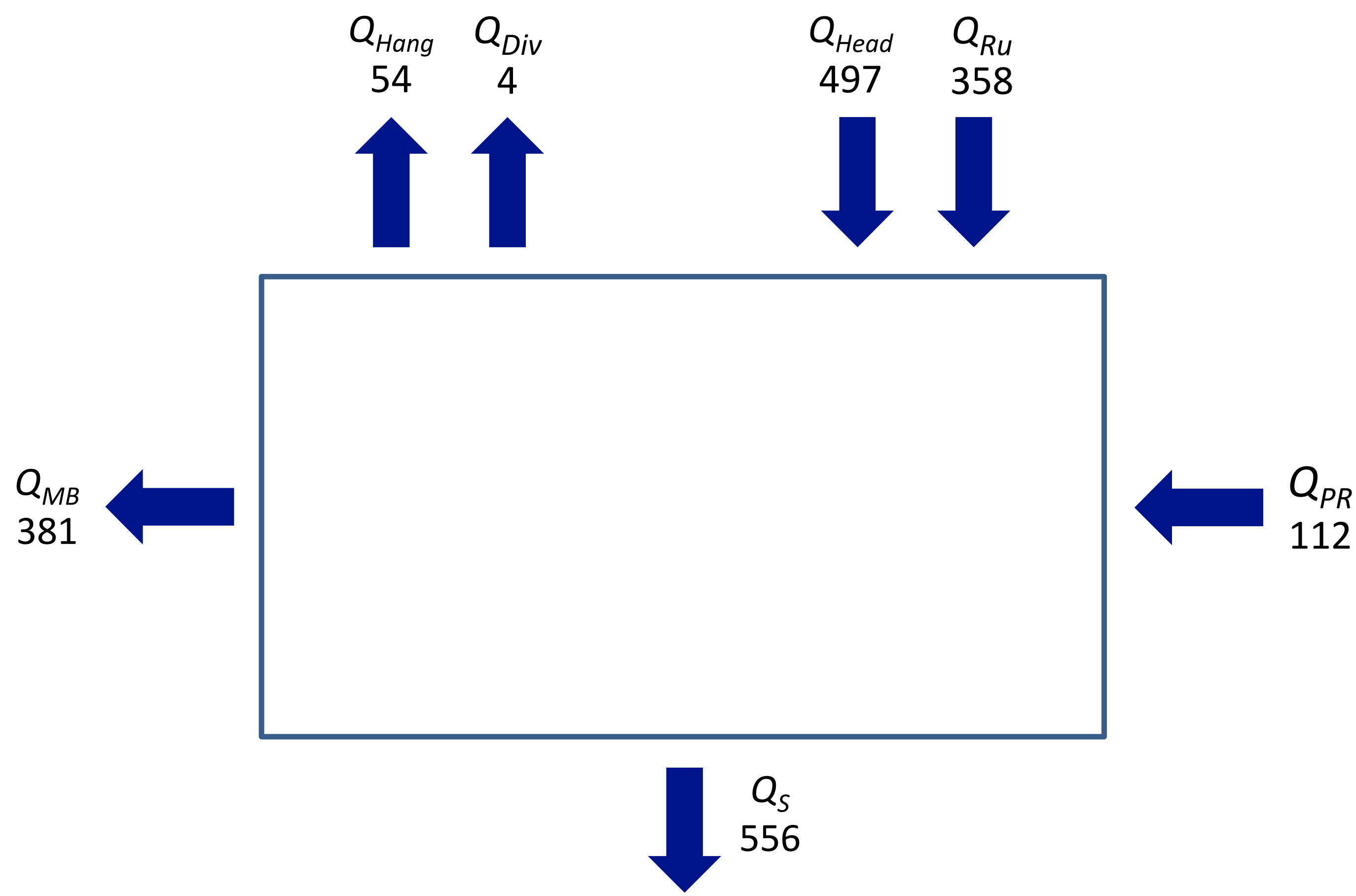
Average Annual Surface Water Budget, Historical Scenario

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025

No Projects Scenario

Area: **Entire Model Domain**

Year Type: **All**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-38

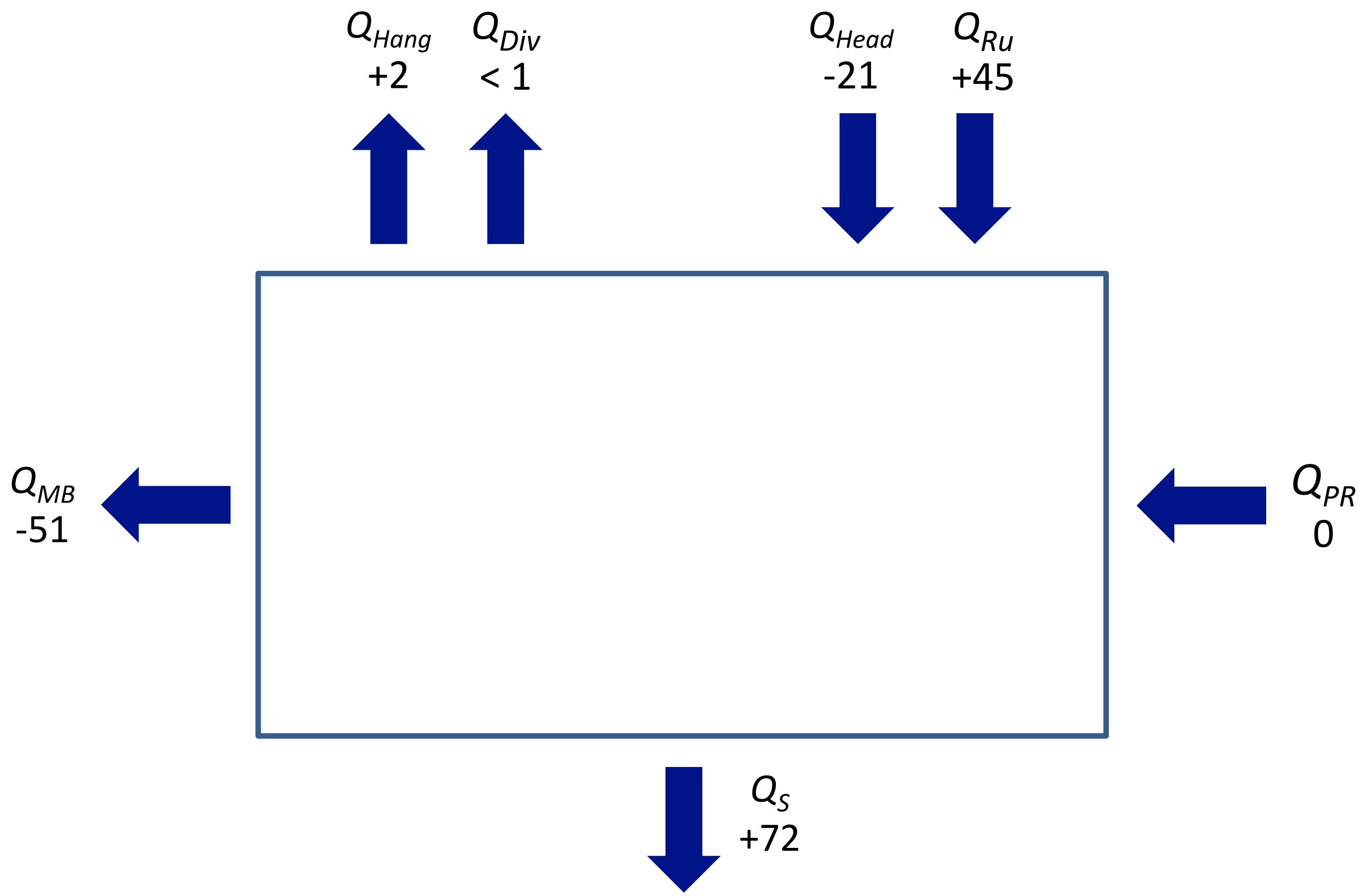
Average Annual Surface Water Budget, No Projects Scenario

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025

Difference Between Scenarios

Area: **Entire Model Domain**

Year Type: **All**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

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Figure 3-39

Average Annual Surface Water Budget, Difference Between Scenarios

Monterey County Water Resources Agency
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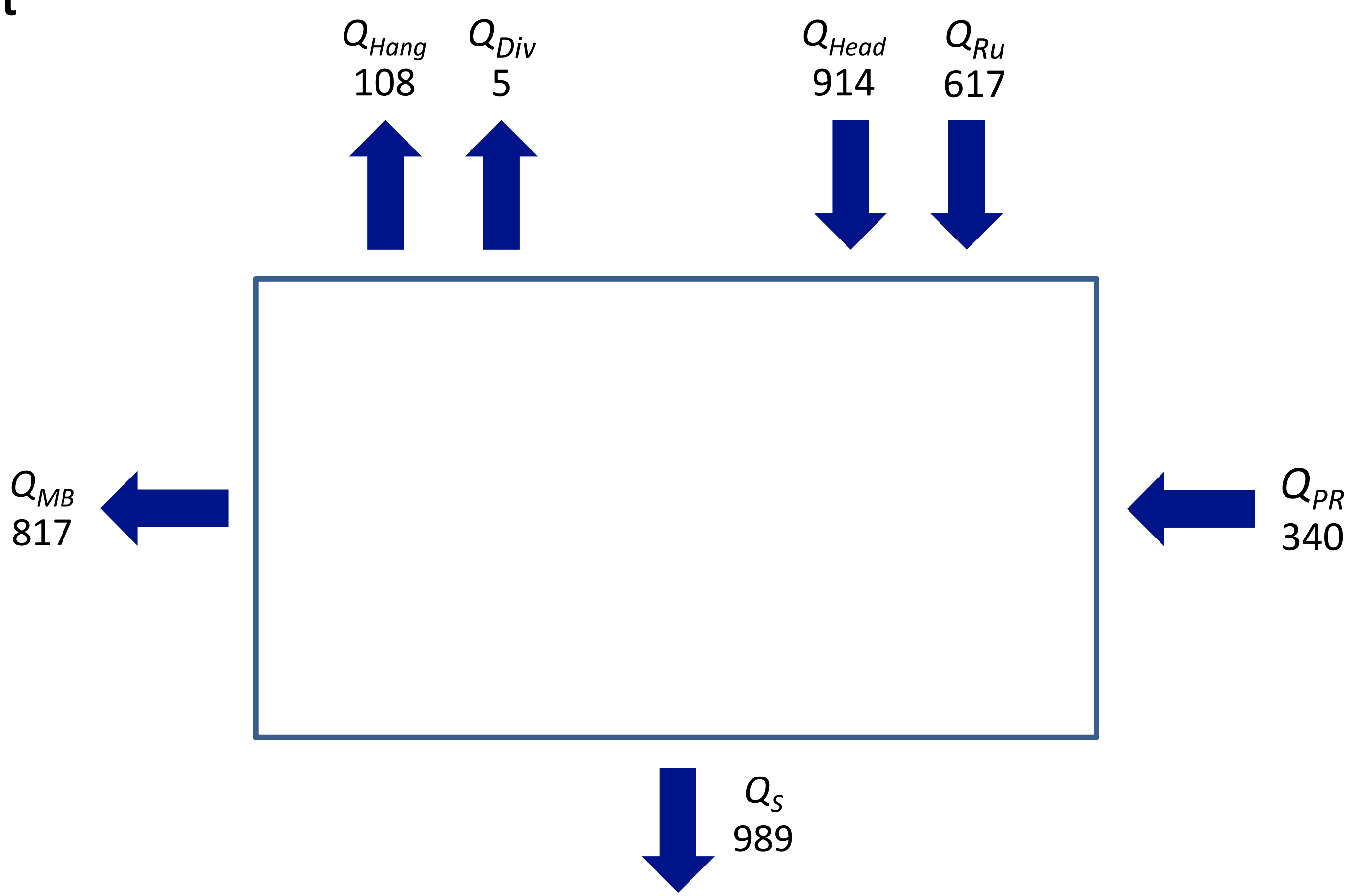
Historical Scenario

Area: **Entire Model Domain**

Year Type: **Wet**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-40

Average Annual Wet-Year Surface Water Budget, Historical Scenario

Monterey County Water Resources Agency
Historical Benefits Analysis Update
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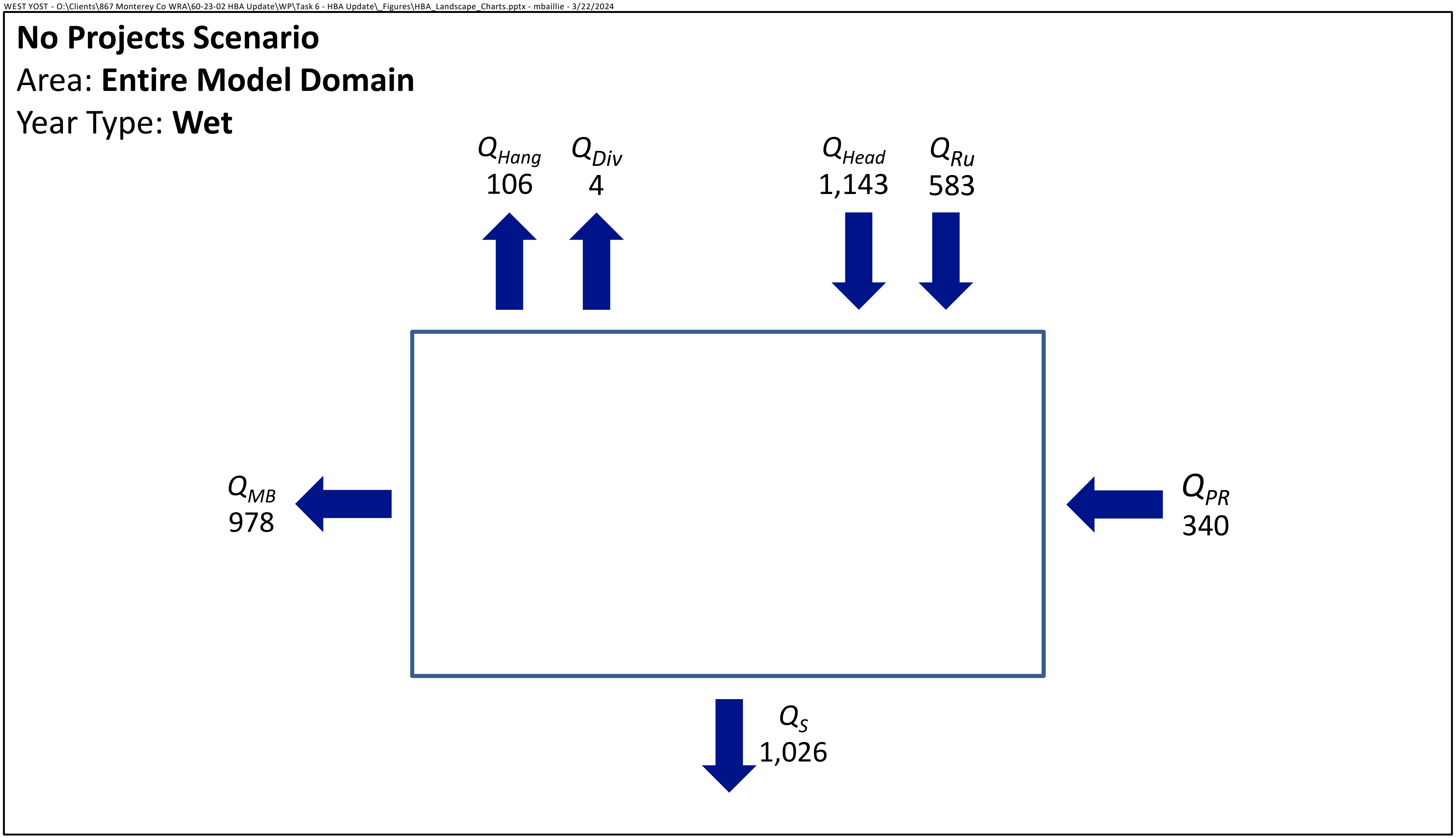


Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-41

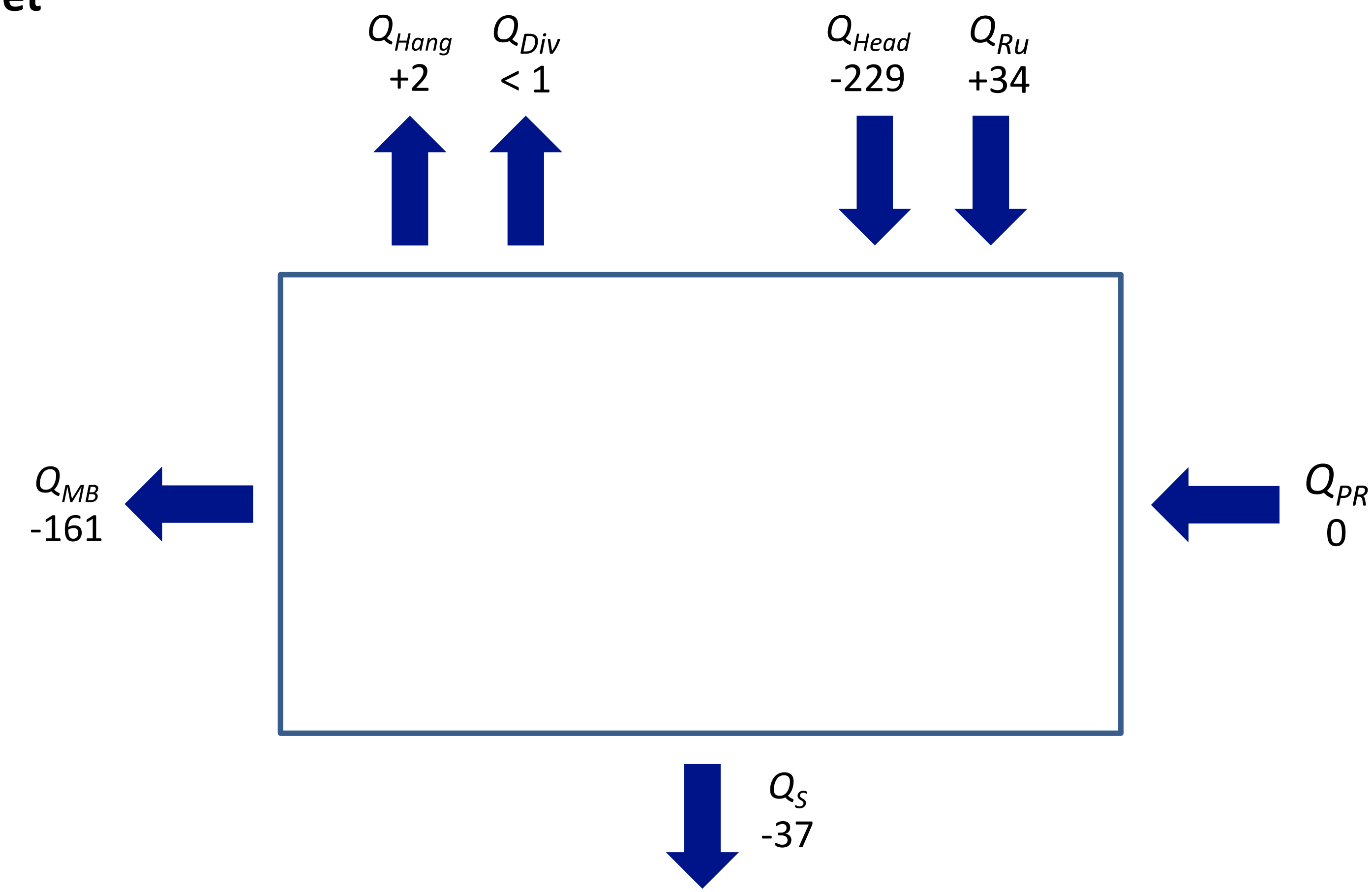
Average Annual Wet-Year Surface Water Budget, No Projects Scenario

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025

Difference Between Scenarios

Area: **Entire Model Domain**

Year Type: **Wet**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-42

Average Annual Wet-Year Surface Water Budget, Difference Between Scenarios

Monterey County Water Resources Agency

Historical Benefits Analysis Update

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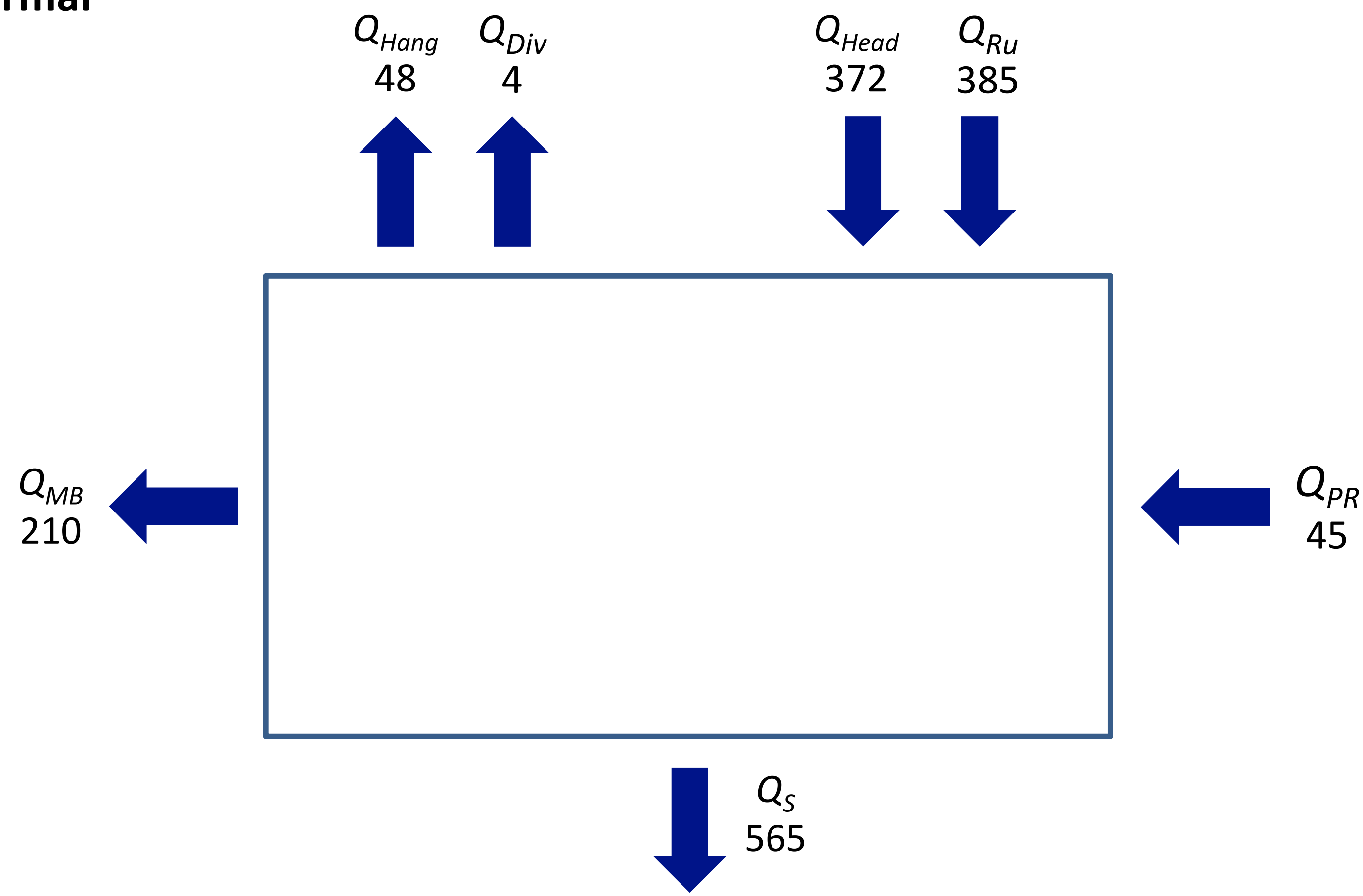
Historical Scenario

Area: **Entire Model Domain**

Year Type: **Normal**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-43

Average Annual Normal-Year Surface Water Budget, Historical Scenario

Monterey County Water Resources Agency
Historical Benefits Analysis Update
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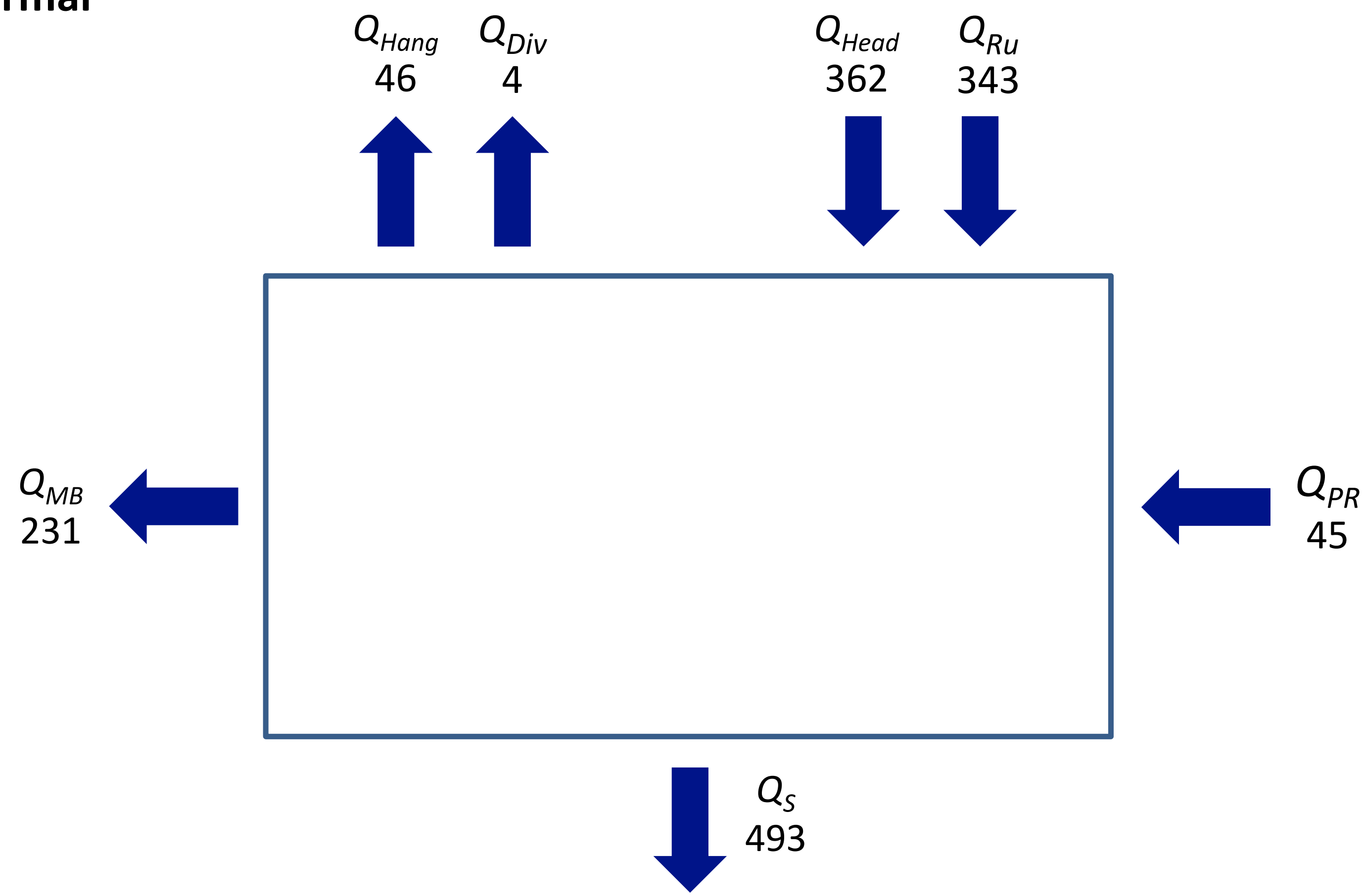
No Projects Scenario

Area: **Entire Model Domain**

Year Type: **Normal**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-44

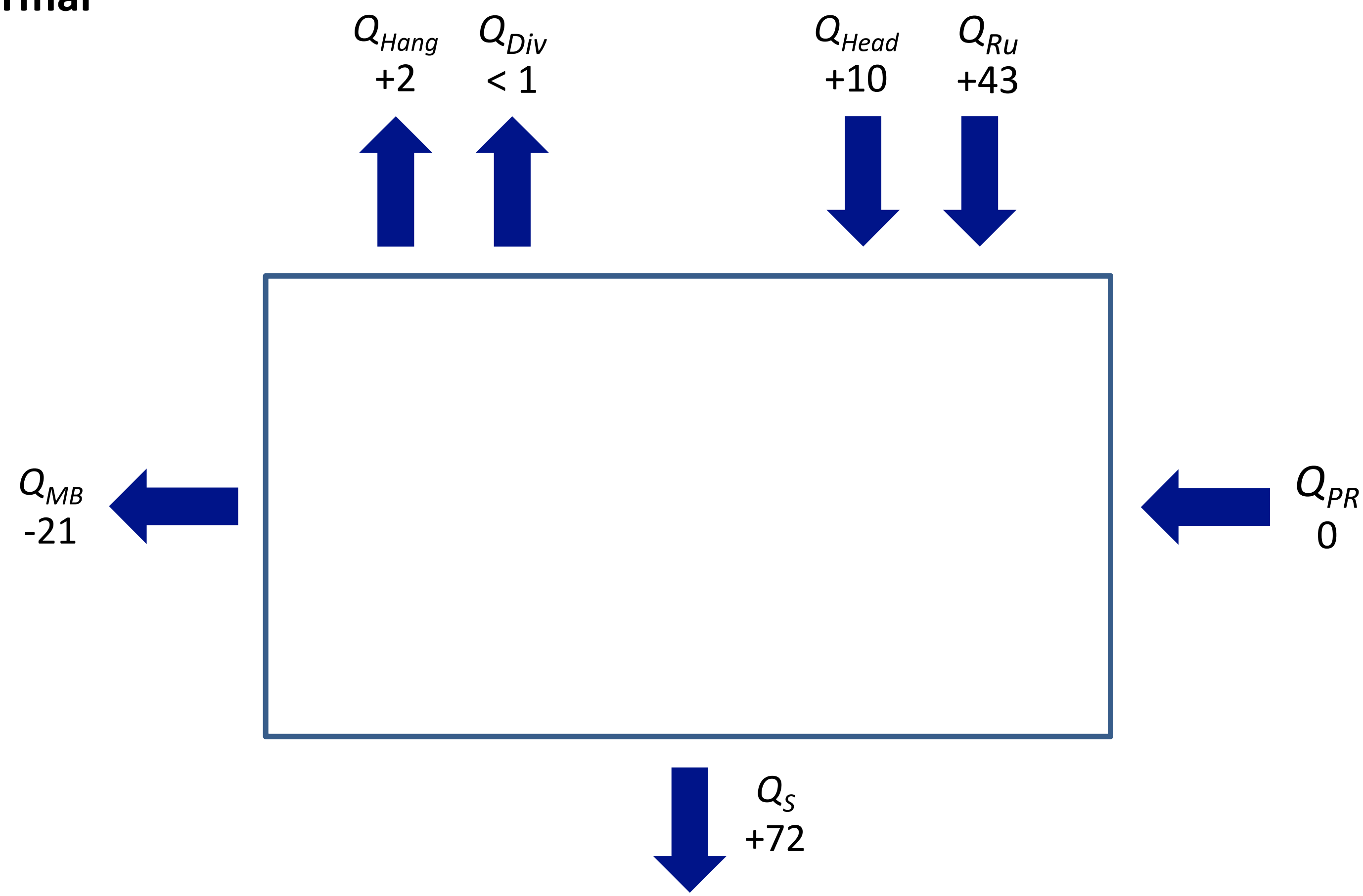
Average Annual Normal-Year Surface Water Budget, No Projects Scenario

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025

Difference Between Scenarios

Area: **Entire Model Domain**

Year Type: **Normal**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-45

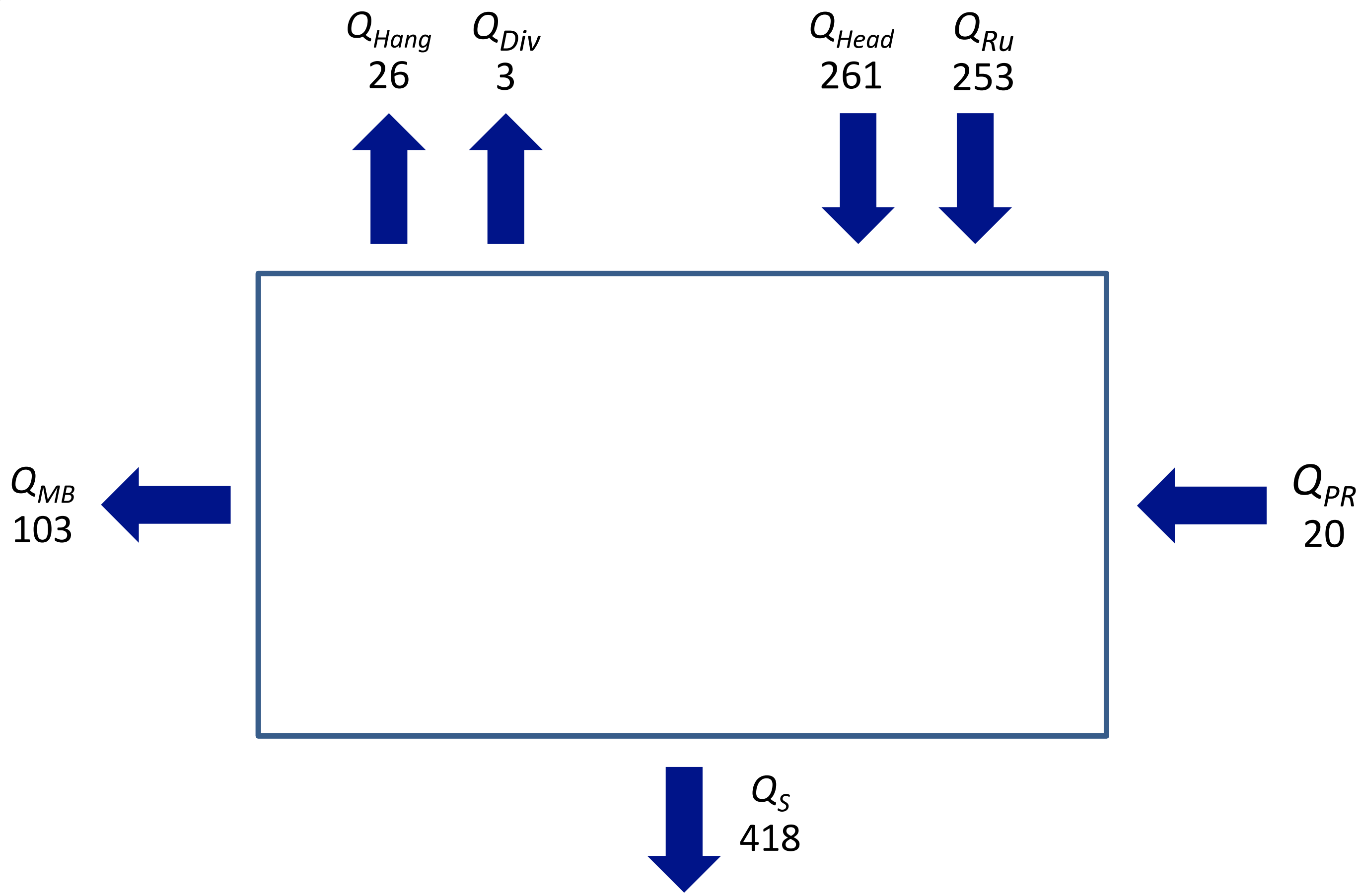
Average Annual Normal-Year Surface Water Budget, Difference Between Scenarios

Monterey County Water Resources Agency
Historical Benefits Analysis Update
April 2025

Historical Scenario

Area: **Entire Model Domain**

Year Type: **Dry**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:

1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-46

Average Annual Dry-Year Surface Water Budget, Historical Scenario

Monterey County Water Resources Agency
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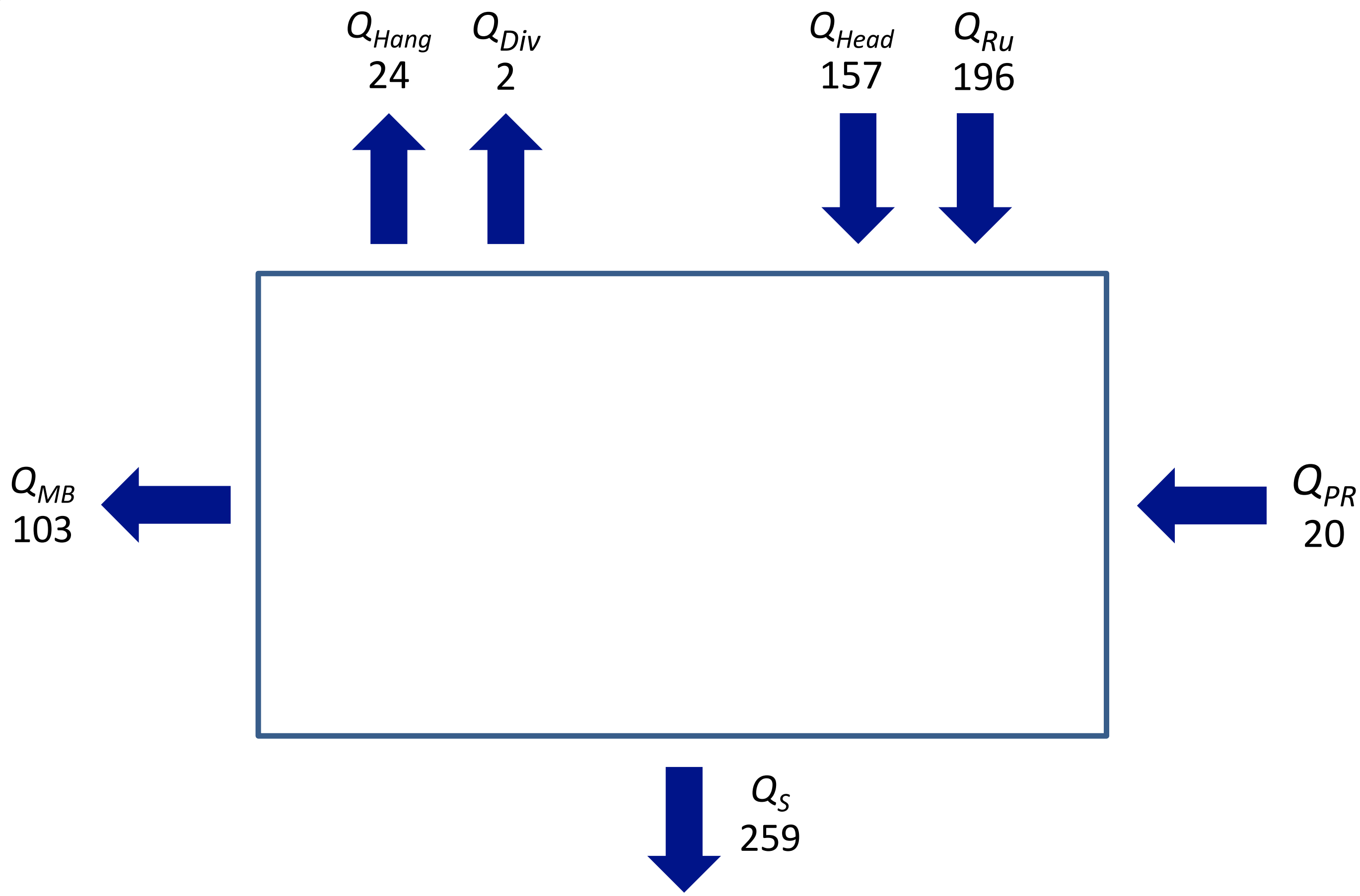
No Projects Scenario

Area: **Entire Model Domain**

Year Type: **Dry**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-47

Average Annual Dry-Year Surface Water Budget, No Projects Scenario

Monterey County Water Resources Agency
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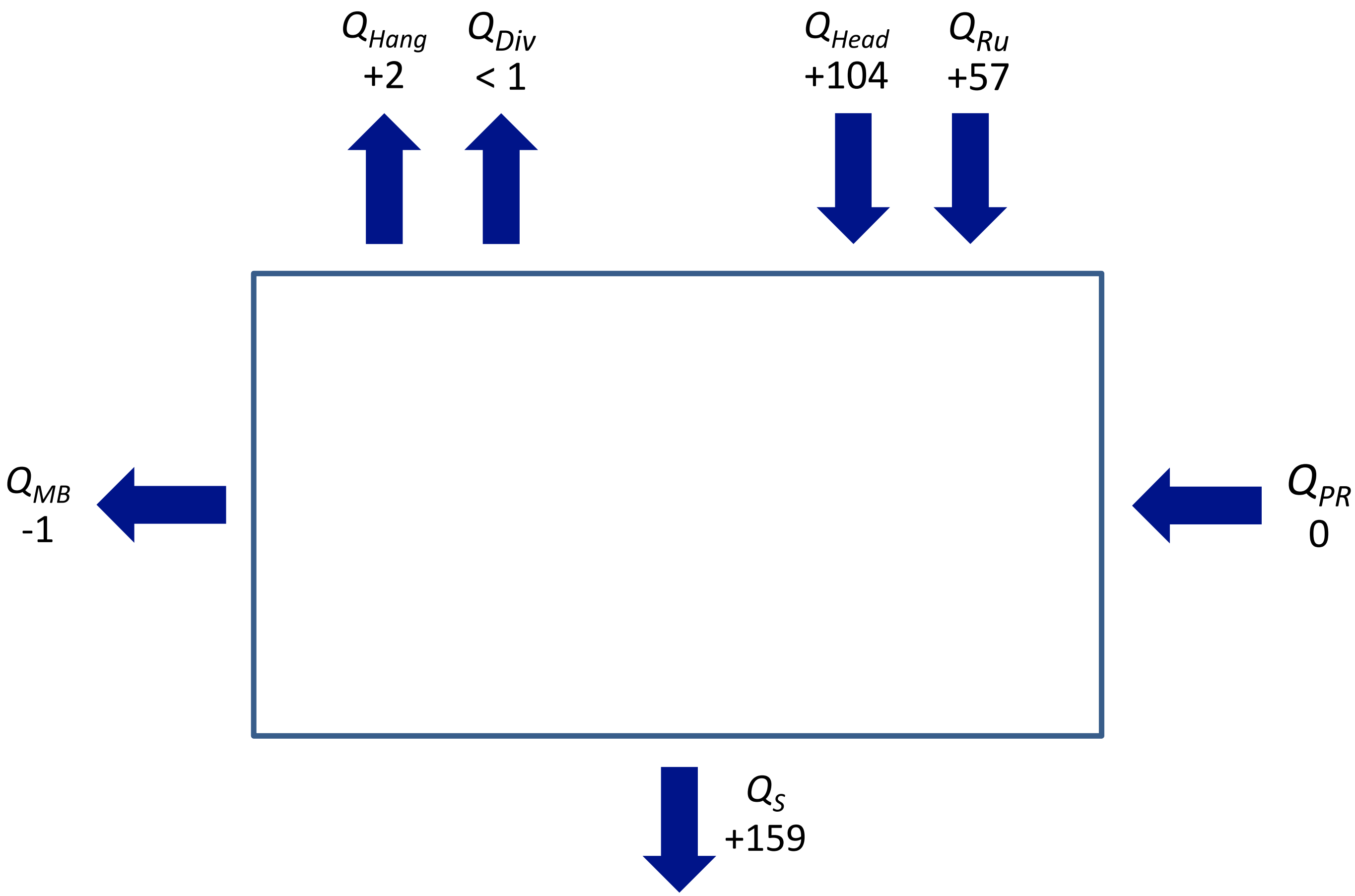
Difference Between Scenarios

Area: **Entire Model Domain**

Year Type: **Dry**



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion
Q_{PR} = Salinas River Inflow from Paso Robles Basin
Q_{MB} = Outflow to Monterey Bay

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding.
2. Arrow orientation denotes direction of surface water flow. Arrows pointing away from the box show surface water leaving the aquifer volume under consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 3-48

Average Annual Dry-Year Surface Water Budget, Difference Between Scenarios

Monterey County Water Resources Agency
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Table 3-9. Average Surface Water Budget for Historical and No Projects Scenario, and Difference Between Scenarios (in afy)				
Surface Water Budget Component		Historical Scenario	No Projects Scenario	Difference
Inflows	Salinas River Inflow from Paso Robles Basin	112,000	112,000	0
	Inflow at Headwaters and from Tributaries	475,000	497,000	-21,000
	Land Surface Runoff	403,000	358,000	+45,000
	Total In	**990,000**	**967,000**	**+23,000**
Outflows	Groundwater-Surface Water Flux	627,000	556,000	+72,000
	Hanging Streams	57,000	54,000	+2,000
	Clark Colony Diversion	4,000	4,000	< 1,000
	SRDF Diversion	< 1,000	0	< 1,000
	Salinas River Outflow to Monterey Bay	273,000	324,000	-51,000
	Outflow from Other Monterey Bay Tributaries	58,000	58,000	< 1,000
	Total Out	**1,019,000**	**995,000**	**+24,000**
Mass Balance Difference		**-28,000**	**-28,000**	**-1,000**

Notes:
- Surface water budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Table 3-10. Average Annual Wet-Year Surface Water Budget for Historical and No Project Scenario, and Difference Between Scenarios (in afy)

	Surface Water Budget Component	Historical Scenario	No Projects Scenario	Difference
Inflows	Salinas River Inflow from Paso Robles Basin	340,000	340,000	0
	Inflow at Headwaters and from Tributaries	914,000	1,143,000	-229,000
	Land Surface Runoff	617,000	583,000	+34,000
	Total In	**1,871,000**	**2,066,000**	**-195,000**
Outflows	Groundwater-Surface Water Flux	989,000	1,026,000	-37,000
	Hanging Streams	108,000	106,000	+2,000
	Clark Colony Diversion	4,000	4,000	< 1,000
	SRDF Diversion	< 1,000	0	< 1,000
	Salinas River Outflow to Monterey Bay	715,000	876,000	-161,000
	Outflow from Other Monterey Bay Tributaries	102,000	102,000	< 1,000
	Total Out	**1,918,000**	**2,113,000**	**-195,000**
Mass Balance Difference		**-48,000**	**-47,000**	**< 1,000**

Notes:
- Surface water budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Table 3-11. Average Normal-Year Surface Water Budget for Historical and No Project Scenario, and Difference Between Scenarios (in afy)

Surface Water Budget Component		Historical Scenario	No Projects Scenario	Difference
Inflows	Salinas River Inflow from Paso Robles Basin	44,784	44,784	0
	Inflow at Headwaters and from Tributaries	372,066	362,021	+10,045
	Land Surface Runoff	385,385	342,750	+42,635
	Total In	**802,235**	**749,555**	**+52,680**
Outflows	Groundwater-Surface Water Flux	565,167	493,366	+71,802
	Hanging Streams	48,234	45,896	+2,338
	Clark Colony Diversion	4,190	4,215	-25
	SRDF Diversion	234	-36	+270
	Salinas River Outflow to Monterey Bay	158,499	180,185	-21,686
	Outflow from Other Monterey Bay Tributaries	51,291	50,952	+339
	Total Out	**827,614**	**774,577**	**+53,037**
Mass Balance Difference		**-25,379**	**-25,022**	**-357**

Notes:
- Surface water budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Table 3-12. Average Annual Dry-Year Surface Water Budget for Historical and No Project Scenario, and Difference Between Scenarios (in afy)

	Surface Water Budget Component	Historical Scenario	No Projects Scenario	Difference
Inflows	Salinas River Inflow from Paso Robles Basin	20,000	20,000	0
	Inflow at Headwaters and from Tributaries	261,000	157,000	+104,000
	Land Surface Runoff	253,000	196,000	+57,000
	Total In	**534,000**	**373,000**	**+161,000**
Outflows	Groundwater-Surface Water Flux	418,000	259,000	+159,000
	Hanging Streams	26,000	24,000	+2,000
	Clark Colony Diversion	2,000	2,000	< 1,000
	SRDF Diversion	1,000	0	+1,000
	Salinas River Outflow to Monterey Bay	72,000	72,000	-1,000
	Outflow from Other Monterey Bay Tributaries	31,000	31,000	< 1,000
	Total Out	**550,000**	**388,000**	**+162,000**
Mass Balance Difference		**-16,000**	**-15,000**	**-1,000**

Notes:
- Surface water budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

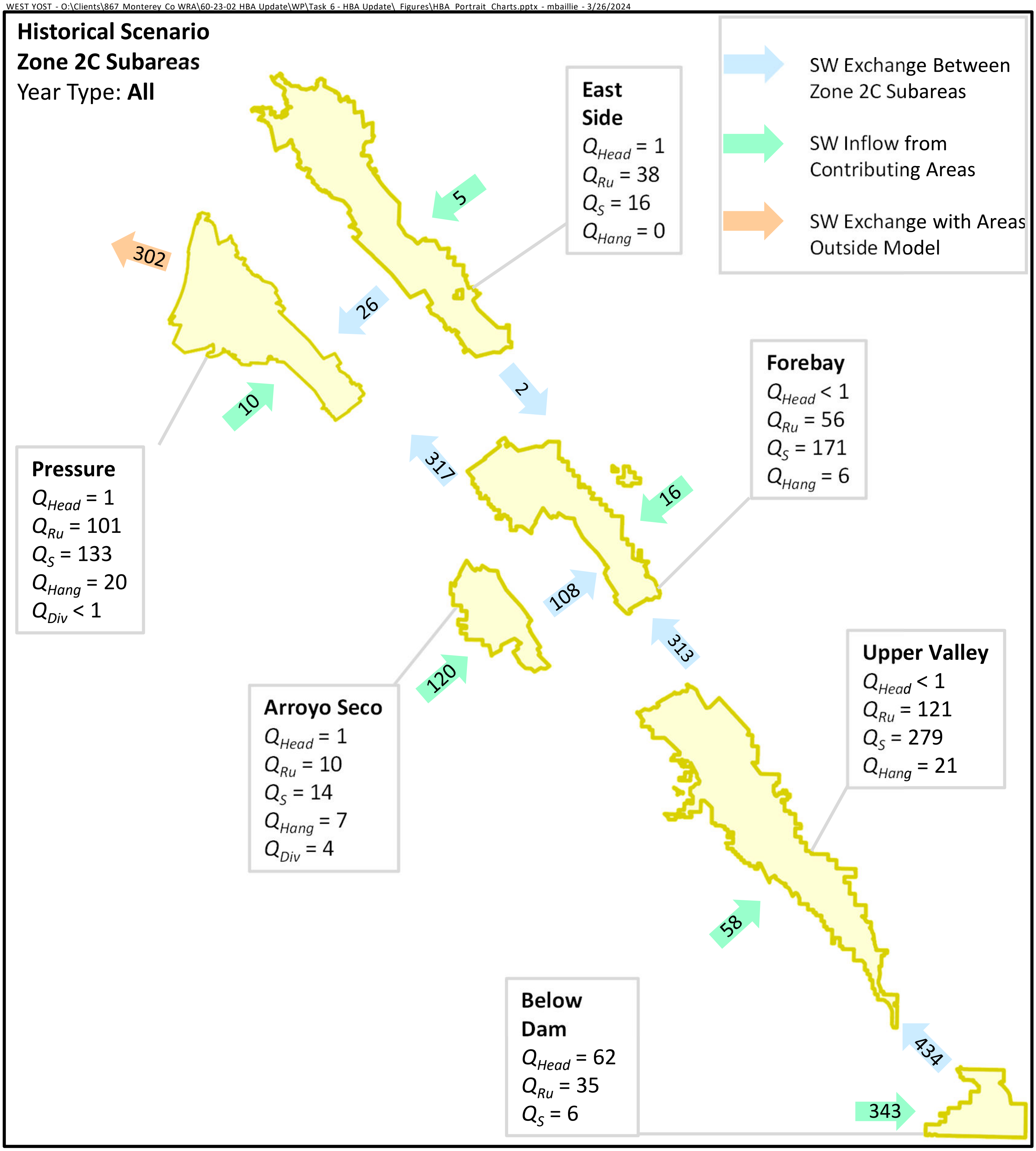
3.4.3 Subarea Surface Water Budgets

A more detailed understanding of the impact of the Projects on surface water conditions in the Basin can be achieved by looking at surface water budgets for individual Zone 2C Subareas (see Figure 1-6 for the Subarea locations). Zone 2C includes the Pressure, East Side, Arroyo Seco, Forebay, Upper Valley, and Below Dam Subareas (the Above Dam Subarea is located outside of the active model domain and is therefore excluded from all groundwater budgets). The portion of the active model domain located south of the Monterey-San Luis Obispo County Line is considered part of the contributing area to the Below Dam Subarea for the surface water budgets. Areas of the active model domain that do not fall into any of the above categories are assigned to the contributing areas for Zone 2C Subareas based on where individual streams flow (e.g., if a stream enters the Forebay Subarea from outside of Zone 2C, it is assigned to the Forebay Subarea contributing area). A few streams in the northern part of the study area are tributary to Monterey Bay rather than the Salinas River; outflow from these streams to Monterey Bay is accounted for separately from Salinas River outflow. The area of the active model domain off the coast is not included in the surface water budgets as no streams are present.

Figure 3-49 and Table 3-13 present the average annual groundwater budget for the Historical Scenario, by Zone 2C Subarea. Figure 3-50 and Table 3-14 present the average annual groundwater budget for the No Projects Scenario, by Subarea. Figure 3-51 and Table 3-15 present the differences between the Subarea groundwater budget results for the two scenarios.

As described in Section 3.4.2, the largest surface water budget differences between the Historical and No Projects Scenarios occur as increased streamflow loss to groundwater, land surface runoff, and loss of streamflow from hanging streams and decreased Salinas River outflow to Monterey Bay and inflow from the Nacimiento and San Antonio Rivers. The increase in streamflow loss under the Historical Scenario is greatest in the Upper Valley Subarea (about 44,000 afy), followed by the Forebay Subarea (about 20,000 afy), the Pressure Subarea (about 6,000 afy), and the Below Dam and Arroyo Seco Subareas (each about 1,000 afy). Changes to streamflow losses in the East Side Subarea, contributing areas to the various subareas, and areas outside Zone 2C tributary to Monterey Bay are all less than 1,000 afy (these differences are identical to the differences in groundwater-surface water flux given in Section 3.3.3 because it is the same flux, just from the perspective of the surface water system rather than the groundwater system).

The increase in land surface runoff is spatially distributed in much the same way as the increase in streamflow loss. The greatest difference occurs in the Upper Valley Subarea (about 19,000 afy), followed by the Pressure Subarea (about 10,000 afy), the Forebay Subarea (about 8,000 afy), the Below Dam Subarea (about 5,000 afy), and the Arroyo Seco Subarea, Upper Valley Subarea contributing area, and Below Dam Subarea contributing area (each about 1,000 afy). Increased land surface runoff in the southern part of the study area (the Arroyo Seco, Forebay, Upper Valley, and Below Dam Subareas and their contributing areas) is likely related to the increased streamflow losses in this area, which results in higher groundwater head and less opportunity for water present at the land surface to become recharge. In the northern part of the study area (the Pressure Subarea), the increased land surface runoff likely reflects increased crop irrigation due to the provision of recycled water and surface water supplies to the CSIP area, some of which ends up running off into the stream system.



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per y and displayed in thousands of acre-feet per year; totals may not sum du to rounding and imperfect closure of the model mass balance.
2. Arrow orientation denotes direction of surface water flow. Arrows point away from the box show surface water leaving the aquifer volume unde consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-49

Average Annual Surface Water Budget by Subarea, Historical Scenario

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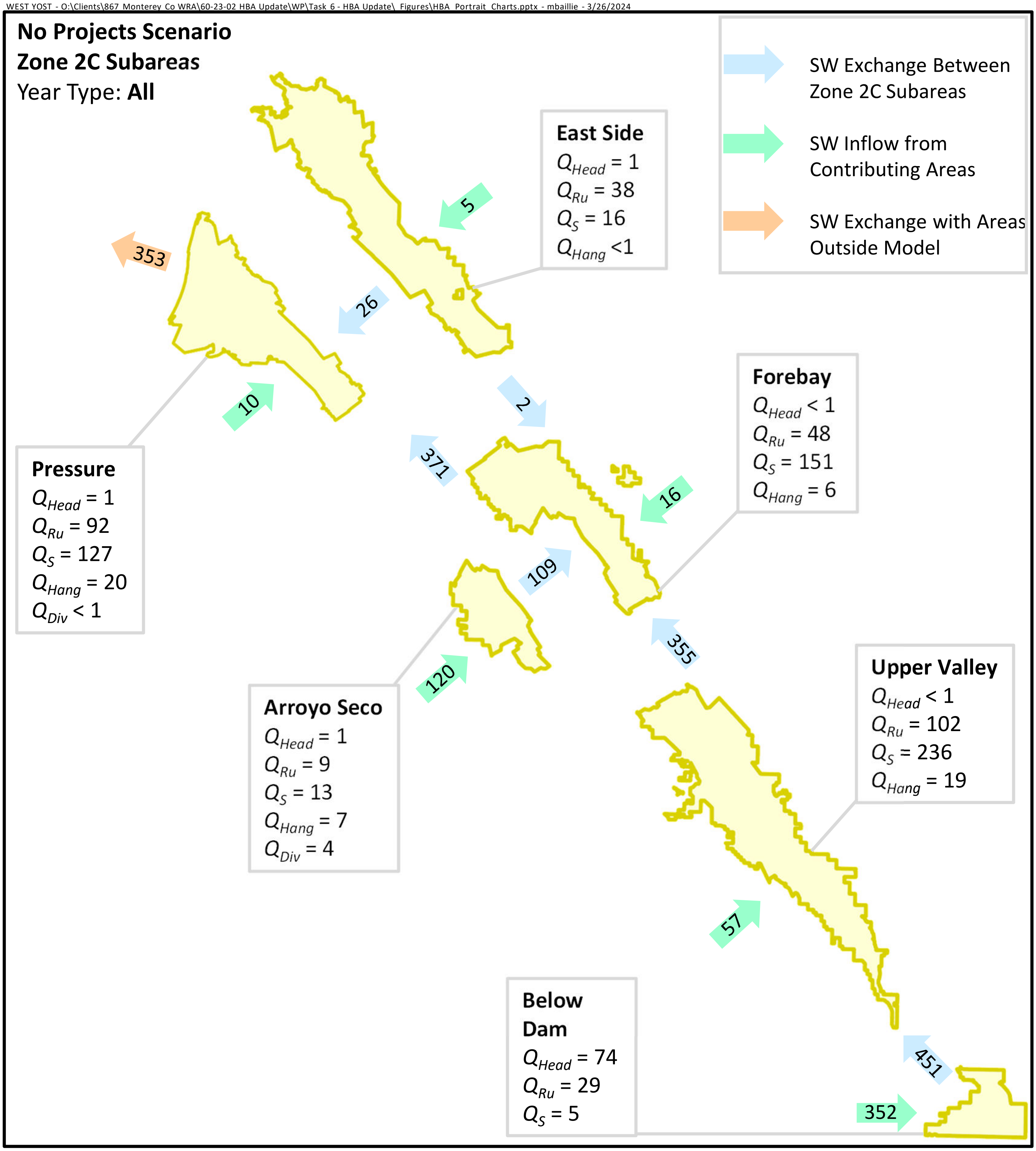

Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per y and displayed in thousands of acre-feet per year; totals may not sum du to rounding and imperfect closure of the model mass balance.
2. Arrow orientation denotes direction of surface water flow. Arrows point away from the box show surface water leaving the aquifer volume unde consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.

Figure 3-50

Average Annual Surface Water Budget by Subarea, No Projects Scenario

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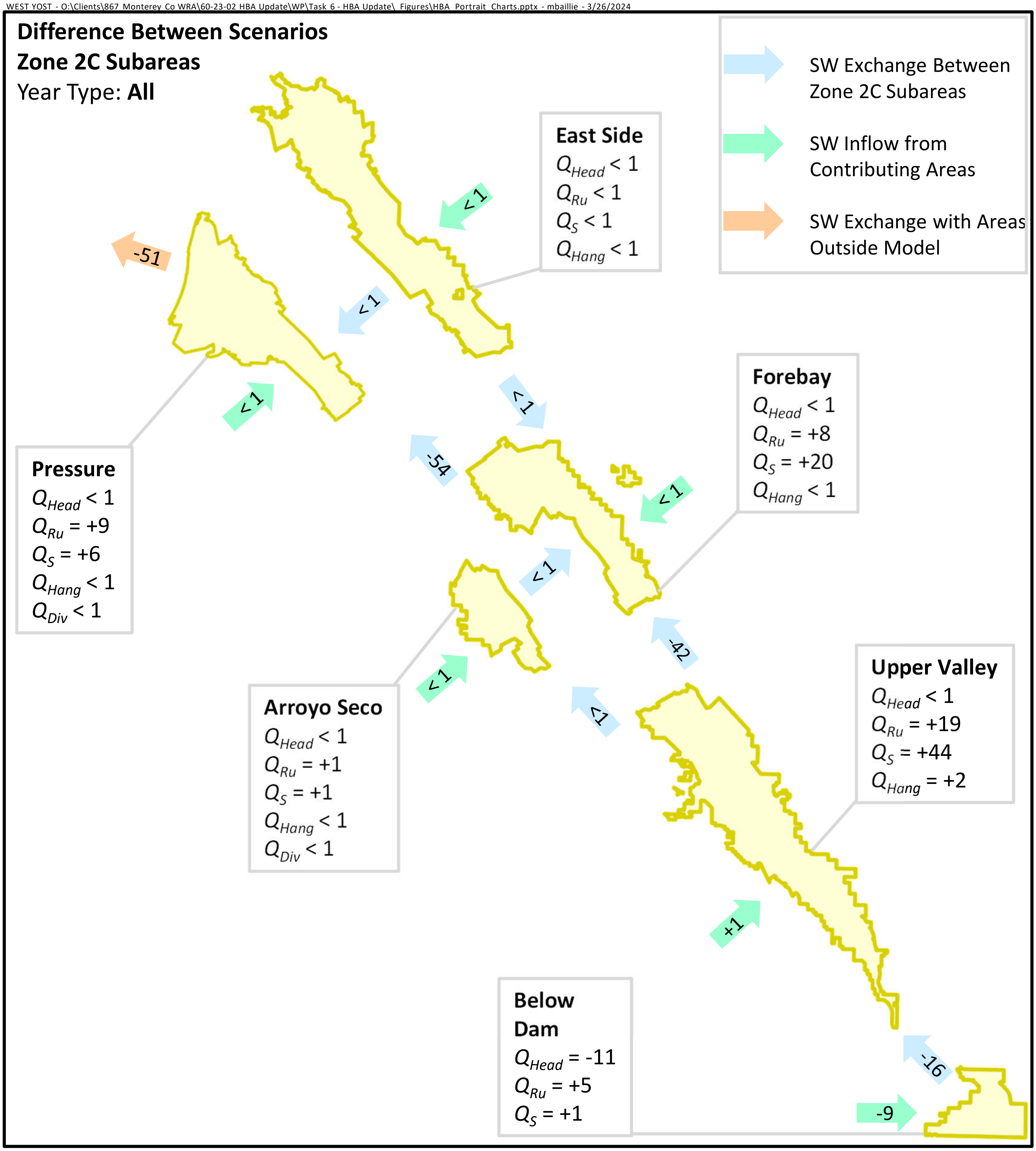
Historical Benefits Analysis Update
April 2025



Q_{Head} = Inflow at Stream Headwaters
Q_{Ru} = Land Surface Runoff
Q_S = Groundwater-Surface Water Exchange
Q_{Hang} = Outflow from Hanging Streams
Q_{Div} = Streamflow Diversion

Notes:
1. Water budget components are rounded to nearest 1,000 acre-feet per y and displayed in thousands of acre-feet per year; totals may not sum du to rounding and imperfect closure of the model mass balance.
2. Arrow orientation denotes direction of surface water flow. Arrows point away from the box show surface water leaving the aquifer volume unde consideration. Arrows pointing toward the box show surface water entering the aquifer volume.
3. See Section 3.4 of the text for the development of the SVIHM surface water budget equation.
4. Difference between scenarios is calculated as Historical Scenario minus Projects Scenario

Figure 3-51

Average Annual Surface Water Budget by Subarea, Difference Between Scenarios

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Table 3-13. Average Annual Surface Water Budget by Subarea, Historical Scenario (in afy)								
Surface Water Budget Component		Zone 2C Subareas (Including Contributing Areas)						Area Draining to Monterey Bay
		Pressure	East Side	Arroyo Seco	Forebay	Upper Valley	Below Dam	
Inflows	Salinas River Inflow from Paso Robles Basin	0	0	0	0	0	112,000	0
	Inflow at Headwaters and from Tributaries	7,000	6,00	124,000	12,000	49,000	277,000	0
	Land Surface Runoff	105,000	40,000	13,000	60,000	132,000	53,000	0
	Inflow from Other Subareas	343,000	0	5,000	428,000	434,000	0	29,000
	Total In	**456,000**	**46,000**	**142,000**	**500,000**	**615,000**	**442,000**	**29,000**
Outflows	Groundwater-Surface Water Flux	134,000	17,000	16,000	171,000	280,000	8,000	< 1,000
	Hanging Streams	20,000	1,000	9,000	6,000	21,000	0	0
	Clark Colony Diversion	0	0	4,000	0	0	0	0
	SRDF Diversion	< 1,000	0	0	0	0	0	0
	Salinas River Outflow to Monterey Bay	273,000	0	0	0	0	0	0
	Outflow from Other Monterey Bay Tributaries	29,000	0	0	0	0	0	29,000
	Outflow to Other Subareas	0	28,000	113,000	323,000	313,000	434,000	0
	Total Out	**457,000**	**46,000**	**142,000**	**500,000**	**614,000**	**442,000**	**29,000**
Mass Balance Difference		**-1,000**	**< 1,000**	**< 1,000**	**< 1,000**	**1,000**	**< 1,000**	**< 1,000**

Notes:
- Surface water budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding

Table 3-14. Average Annual Surface Water Budget by Subarea, No Project Scenario (in afy)								
	Surface Water Budget Component	Zone 2C Subareas (Including Contributing Areas)						Area Draining to Monterey Bay
		Pressure	East Side	Arroyo Seco	Forebay	Upper Valley	Below Dam	
Inflows	Salinas River Inflow from Paso Robles Basin	0	0	0	0	0	112,000	0
	Inflow at Headwaters and from Tributaries	7,000	6,000	124,000	12,000	49,000	298,000	0
	Land Surface Runoff	96,000	40,000	12,000	52,000	112,000	47,000	0
	Inflow from Other Subareas	397,000	0	5,000	470,000	451,000	0	29,000
	Total In	**500,000**	**46,000**	**141,000**	**533,000**	**612,000**	**457,000**	**29,000**
Outflows	Groundwater-Surface Water Flux	128,000	17,000	16,000	151,000	237,000	7,000	< 1,000
	Hanging Streams	20,000	1,000	8,000	6,000	19,000	0	0
	Clark Colony Diversion	0	0	4,000	0	0	0	0
	SRDF Diversion	0	0	0	0	0	0	0
	Salinas River Outflow to Monterey Bay	324,000	0	0	0	0	0	0
	Outflow from Other Monterey Bay Tributaries	29,000	0	0	0	0	0	29,000
	Outflow to Other Subareas	0	28,000	113,000	376,000	355,000	451,000	0
	Total Out	**501,000**	**46,000**	**141,000**	**533,000**	**611,000**	**457,000**	**29,000**
Mass Balance Difference		**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**	**1,000**	**< 1,000**	**< 1,000**

Notes:
- Surface water budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding

Table 3-15. Average Annual Surface Water Budget by Subarea, Difference Between Scenarios (in afy)									
	Surface Water Budget Component	Zone 2C Subareas (Including Contributing Areas)						Area Draining to Monterey Bay
		Pressure	East Side	Arroyo Seco	Forebay	Upper Valley	Below Dam	
Inflows	Salinas River Inflow from Paso Robles Basin	0	0	0	0	0	0	0
	Inflow at Headwaters and from Tributaries	0	< 1,000	0	0	0	-21,000	0
	Land Surface Runoff	+10,000	< 1,000	+1,000	+8,000	+20,000	+6,000	0
	Inflow from Other Subareas	-54,000	0	+1,000	-41,000	-16,000	0	< 1,000
	Total In	**-44,000**	**< 1,000**	**+1,000**	**-33,000**	**+4,000**	**-15,000**	**< 1,000**
Outflows	Groundwater-Surface Water Flux	+6,000	< 1,000	+1,000	+20,000	+44,000	+1,000	< 1,000
	Hanging Streams	< 1,000	0	< 1,000	< 1,000	+2,000	0	0
	Clark Colony Diversion	0	0	< 1,000	0	0	0	0
	SRDF Diversion	< 1,000	0	0	0	0	0	0
	Salinas River Outflow to Monterey Bay	-51,000	0	0	0	0	0	0
	Outflow from Other Monterey Bay Tributaries	< 1,000	0	0	0	0	0	< 1,000
	Outflow to Other Subareas	0	< 1,000	< 1,000	-53,000	-42,000	-16,000	0
	Total Out	**-44,000**	**< 1,000**	**+1,000**	**-33,000**	**+4,000**	**-15,000**	**< 1,000**
Mass Balance Difference		**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**	**< 1,000**

Notes:
- Surface water budget components are rounded to the nearest 1,000 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

The increase in loss from the ends of hanging streams occurs in the Upper Valley Subarea (about 2,000 afy), with this increase being less than 1,000 afy in all other areas.

The reduction in inflow from the Nacimiento and San Antonio Rivers occurs in the Below Dam Subarea (about 11,000 afy), where the San Antonio River enters the active model domain, and in the Below Dam Subarea contributing area (about 10,000 afy), where the Nacimiento River enters the active model domain. The reduction in Salinas River outflow to Monterey Bay (about 51,000 afy) occurs in the Pressure Subarea, where the river mouth is located.

3.4.4 Surface Water Budgets Summary

This section described the results of the effects of the Projects on the streamflows in the Basin. The largest change to the surface water budget was an increase in groundwater-surface water flux (i.e., streamflow loss), which is discussed from the perspective of the groundwater system in Section 3.3.4. The stream network lost less water to the aquifers during wet years, but substantially more during normal and dry years. The change in streamflow loss was greatest in the Upper Valley and Forebay Subareas, with less difference occurring in the Pressure Subarea and very little difference elsewhere.

The change in streamflow loss between the scenarios results from reduced flow in the Salinas River during wet years and increased flow during normal and dry years because of the storage and subsequent release of wet year flows along the Nacimiento and San Antonio Rivers. In wet years, the Basin received about 229,000 afy less inflow from these rivers with the reservoirs in place. During normal years, this changed to an increase of about 10,000 afy; during dry years, the increase was about 104,000 afy. The overall average change across all model years was a decrease of about 21,000 afy.

The presence of the Projects results in the retention of more water within the Basin than would otherwise occur. One manifestation of this in the model was a reduction in the amount of water flowing out to Monterey Bay from the Salinas River. The overall average change in this outflow was a reduction of about 51,000 afy for all year types. The reduction was largest in wet years (about 161,000 afy), with less during normal years (about 22,000 afy) and very little during dry years (about 1,000 afy).

The increased recharge that occurred with the Projects in certain places led to higher groundwater head values and a greater propensity for groundwater head to be close to the land surface, which would result in more precipitation (and applied water) running off into the stream system because there is less available storage space in the unsaturated zone.

3.5 WELL IMPACTS ANALYSIS

The 1998 HBA included an analysis of the effect of the Projects on the ability of extraction wells to operate. This analysis focused on groundwater head at the pumping wells for which detailed construction information (well location, well depth, and well perforation interval) were available from MCWRA. A pumping well was considered “impacted” if the pumping groundwater head was simulated to drop a threshold of at least 10 feet below the top of the perforated interval. This threshold value was chosen to account for the fact that the SVIGSM was, like the SVIHM, a regional model, and was designed to re-create overall regional conditions rather than conditions at any single model location (e.g., a well).

Chapter 2 describes some key differences between the SVIGSM and the SVIHM that have bearing on this HBA Update. One important difference is how each model simulates pumping. The SVIGSM simulated the same amount of pumping under the historical and “without reservoirs” cases, indicating that SVIGSM had no mechanism for modifying pumping based on changes to crop demand, or that crop demand was identical between cases. FMP, which calculates crop water demand and satisfies it using available sources, can increase or decrease the amount of agricultural well pumping due to differences in the availability of other water sources.

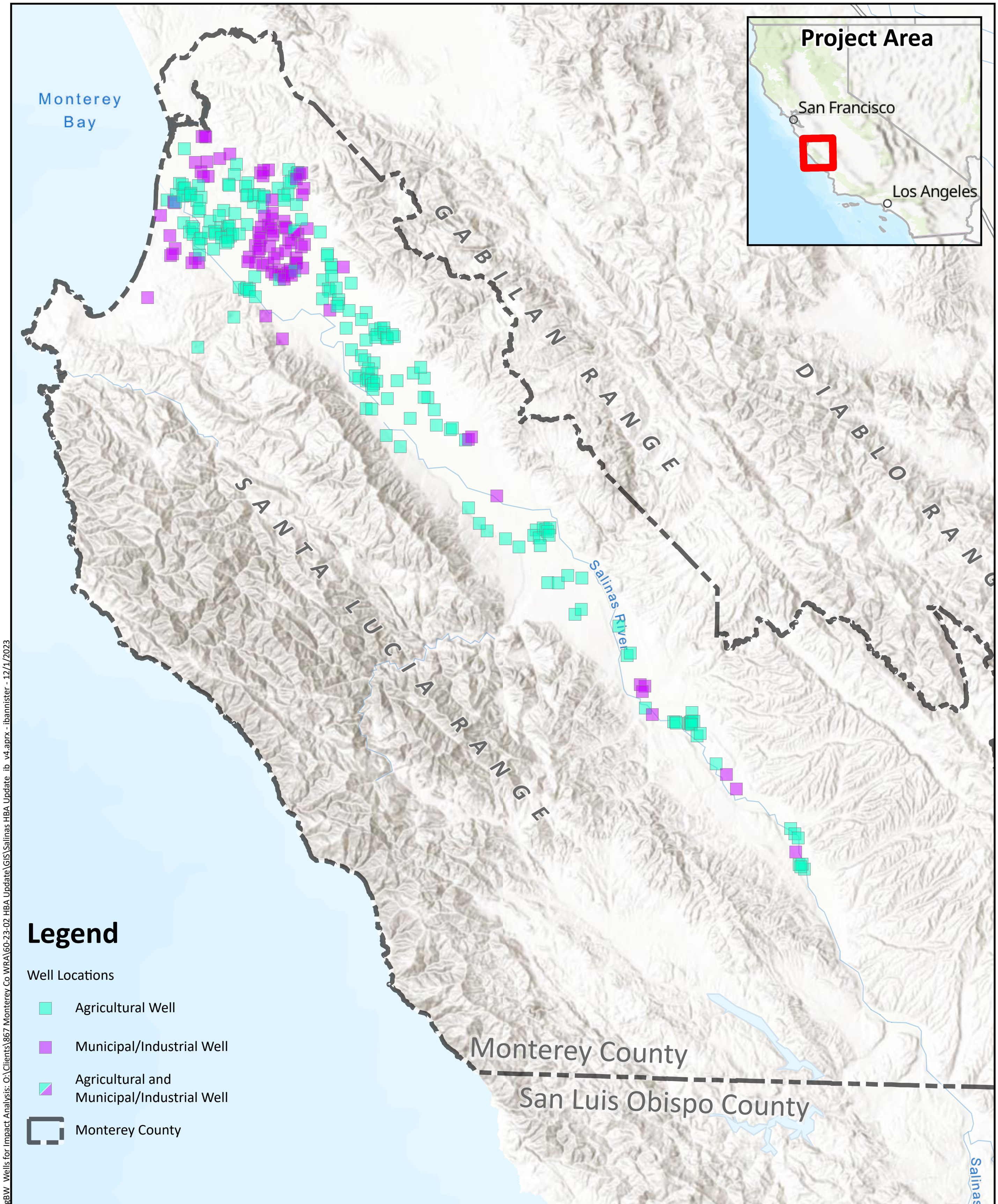
Because of the above, impact to wells can be considered in two ways. First, the approach of the 1998 HBA can be maintained (i.e., a well is impacted if pumping head drops at least 10 feet below the top of the screened interval). A second indication of impact to wells is changes to well pumping due to increased reliance on groundwater pumping to satisfy crop demands. Both approaches are investigated in this section. Results of this well impact analysis are presented in tabular form only; this follows the approach of the 1998 HBA.

3.5.1 Well Head Impact Analysis

The 1998 HBA only considered impacts on pumping heads when assessing well impacts, determining that about 5 percent of wells included in the analysis experienced some amount of impact. For wells in the northern part of the study area, the 1998 HBA determined that impacted wells could largely be modified (e.g., have their pump bowls lowered), whereas a portion of the impacted wells in the southern part of the study area would have to be replaced due to the magnitude of the impact.

Following the approach of the 1998 HBA, the well head impact analysis is limited to those wells for which detailed construction information was available from MCWRA; this represents a subset of 292 wells (out of 2,356 wells included in the model, not all of which actively pump during the model duration). Of the analyzed wells, 131 are in the Pressure Subarea, 100 in the East Side Subarea, 6 in the Arroyo Seco Subarea, 22 in the Forebay Subarea, 32 in the Upper Valley Subarea, none in the Below Dam Subarea, and 1 outside of the defined subareas. Municipal or industrial wells make up 96 of the 292 analyzed, and the remaining 196 are agricultural. Table 3-16 provides a tabulation of the number of wells included in the SVIHM in each subarea, plus how many of them were included in the well impact analysis. Figure 3-52 shows the locations of these wells; note that the locations are approximate, with the center of the well symbol representing the center of the model grid cell containing the well, rather than the coordinates of the well location itself.

Of the 292 wells included in the well head impact analysis, only two (one in the Pressure Subarea and one in the Upper Valley Subarea) experienced pumping head below the impact threshold (10 feet below the top of the screened interval) under the No Projects Scenario but not the Historical Scenario. In other words, due to the presence of the Projects, there are only two wells where head stays above the impact threshold. Both of these wells are agricultural. Table 3-17 presents the number of impacted wells in each subarea under the Historical and No Projects Scenarios and indicates the number of wells that are impacted without the Projects; Table 3-18 presents the same information by ESU. The two wells impacted under the No Projects Scenario but not under the Historical Scenario are located in ESUs 3 and 11.



Note: Symbols represent model cells containing at least one well included in the well impact analysis. Symbol locations do not correspond to exact well locations. Model cells containing both a municipal/industrial well and an agricultural well are shown as bi-colored.

Prepared by:

WEST YOST

0 5 10 Miles

0 8 16 Km

Prepared for:
Monterey County
Water Resources Agency
Salinas Valley HBA
April 2025

Wells Included in
Well Impact Analysis

Figure 3-52

Table 3-16. Wells in Each Subarea, with Proportion Included in Well Impact Analysis									
Area		Wells in SVIHM				Wells in Well Head Impact Analysis			
		Municipal/Industrial	Agricultural	Other	Total	Municipal/Industrial	Agricultural	Other	Total
Zone 2 C Subareas	**Pressure**	146	648	8	**802**	47	84	0	**131**
	East Side	85	446	0	**531**	39	61	0	**100**
	Arroyo Seco	12	166	0	**178**	0	6	0	**6**
	Forebay	42	306	0	**348**	3	19	0	**22**
	Upper Valley	54	373	0	**427**	7	25	0	**32**
	Below Dam	2	18	0	**20**	0	0	0	**0**
Paso Robles Basin		0	0	0	**0**	0	0	0	**0**
Offshore		0	0	0	**0**	0	0	0	**0**
Other Non-Zone 2C Areas		5	45	0	**50**	0	1	0	**1**

Table 3-17. Well Impact Analysis Results by Subarea

Area		Wells Impacted Under Historical Scenario				Wells Impacted Under No Projects Scenario			
		Municipal/Industrial	Agricultural	Other	Total	Municipal/ Industrial	Agricultural	Other	Total
Zone 2 C Subareas	**Pressure**	9	14	0	**23**	9	15	0	**24**
	East Side	29	21	0	**50**	29	21	0	**50**
	Arroyo Seco	0	1	0	**1**	0	1	0	**1**
	Forebay	1	3	0	**4**	1	3	0	**4**
	Upper Valley	3	13	0	**16**	3	14	0	**17**
	Below Dam	0	0	0	**0**	0	0	0	**0**
Paso Robles Basin		0	0	0	**0**	0	0	0	**0**
Offshore		0	0	0	**0**	0	0	0	**0**
Other Non-Zone 2C Areas		0	1	0	**1**	0	1	0	**1**

Table 3-18. Wells Head Impact Analysis Results by ESU								
ESU	Wells Impacted Under Historical Scenario				Wells Impacted Under No Projects Scenario			
	Municipal/Industrial	Agricultural	Other	Total	Municipal/ Industrial	Agricultural	Other	Total
1	0	0	0	0	0	0	0	0
2	28	10	0	38	28	10	0	38
3	8	6	0	14	8	7	0	15
4	1	1	0	2	1	1	0	2
5	1	11	0	12	1	11	0	12
6	0	0	0	0	0	0	0	0
7	0	7	0	7	0	7	0	7
8	0	0	0	0	0	0	0	0
9	1	3	0	4	1	3	0	4
10	0	1	0	1	0	1	0	1
11	1	12	0	13	1	13	0	14
12	2	1	0	3	2	1	0	3
13	0	0	0	0	0	0	0	0
14	0	1	0	1	0	1	0	1

3.5.2 Well Pumping Impact Analysis

As discussed above, the SVIGSM simulated the same amount of well pumping under the historical and "without reservoirs" cases. Because of this, the 1998 HBA did not include an analysis on the effects of the reservoirs on well pumping. Because the SVIHM uses FMP to simulate agricultural supply and demand, effects on well pumping could be analyzed for this HBA Update. This could include increased well pumping because of increased agricultural demand or reduced well pumping because of decreased agricultural demand or head in pumping wells being reduced beyond the well's capability to continue pumping.

As noted in Section 3.3.2, there is about 10,000 afy less agricultural pumping simulated under the Historical Scenario than the No Projects Scenario. Over the entire model duration, this difference amounts to about 500,000 af. The largest proportion of this difference (about 299,000 af) occurs in the Pressure Subarea, followed by the Upper Valley Subarea (about 104,000 af), Forebay Subarea (about 76,000 af), Arroyo Seco Subarea (about 12,000 af), East Side Subarea (about 7,000 af), and other areas outside of Zone 2C (about 2,000 af). There is approximately no difference in agricultural pumping in the Below Dam Subarea or Paso Robles Basin.

Figure 3-53 shows a time series of the cumulative difference in agricultural pumping between the Historical and No Projects Scenario by subarea. The difference in agricultural pumping in the Pressure and East Side Subareas increases substantially once CSIP starts operating in 1998; up to that point (covering the first 31 years of the model duration), the cumulative difference (i.e., decreased pumping) in agricultural pumping was about 24,000 af in the Pressure Subarea and less than 1,000 af in the East Side Subarea. Over the remaining 20 years of the model duration, the cumulative difference in agricultural pumping increases by about 275,000 af in the Pressure Subarea and 7,000 af in the East Side Subarea. The bulk of this difference is likely due to the operation of CSIP, which receives recycled water from Monterey One Water and Salinas River water from the SRDF. The application of these water sources to agricultural fields within the CSIP area results in reduced demand from wells supplying those fields. Impacts extend into the East Side Subarea likely due to increased water present within the root zone of crops, reducing the need for groundwater pumping to supply crops.

In contrast, the cumulative difference in agricultural pumping increases more uniformly in the other parts of the study area (Figure 3-53). In the Arroyo Seco, Forebay, and Upper Valley Subareas, the cumulative difference over the entire model duration is about 193,000 af. Through 1998 (61 percent of the model duration), the cumulative difference is about 104,000 af, about 54 percent of the total. The difference in agricultural pumping in these subareas is likely due to operation of the reservoirs raising groundwater head levels, increasing the ability for agricultural crops to rely on water present in the soil zone and reducing the need for groundwater pumping for irrigation.

There is effectively no difference (less than 1,000 af total over entire domain and duration of the model) in municipal and industrial pumping, indicating that operation of municipal and industrial wells is not affected by the presence of the Projects.

Table 3-19 presents the average annual pumping by well type for each ESU for the Historical and No Projects Scenarios, as well as the difference between the two scenarios. Average annual pumping is largest in ESUs 11 and 3, which are within the Upper Valley and Pressure Subareas, respectively. These ESUs also see the largest difference in pumping between the scenarios; pumping is about 5,400 afy lower in ESU 3 under the Historical Scenario than under the No Projects Scenario, and about 1,100 afy smaller in ESU 11. ESUs 9 and 12 each had about 900 afy less pumping under the Historical Scenario than under the No Projects Scenario, and ESU 8 had about 600 afy less. All other ESUs had 300 afy or less difference between the scenarios.

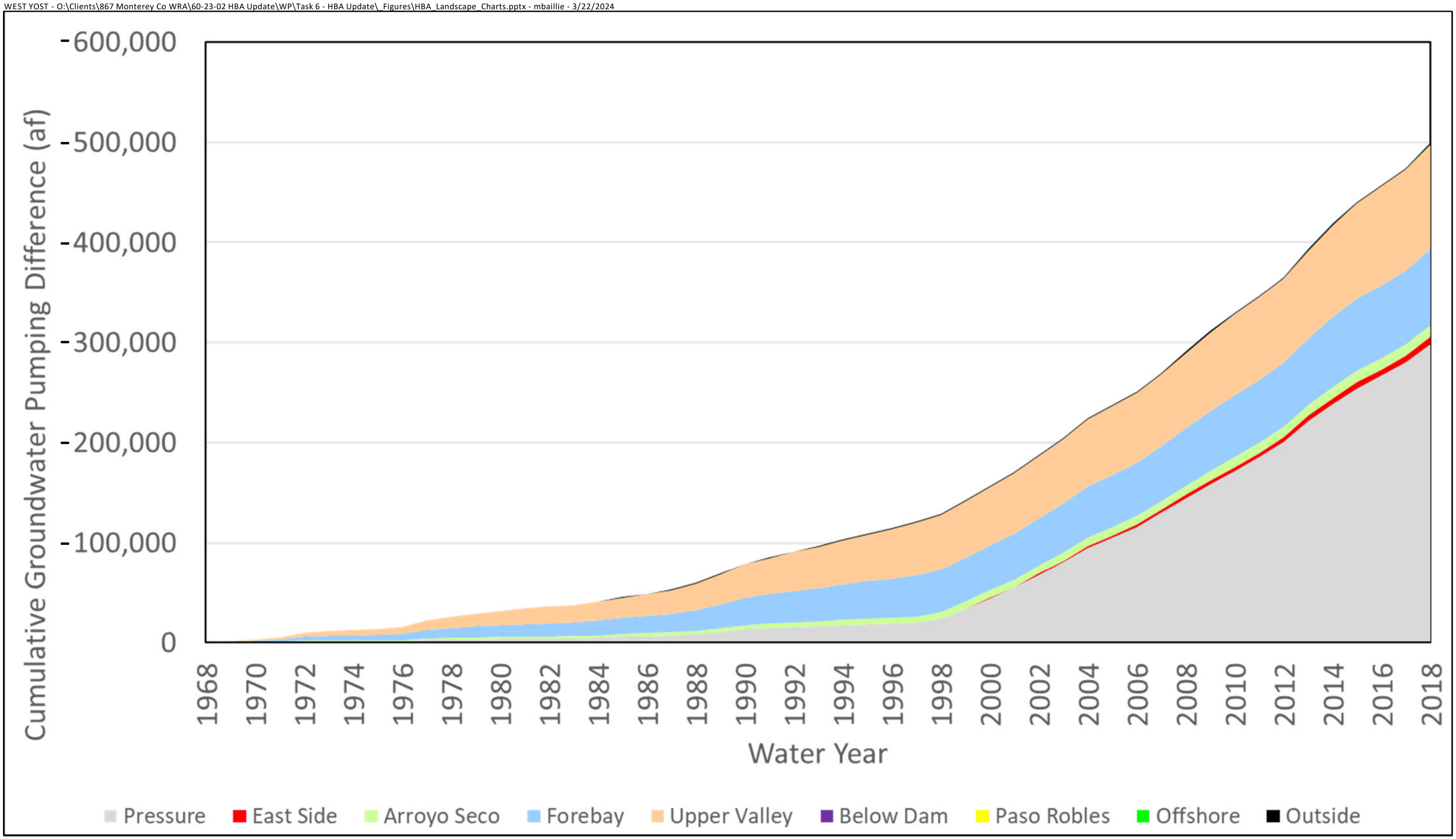


Figure 3-53

Cumulative Difference in Agricultural Pumping by Subarea

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Table 3-19. Average Annual Pumping (in afy) by ESU, Historical and No Projects Scenarios

	Historical Scenario				No Projects Scenario				Difference Between Scenarios			
ESU	Municipal/ Industrial	Agricultural	Other	Total	Municipal/ Industrial	Agricultural	Other	Total	Municipal/ Industrial	Agricultural	Other	Total
1	100	100	0	100	100	100	0	100	0	0	0	0
2	9,700	17,800	0	27,500	9,700	18,000	0	27,700	< 100	-100	0	-100
3	17,000	44,200	0	61,200	17,000	49,500	0	66,600	0	-5,400	0	-5,400
4	4,600	300	0	5,000	4,600	300	0	5,000	< 100	< 100	0	< 100
5	2,100	50,500	0	52,600	2,100	50,500	0	52,600	0	< 100	0	< 100
6	700	25,100	0	25,800	700	25,400	0	26,100	0	-300	0	-300
7	1,200	29,100	0	30,300	1,200	29,300	0	30,500	0	-200	0	-200
8	2,600	40,000	0	42,600	2,600	40,600	0	43,200	0	-600	0	-600
9	2,400	47,800	0	50,200	2,400	48,700	0	51,200	0	-900	0	-900
10	1,700	35,500	0	37,200	1,700	35,700	0	37,400	< 100	-200	0	-200
11	2,800	86,300	0	89,100	2,800	87,400	0	90,200	0	-1,100	0	-1,100
12	1,100	32,600	0	33,700	1,100	33,600	0	34,700	0	-900	0	-900
13	100	1,100	0	1,200	100	1,100	0	1,200	0	0	0	0
14	1,700	8,500	0	10,200	1,700	8,500	0	10,300	0	< 100	0	< 100

Notes:

- Pumping totals are rounded to the nearest 100 acre-feet per year; totals may not sum due to rounding

3.6 SEAWATER INTRUSION

As discussed in Chapter 2, the SVIHM does not have the capability to directly simulate the intrusion of seawater into freshwater aquifers, which is driven in part by the density difference between seawater and freshwater. The interfaces between the freshwater aquifers simulated by the SVIHM and the Pacific Ocean at Monterey Bay are characterized as general head boundaries (i.e., head-dependent flux boundaries), which allows the model to calculate flux across the boundary based on the user-specified head at the boundary, user-specified conductance of the boundary, and simulated head within the model. Head at these interfaces is set based on the fluctuation of sea level over the historical period, scaled by a factor to account for the difference between seawater and freshwater density (i.e., turning the sea level data into "equivalent freshwater head" values). The SVIHM includes undersea general head boundaries on Model Layers 1, 3, 5, 8, and 9. Within the Pressure Subarea, these model layers generally represent the Shallow Aquifer (Model Layer 1), 180-Foot Aquifer (Model Layer 3), 400-Foot Aquifer (Model Layer 5), and Deep Aquifers (Model Layers 8 and 9). It is important to note that the connection between the Deep Aquifers and the Pacific Ocean is currently not well-understood, and that the presence of a boundary condition allowing communication between the Deep Aquifers and the Pacific Ocean represents an assumption about the system that cannot be confirmed or disproven without further studies.

The SVIHM-simulated flux of groundwater across the coast can be taken as a reasonable estimate of the rate of seawater intrusion into the freshwater aquifers of the study area, keeping in mind the limitations noted above. The difference in this coastal flux represents the effect of the Projects on the amount of seawater intrusion.

The cumulative simulated seawater intrusion flux across the coast was about 763,000 af under the Historical Scenario and about 831,000 af under the No Projects Scenario, indicating that the Projects have resulted in a total decrease in seawater intrusion of about 68,000 af over the 51-year period of this analysis. Table 3-20 provides the cumulative total and average annual simulated seawater intrusion for the entire model duration for each of the important freshwater aquifers identified in the Pressure Subarea (the Shallow, 180-Foot, 400-Foot, and Deep Aquifers). The largest difference between the scenarios (about 38,000 af) occurred in the 400-Foot Aquifer (Model Layer 5). An additional difference of about 24,000 af occurred in the 180-Foot Aquifer (Model Layer 3). The Shallow (Model Layer 1) and Deep (Model Layers 7 through 9) Aquifers each had about 3,000 af less seawater intrusion under the Historical Scenario.

Figures 3-54 and 3-55 show the simulated seawater intrusion flux into the 180-Foot and 400-Foot Aquifers, respectively, under both scenarios, as well as the difference between the scenarios. These time series charts show that there is a major inflection in the difference between scenarios after 1998, with the bulk of the difference between scenarios in both aquifers occurring mainly after this point. The cumulative difference between the scenarios was only about 1,000 af up to this point in both aquifers, meaning that there was a reduction in seawater intrusion of about 23,000 af in the 180-Foot Aquifer and about 37,000 af in the 400-Foot Aquifer. This indicates that the difference between the scenarios in terms of seawater intrusion was likely the result of operation of the CSIP system, which deceased agricultural pumping demand in the coastal area, leading to higher groundwater heads in this area and a smaller landward head gradient.

The active model domain at the coast falls into two Zone 2C Subareas (the Pressure and East Side Subareas), plus areas outside of Zone 2C (e.g., parts of the Seaside Basin). The coastal part of the East Side Subarea is extremely small, limited to 2 model cells (i.e., about 1,000 feet). The total cumulative simulated seawater intrusion into the East Side Subarea was about 1,000 af for both scenarios, and is not considered further in this discussion. Under the Historical Scenario, about 63 percent of the simulated seawater intrusion (about 483,000 af) occurred into the Pressure Subarea, with the remaining 37percent (about 280,000 af) occurring outside of Zone 2C. Under the No Projects Scenario, about 64 percent (about 533,000 af) occurred into the Pressure Subarea, with the remaining 36 percent (about 297,000 af) occurring outside of Zone 2C. The difference between scenarios was about 50,000 af into the Pressure Subarea, and about 17,000 af outside of Zone 2C.

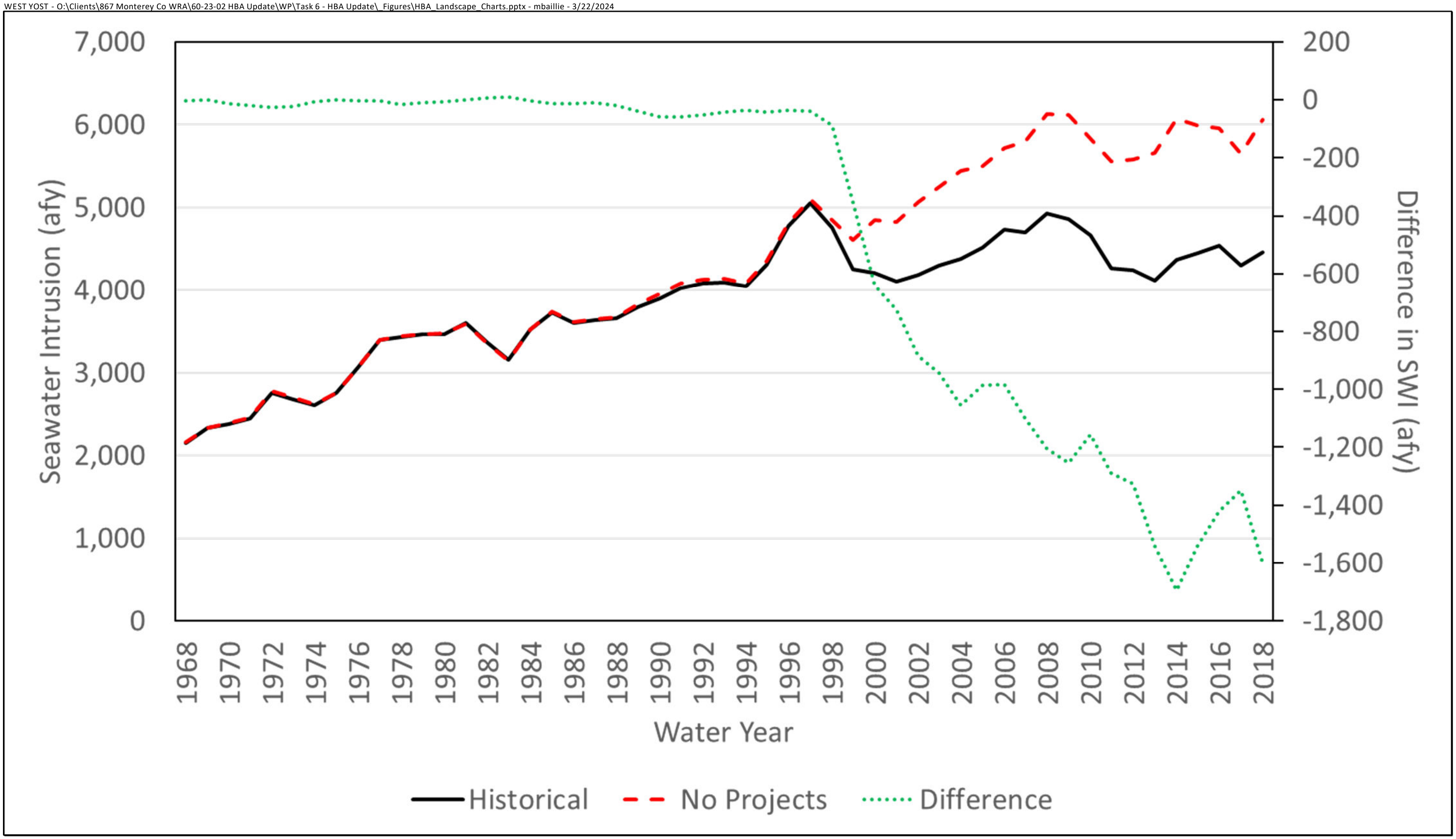

Figure 3-54

Annual Seawater Intrusion into 180-Foot Aquifer and Equivalent, Historical and No Projects Scenarios

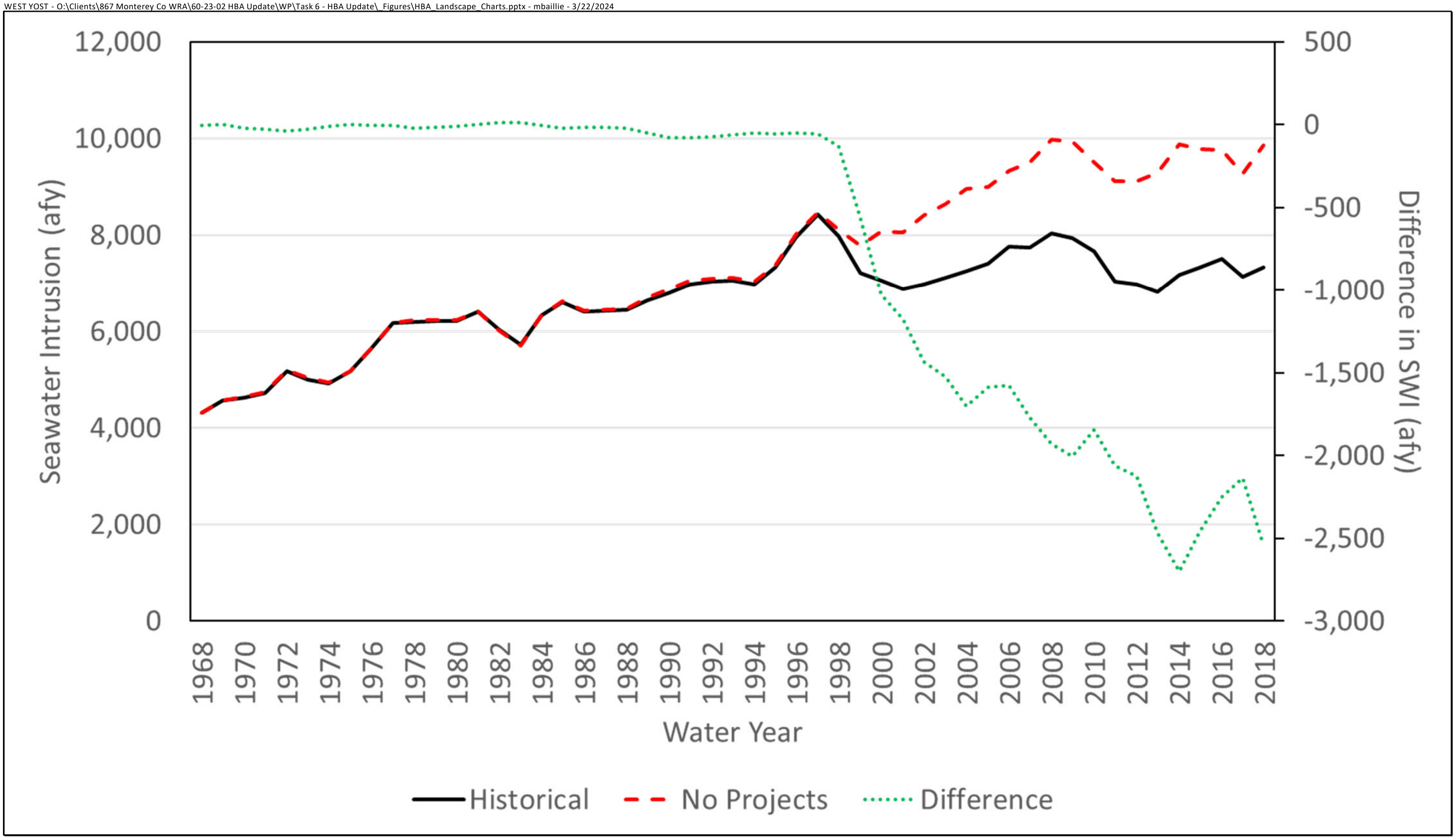

Figure 3-55

Annual Seawater Intrusion into 400-Foot Aquifer and Equivalent, Historical and No Projects Scenarios

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Table 3-20. Cumulative and Average Annual Simulated Seawater Intrusion Flux by Aquifer

Aquifer	Model Layer(s)	Historical		No Projects		Difference	
		Cumulative, af	Average, afy	Cumulative, af	Average, afy	Cumulative, af	Average, afy
Shallow	1	136,000	2,680	139,000	2,740	-3,000	-60
180-Foot	3	197,000	3,860	220,000	4,320	-24,000	-470
400-Foot	5	339,000	6,650	377,000	7,390	-38,000	-740
Deep	7-9	91,000	1,780	94,000	1,840	-3,000	-60

Notes:
- Cumulative seawater intrusion volumes are rounded to the nearest 1,000 acre-feet and average annual seawater intrusion fluxes are rounded to the nearest 10 acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

CHAPTER 4
Flood Control Benefits Analysis

This chapter of the HBA Update describes the effects that the Projects have had on the frequency and severity of inundation under peak flows in the Salinas River within the study area. This analysis quantifies how the statistical distribution of peak flows has changed due to the presence and operation of the Nacimiento and San Antonio Reservoirs and related projects and programs since San Antonio Reservoir began operating (WY 1968). This analysis of the Flood Control Benefit relies on a combination of historical streamflow measurements, streamflow simulation, and groundwater-surface water modeling.

4.1 DATA SOURCES

The Flood Control Benefits Analysis relies on several different sources of data. At its core, this analysis is built from streamflow observations collected by the USGS. These are supplemented by various modeling results to produce estimates of streamflow with and without the Projects.

Figure 1-7 shows the locations of USGS streamflow gauges (active and inactive) in and surrounding the study area. This Flood Control Benefits Analysis utilized data from the stream gauges listed in Table 4-1, especially the gauge in the Salinas River at Bradley.

In addition to streamflow observations from the USGS gauges, this Flood Control Benefits Analysis utilizes simulated streamflow data to develop flood frequency curves and to simulate the effects of peak flows on the Salinas River floodplain. These include simulated streamflow from the USGS SVWM and simulated groundwater-surface water interaction from the SVIHM. The SVWM provides simulated mean daily streamflow for the historical period in the Salinas River at a point just downstream of San Miguel (i.e., the location where the Salinas River enters the SVIHM domain). The SVIHM provides simulated groundwater-surface water flux along the Salinas River from where it enters the SVIHM domain to the location of the Salinas River at Bradley stream gauge and along the Nacimiento and San Antonio Rivers from their respective dams to their confluences with the Salinas River.

The SVIHM results represent simulated groundwater-surface water flux representative of conditions during each model timestep, which is from five to six days depending on the length of each month. The simulated streamflow values used to calculate the groundwater-surface water flux are highly dependent on the monthly streamflow inputs that occur along the edges of the model (e.g., the San Antonio River at San Antonio Dam, the Nacimiento River about five miles downstream of the Nacimiento Dam, and the Salinas River just downstream of San Miguel). The time discretization of the SVIHM (5- to 6-day timesteps within monthly stress periods) has a major impact on the time series of simulated streamflow within that model, making SVIHM-simulated streamflow poorly suited to direct use for understanding the statistical distribution of peak flows.

Section 4.2 below summarizes the SVIHM-simulated effects on total streamflow at selected locations in the surface water network. Section 4.3 describes how the available data were used to determine the statistical distribution of peak flows in the Salinas River at Bradley.

Table 4-1. Stream Gauges Used in Flood Control Benefit Analysis

Gauge Name	Gauge Number	Latitude	Longitude	Datum	Mean Daily Observations		15-Minute Observations		Status	Type
					Start Date	End Date	Start Date	End Date		
NACIMIENTO R BL SAPAQUE C NR BRYSON CA	11148900	35.78861111	121.0927778	NAD27	9/16/1971	Present	10/1/1988	Present	Active	Stream
NACIMIENTO RES NR BRADLEY CA	11149300	35.75782222	120.8845417	NAD83	None	None	11/19/2020	Present	Active	Lake
NACIMIENTO R BL NACIMIENTO DAM NR BRADLEY CA	11149400	35.76138889	120.8544444	NAD27	10/1/1957	Present	10/1/1988	Present	Active	Stream
SAN ANTONIO R NR LOCKWOOD CA	11149900	35.89666667	121.0872222	NAD27	10/1/1965	Present	12/14/1986	Present	Active	Stream
SAN ANTONIO RES NR BRADLEY CA	11150100	35.79681667	120.8857806	NAD83	None	None	12/9/2020	Present	Active	Lake
SALINAS R NR BRADLEY CA	11150500	35.93027778	120.8677778	NAD27	10/1/1948	Present	10/1/1988	Present	Active	Stream
SAN LORENZO C BL BITTERWATER C NR KING CITY CA	11151300	36.26805556	121.0652778	NAD27	10/1/1958	Present	10/1/1988	Present	Active	Stream
SALINAS R A SOLEDAD CA	11151700	36.41111111	121.3183333	NAD27	10/1/1968	Present	10/1/1988	Present	Active	Stream
ARROYO SECO BL RELIZ C NR SOLEDAD CA	11152050	36.39972222	121.3230556	NAD27	10/1/1944	Present	11/1/1994	Present	Active	Stream
SALINAS R NR CHUALAR CA	11152300	36.55361111	121.5483333	NAD27	10/1/1976	Present	10/1/1988	Present	Active	Stream
SALINAS R NR SPRECKELS CA	11152500	36.63111111	121.6713889	NAD27	10/1/1929	Present	1/25/1989	Present	Active	Stream

4.2 MEAN ANNUAL SIMULATED STREAMFLOW

Changes to the average annual streamflow at various locations in the stream network indicate how the Projects have affected the Salinas River and its tributaries. This section describes the simulated changes to streamflow at selected locations in the stream network based on simulated streamflows from the SVIHM. As noted above, the SVIHM is not well-suited to the estimation of peak streamflows due to the temporal discretization of the model, but it is useful for understanding overall streamflow changes under averaged conditions.

Table 4-2 provides the average annual streamflow at various points in the Salinas River and its tributaries for the Historical and No Projects Scenarios, as well as the difference between the scenarios. Annual averages are provided in both afy and cfs for all years as well as wet, normal, and dry years.

On average, there was about 445,000 afy of flow in the Salinas River at Bradley under the Historical Scenario, which combines inflows from the Paso Robles Basin to the south, the Nacimiento River (about 194,000 afy), and the San Antonio River (about 62,000 afy). This flow decreased to about 270,000 afy in the Salinas River at Soledad. With inflow of about 117,000 afy from Arroyo Seco, streamflow in the Salinas River increased to about 295,000 afy at Chualar. Flow in the Salinas River decreased to about 264,000 afy at Spreckels. The average annual streamflow varies little below Spreckels, increasing very slightly to about 272,000 afy at the head of the Salinas River Lagoon and about 273,000 afy at the mouth of the Salinas River, representing outflow to Monterey Bay. Changes to streamflow below Spreckels result from simulated land surface runoff and agricultural return flow entering the Salinas River.

Under the No Projects Scenario, there was slightly more flow entering the Salinas River from the Nacimiento River (about 204,000 afy, about 10,000 afy more than the Historical Scenario) and San Antonio River (about 73,000 afy, about 11,000 afy more compared to the Historical Scenario). At Bradley, the No Projects Scenario simulated about 460,000 afy of streamflow, about 15,000 afy more than under the Historical Scenario.

The differences of flows between the two scenarios increased below Bradley. Under the No Projects Scenario, average annual simulated streamflow was about 319,000 afy in the Salinas River at Soledad (about 49,000 afy more than under the Historical Scenario), about 350,000 afy at Chualar (about 55,000 afy more than under the Historical Scenario), about 317,000 afy at Spreckels (about 53,000 afy more than under the Historical Scenario), about 323,000 afy at the head of the Salinas River Lagoon, and about 324,000 afy at the mouth of the Salinas River (both about 51,000 afy more than under the Historical Scenario).

Simulated average annual flow during wet years was substantially higher compared to normal and dry years. The differences between the scenarios was also largest during wet years throughout the system, with about 161,000 afy less flow out to Monterey Bay under the Historical Scenario compared to the No Projects Scenario (there was also less outflow to the ocean during average normal and dry years as a result of the Projects). This demonstrates the ability of the Projects to keep additional water within the Basin, resulting from the storage of high flows during wet periods in the Nacimiento and San Antonio Reservoirs and subsequent release during drier periods. Much of this difference in streamflow represents additional recharge to the groundwater system through increased streamflow losses with the Projects in place. This is demonstrated by the differences in streamflow simulated during dry years; the Projects resulted in about 112,000 afy of additional flow in the Salinas River at Bradley during dry years, but this difference disappeared by about Chualar.

Table 4-2. Average Annual Simulated Streamflow (in acre-feet per year and cubic feet per second) at Selected Locations in Stream Network

Average Annual Streamflow, acre-feet per year	Historical Scenario				No Projects Scenario				Difference			
	All Years	Wet Years	Normal Years	Dry Years	All Years	Wet Years	Normal Years	Dry Years	All Years	Wet Years	Normal Years	Dry Years
Nacimiento River below Nacimiento Dam	194,000	324,000	164,000	131,000	204,000	451,000	155,000	72,000	-10,000	-127,000	+9,000	+59,000
San Antonio River below San Antonio Dam	62,000	72,000	52,000	68,000	73,000	175,000	51,000	22,000	-11,000	-102,000	+1,000	+46,000
Salinas River below San Antonio River Confluence	422,000	846,000	302,000	242,000	439,000	1,072,000	288,000	132,000	-17,000	-225,000	+14,000	+110,000
Salinas River at Bradley	445,000	889,000	321,000	254,000	460,000	1,112,000	305,000	142,000	-15,000	-223,000	+16,000	+112,000
Salinas River at Soledad	270,000	681,000	158,000	90,000	319,000	867,000	176,000	70,000	-49,000	-186,000	-18,000	+20,000
Arroyo Seco below Reliz Creek	117,000	242,000	98,000	43,000	117,000	242,000	97,000	43,000	< 1,000	< 1,000	< 1,000	< 1,000
Salinas River at Chualar	295,000	767,000	175,000	76,000	350,000	939,000	201,000	76,000	-55,000	-173,000	-26,000	< 1,000
Salinas River at Spreckels	264,000	706,000	148,000	64,000	317,000	872,000	172,000	67,000	-53,000	-166,000	-24,000	-3,000
Salinas River Lagoon	272,000	713,000	157,000	71,000	323,000	875,000	179,000	72,000	-51,000	-161,000	-22,000	-1,000
Salinas River Outflow to Monterey Bay	273,000	715,000	158,000	72,000	324,000	876,000	180,000	72,000	-51,000	-161,000	-22,000	-1,000

Notes:
- Streamflow totals are rounded to the nearest 1,000 acre-feet per year and displayed in thousands of acre-feet per year; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Table 4-2. Average Annual Simulated Streamflow (in acre-feet per year and cubic feet per second) at Selected Locations in Stream Network												
Average Annual Streamflow, cubic feet per second	Historical Scenario				No Projects Scenario				Difference			
	All Years	Wet Years	Normal Years	Dry Years	All Years	Wet Years	Normal Years	Dry Years	All Years	Wet Years	Normal Years	Dry Years
Nacimiento River below Nacimiento Dam	268	447	226	180	282	622	213	99	-14	-175	+13	+81
San Antonio River below San Antonio Dam	85	100	71	93	101	241	70	30	-16	-141	+1	+63
Salinas River below San Antonio River Confluence	582	1,169	417	334	606	1,480	397	183	-23	-311	+19	+151
Salinas River at Bradley	614	1,227	443	350	635	1,535	421	196	-21	-308	+22	+154
Salinas River at Soledad	373	941	218	124	440	1,197	243	96	-67	-256	-25	+28
Arroyo Seco below Reliz Creek	162	334	135	60	162	334	135	59	0	0	0	0
Salinas River at Chualar	407	1,059	242	105	483	1,297	278	105	-76	-239	-36	0
Salinas River at Spreckels	364	975	204	88	438	1,204	237	92	-74	-229	-33	-4
Salinas River Lagoon	375	985	217	98	446	1,208	247	99	-70	-223	-30	-2
Salinas River Outflow to Monterey Bay	377	987	219	99	447	1,210	249	100	-70	-223	-30	-1

Notes:
- Streamflow totals are rounded to the nearest cfs; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 4-1 shows the mean monthly streamflow in the Salinas River at Bradley for the Historical and No Projects Scenarios. The No Projects Scenario simulated much higher mean monthly streamflow in the winter, and very little flow from May to November. Figure 4-2 provides time series of observed and simulated total annual streamflow in the Salinas River at Bradley. Again, the Historical Scenario largely matched the pattern of historical streamflow, although it over-predicted streamflow for certain high-flow years (e.g., WY 1998). The No Projects Scenario simulated much higher total streamflow during many of the wet years (e.g., WY 1995 and 1998), and lower total streamflow during the driest years (e.g., WY 1976 and 1977). These figures provide another demonstration of how the Projects have affected the distribution of streamflow in the Salinas River. The Projects effectively redistribute streamflow from wet years and wet months of the year to drier periods, moderating the natural pattern of streamflow variability in the system.

4.3 FLOOD FLOW FREQUENCY ANALYSIS

The estimation of the magnitude of peak flows with and without the reservoirs relies on a statistical analysis of annual peak flows. As with the 1998 HBA, this HBA Update estimates the peak instantaneous, 1-day, 3-day, and 5-day flows corresponding to various return periods for the system. These peak flows represent the highest flow observed each water year (instantaneous), as well as the highest mean daily flow (1-day), 3-day average flow (3-day), and 5-day average flow (5-day). The peak instantaneous flow is equal to or higher than the peak 1-day flow, which is equal to or higher than the peak 3-day flow, which is equal to or higher than the peak 5-day flow. Peak instantaneous flows are determined from the data, and so may be affected by the data resolution. The USGS' automated stream gauges measure streamflow every 15 minutes, which is a fine enough temporal resolution to capture the approximate peak flow.

This section summarizes the approach that was used to estimate the parameters of the peak flow statistical distribution for the Salinas River at Bradley, which informed the shape of the Flood Frequency Curves. Because the analysis required the development of Flood Frequency Curves for the No Projects Scenario, an approach that could estimate peak flows from the available modeling tools head to be developed. The approach is described in more detail in Appendix B, including comparisons between the statistical peak flow distributions for the streamflow measurements taken during the historical period and those estimated based on the available modeling results.

The streamflow estimation process performs a simple mass balance of mean daily streamflow in the system above the location of the Salinas River at Bradley gauge (see Figure 4-3 for the area of the streamflow estimation). The data sources used for this analysis are described in Section 4.1; the exact data sources used depended on the scenario being analyzed. Both scenarios utilized the daily inflow into the Salinas River near San Miguel as the inflow along the Salinas River. The Historical Scenario used the mean daily reservoir release from Nacimiento and San Antonio Reservoirs, provided by MCWRA, as the inflows into the Nacimiento and San Antonio Rivers. The No Projects Scenario used the estimated mean daily reservoir inflow to the Nacimiento and San Antonio Reservoirs, provided by MCWRA, as inflows at the same locations. For each scenario, the groundwater-surface water flux was derived from the results of the respective SVIHM scenario; as noted above, the model timestep for the SVIHM lasts from 5 to 6 days, and the mean daily streamflow estimation used the simulated groundwater-surface water flux corresponding to each day of the analytical period. For example, the mean daily streamflow estimation for the period from September 1, 1967 to September 5, 1967 (the period of the first model timestep) used a single value of simulated groundwater-surface water flux while the various inflow components changed each day. Because the timescale of groundwater flow is substantially longer than surface water flow, and because the magnitude of the groundwater-surface water flux is very small compared to the streamflow (especially during the peak flows used for this analysis), this was considered an acceptable approximation.

As noted, Appendix B provides a comprehensive discussion of the streamflow estimation process, along with a comparison between its results and the historical streamflow measurements, including how the estimation process matches the statistical distribution of annual peak flows in the historical measurement time series.

Figure 4-4 provides a time series of annual (water year) peak instantaneous streamflow in the Salinas River at Bradley for the historical record, Historical Scenario, and No Projects Scenario, covering the period from WY 1968 to 2018. Differences in total and mean monthly streamflow between the Historical Scenario and the observed record (Figures 4-1 and 4-2) do not affect the ability of the estimation method to match the observed annual peak instantaneous flows. Figure 4-5 provides a cumulative distribution function (CDF) of the annual peak instantaneous streamflows in the observed record (WY 1968 to 2018) and estimated for the Historical and No Projects Scenario. Together, Figures 4-4 and 4-5 show that the streamflow estimation approach does an excellent job of re-creating the distribution of annual peak flows in the Salinas River at Bradley. The figures also demonstrate the effect that the Projects have on the peak flow distribution, substantially decreasing the magnitude of peak flows, particularly for the highest peak flows.

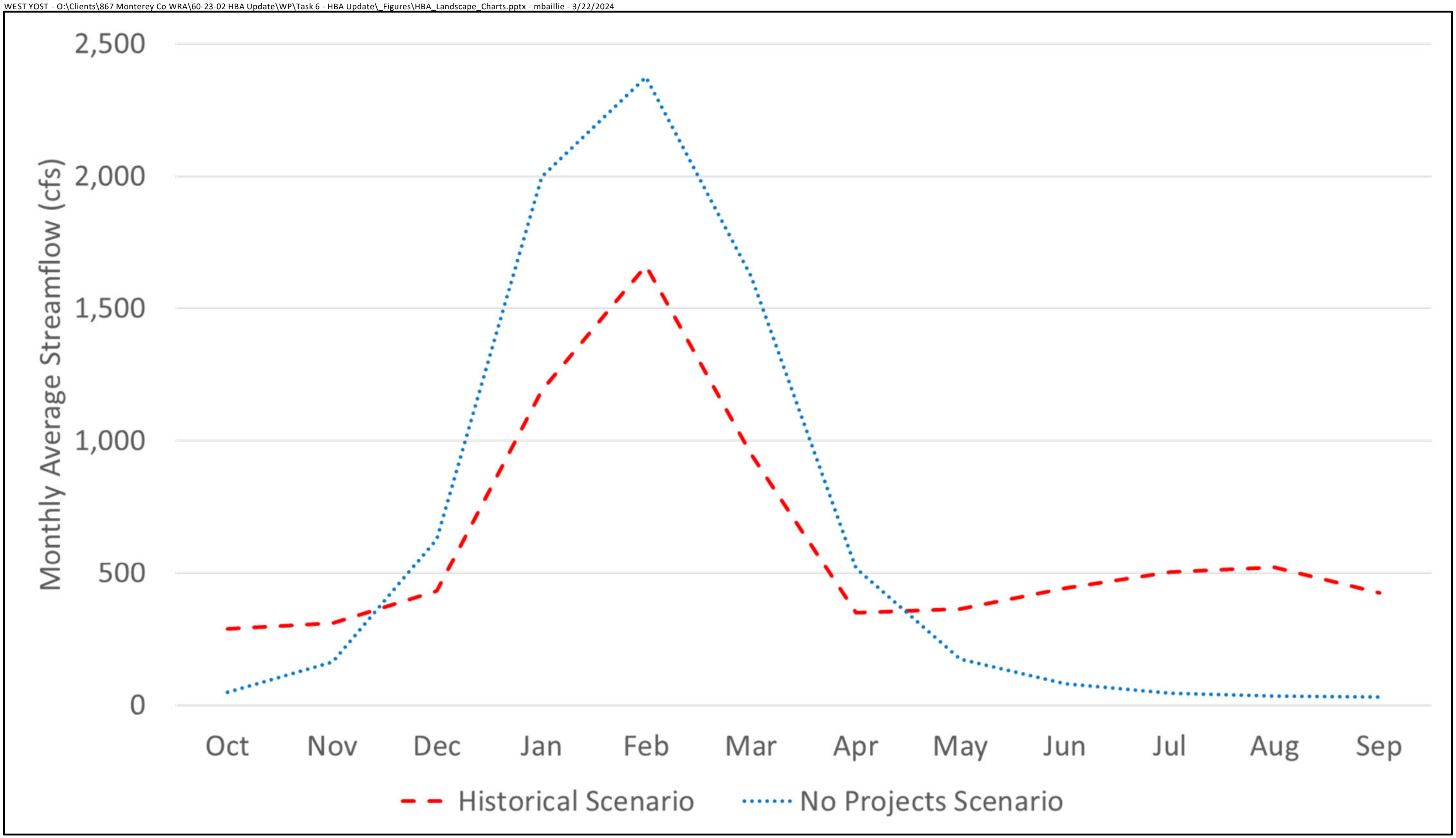

Figure 4-1

Monthly Average Simulated Streamflow in the Salinas River at Bradley

Monterey County Water Resources Agency

Historical Benefits Analysis Update

April 2025

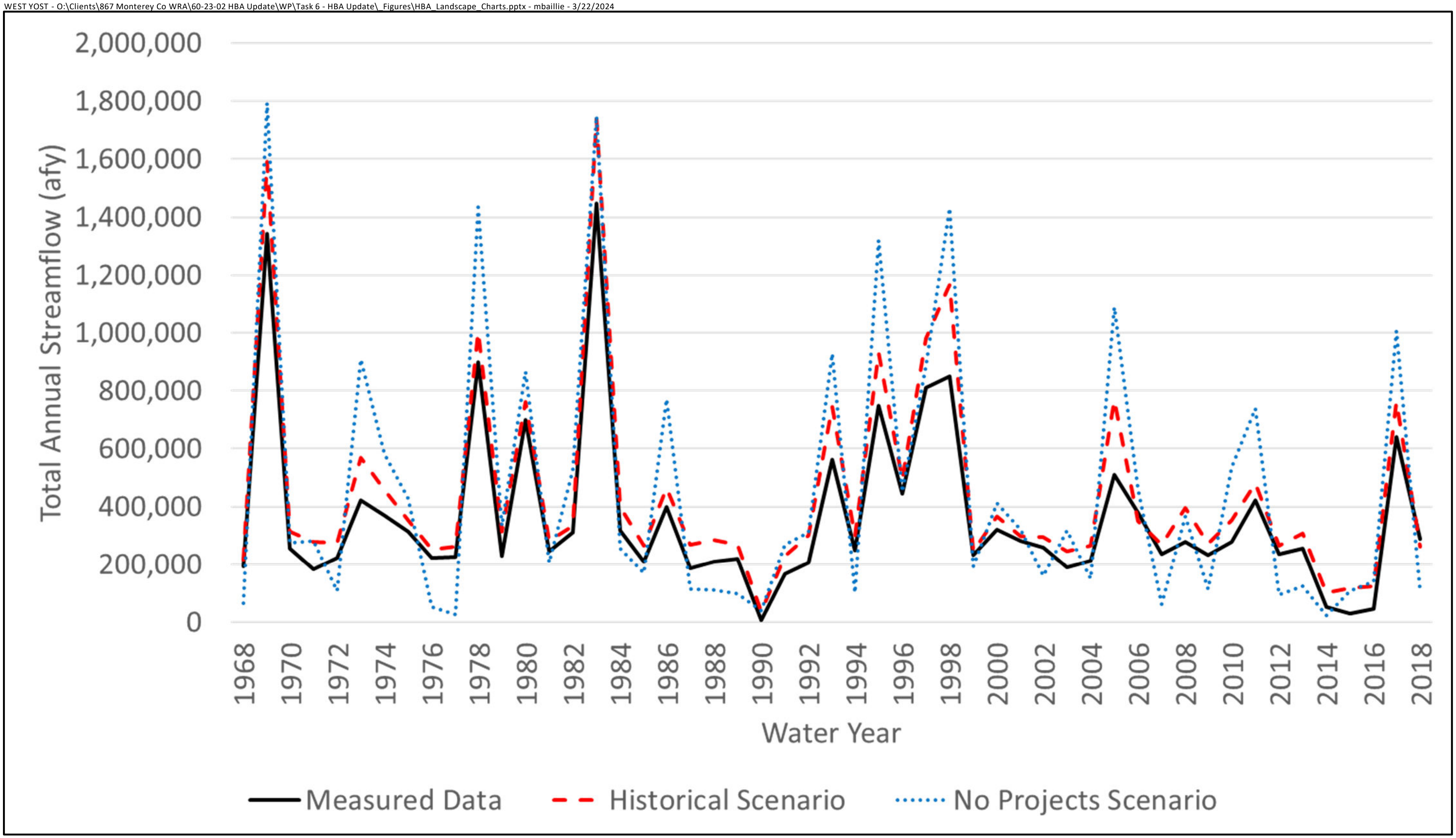

Figure 4-2

Annual Total Streamflow in the Salinas River at Bradley, Observed and Simulated

Monterey County Water Resources Agency

Historical Benefits Analysis Update

April 2025

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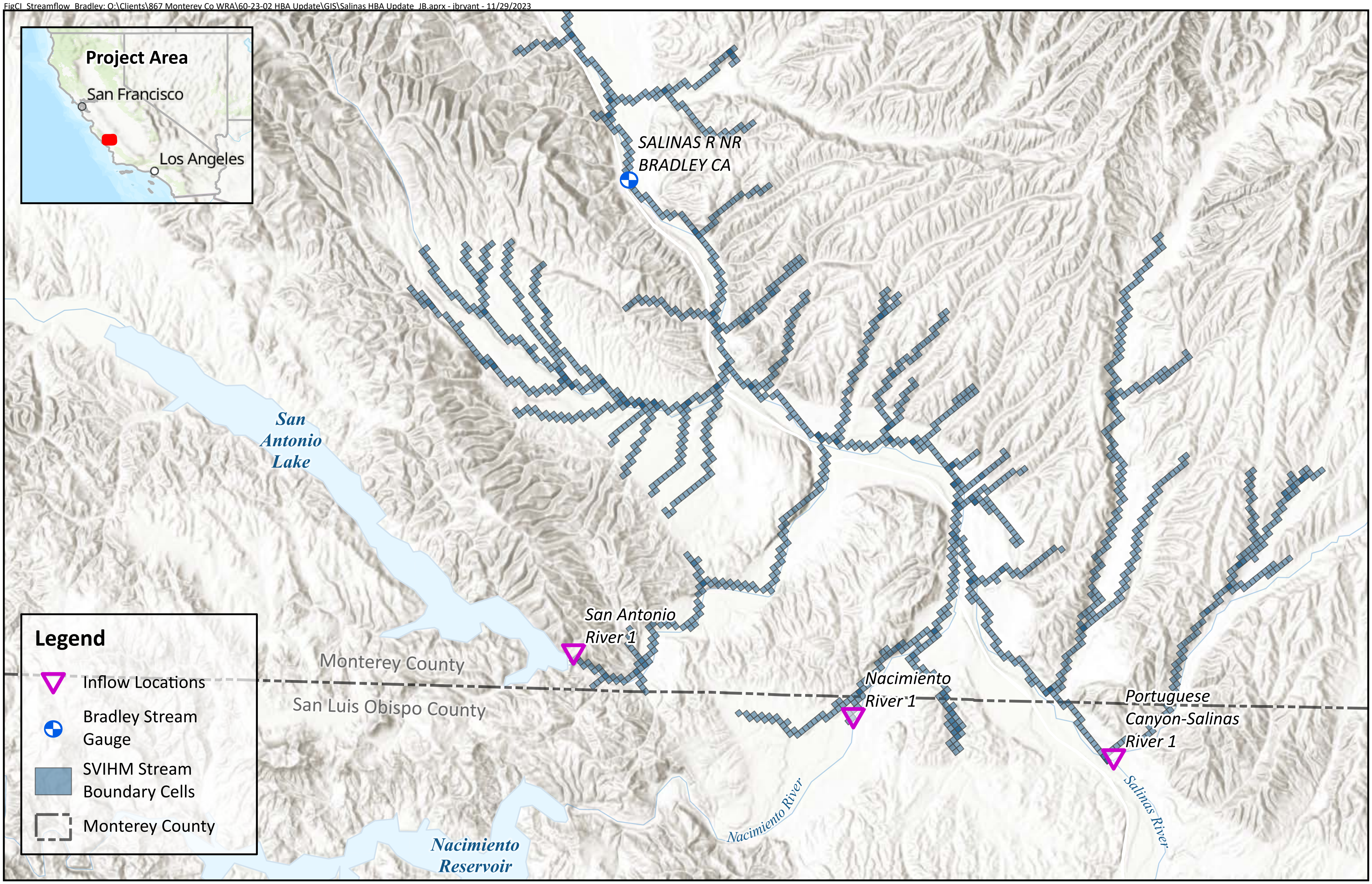

Prepared by:

WEST YOST

Prepared for:
Monterey County Water Resources Agency
Salinas Valley HBA
April 2025

Area of Streamflow Estimation for the Salinas River at Bradley
Figure 4-3

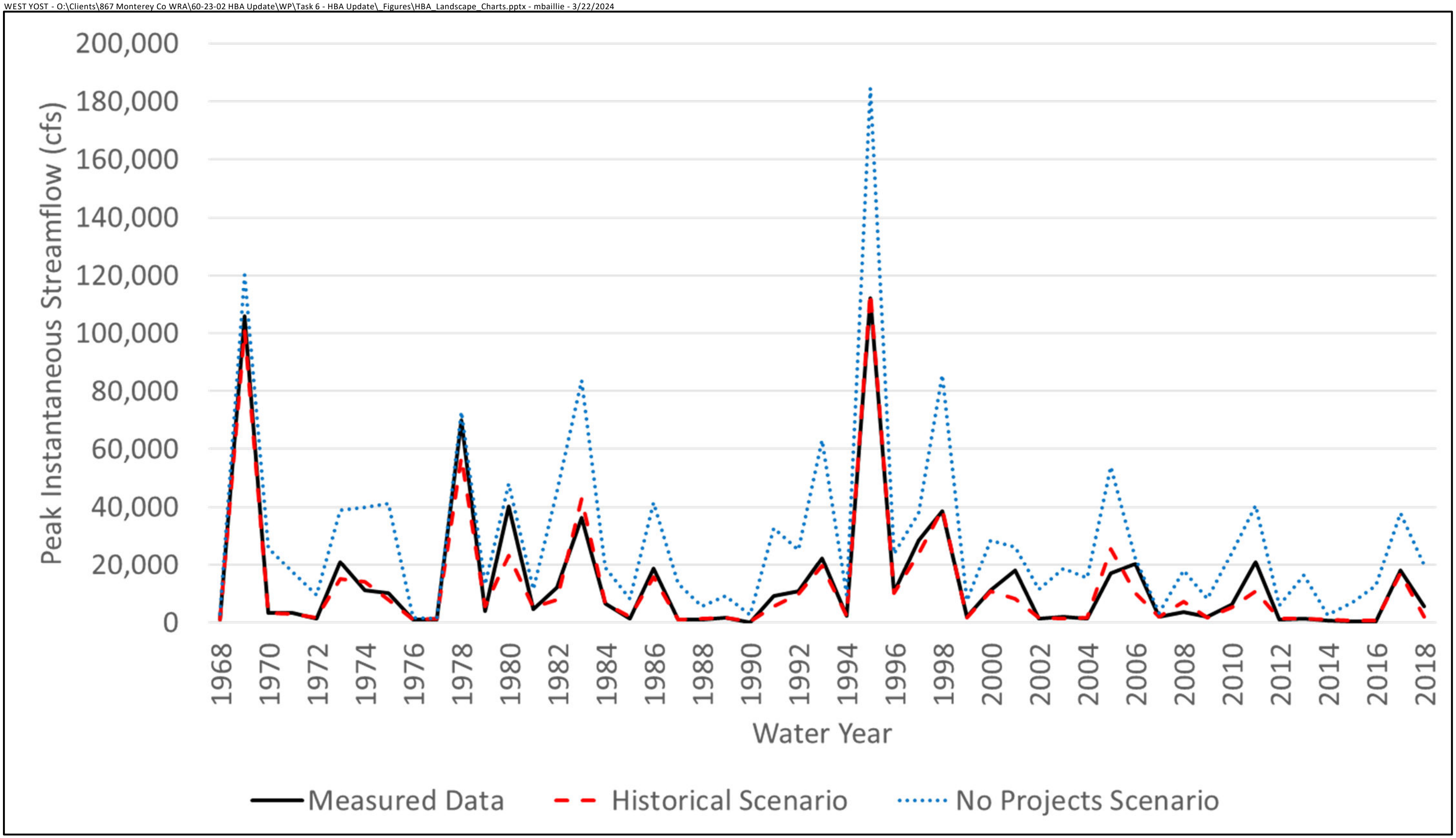

Figure 4-4

Annual Peak Streamflow in the Salinas River at Bradley, Observed and Estimated

Monterey County Water Resources Agency

Historical Benefits Analysis Update

April 2025

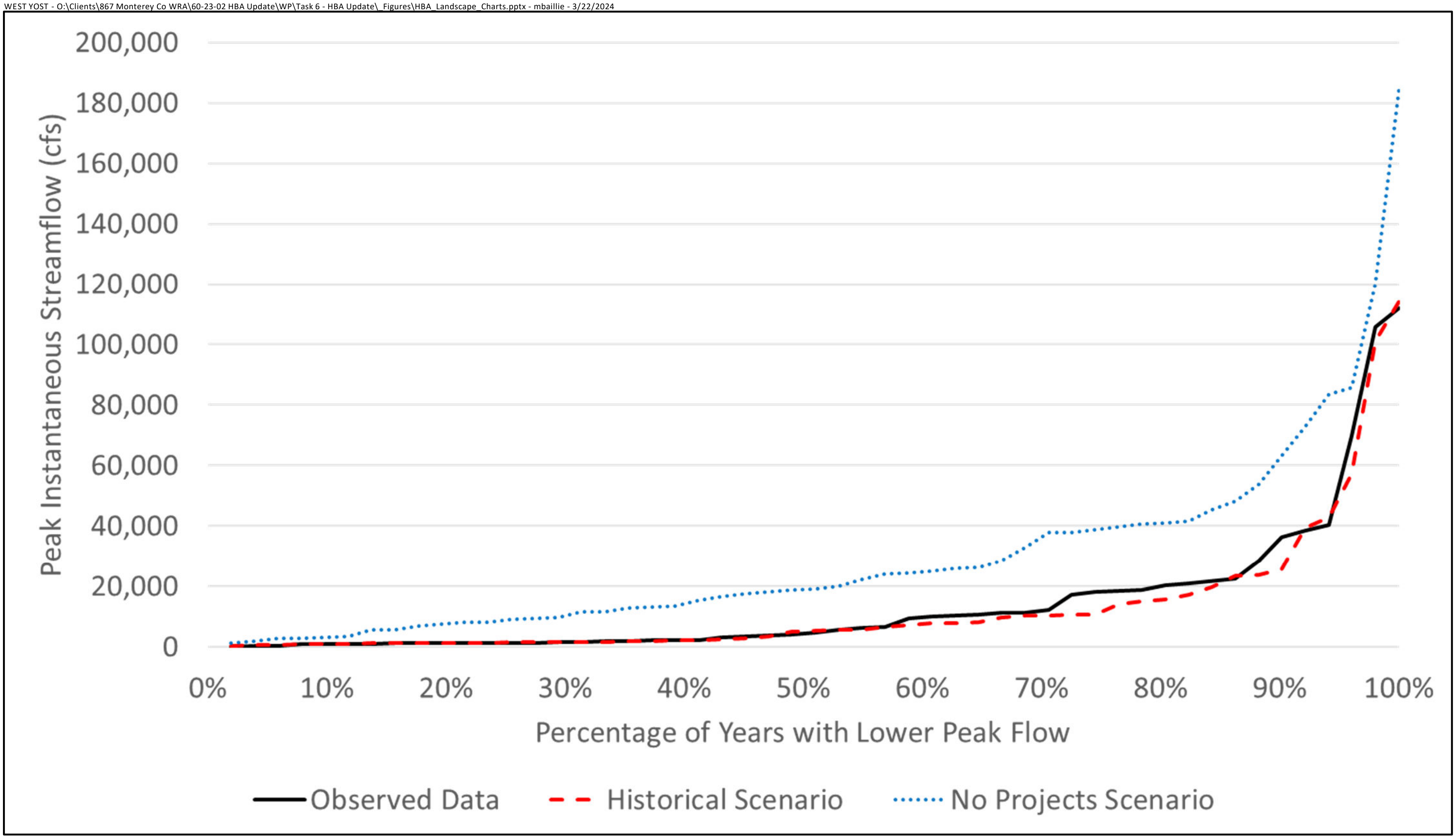

Figure 4-5

Cumulative Distribution Function of Annual Peak Streamflow in the Salinas River at Bradley, Observed and Estimated

Monterey County Water Resources Agency

Historical Benefits Analysis Update

April 2025

4.3.1 Flood Flow Frequency Approach

The 1998 HBA provided the magnitude of peak flow for selected flood events (25-year and 100-year floods), as well as the extent of inundation experienced under these events. The determination of the magnitude of these flood events relied on an analysis that matched a statistical distribution to the observed and simulated peak flow datasets. The parameters of this statistical distribution were used to estimate the magnitude of the peak flows. The statistical distribution determines the peak flow magnitude that corresponds to a given Annual Exceedance Probability (AEP). The peak flow with an AEP of 0.1 has a 10 percent probability during any given year of being met or exceeded; the peak flow with an AEP of 0.01 has a 1 percent probability of being met or exceeded each year. Typically, the AEP = 0.01 event is referred to as the 100-year flood (or to have a 100-year Return Period). In reality, the 100-year flood can occur several times during a given 100-year period, or not at all. The AEP is a more precise framework for describing peak flows compared to the Return Period, but this HBA Update preserves the use of the terminology of the Return Period to follow the approach of the 1998 HBA.

The Flood Flow Frequency Analysis for this HBA Update relied on updated guidelines for the determination of the peak flow statistical distribution (England et al., 2019). The USGS software package PeakFQ (Flynn et al., 2006) was used to automatically fit Flood Flow Frequency Curves to the annual peak flow values for the observed streamflow record (WY 1968 to 2018) and the estimated streamflow under the Historical and No Projects Scenarios for the Salinas River at Bradley. Limitations to the approach for determining the Flood Flow Frequency Curves are included in Appendix B. It is important to note that the shape of a Flood Flow Frequency Curve can change over time as additional years of data are added to the period of record, expanding the sample size and theoretically improving the ability to characterize the “real” state of the system. The curves can also change due to changes to the physical system, including natural channel modification processes and the construction and operation of surface water control features such as reservoirs. The presence of flow structures is a critical consideration for this HBA Update, which is concerned with the effect that the Nacimiento and San Antonio Reservoirs (and related projects and programs) have had on the system, including on the frequency and severity of flood flows. The application of this Flood Flow Frequency Analysis to this system must be made with these limitations in mind. It is noted that the analysis performed for the 1998 HBA included a period (WY 1958 to 1967) when only Nacimiento Reservoir was operating; for this HBA Update, the analysis covers the period from WY 1968 to 2018, when both reservoirs had already been constructed and were operating. This means that this HBA Update uses an analytical period during which the system was closer to “stationary” because there were no major changes to the infrastructure above Bradley (although it is important to note that the operational approach for the reservoirs has changed during the analytical period).

4.3.2 Flood Flow Frequency Curves

Figure 4-6 presents the peak instantaneous, 1-day, 3-day, and 5-day flood flow frequency curves for the observed streamflow data in the Salinas River at Bradley for the period from WY 1968 to 2018. Figure 4-7 provides the Flood Flow Frequency Curves for the Historical Scenario, and Figure 4-8 for the No Projects Scenario. Figure 4-9 shows curves that represent the difference between the Historical Scenario and No Projects Scenario Flood Flow Frequency Curves (note that this figure uses a difference calculated as the No Projects Scenario minus the Historical Scenario to keep the differences positive). Table 4-3 lists the magnitude of peak flows for selected AEPs for each dataset presented in these figures.

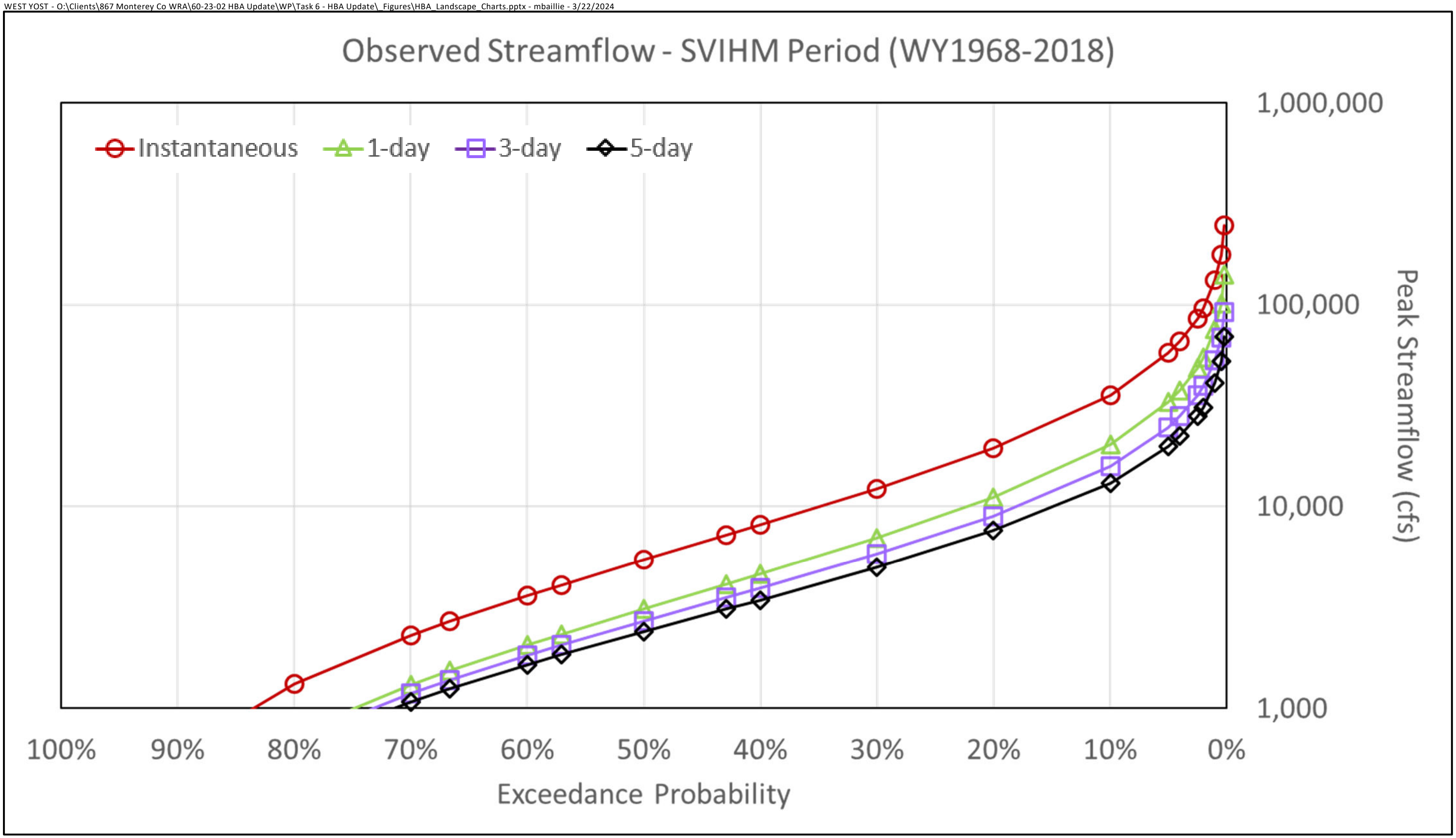

Figure 4-6

Flood Flow Frequency Curves for the Salinas River at Bradley, Observed Data

Monterey County Water Resources Agency
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April 2025

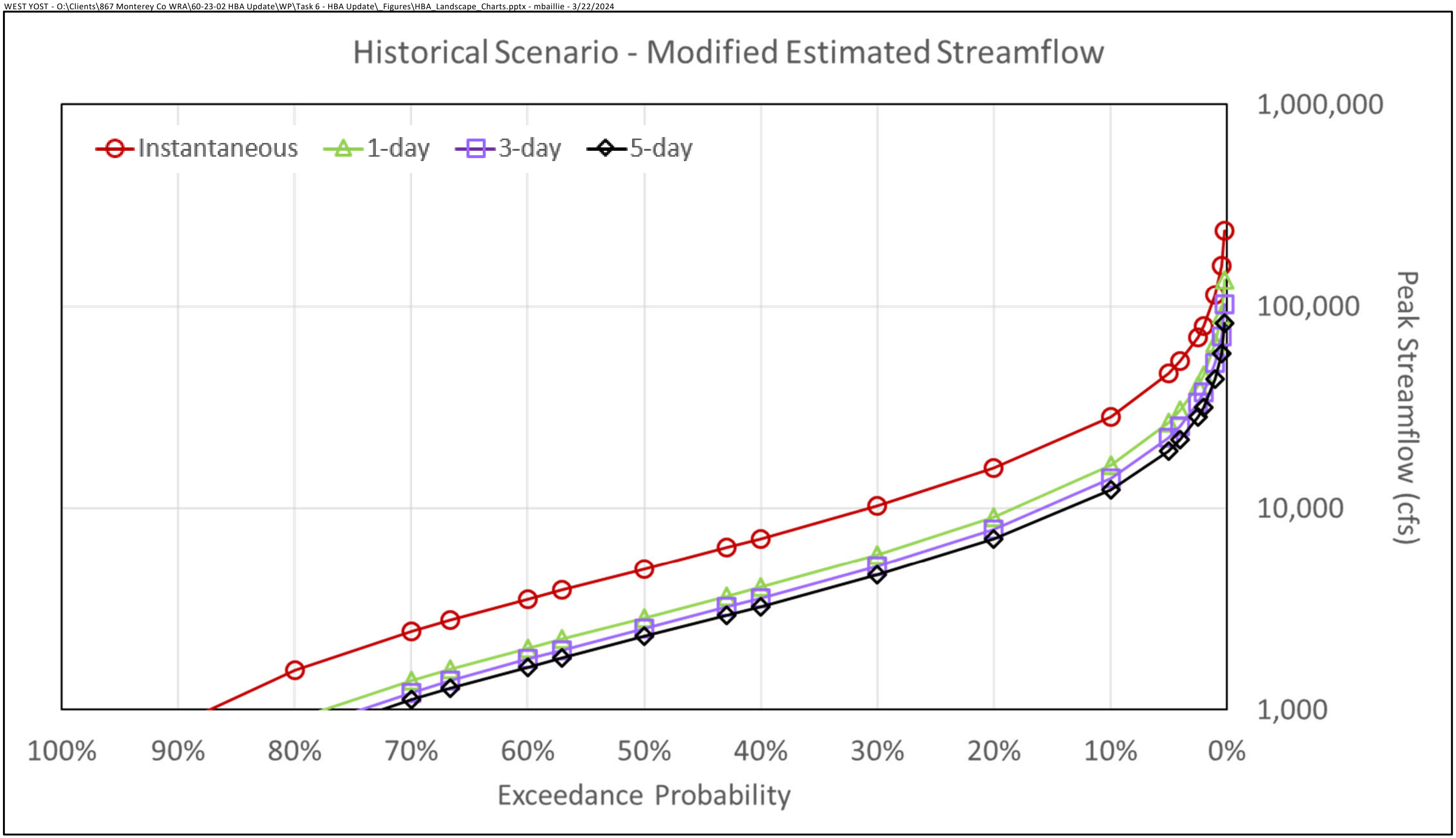

Figure 4-7

Flood Flow Frequency Curves for the Salinas River at Bradley, Historical Scenario

Monterey County Water Resources Agency
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April 2025

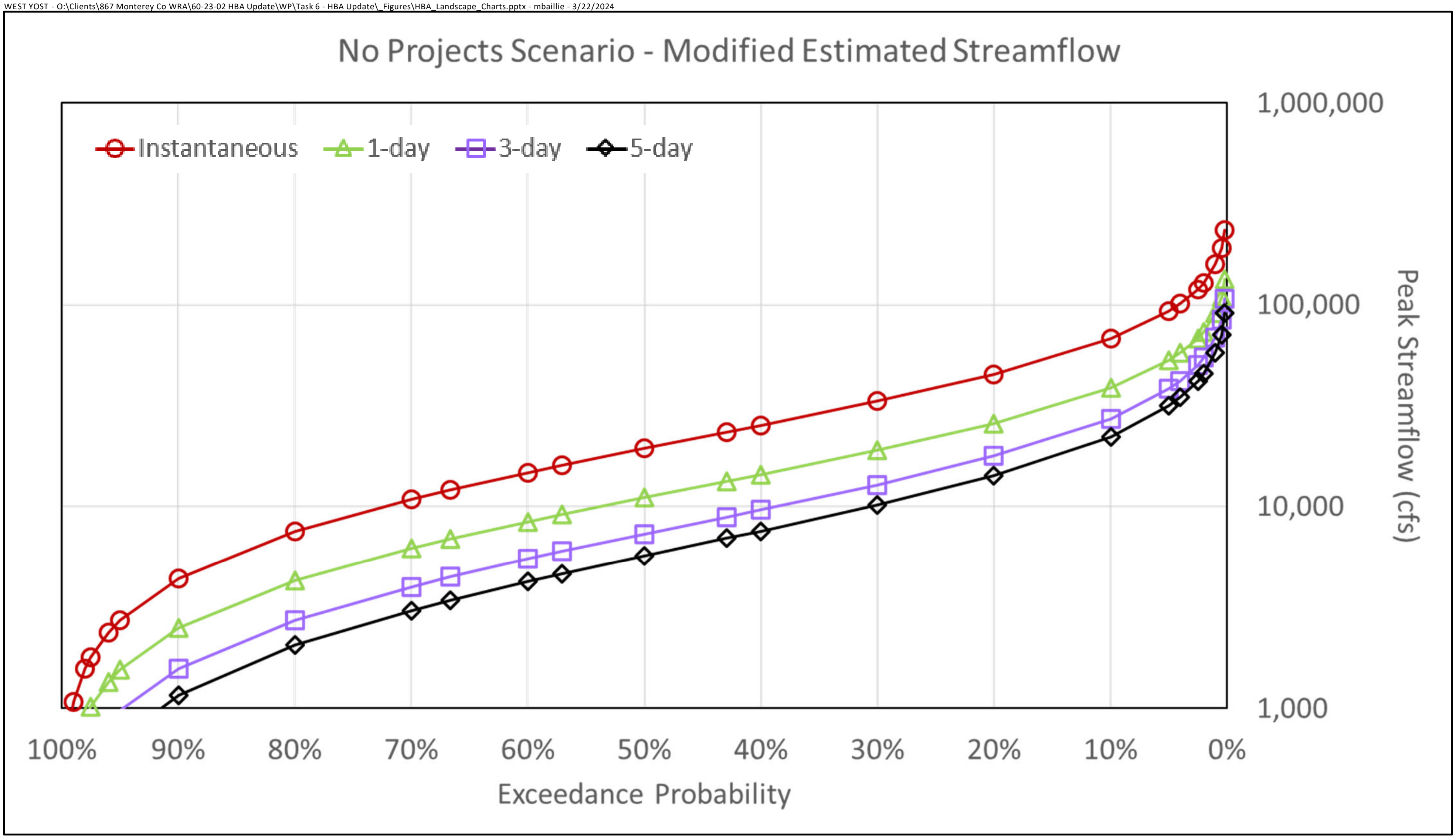

Figure 4-8

Flood Flow Frequency Curves for the Salinas River at Bradley, No Projects Scenario

Monterey County Water Resources Agency
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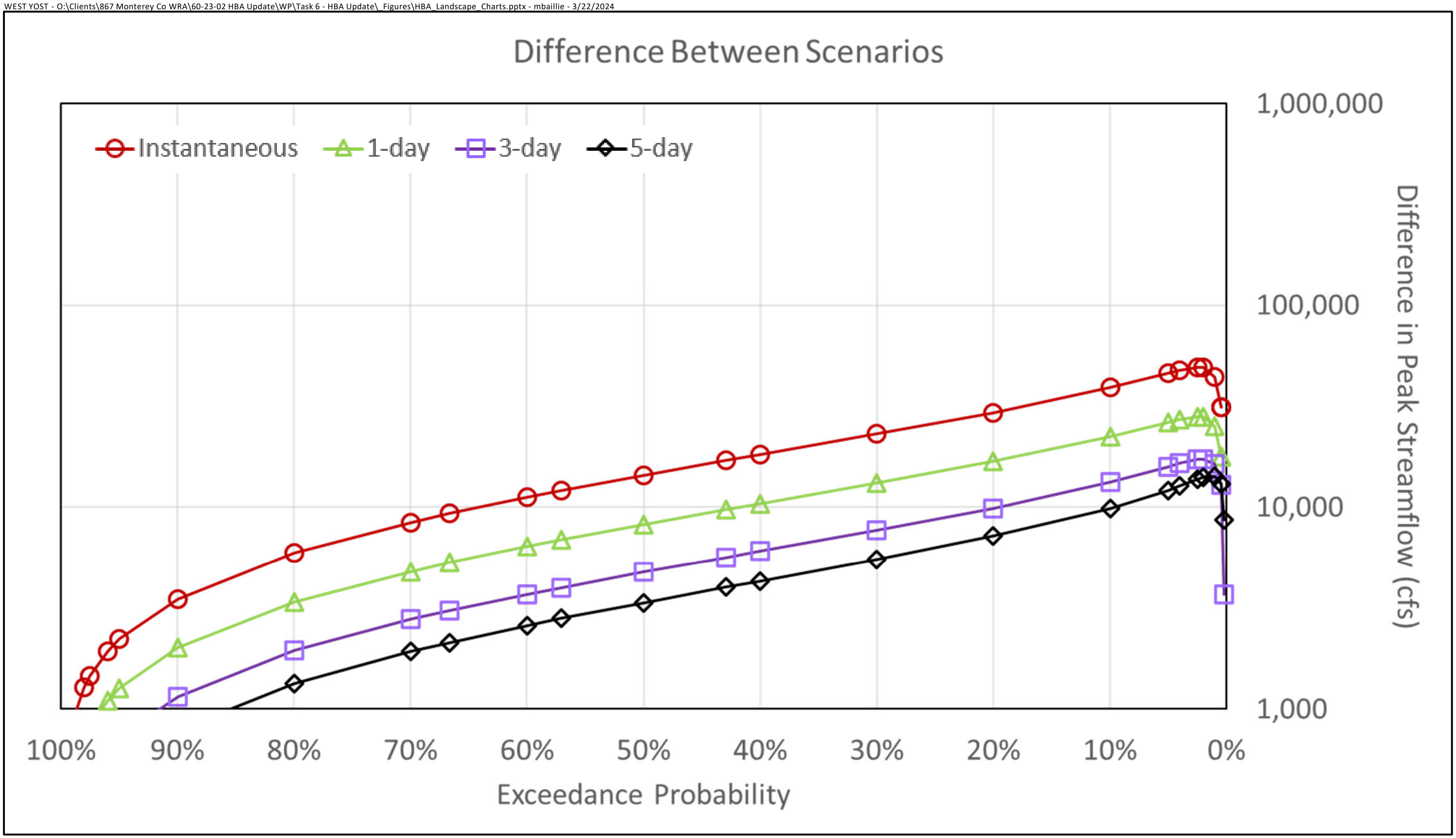

Figure 4-9

Flood Flow Frequency Curves for the Salinas River at Bradley, Difference Between Scenarios

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Historical Benefits Analysis Update
April 2025

Table 4-3. Peak Flow Magnitudes for Selected Annual Exceedance Probabilities, Observed and Estimated Streamflow Datasets

	Instantaneous Peak Flow					1-Day Mean Streamflow					3-Day Mean Streamflow					5-Day Mean Streamflow				
Return Period (Years)	5	10	25	50	100	5	10	25	50	100	5	10	25	50	100	5	10	25	50	100
AEP	0.2	0.1	0.04	0.02	0.01	0.2	0.1	0.04	0.02	0.1	0.2	0.01	0.04	0.02	0.01	0.2	0.1	0.04	0.02	0.01
Observed Streamflow (WY 1968-2018)	19,300	35,700	65,900	96,000	132,900	11,000	20,400	37,600	54,800	75,900	9,000	15,800	27,900	39,400	52,900	7,600	13,100	22,400	31,100	41,100
Historical Scenario	15,700	28,500	53,400	79,900	114,600	9,000	16,300	30,500	45,600	65,500	7,900	14,000	25,500	37,400	52,400	7,000	12,300	21,900	31,600	43,600
No Projects Scenario	45,200	67,600	100,900	128,800	158,700	27,800	28,600	57,600	73,500	90,600	17,700	27,300	42,000	54,700	68,700	14,200	22,200	34,700	45,600	57,800
Difference Between Scenarios	+29,400	+39,100	+47,500	+48,900	+44,100	+16,800	+22,300	+27,200	+27,900	+25,200	+9,900	+13,300	+16,500	+17,300	+16,300	+7,200	+9,900	+12,700	+14,000	+14,200
Percent Decrease Due to Projects	65%	58%	47%	38%	28%	65%	58%	47%	38%	28%	56%	49%	39%	32%	24%	51%	45%	37%	31%	25%

Notes:
- All peak flows are in cubic feet per second (cfs); flows are rounded to the nearest 100 cfs and totals may not sum due to rounding
- Difference between scenarios is calculated as No Projects Scenario peak flow minus Historical Scenario peak flow; this is the opposite of the calculation used in the Hydrologic Benefits Analysis, and is used here to avoid plotting negative differences on logarithmic charts
- AEP = Annual Exceedance Probability
- WY = Water Year

This analysis indicates that the magnitude of the 100-year flood in the Salinas River at Bradley under the Historical Scenario was about 115,000 cfs, versus about 159,000 cfs under the No Projects Scenario, meaning that the Projects have reduced the magnitude of the 100-year flood by about 44,000 cfs (a decrease of about 28 percent). Flood flows with a higher AEP (i.e., lower return period) experienced larger percentage decreases, ranging from about 65 percent for the 5-year event to about 38 percent for the 50-year event (Table 4-3).

The 100-year flood event under the Historical Scenario, with a magnitude of about 115,000 cfs, corresponds to an AEP under the No Projects Scenario of about 2.9 percent, equating to a return period of about 34 years. This means that the magnitude of the flood event that might only occur once every 100 years on average under the current configuration of the system (i.e., the Historical Scenario) may have happened about three times as frequently without the Projects. Indeed, the Historical Scenario 100-year flood flow was exceeded twice during the 51-year analytical period under the No Projects Scenario (in WY 1969 and 1995), compared to the Historical Scenario that had no exceedances of this flow.

4.4 PEAK FLOW INUNDATION SIMULATION

To understand the effects on the study area, the peak flows estimated with the Flood Flow Frequency Analysis (see Section 4.3) were used as inflow conditions for an existing hydraulic model of the Salinas River and its floodplain (FlowWest, 2015). This model was developed using HEC-RAS 2D to investigate the management of flood risk along the Salinas River from San Ardo to Highway 1. It is being used for this HBA Update without modification, aside from the magnitude of the inflows. FlowWest (2015) noted one limitation of the HEC-RAS software is its inability to simulate groundwater-surface water interactions. However, at the peak flow magnitudes being simulated for this study, losses to the groundwater system are assumed to be relatively small.

The Salinas River HEC-RAS Model takes as input streamflow in the Salinas River at Bradley (Figure 1-7) as well as tributary flows from Arroyo Seco and San Lorenzo Creek (the major gauged tributaries to the Salinas River below Bradley). Appendix B details the approach for estimating tributary inflows at these two locations for the Salinas River at Bradley peak flows. The 100-year, 50-year, 25-year, and 10-year flood event for both the Historical and No Projects Scenarios were used as inputs to the HEC-RAS model (see Section 4.3.2 for the development of these event flows, and Table 4-3 for the flow magnitudes). This section presents the results of the HEC-RAS modeling of these peak flows, analyzing how they affect the study area in terms of the extent and depth of inundation, as well as flood flow velocities within the inundated area.

The Salinas River HEC-RAS Model does not simulate the passage of a realistic hydrograph, with rising and falling limbs, through the system. Instead, the model simulates the quasi-steady state effects of the peak flow on the system. The input hydrograph for the HEC-RAS model starts at a relatively low flow, then ramps up to the peak flow. The peak flow in effect acts as the model inflow for an extended period. This approach results in simulated inundation that is representative of the effects of the peak flow magnitude, but not the realistic movement of an event hydrograph through the system. This analysis is useful for understanding the maximum extent of inundation under each peak flow value, but not temporal aspects of the event, such as duration of inundation.

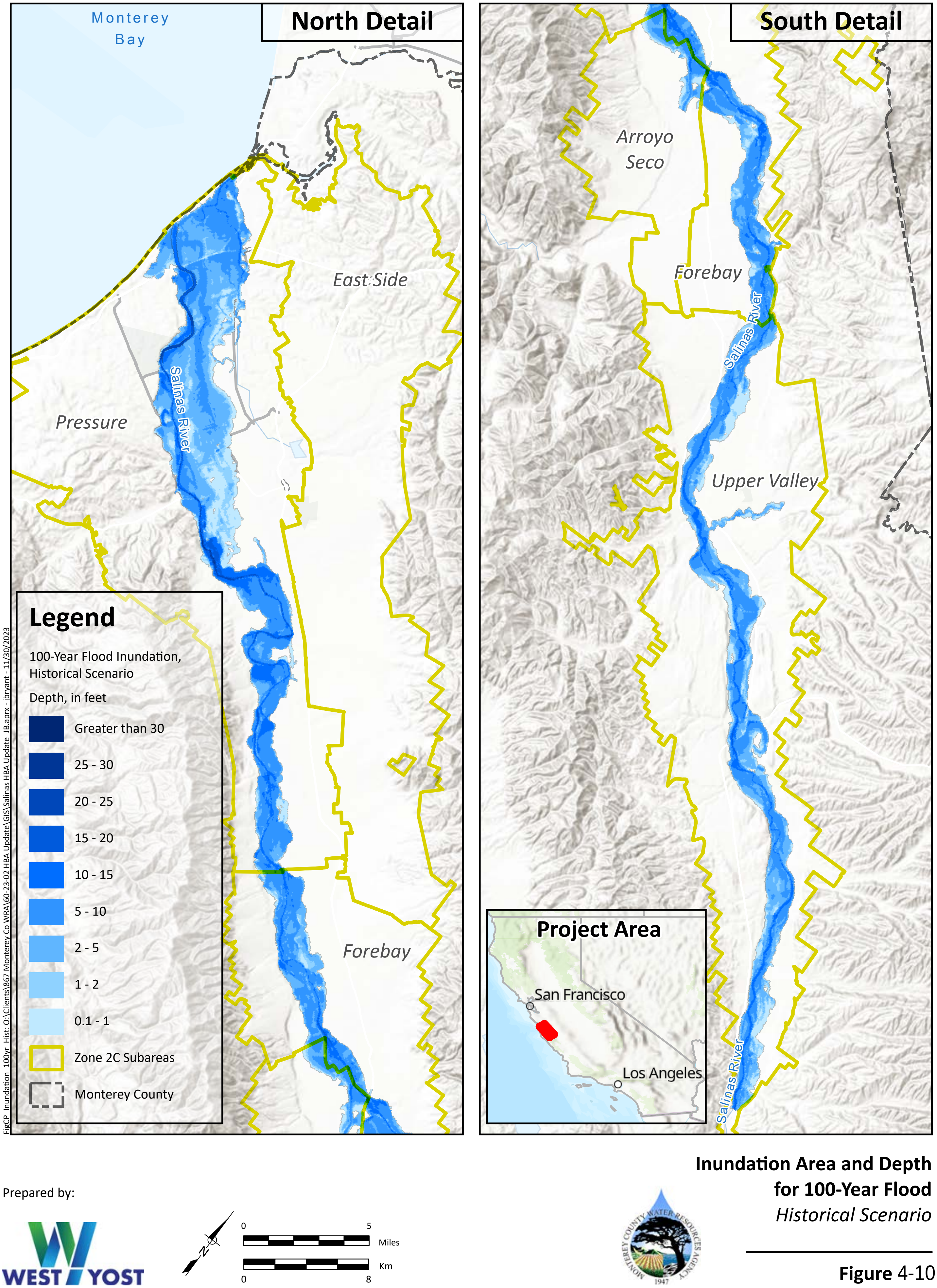
4.4.1 Extent and Depth of Inundation

The extent of inundation represents the area of the floodplain that is covered by floodwater under each peak flow value. To avoid inclusion of areas experiencing minimal inundation depth, a minimum inundation threshold of 0.1 feet was used in determining the extent of inundation. This section presents the extent of inundation for the 100-year, 50-year, 25-year, and 10-year flood events under the Historical and No Projects Scenarios simulated using the Salinas River HEC-RAS model. The peak flowrates for each of these events are provided in Table 4-3.

Figure 4-10 shows the inundated area and inundation depth under the 100-year flood event for the Historical Scenario, with a peak flow of about 115,000 cfs. For this event, the simulated extent of inundation was about 60,000 acres and the maximum depth of inundation was about 31 feet within the Salinas River channel around Spreckels. Table 4-4 provides the simulated inundation area above selected depth thresholds for this and the other model scenarios, as well as the maximum simulated inundation depth for each. The 100-year flood for the Historical Scenario simulated an area of about 34,000 acres under at least 5 feet of inundation, and about 56,000 acres under at least 1 foot of inundation.

Figure 4-11 shows the inundated area and inundation depth under the 50-year flood event for the Historical Scenario, with a peak flow of about 80,000 cfs. For this event, the simulated extent of inundation was about 54,000 acres and the maximum depth of inundation was about 30 feet. Figure 4-12 shows the inundated area and inundation depth under the 25-year flood event for the Historical Scenario, with a peak flow of about 53,000 cfs. For this event, the simulated extent of inundation was about 45,000 acres and the maximum depth of inundation was about 29 feet. Figure 4-13 shows the inundated area and inundation depth under the 10-year flood event for the Historical Scenario, with a peak flow of about 28,000 cfs. For this event, the simulated extent of inundation was about 32,000 acres and the maximum depth of inundation was about 28 feet.

Figure 4-14 shows the inundated area and inundation depth under the 100-year flood event for the No Projects Scenario, with a peak flow of about 159,000 cfs. For this event, the simulated extent of inundation was about 65,000 acres and the maximum depth of inundation was about 33 feet within the Salinas River channel near Spreckels. This event simulated an area of about 42,000 acres under at least 5 feet of inundation and about 62,000 acres under at least 1 foot of inundation. The total area of inundation was about 5,000 acres larger than the inundated area for the Historical Scenario 100-year event; the area of at least 5 feet of inundation was about 8,000 acres larger and the area of at least 1 foot of inundation was about 5,000 acres larger compared to the Historical Scenario 100-year event.



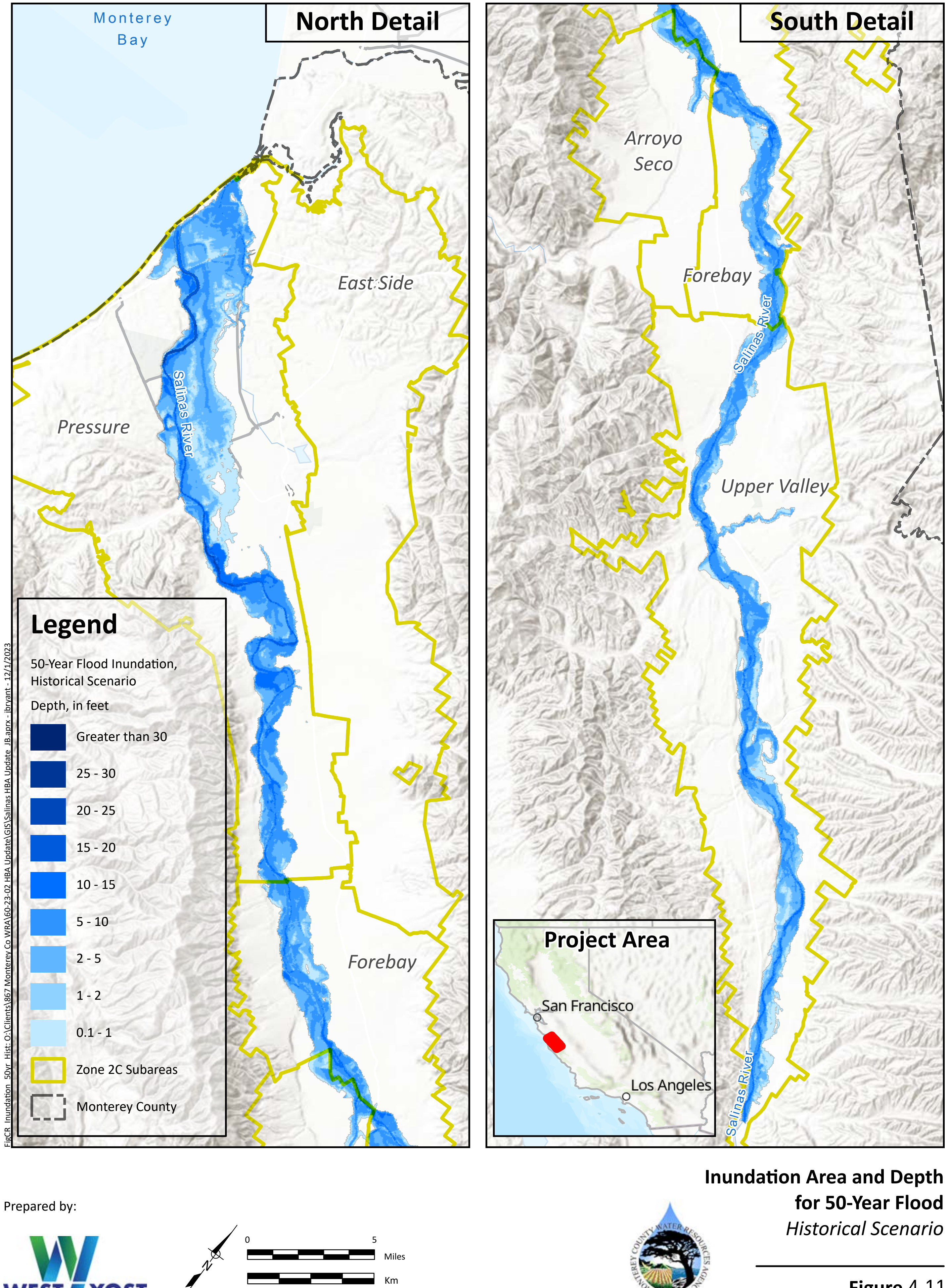
FigCP_Inundation_100yr_Hist: O:\Clients\867 Monterey Co WRA\60-23-02 HBA Update\GIS\Salinas HBA Update_JB.aprx - ibryant - 11/30/2023

Prepared by:

WEST YOST

Inundation Area and Depth for 100-Year Flood
Historical Scenario

Figure 4-10



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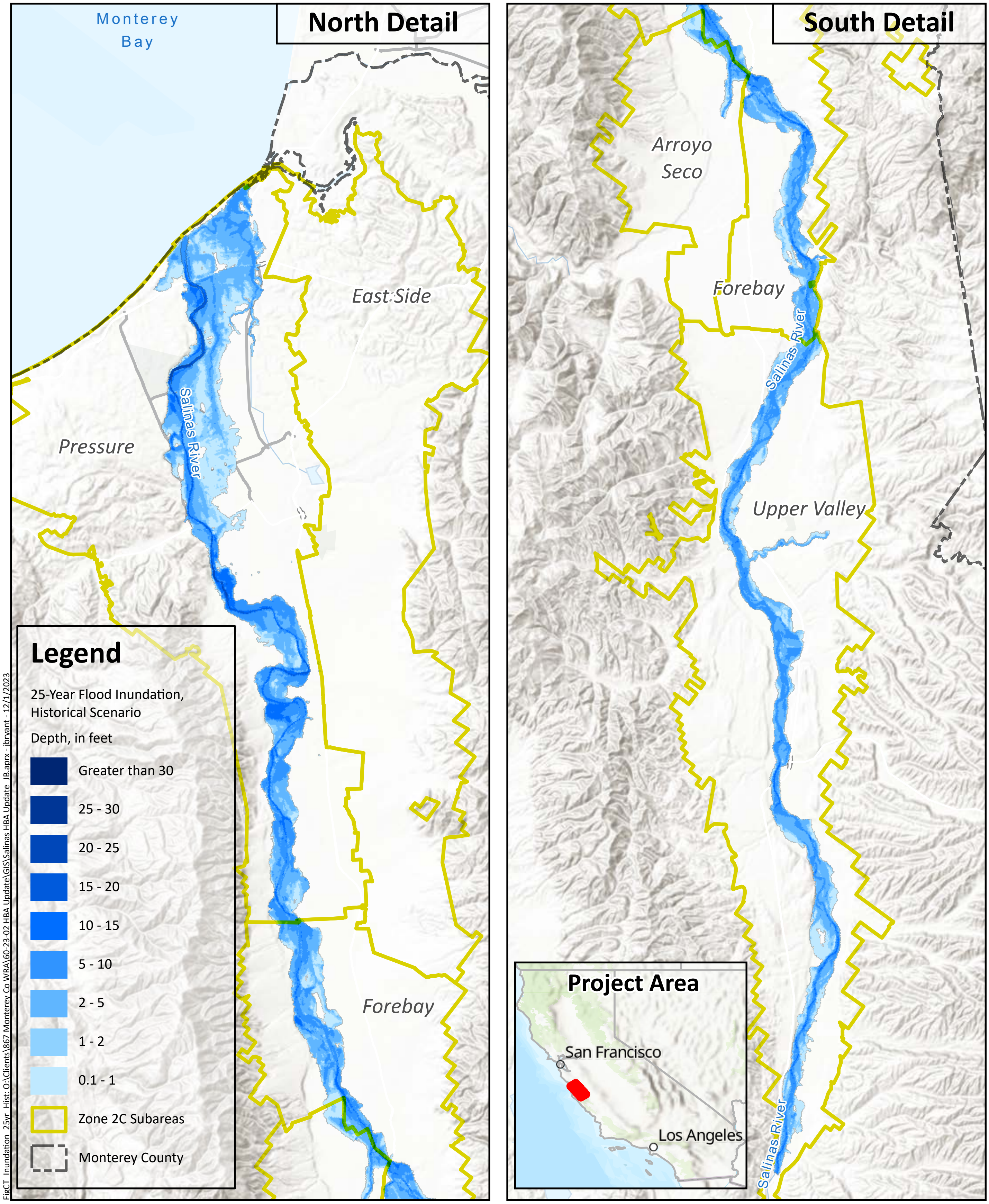
Inundation Area and Depth for 50-Year Flood
Historical Scenario

Figure 4-11



FigCT_Inundation_25yr_Hist: O:\Clients\867 Monterey Co WRA\60-23-02 HBA Update\GIS\Salinas HBA Update_JB.aprx - jbryant - 12/1/2023

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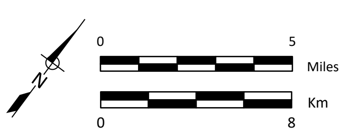
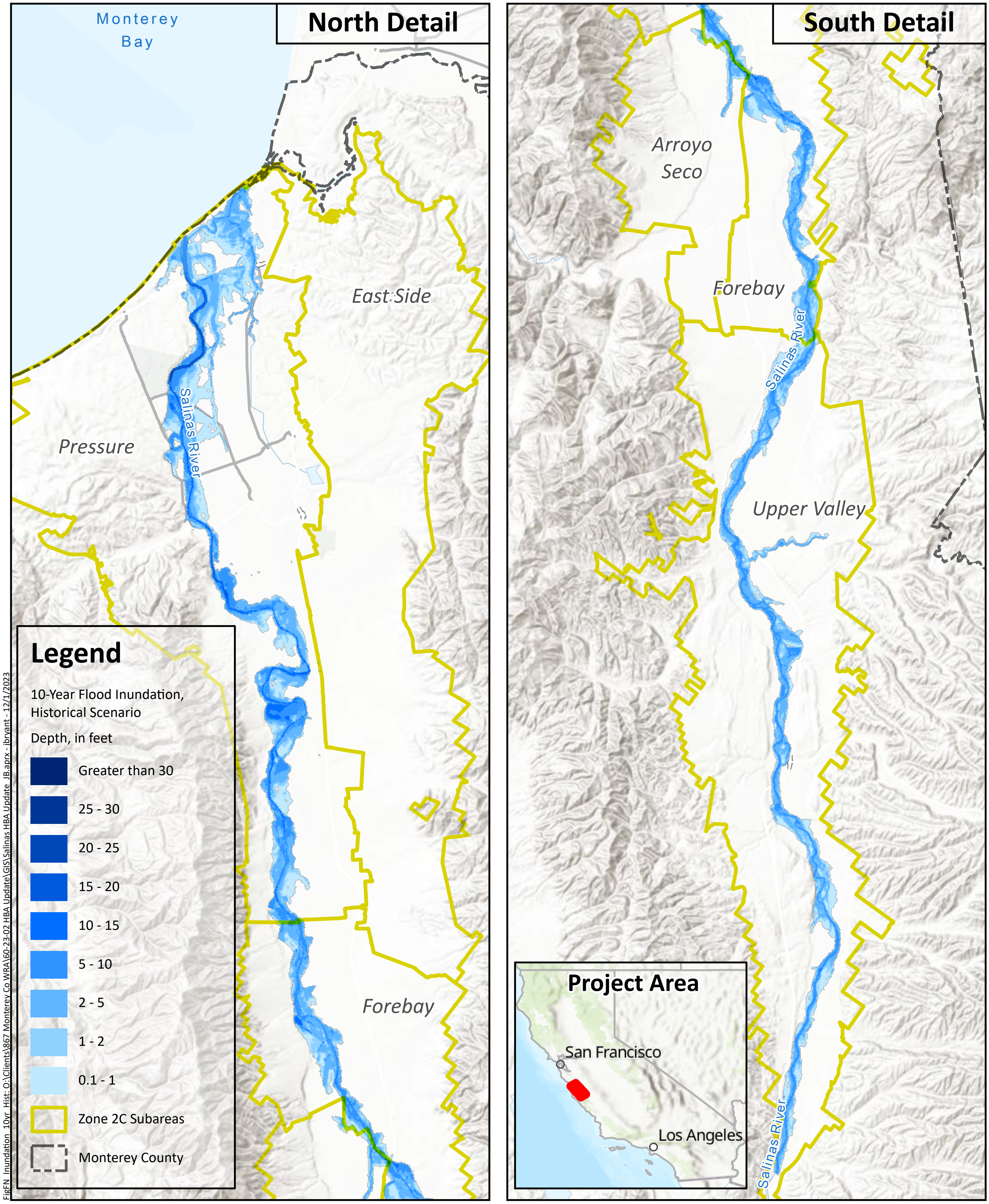


Inundation Area and Depth for 25-Year Flood
Historical Scenario

Figure 4-12



FigFN_Inundation_10yr_Hist: O:\Clients\867 Monterey Co WRA\60-23-02 HBA Update\GIS\Salinas HBA Update_JB.aprx - jbryant - 12/1/2023

Prepared by:

WEST YOST

0 5 Miles

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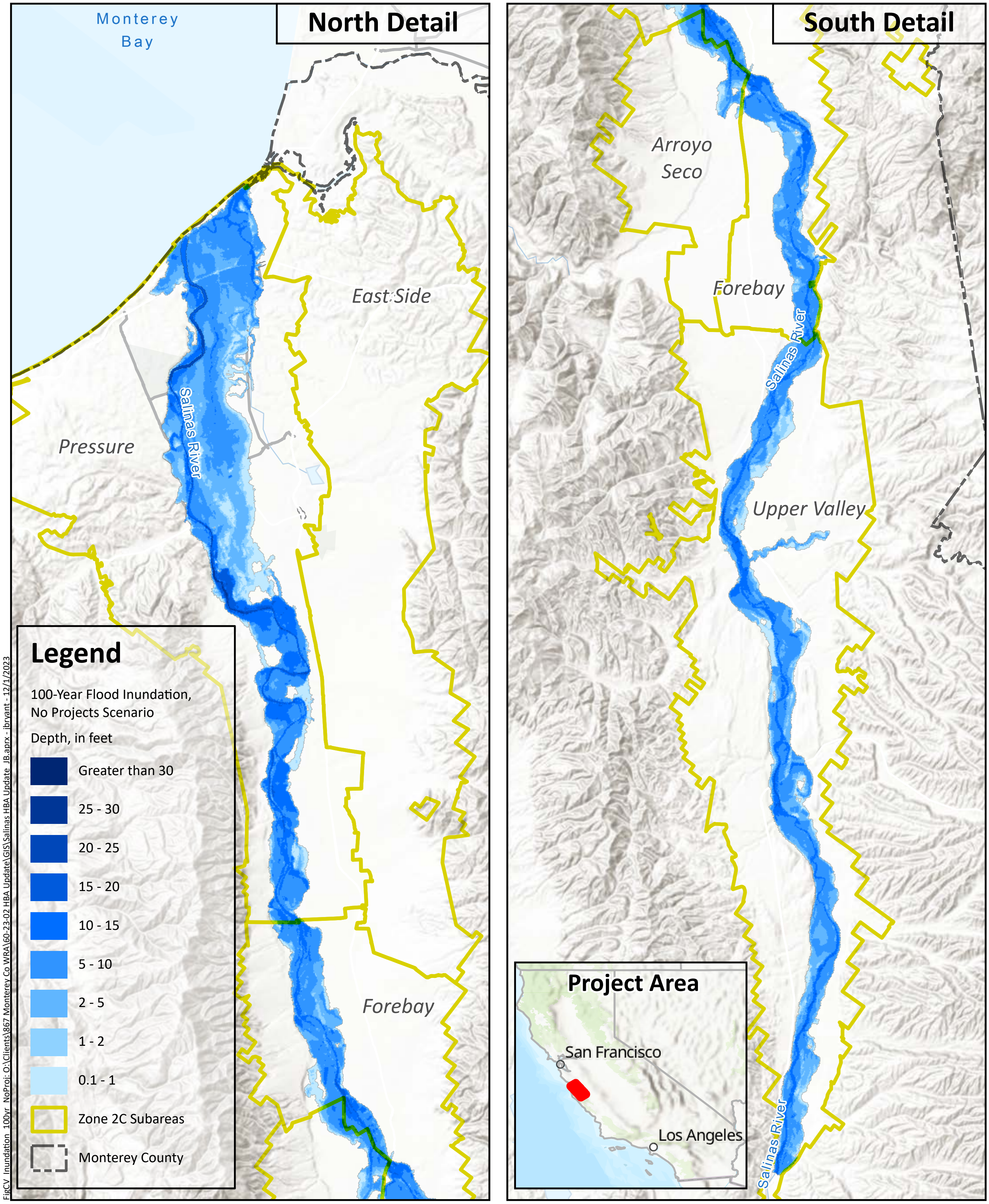
Inundation Area and Depth for 10-Year Flood
Historical Scenario

Figure 4-13



FigCV_Inundation_100yr_NoProj: O:\Clients\867 Monterey Co WRA\60-23-02 HBA Update\GIS\Salinas HBA Update_JB.aprx - lbryant - 12/1/2023

Prepared by:

WEST YOST

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Inundation Area and Depth for 100-Year Flood

No Projects Scenario

Figure 4-14

Table 4-4. Maximum Inundation Depth and Area Inundated Under Selected Depths, Historical and No Projects Scenario

Scenario			100-year Event	50-year Event	25-year Event	10-year Event
Historical Scenario	Maximum Depth, ft		31	30	29	28
	Area Above Inundation Depth (acres)	30’	6	0	0	0
		25’	100	50	20	0
		20’	320	260	200	80
		15’	1,440	880	560	320
		10’	8,130	5,510	3,710	1,740
		5’	34,000	24,600	16,700	9,100
		2’	51,200	43,200	33,700	21,100
		1’	56,100	48,900	39,700	26,600
		0.1’	60,000	53,500	45,400	31,700
No Projects Scenario	Maximum Depth, ft		33	31	30	29
	Area Above Inundation Depth (acres)	30'	17	6	0	0
		25'	150	100	70	30
		20'	410	320	280	220
		15'	2,400	1,550	1,070	620
		10'	13,020	8,800	6,460	4,200
		5'	42,200	35,400	28,700	18,900
		2'	57,400	52,200	47,100	36,500
		1'	61,500	56,900	52,200	42,600
		0.1'	65,000	60,700	56,500	48,100
Difference Between Scenarios	Maximum Depth, ft		-1	-1	-1	-1
	Area Above Inundation Depth (acres)	30'	-11	-6	0	0
		25'	-50	-50	-40	-30
		20'	-90	-60	-80	-130
		15'	-960	-670	-510	-300
		10'	-4,890	-3,290	-2,750	-2,450
		5'	-8,200	-10,800	-12,000	-9,900
		2'	-6,300	-9,000	-13,400	-15,400
		1'	-5,400	-8,000	-12,500	-15,900
		0.1’	-4,900	-7,200	-11,100	-16,500

Notes:

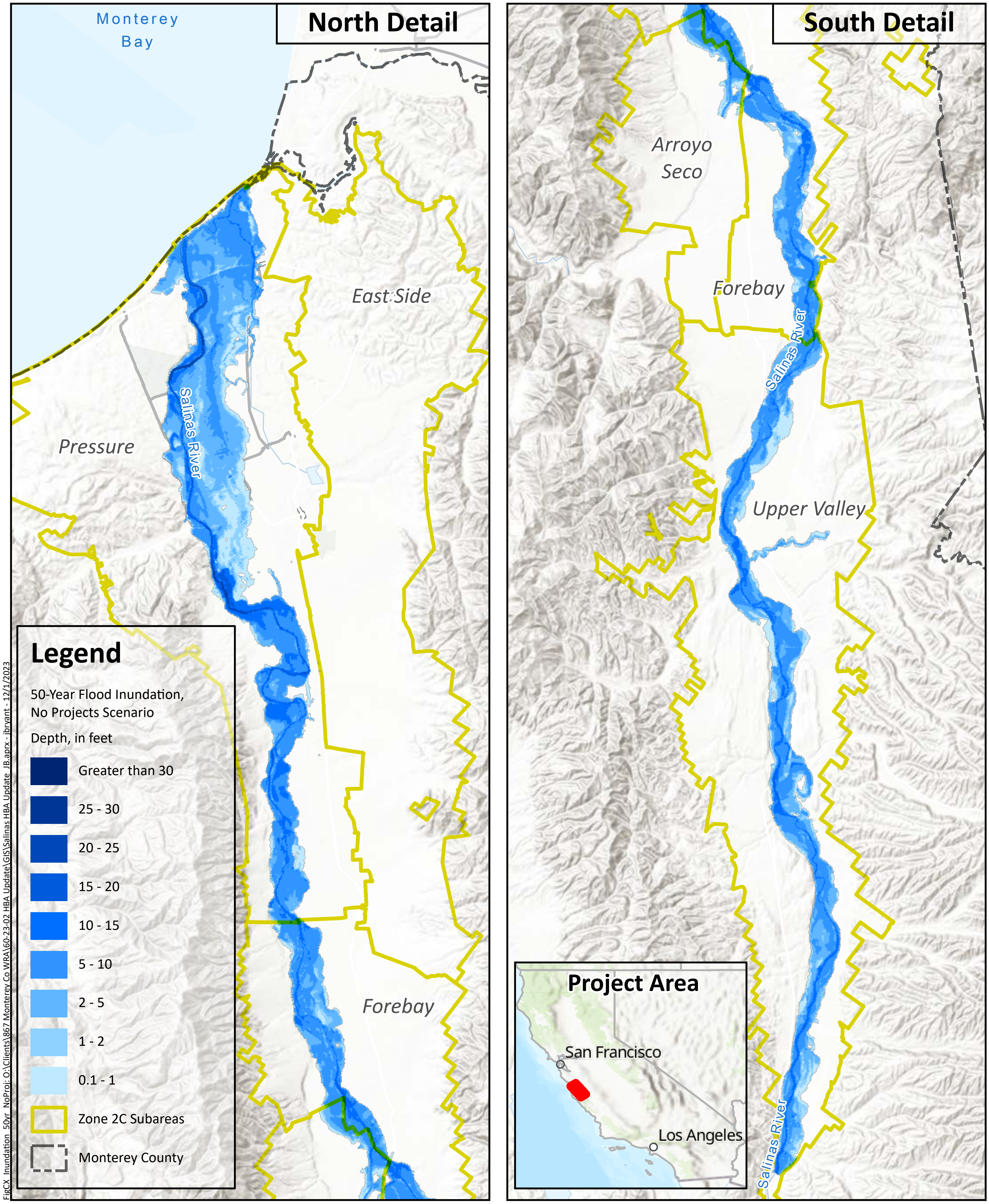
- Areas are rounded to the nearest acre (30’ inundation depth), 10 acres (10’ to 25’ inundation depth), or 100 acres (0.1’ to 5’ inundation depth) depending on the magnitude of the values; totals may not sum due to rounding
- Maximum inundation depth is rounded to the nearest foot; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

Figure 4-15 shows the inundated area and inundation depth under the 50-year flood event for the No Projects Scenario, with a peak flow of about 129,000 cfs. For this event, the simulated extent of inundation was about 61,000 acres and the maximum depth of inundation was about 31 feet. Figure 4-16 shows the inundated area and inundation depth under the 25-year flood event for the No Projects Scenario, with a peak flow of about 101,000 cfs. For this event, the simulated extent of inundation was about 56,000 acres and the maximum depth of inundation was about 30 feet. Figure 4-17 shows the inundated area and inundation depth under the 10-year flood event for the No Projects Scenario, with a peak flow of about 68,000 cfs. For this event, the simulated extent of inundation was about 48,000 acres and the maximum depth of inundation was about 29 feet.

Table 4-4 includes the difference in the inundated areas between scenarios. These results indicate that the Projects result in about 16,000 fewer acres (about 34 percent fewer) inundated during a 10-year event, 11,000 fewer acres (about 20 percent) inundated during a 25-year event, 7,000 fewer acres (about 12 percent) inundated during a 50-year event, and 5,000 fewer acres (about 8 percent) inundated during a 100-year event. These differences indicate areas that are protected from inundation by the presence and operation of the Projects.

In addition to the area protected from inundation, the results indicate that the depth of inundation is lower in those areas that are still flooded with the Projects in place. Figure 4-18 shows the difference in inundation depth for the 100-year floods under the Historical and No Projects Scenarios (for this and other inundation depth figures, the difference is calculated as the No Projects Scenario depth minus the Historical Scenario depth). Figure 4-19 shows the difference in inundation depth for the 50-year floods under the Historical and No Projects Scenarios. Figure 4-20 shows the difference in inundation depth for the 25-year floods under the Historical and No Projects Scenarios. Figure 4-21 shows the difference in inundation depth for the 10-year floods under the Historical and No Projects Scenarios. Table 4-4 also includes the difference between scenarios in the area inundated by each depth threshold.

These results indicate that the Projects have greatly decreased the extent and severity of flood-driven inundation of the Salinas River floodplain. The effect of the Projects is relatively modest for the largest events (e.g., an 8 percent reduction for the 100-year flood), because the reservoirs can only store part of the inflow for the biggest events generated in the watersheds feeding the Nacimiento and San Antonio Reservoirs. Events with a shorter recurrence interval experience a larger decrease in the inundated area, up to a 34 percent reduction for the 10-year event. This demonstrates the ability of the Projects to protect stakeholders in the Basin from repeated inundation from floods that occur more frequently. As shown in Table 4-4, the inundation for the 100-year event under the Historical Scenario is smaller than the inundation for the 50-year event under the No Projects Scenario, the inundation for the 50-year event under the Historical Scenario is smaller than the inundation for the 25-year event under the No Projects Scenario, and the inundation for the 25-year event under the Historical Scenario is smaller than the inundation for the 10-year event under the No Projects Scenario.



Prepared by:

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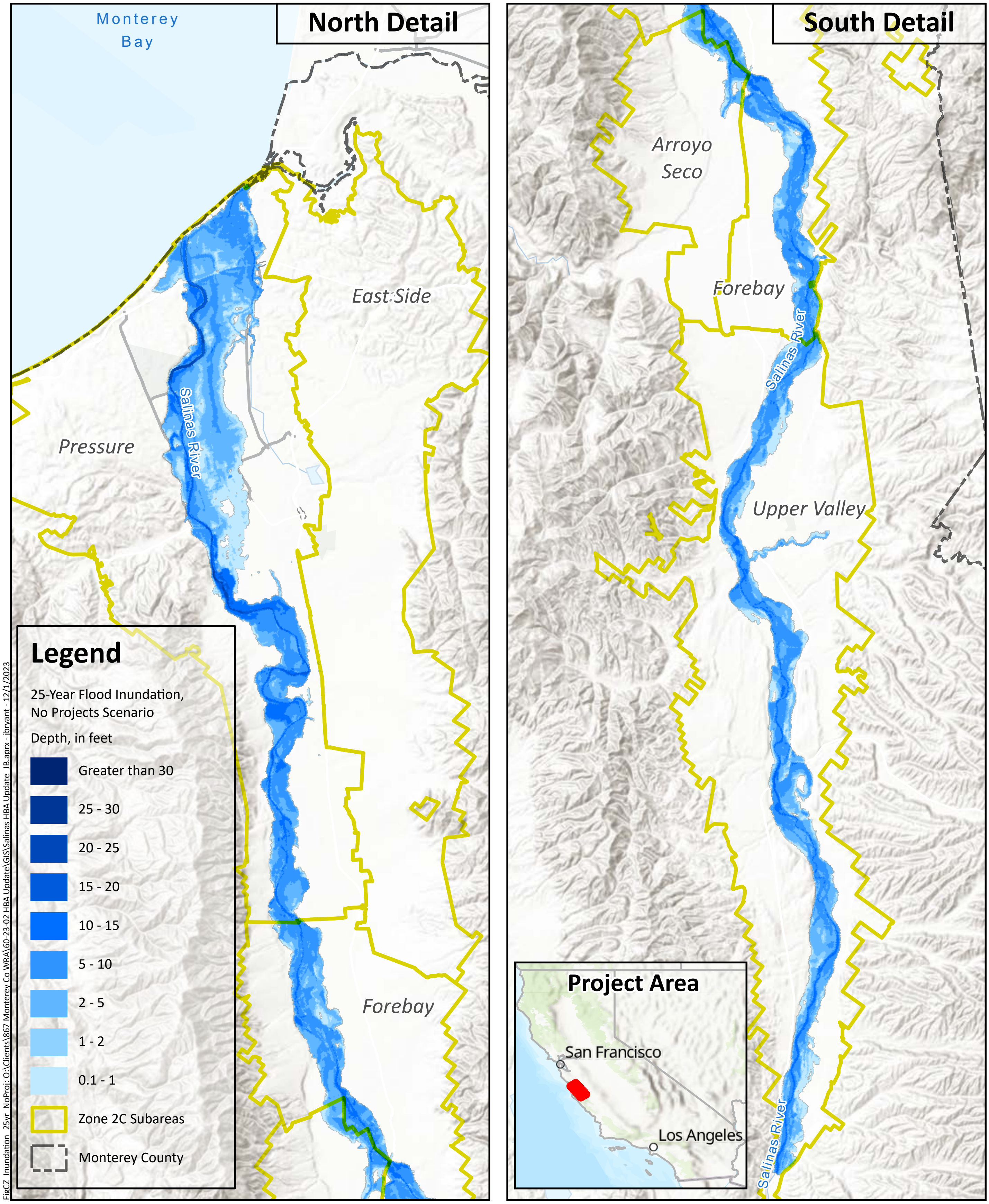
Inundation Area and Depth for 50-Year Flood

No Projects Scenario

Figure 4-15



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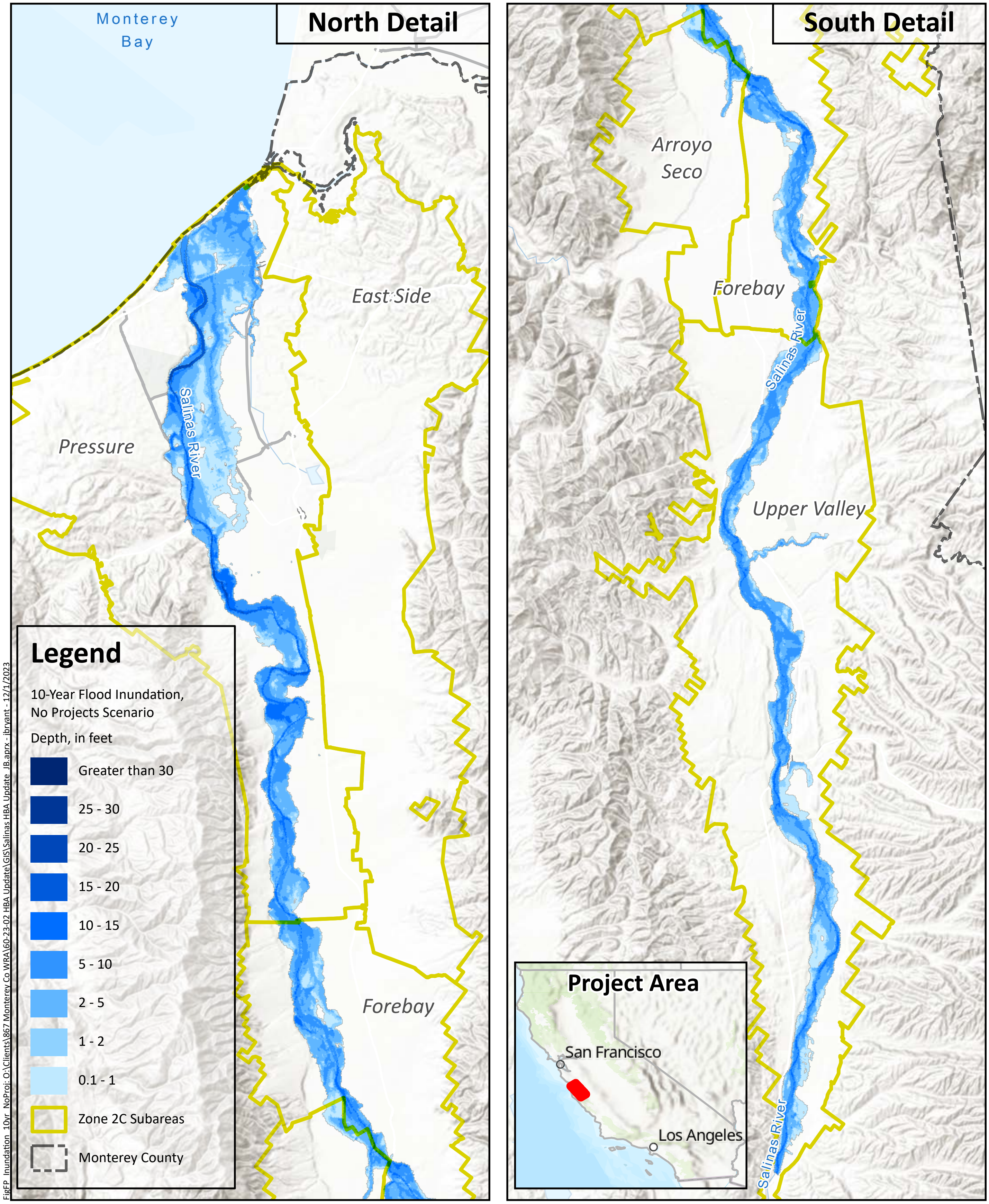
Inundation Area and Depth for 25-Year Flood

No Projects Scenario

Figure 4-16



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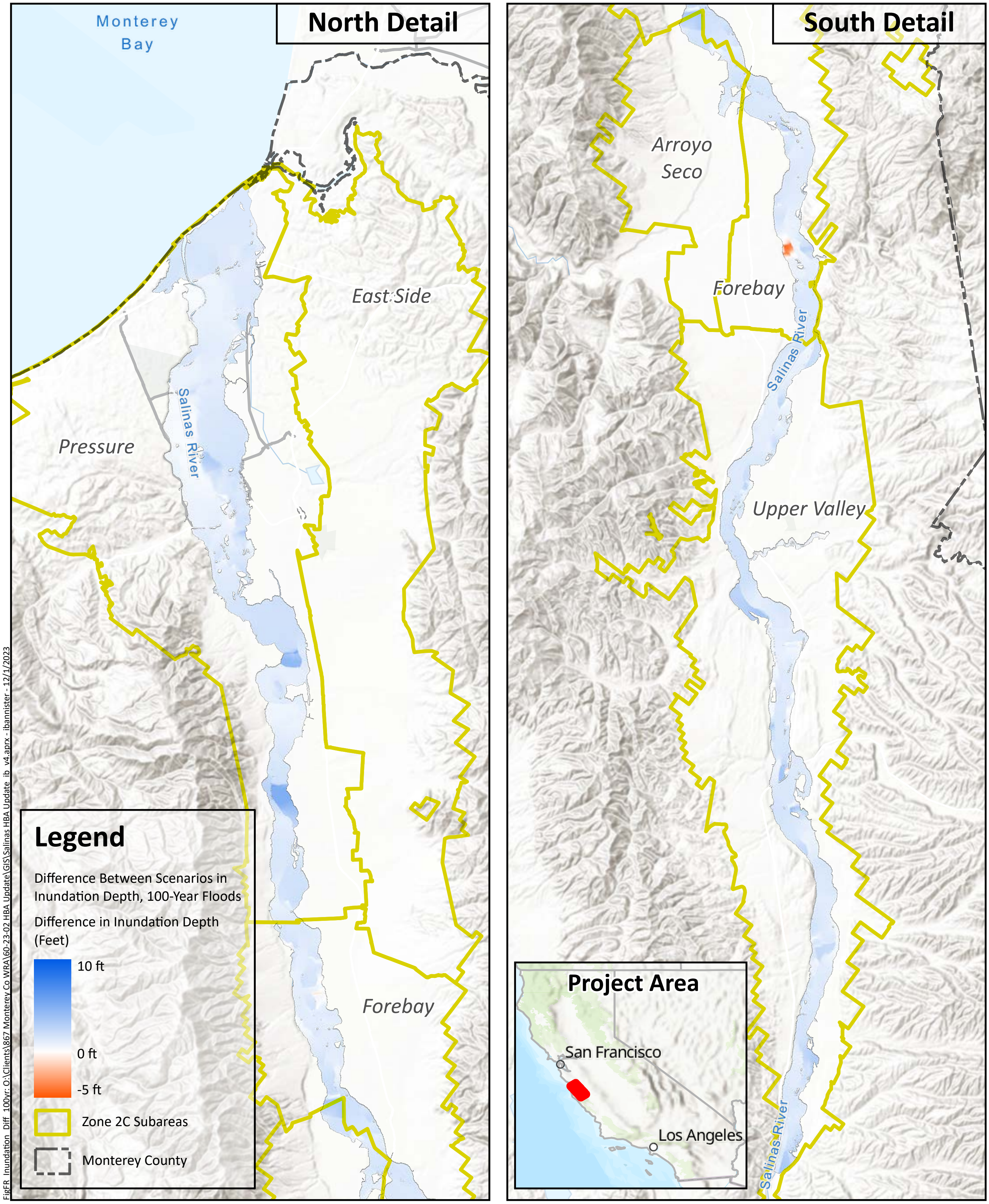
Inundation Area and Depth for 10-Year Flood

No Projects Scenario

Figure 4-17



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Prepared by:

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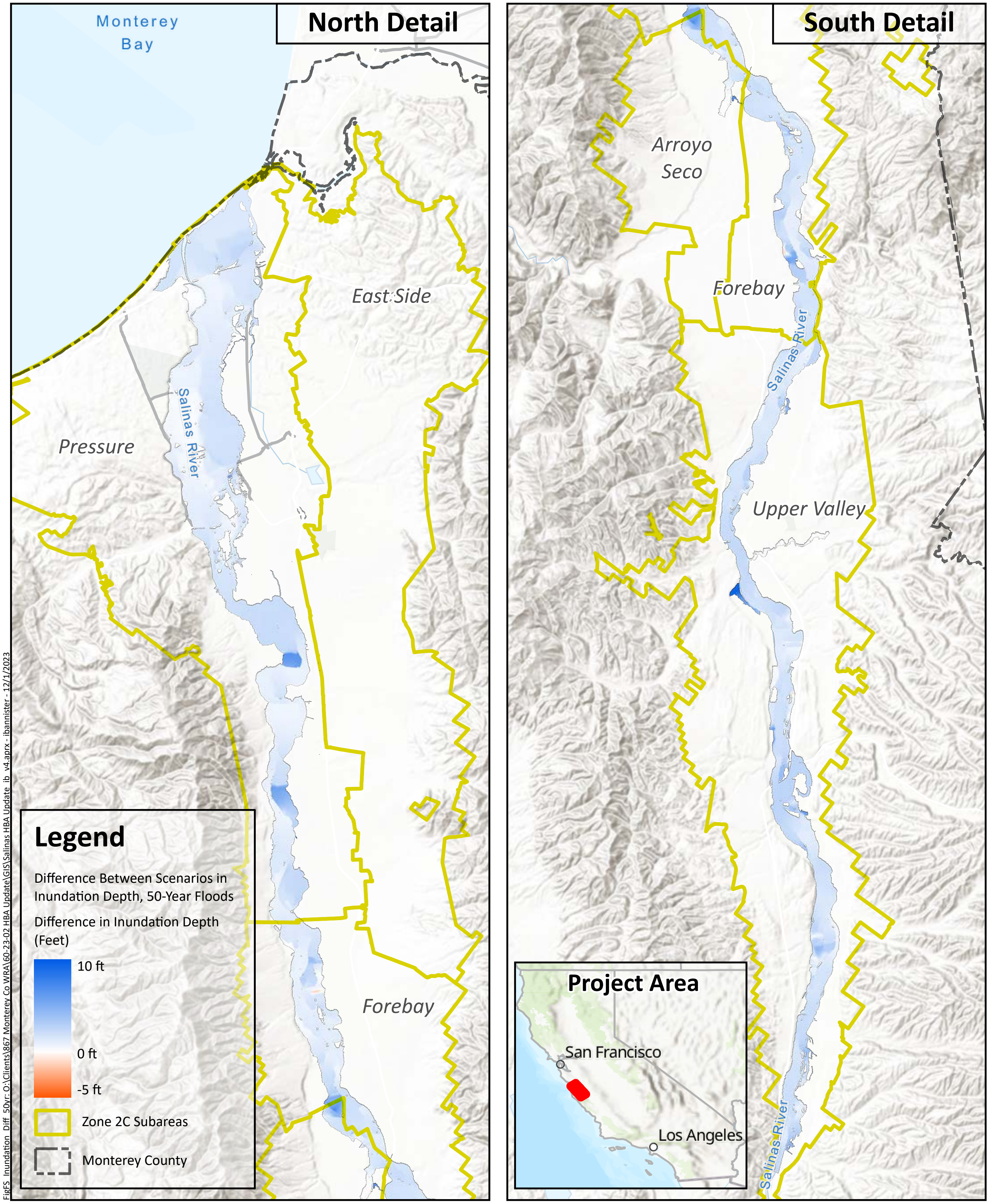
Difference Between Scenarios in Inundation Depth for 100-Year Flood

Figure 4-18



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Prepared by:

WEST YOST

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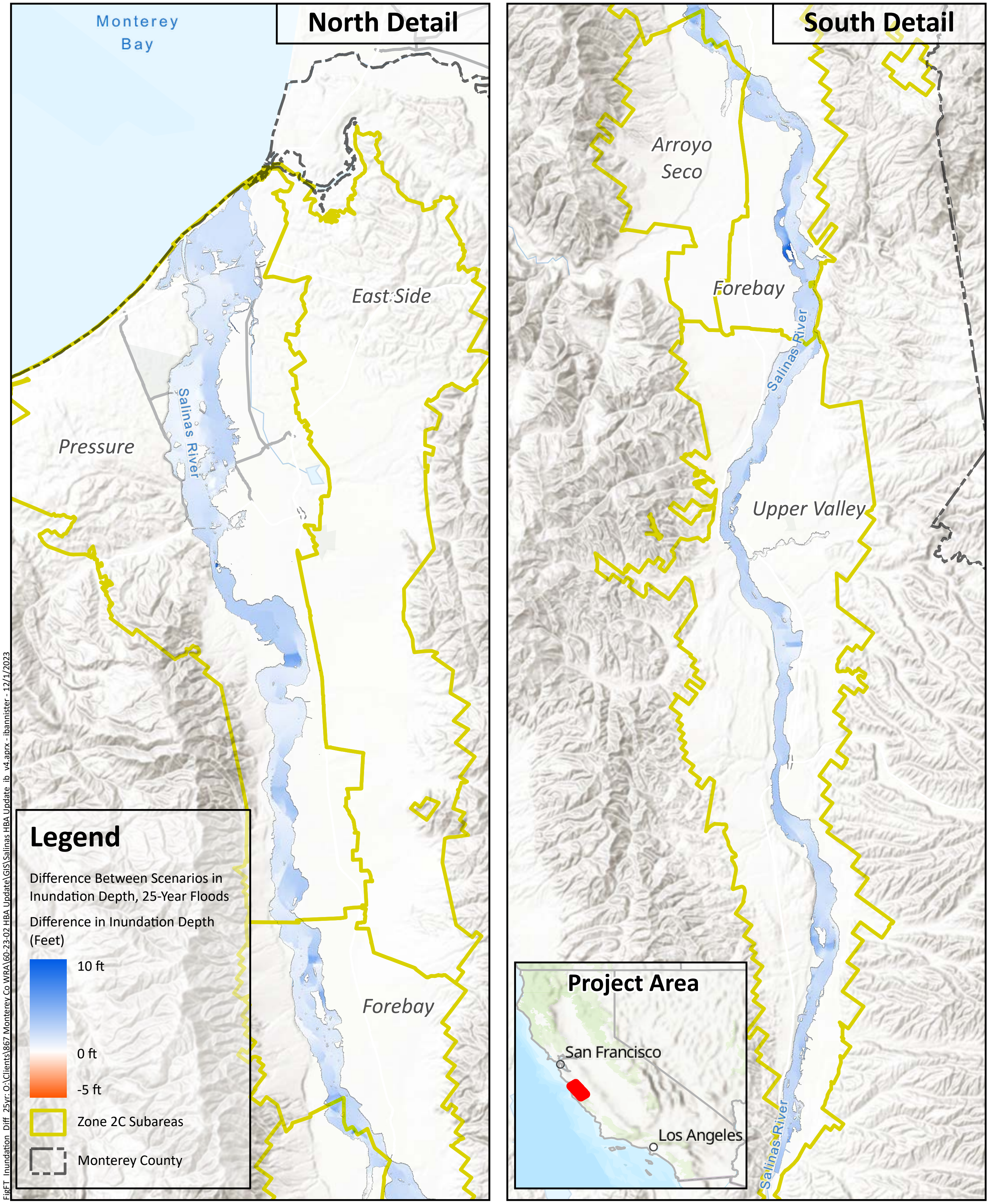
0 8 Km

Difference Between Scenarios in Inundation Depth for 50-Year Flood

Figure 4-19



FigFT_Inundation_Diff_25yr: O:\Clients\867 Monterey Co WRA\60-23-02 HBA Update\GIS\Salinas HBA Update_ib_v4.aprx - ibannister - 12/1/2023

Prepared by:

0 5 Miles

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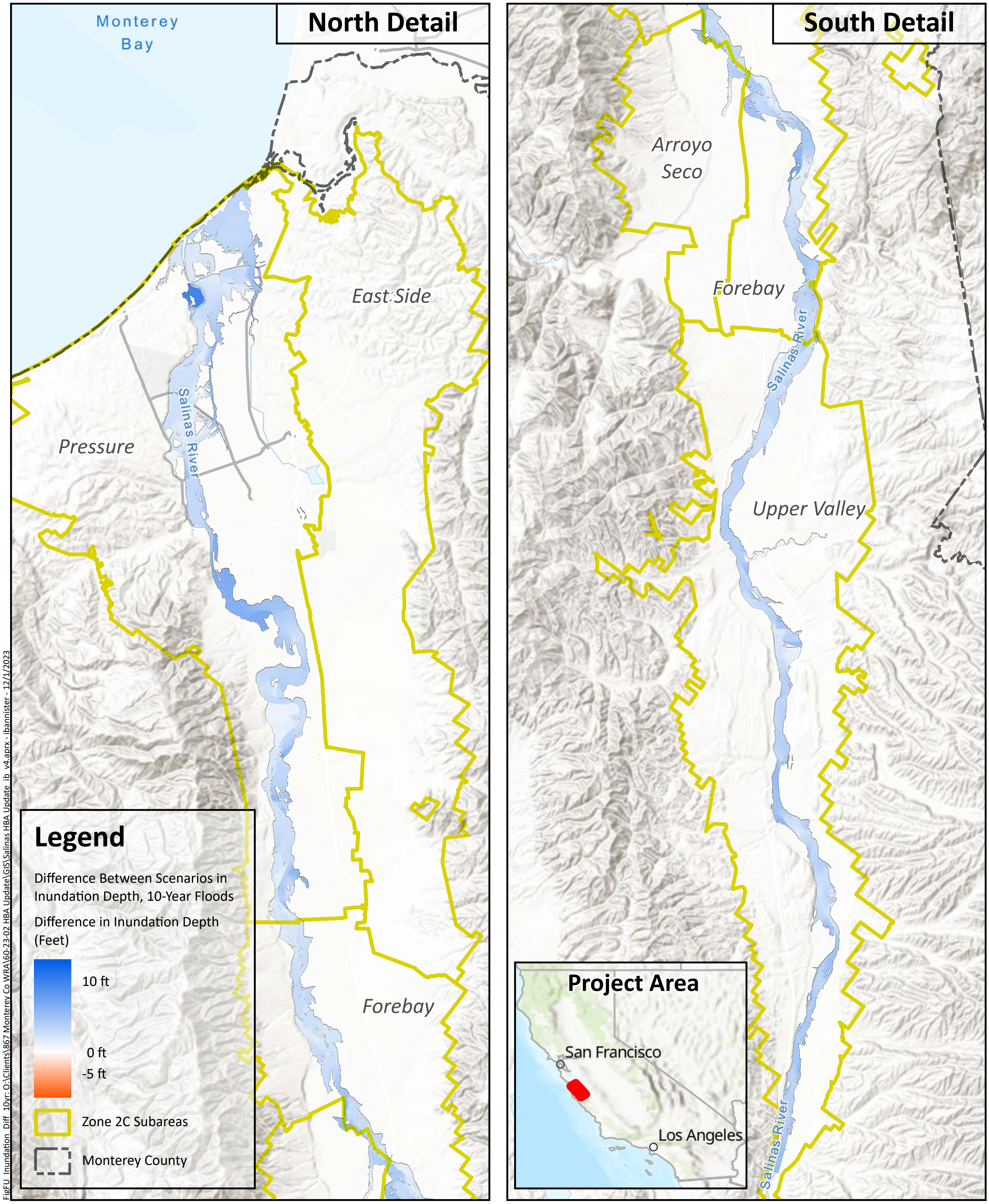
Difference Between Scenarios in Inundation Depth for 25-Year Flood

Figure 4-20



FigFU_Inundation_Diff_10yr: O:\Clients\867 Monterey Co WRA\60-23-02 HBA Update\GIS\Salinas HBA Update_ib_v4.aprx - ibannister - 12/1/2023

Prepared by:

WEST YOST

0 5 Miles

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Difference Between Scenarios in Inundation Depth for 10-Year Flood

Figure 4-21

Figure 4-22 shows a map of Flood Study Units (FSUs), which (as in the 1998 HBA) are derived directly from the extent of the ESUs (see Section 3.2.3). The extent of each FSU is equivalent to the extent of the corresponding ESU, clipped to the extent of the Salinas River HEC-RAS Model domain. Because the HEC-RAS model does not cover the entire area of Zone 2C, some ESUs (i.e., 1 and 13) do not have corresponding FSUs. Table 4-5 provides the inundated acreage for the 100-year, 50-year, 25-year, and 10-year events under the Historical and No Projects Scenarios by FSU; as above, an area is considered inundated if the HEC-RAS model simulates at least 0.1 foot depth of water there. Reductions in inundated area are spread across the FSUs, with the largest reductions occurring in FSU 3. The reductions in inundated acreage are largest for the 10-year event, both in magnitude and percentage, reflecting the fact that the Projects have the greatest effect on these more frequent events, as noted above.

4.4.2 Flow Velocity

The velocity of water flowing in inundated areas has important ramifications for the degree of impact that flood events will have on agricultural resources (e.g., crops and soil) and the built environment (e.g., buildings) within the inundated area. This section presents the distribution of flow velocity within the inundated area under each of the events included in this Flood Benefits Analysis.

Figure 4-23 shows the simulated flow velocity for the 100-year flood event under the Historical Scenario. The flow velocity of water in the inundated area is mostly about 5 feet per second (fps) or less. Flow velocities tend to be lower in the northern part of the study area compared to the southern area, where the floodplain is more constrained laterally. Flow velocities within the Salinas River channel are generally below 20 fps.

Figures 4-24, 4-25, and 4-26 show the simulated flow velocities for the 50-year, 25-year, and 10-year flood events, respectively, under the Historical Scenario. As the recurrence period shortens, the simulated flow velocities decline, with the lowest simulated flow velocities occurring under the 10-year event. For each, flow velocities are highest in the southern part of the study area, where the floodplain is narrower.

Figure 4-27 shows the simulated flow velocity for the 100-year flood event under the No Projects Scenario. The overall pattern of flow velocities is similar to the Historical Scenario 100-year event (Figure 4-23), but flow velocities are generally higher under the No Projects Scenario. In the southern part of the study area, flow velocities are generally between 5 and 10 fps across the majority of the floodplain, compared to between 2 and 10 fps under the Historical Scenario. In the northern part of the study area, north of about Chualar, flow velocities are generally about 2 to 10 fps, compared to mostly about 1 to 5 fps under the Historical Scenario.

Figures 4-28, 4-29, and 4-30 show the simulated flow velocities for the 50-year, 25-year, and 10-year flood events, respectively, under the No Projects Scenario. As under the Historical Scenario, simulated flow velocities decrease as the recurrence period shortens. Simulated flow velocities are higher for each event under the No Projects Scenario than under the Historical Scenario.

These results show that, by reducing the magnitude of peak flow events, the Projects reduce the velocity of flow within the inundated area of the Salinas River floodplain during floods. Because the floodplain is fairly narrow south of about King City, this area still experiences higher flow velocities compared to the northern part of the study area, but the Projects reduce flow velocities throughout. These reduced flow velocities reduce the chances of flood-induced damage to crops, agricultural soils, buildings, and other structures.

Prepared by:

WEST YOST

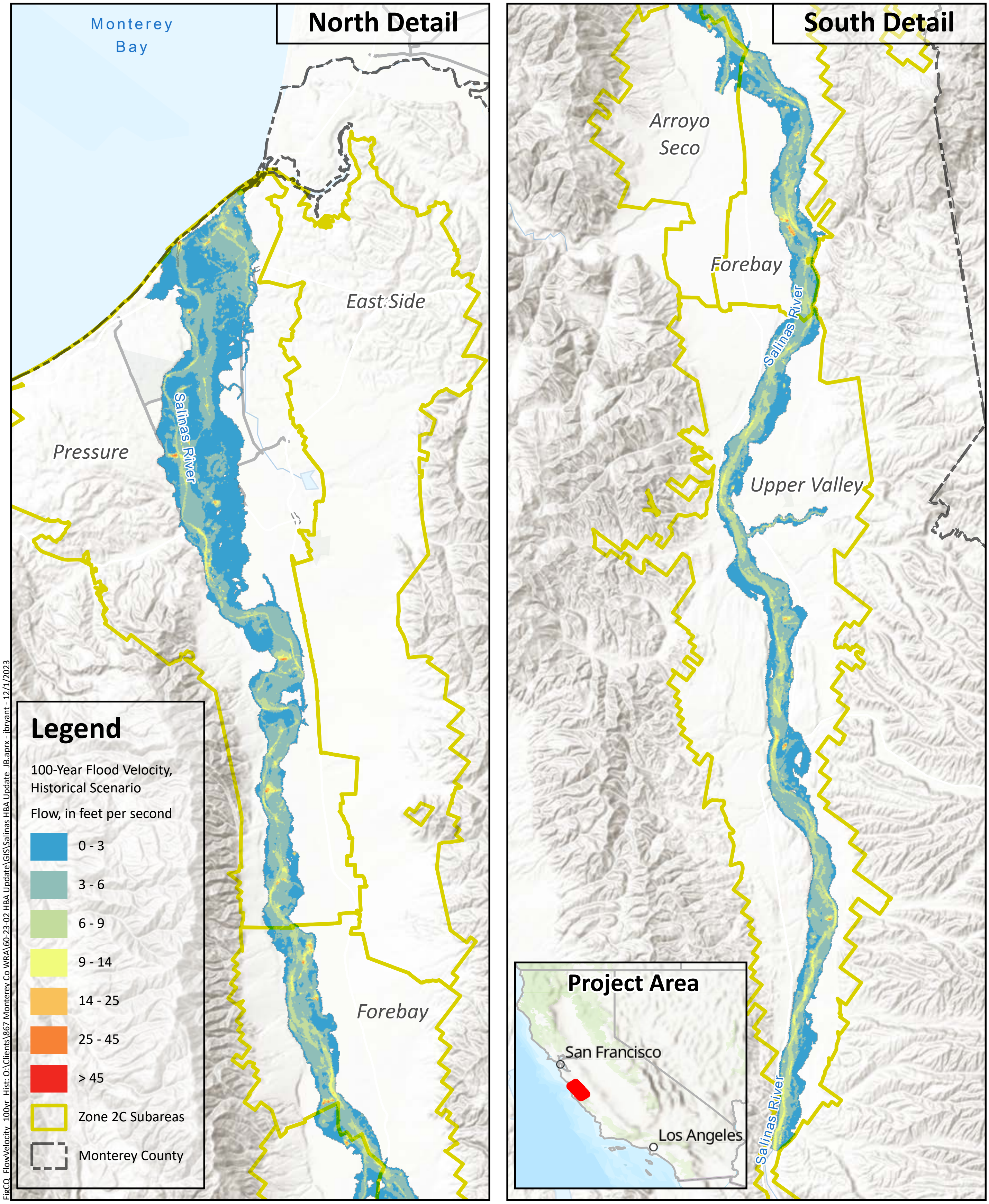
0 5 10 Miles

0 8 16 Km

N

Flood Study Units

Figure 4-22



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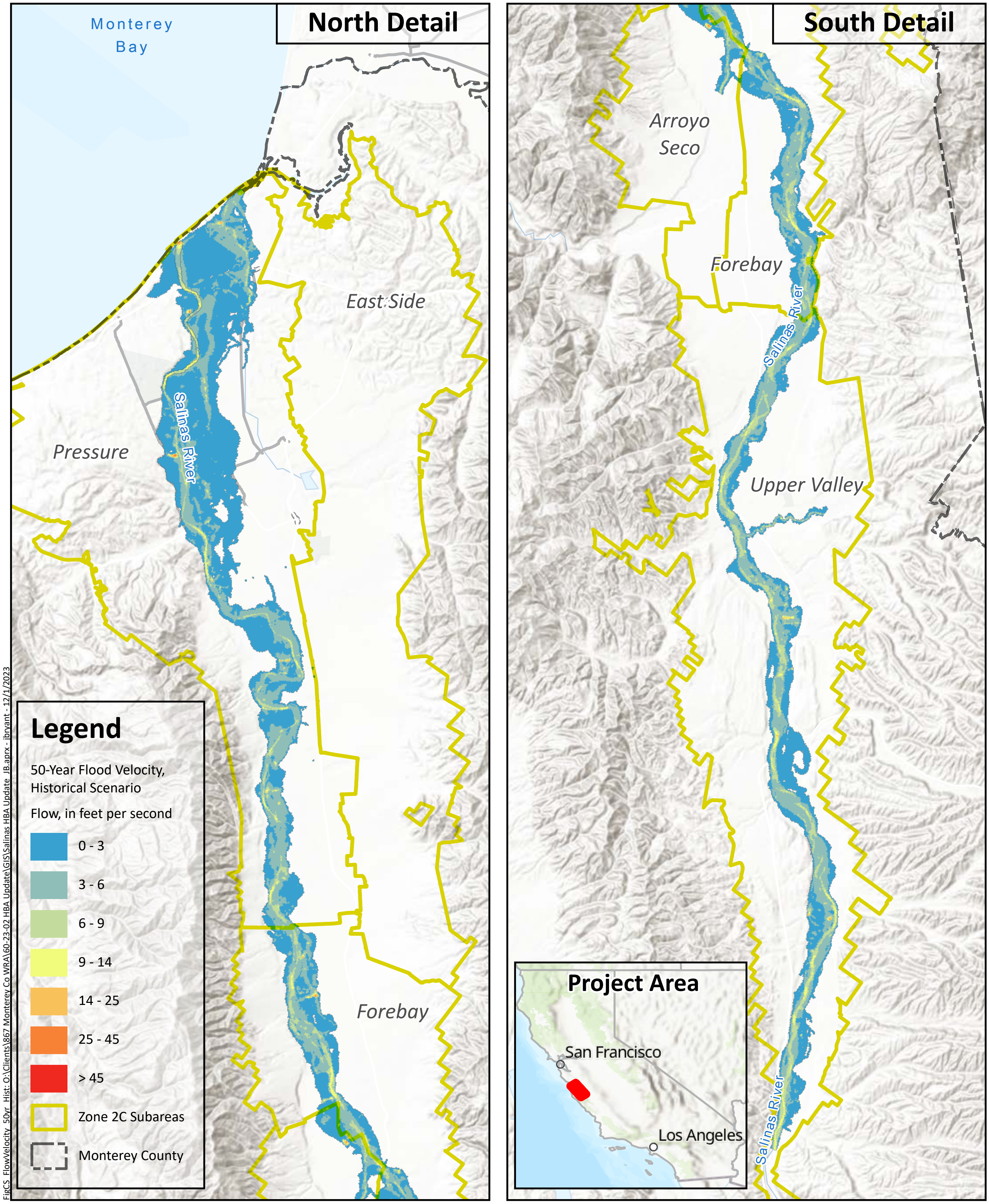
Flow Velocity for
100-Year Flood
Historical Scenario

Figure 4-23



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Prepared by:

WEST YOST

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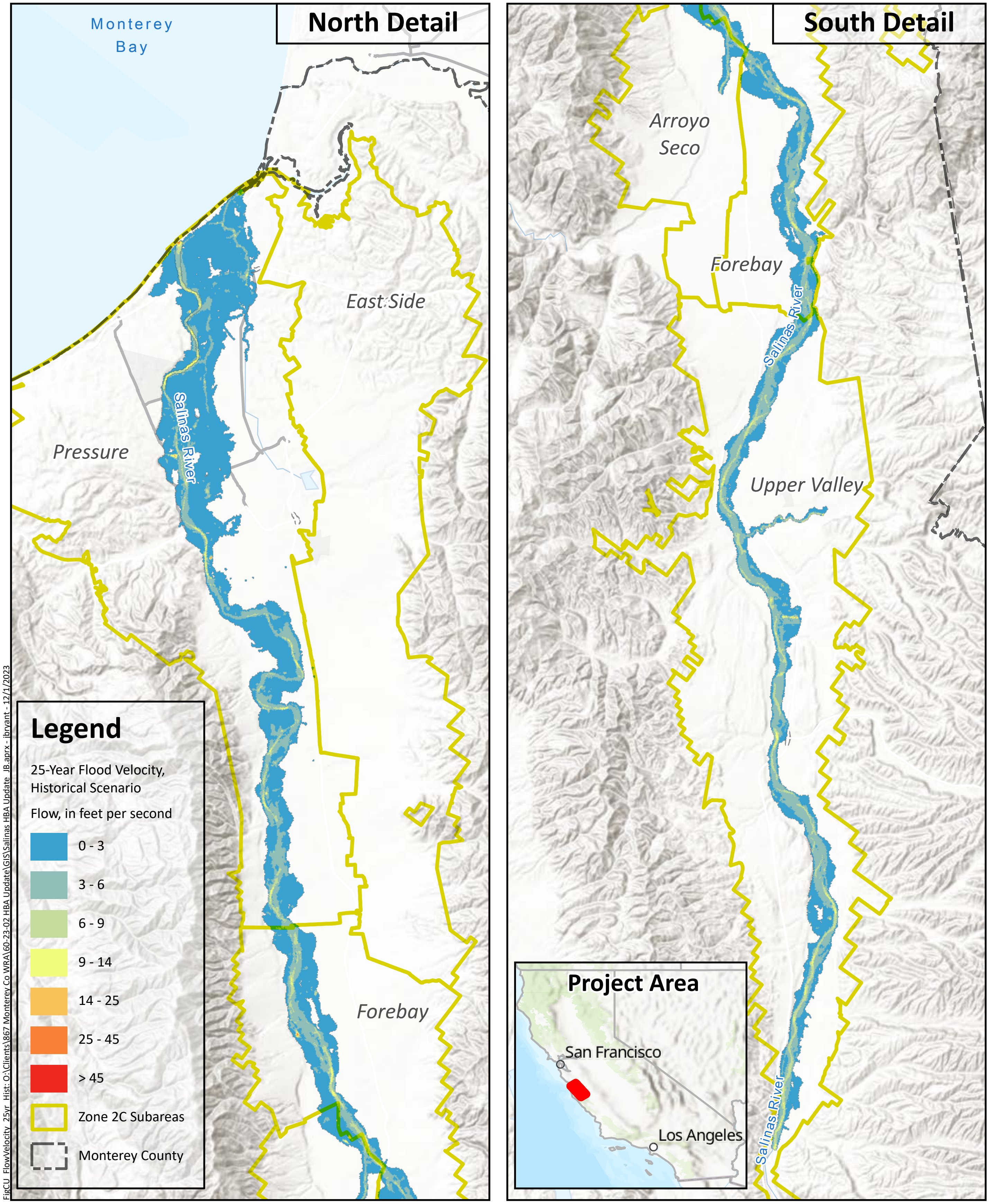
Flow Velocity for
50-Year Flood
Historical Scenario

Figure 4-24



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Prepared by:

WEST YOST

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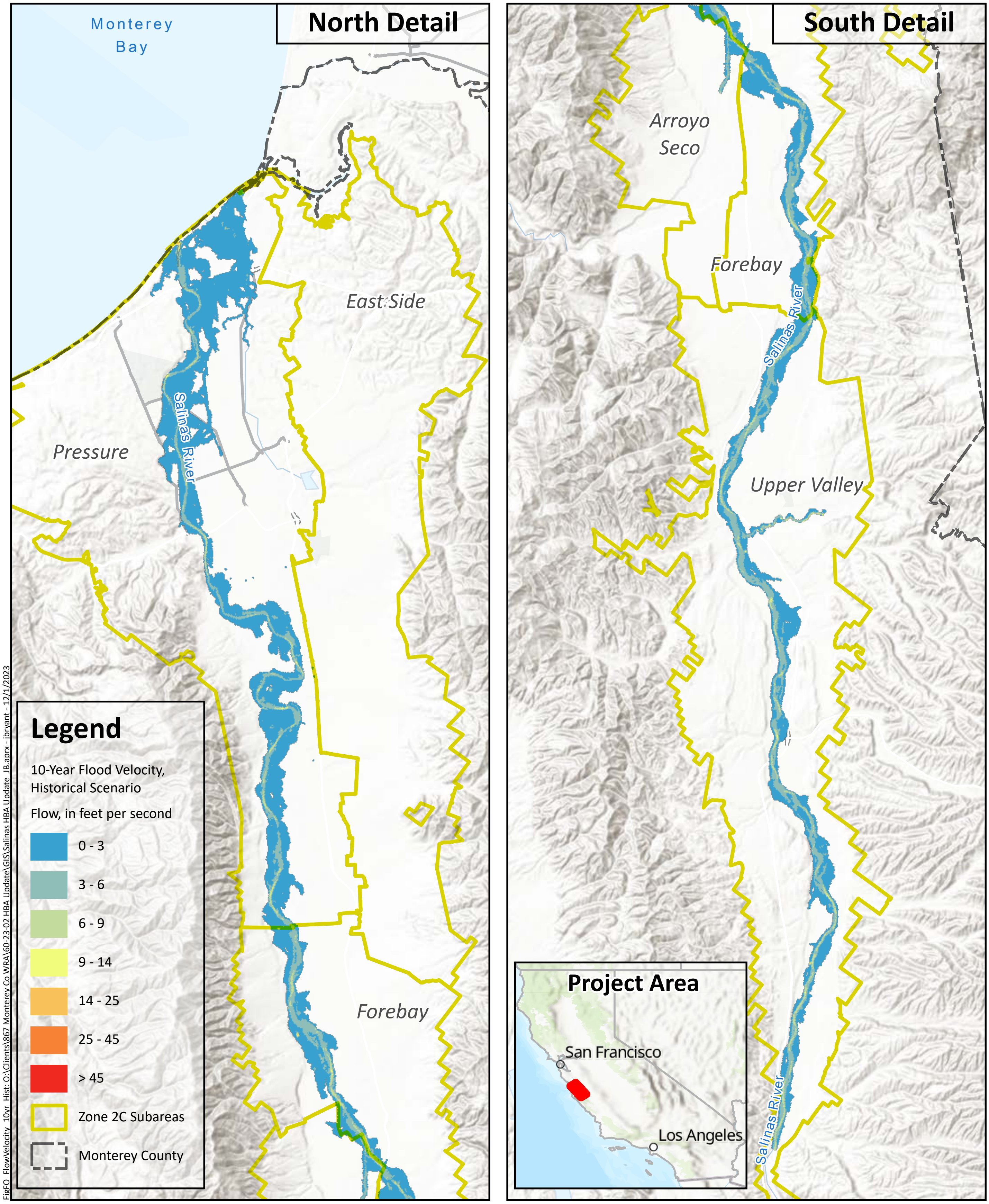
Flow Velocity for 25-Year Flood
Historical Scenario

Figure 4-25



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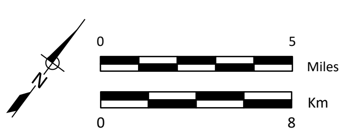
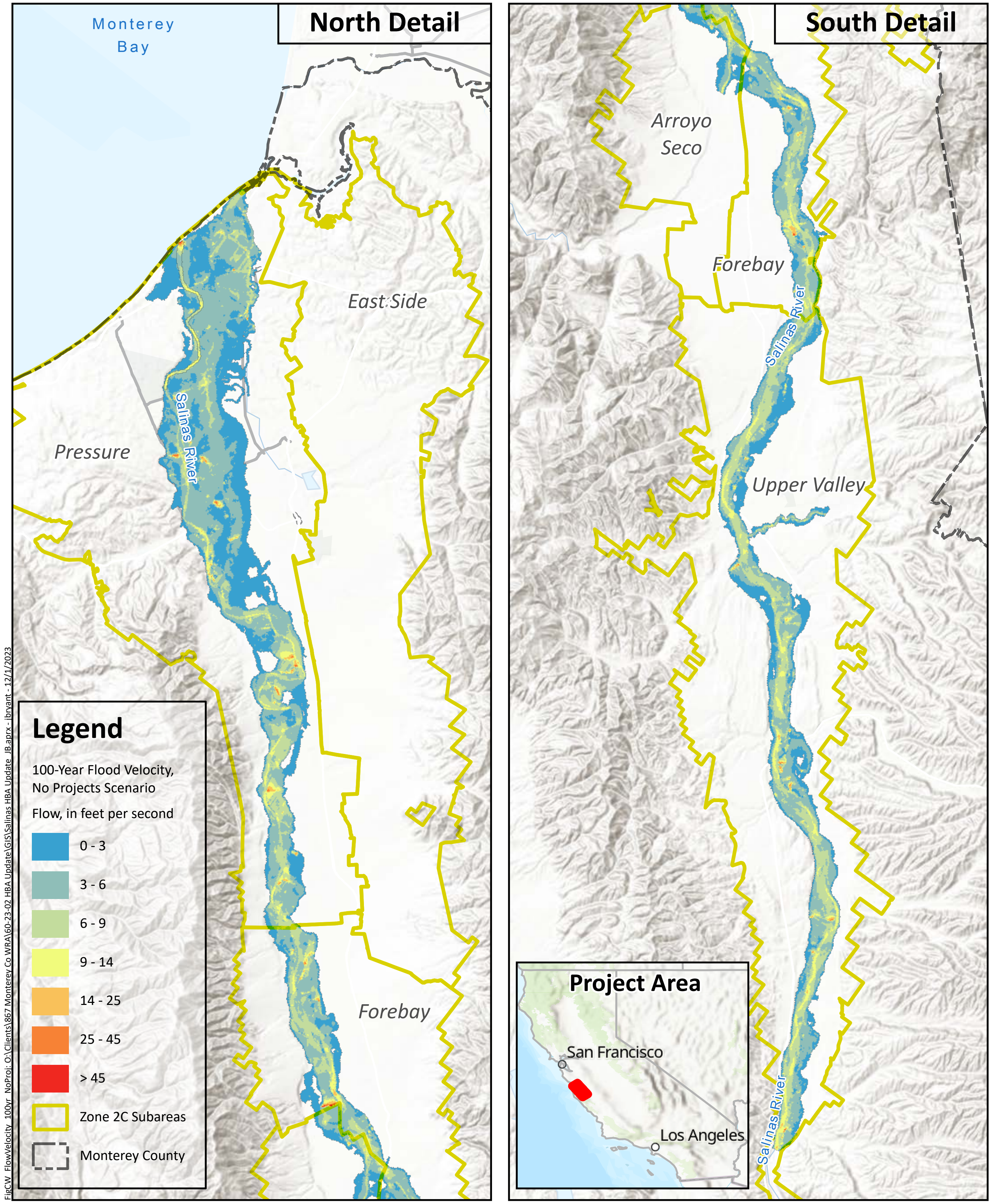


Flow Velocity for 10-Year Flood
Historical Scenario

Figure 4-26



Prepared by:

WEST YOST

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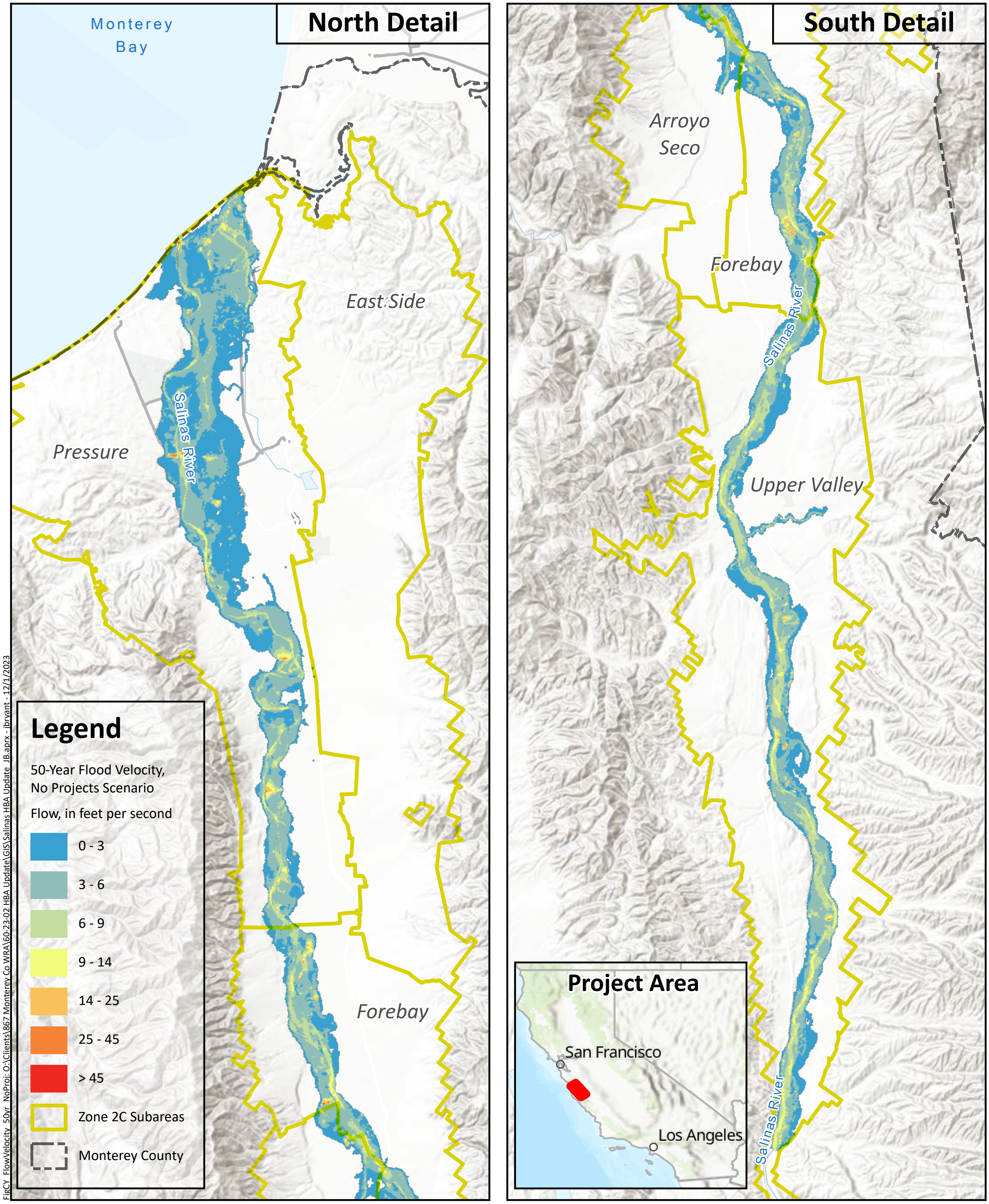
0 5 Miles

0 8 Km

MONTEREY COUNTY WATER RESOURCES AGENCY 1947

Flow Velocity for
100-Year Flood
No Projects Scenario

Figure 4-27



Prepared by:

WEST YOST

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0 5 Miles

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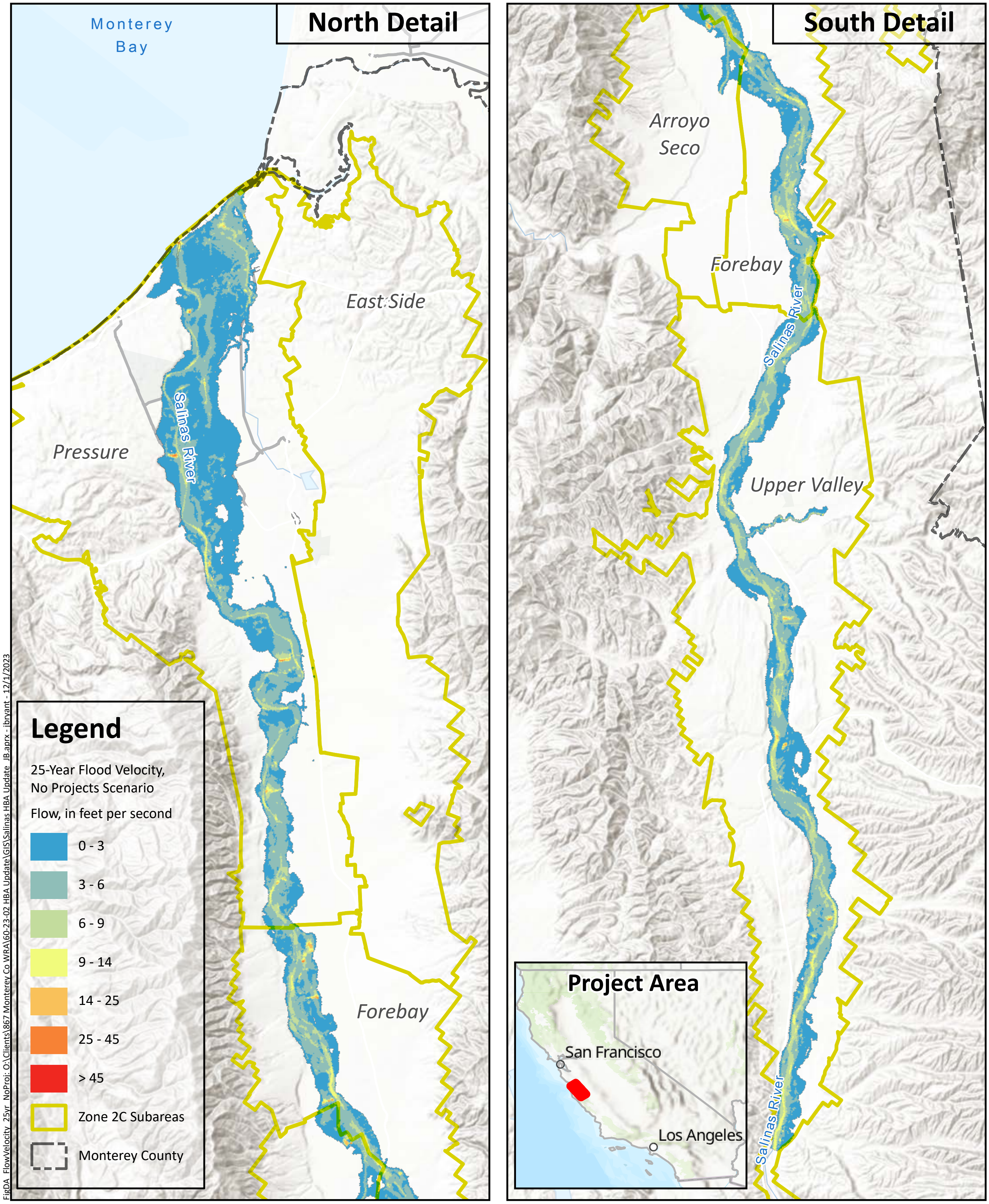
Flow Velocity for 50-Year Flood

No Projects Scenario

Figure 4-28

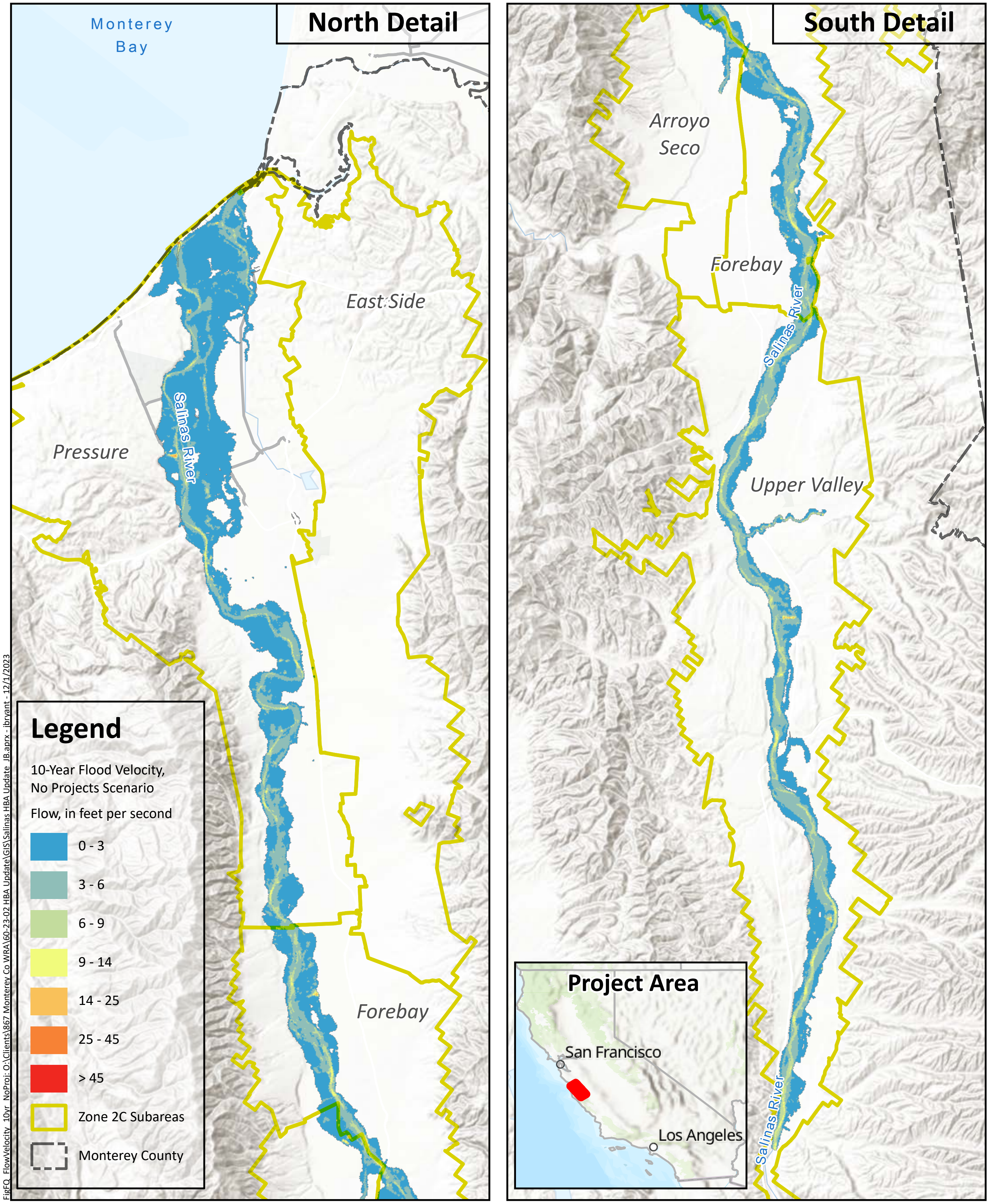


Prepared by:

0 5 Miles
0 8 Km

Flow Velocity for
25-Year Flood
No Projects Scenario

Figure 4-29



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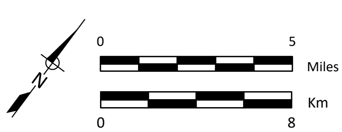
Prepared by:

WEST YOST



Flow Velocity for 10-Year Flood

No Projects Scenario

Figure 4-30

Table 4-5. Inundated Area (in acres) by FSU, Historical and No Projects Scenarios

	Historical Scenario				No Projects Scenario				Difference Between Scenarios			
Return Period	100	50	25	10	100	50	25	10	100	50	25	10
Annual Exceedance Probability	0.01	0.02	0.04	0.1	0.01	0.02	0.04	0.1	0.01	0.02	0.04	0.1
FSU 2	0	0	0	0	0	0	0	0	0	0	0	0
FSU 3	18,900	16,700	13,800	8,100	20,300	18,900	17,300	14,400	-1,500	-2,300	-3,500	-6,300
FSU 4	310	290	260	150	370	300	290	260	-60	-20	-40	-120
FSU 5	0	0	0	0	0	0	0	0	0	0	0	0
FSU 6	6,500	6,000	5,500	4,600	7,400	6,600	6,100	5,600	-800	-600	-600	-1,000
FSU 7	3,800	3,700	3,500	2,700	4,200	3,800	3,700	3,500	-300	-200	-200	-800
FSU 8	4,900	4,600	4,300	2,800	5,200	4,900	4,700	4,400	-300	-200	-500	-1,600
FSU 9	7,000	6,600	5,700	4,300	7,300	7,100	6,900	6,100	-200	-500	-1,200	-1,800
FSU 10	1,500	1,200	1,000	400	1,700	1,500	1,300	1,000	-200	-300	-300	-500
FSU 11	7,500	6,400	5,700	4,400	8,500	7,800	7,100	6,000	-900	-1,400	-1,400	-1,600
FSU 12	9,500	8,200	5,800	4,200	10,100	9,800	9,200	6,900	-600	-1,600	-3,400	-2,700

Notes:

- Areas are rounded to the nearest hundred acres, except for FSU 4, which is rounded to the nearest ten acres because of the smaller areas; totals may not sum due to rounding.
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

4.4.3 Soil Erosion Susceptibility

The 1998 HBA presented an estimation of the extent to which soil present within the Salinas River floodplain might be susceptible to erosion due to inundation during flood events. Soils were categorized into low, medium, or high erosion potential index categories based on published soil information and simulated flow velocities from inundation modeling under peak flow events. A similar approach was utilized here to estimate the potential for soil erosion with and without the Projects.

The estimation of soil erosion susceptibility for this HBA Update utilized a similar approach to that of the 1998 HBA. Two data sources contributed to this analysis: published soil data from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Series Geographic (SSURGO) Database (Soil Survey Staff, 2023) and streamflow velocities output by the Salinas River HEC-RAS Model (see Section 4.4).

The SSURGO database contains data related to mapped soil types throughout the study area. Spatial data consist of soil map units, each of which may contain several different soil types. Each soil type is assigned a soil erodibility factor (K_w) that denotes the susceptibility of that soil type to erosion by runoff; soils with multiple horizons (i.e., vertical variability) may have different K_w values for different soil horizons. For simplicity, the K_w value for the shallowest soil horizon was used, since the shallowest soil layer would be most exposed to erosion by runoff. For map units with multiple different soil types present, the K_w value for the soil making up the largest percentage of the map unit was used. Within the study area, K_w values vary from 0.02 to 0.49. This analysis used the same soil erodibility factor categories as the 1998 HBA, except that the lower end of the range was lowered to the minimum value of 0.02: low from 0.02 to 0.28; medium from 0.29 to 0.47; and high from 0.48 to 0.64.

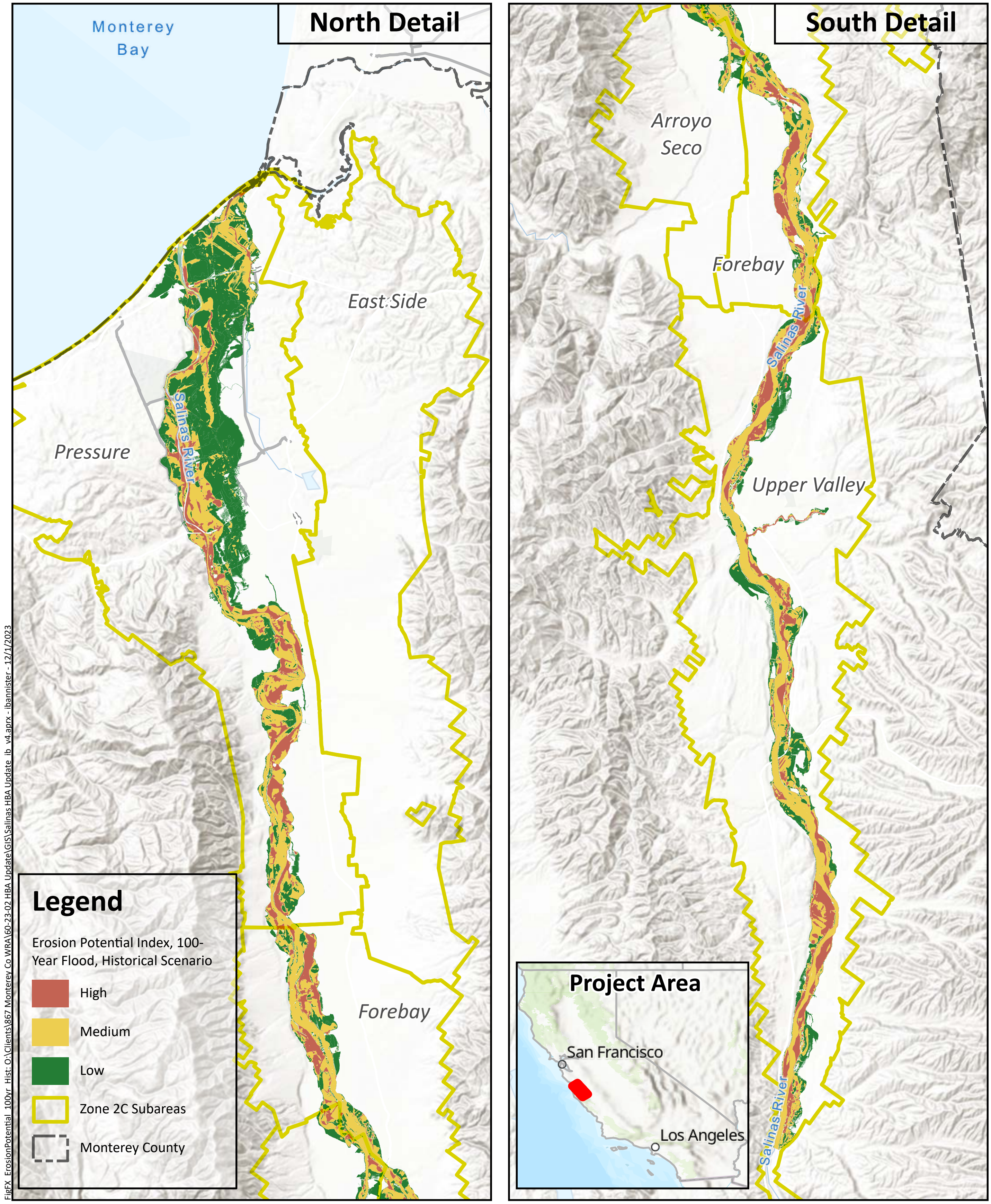
Following the approach of the 1998 HBA, inundation flow velocities were categorized into low (0 to 2 feet per second), medium (2 to 4 feet per second) and fast (at least 4 feet per second). See Figures 4-23 and 4-27 for the simulated flow velocities for the 100-year floods under the Historical and No Projects scenarios, respectively.

The categorization based on K_w and the categorization based on flow velocity were combined to create a categorization of soil erosion susceptibility, termed the Erosion Potential Index (EPI) to follow the 1998 HBA. The three categorizations relate to each other as follows:

- low EPI groups areas with low K_w and low velocity, low K_w and medium velocity, and medium K_w and low velocity;
- medium EPI groups areas with low K_w and high velocity, medium K_w and medium velocity, and high K_w and low velocity; and
- high EPI groups areas with medium K_w and high velocity, high K_w and medium velocity, and high K_w and high velocity.

Figure 4-31 shows the EPI categories for the Historical Scenario 100-year flood. Figure 4-32 shows the EPI categories for the No Projects 100-year flood. Table 4-6 provides a tabulation of the acreage within each FSU of low, medium, and high EPI for the 100-year flood for both scenarios. Because the 100-year flood under the No Projects Scenario inundates a larger area than the same event under the Historical Scenario, the total area is larger for the No Projects Scenario than the Historical Scenario. The No Projects Scenario 100-year flood results in larger acreages of medium and high EPI and fewer acres of low EPI compared to the Historical Scenario. The differences between the 100-year flood events for the two scenarios represents the benefit provided by the Projects in terms of the prevention of soil erosion. The largest reductions in the area of high EPI occurred in FSUs 12 (about 1,300 acres), 6 (about 1,000 acres), and 3 (about 900 acres). No FSU experienced an increase in the area of high EPI.

This analysis does not take into account the duration of flooding, since the Salinas River HEC-RAS Model was run in a quasi-steady state to only represent the conditions under the peak flow magnitude.



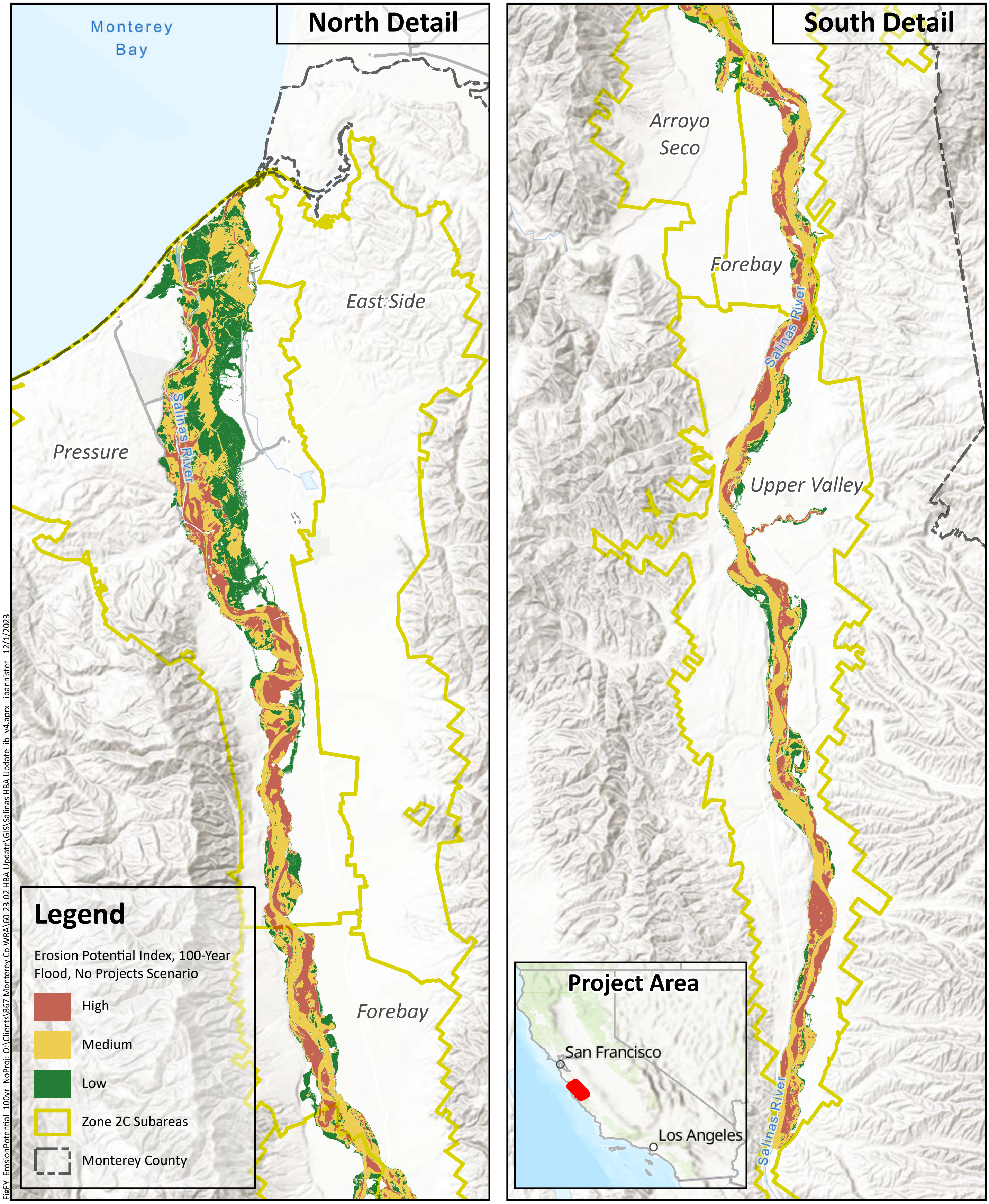
Prepared by:

0 5 Miles

0 8 Km

Erosion Potential Index
100-Year Flood
Historical Scenario

Figure 4-31



FigFY_ErosionPotential_100yr_NoProj: O:\Clients\867 Monterey Co WRA\60-23-02 HBA Update\GIS\Salinas HBA Update_ib_v4.aprx - ibannister - 12/1/2023

Prepared by:

WEST YOST

0 5 Miles

0 8 Km

Erosion Potential Index

100-Year Flood

No Projects Scenario

Figure 4-32

Table 4-6. Area (in acres) in Each Erosion Potential Index Category by FSU for 100-Year Event, Historical and No Projects Scenarios

Erosion Potential Index Category	Historical Scenario			No Projects Scenario			Difference Between Scenarios		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
FSU 2	0	0	0	0	0	0	0	0	0
FSU 3	12,080	5,040	1,480	9,900	7,710	2,380	+2,180	-2,670	-900
FSU 4	100	120	70	130	110	110	-30	+10	-40
FSU 5	0	0	0	0	0	0	0	0	0
FSU 6	2,050	2,950	1,580	2,020	2,840	2,600	+30	+110	-1,020
FSU 7	890	2,030	920	730	2,140	1,290	+160	-120	-370
FSU 8	1,100	2,630	1,150	970	2,560	1,710	+130	+60	-550
FSU 9	1,380	790	1,430	820	4,220	2,130	+550	-3,430	-700
FSU 10	530	790	190	460	850	370	+60	-50	-180
FSU 11	1,990	3,730	1,870	1,610	4,210	2,670	+380	-480	-800
FSU 12	2,170	5,130	2,280	1,150	5,410	3,600	+1,030	-280	-1,320

Notes:
- Areas are rounded to the nearest 10 acres; totals may not sum due to rounding
- Difference between scenarios is calculated as Historical Scenario minus No Projects Scenario

CHAPTER 5
Economic Benefits Analysis

The goal of the 1998 HBA was to develop an estimate for the benefit that stakeholders in the Salinas Valley have received due to the construction and operation of the Nacimiento and San Antonio Reservoirs. This Economic Benefit Analysis was accomplished by translating the Hydrologic and Flood Control Benefits into monetary benefits.

This HBA Update does not include an Economic Benefits Analysis; it is being prepared by One Water Econ under separate cover based on the results of this report.

CHAPTER 6
Other Benefits

The 1998 HBA included a qualitative discussion of other benefits that the Nacimiento and San Antonio Reservoirs have provided to stakeholders in the Basin. None of these additional benefits were included in the Hydrologic, Flood Control, or Economic Benefits in the 1998 HBA. This HBA Update similarly discusses, in general terms, additional benefits that the Projects provide to stakeholders in the Basin, guided by the equivalent discussion in the 1998 HBA.

6.1 RECREATION AND TOURISM

The Nacimiento and San Antonio Reservoirs provide recreational benefits to the study area. Since they were constructed, they have enabled stakeholders and visitors to the Basin to experience various outdoor activities, including camping, hiking, and fishing. Communities like Heritage Ranch have developed around the reservoirs. Recreation and tourism do not provide stakeholders in the Basin with additional water or flood protection, but they do embody economic benefits. Recreational benefits are evaluated and quantified in further detail in the Economic Benefits Analysis prepared by One Water Econ.

6.2 ENVIRONMENTAL BENEFITS

In addition to the benefits that have accrued to the groundwater system and to lands in the floodplain, the Projects have, through their operation, maintained streamflow in the Salinas, Nacimiento, and San Antonio Rivers that has supported fish and wildlife habitat in the stream network. A major focus of this activity is the migration of endangered Steelhead trout through the Salinas River and its tributaries. The Flow Prescription (MCWRA, 2005) has been used since its publication as a guidance document for MCWRA's operation of the Nacimiento and San Antonio Reservoirs. This document provides information on the life cycle of Steelhead trout in the system and recommendations for streamflow targets whose timing, location, and magnitude are designed to best support migration to and from spawning grounds.

These environmental benefits are not quantified for this HBA Update. Studies are ongoing on how to operate the reservoirs to minimize negative effects on endangered Steelhead trout and other fish and wildlife in the Salinas River and its tributaries.

6.3 SYSTEM RELIABILITY

The model results presented in this HBA Update indicate that the Salinas River and its tributaries are critical to maintaining groundwater head levels in the study area as the stream network loses water to the study area aquifers. While streamflow losses are generally higher with higher streamflow, the proportion of streamflow lost to groundwater is higher during dry and normal years than during wet years (see data in Tables 3-10, 3-11, and 3-12). This indicates that the benefit of water stored during wet years is increased flow in the Salinas River during drier years. The Projects' effect on groundwater head and storage are quantified in Chapter 3. However, there is an unquantifiable benefit to providing peace of mind to stakeholders in the Basin in terms of the reliability of streamflow in the Salinas River and recharge to the groundwater system. Figure 4-2 shows the annual total simulated streamflow in the Salinas River at Bradley. These model results suggest that there might have been many more years with little flow (i.e., below 200,000 af) in the Salinas River without the Projects (dotted line) – as compared to the observed Historical data (solid line).

6.4 INSURANCE AGAINST UNCERTAIN FUTURE CONDITIONS

There is no clear consensus in the available climate projections to indicate that precipitation in the Salinas Valley should be expected to either increase or decrease in the future, although each is possible. However, the year-to-year precipitation is expected to become more variable in the future as a result of climate change (Bedsworth et al., 2018). The Projects may become more and more important in the future as rainfall conditions become even more unpredictable than they already are. This represents a reduction in future risk and a benefit to stakeholders in the future, rather than a historical benefit.

CHAPTER 7
Discussion of Uncertainty

This HBA Update relies on the support of complex numerical models built from conceptual models and historical datasets that have been developed over decades; these tools are considered to be the best available for characterizing the benefits of the Projects. Uncertainties and limitations inherent to the tools and analyses on which this HBA Update are built are acknowledged and discussed in this section. This discussion is not a rigorous quantitative uncertainty analysis, which would involve a systematic modification of model parameters and investigation of the effect of those changes. Instead, presented herein is a listing of the sources of uncertainty and limitations inherent to the analyses.

This chapter categorizes uncertainties and limitations into those related to the understanding of the Basin (based on observed data), the models used, and the interpretation of the model results. This discussion is not exhaustive.

7.1 UNCERTAINTIES RELATED TO THE BASIN CONCEPTUAL MODEL

Natural hydrogeologic systems host a level of complexity that cannot be fully represented with empirical data and models. Hydrogeologic complexity (i.e., heterogeneity) exists on different scales and can impact the system's behavior in many ways. Typically, a calibrated model in its best practice sense seeks to define parameters (such as aquifer hydraulic conductivity) that best represent the overall behavior but may not capture the full range of variability in a hydrogeologic system.

Although a defined hydrostratigraphy (i.e., aquifers and aquitards) helps with conceptualizing a system, it is a simplification of the actual distribution of the materials making up the porous medium in which groundwater exists. Various studies of the Salinas Valley (e.g., Kennedy/Jenks, 2004, Brown and Caldwell, 2015a) focused on the hydrostratigraphy of the Basin aquifers and shown that the recognized aquitards and aquifers in the Basin conceptual model (e.g., the 180-Foot, 400-Foot, and Deep Aquifers in the Pressure Subarea) are highly variable in terms of their thickness and interconnection. Gaps exist in the aquitards separating aquifers from each other, including between the Shallow Aquifer and the 180-Foot Aquifer in the Pressure Subarea. The kind of large-scale hydrostratigraphic heterogeneity discussed here can be captured in a modeling tool like the SVIHM through changes to model layer thickness and parameters. Smaller-scale variability may be difficult to reflect in a modeling tool like the SVIHM that is intended to investigate an entire system.

Of particular importance to future of water resources development in the Salinas Valley is the characteristic of the connection between the Deep Aquifers and the Pacific Ocean. The other major production aquifers, the 180-Foot and 400-Foot Aquifers, have been shown to be directly connected to the Ocean beneath Monterey Bay. Seawater intrusion into the 180-Foot and 400-Foot Aquifers has led to an increase in the number of production wells being drilled in the Deep Aquifers. Increased use of groundwater in the Deep Aquifers has increased the urgency for a resolution of the state of connection with the Pacific Ocean. MCWRA has convened a Deep Aquifer Roundtable of hydrogeologic experts familiar with the study area to address gaps in the understanding of the Deep Aquifers and their connection to the Ocean, and to help guide data collection efforts in the future to address these uncertainties. In January 2022, the Salinas Valley Basin Groundwater Sustainability Agency initiated a study of the Deep Aquifers, the results of which are anticipated in 2024.

7.2 UNCERTAINTIES RELATED TO THE MODELING TOOLS

The models used in this study, the SVIHM and the Salinas River HEC-RAS model, represent the natural environment. They are effective tools for understand the system and are built from conceptual models that best represent the inherent heterogeneity in the study area's surface water and groundwater systems. Although the integrated use of models (SVIHM/HEC-RAS) is very informative, the models are not expected to fully capture the full complexity of the groundwater and surface water systems.

The SVIHM simulates conditions in both the groundwater and surface water systems across a very large geographical area (the model domain is almost 100 miles long from its southern to northern ends) and includes a number of processes that are extremely complex on their own (especially groundwater-surface water interaction and agricultural supply and demand estimation). Developing a complex tool like the SVIHM requires that decisions be made early on to identify the focus of the calibration. For a tool that is designed to simulate conditions throughout a large basin, calibration cannot focus on local conditions everywhere in the model domain. Usually, calibration will concentrate on the overall ability of the model to reproduce observed historical conditions, as quantified using calibration statistics. This report cannot comment on the calibration focus or quality for the SVIHM as its documentation has not yet been published by the USGS. No model produces a perfect match to observed conditions, and the quality of the match varies from place to place. A basin-wide model like the SVIHM should not be expected to reproduce conditions equally well at all locations in the model and should not be considered indicative of small-scale conditions (e.g., at an individual well).

An important assumption made for the SVIHM is that the Nacimiento River is not part of the active model domain until a location about 5 miles downstream of the location of Nacimiento Dam. Figure 4-3 shows where the SVIHM stream boundary condition cells are present along the Nacimiento River. This approach assumes that no interaction occurs between the Nacimiento River and underlying sediments within this 5-mile stretch just downstream of Nacimiento Dam.

The software packages used to build the modeling tools used in this analysis (MODFLOW-OWHM for the SVIHM and HEC-RAS 2D for the Salinas River HEC-RAS Model) rely on their own sets of assumptions to simulated natural groundwater and surface water flow processes. The documentation for these software packages (Boyce et al., 2020; USACE, 2016) discuss these assumptions, and it is beyond the scope of this report to discuss these assumptions here.

7.3 UNCERTAINTIES RELATED TO THE ANALYSIS

The last source of uncertainty affecting the results of the benefit estimation discussed herein stems from the analyses used to prepare the HBA Update. These analyses translate the SVIHM and Salinas River HEC-RAS Model results into indicators of the effects of the Projects on the system. The results of these analyses are presented throughout this HBA Update. Limitations and uncertainties related to the analyses that are specific to the Flood Control Benefits Analysis are presented in their own section in Appendix B.

The benefits quantified in this HBA Update are based on differences between the Historical and No Projects Scenarios results. The Historical Scenario was simulated using the SVIHM as delivered by the USGS with very little modification. Simulation of the No Projects Scenario required certain modifications to the SVIHM to approximate the system without the Projects. This followed the approach used for the 1998 HBA to simulate the Basin in a "without reservoirs" condition. Estimated daily reservoir inflow time series were provided by MCWRA for each reservoir over their periods of operation, and these inflow time series were used as the inputs to the SVIHM where the Nacimiento and San Antonio Rivers enter the active model domain (locations shown on Figure 4-3). The application of the reservoir inflow time series as inputs to the SVIHM assumes that there is no lag between where the inflow is determined and where that water enters the SVIHM domain. It also assumes no interaction between that inflow and the surrounding environment (e.g., no groundwater-surface water interaction). The temporal discretization of the SVIHM (monthly stress periods) means that any lag would be insignificant compared to the stress period length. The Nacimiento and San Antonio Lakes are located in valleys largely floored with bedrock, minimizing the extent to which the rivers would interact with their surroundings.

Other than the changes described in Chapter 2, the SVIHM was not modified from the configuration used for the Historical Scenario to produce the No Projects Scenario. It is reasonable to assume that if the Projects had not been present in the system, groundwater users would have been forced to compensate in certain ways for the impacts they would have experienced; for example, additional wells might have been installed in the Deep Aquifers due to decreased heads in the 180-foot and 400-foot Aquifers in the Pressure Area. This HBA Update does not make changes (for example, to the construction or locations of pumping wells in the study area) to anticipate or respond to conditions without the reservoirs.

As described in Appendix B, the estimation of peak flow magnitudes on which the Flood Control Benefits Analysis is based depends on a number of assumptions and correlative relationships between datasets. Each linear regressions that went into determining the peak flow magnitudes - that fed into the Salinas River HEC-RAS Model - introduces some amount of uncertainty to the results. It is beyond the scope of this study to quantify these uncertainties. A modeling tool that could realistically simulate short-term streamflow conditions (i.e., sub-daily) and longer-term groundwater flow conditions together at the same time might obviate some of these limitations, but no such tool exists for this system. The modeling tools utilized for this HBA Update (the SVIHM and the Salinas River HEC-RAS Model are the best available tools for understanding the dynamic groundwater-surface water system of the Salinas Valley.

CHAPTER 8
Summary and Conclusions

This HBA Update represents an update to the 1998 Salinas Valley Historical Benefits Analysis (MW, 1998), an important document in the hydrology of the study area. The 1998 HBA quantified the benefits that the stakeholders of the Basin have received from the operation of the Nacimiento and San Antonio Reservoirs from when each came online to the end of WY 1994. These benefits were quantified in terms of monetary benefits received due to the avoidance of costs related to modification of wells, reduction of energy required for groundwater pumping, and decreased frequency and magnitude of damaging inundation of the Salinas River floodplain. The 1998 HBA found that the reservoirs had provided, up to the end of the period of analysis, about $11.8 million per year of benefit to stakeholders in the Basin.

In the 25 years since the 1998 HBA was published, there have been numerous changes to the Basin conceptual model, additional data collected, new projects (including the SVWP), and new and better tools for analyzing conditions in the Basin. These changes have resulted in a need for an updated HBA. This study was accomplished by simulating conditions within the Salinas Valley with and without the Projects (including the reservoirs) in place over the historical period from WY 1968 (when San Antonio Reservoir began operating) and WY 2018 (the end of the SVIHM period as of the publication of this document). The difference between the with-Projects (Historical Scenario) and without-Projects (No Projects Scenario) is taken to be the effect of the Projects. An analysis that separately quantifies the benefits of individual Projects (e.g., only Nacimiento Reservoir or just the SVWP) would be impractical because the various Projects are deeply interrelated, and their effects cannot be fully separated from each other. Therefore, this study presents the benefits provided by all the Projects together. This report includes some qualitative discussion of the Project or Projects that are likely to have contributed most substantially to particular differences between the scenarios.

This study utilizes the USGS' SVIHM, which is a preliminary MODFLOW-OWHM model of the groundwater-surface water system of the Salinas Valley, including the dynamic estimation of agricultural supply and demand. As described in Chapter 2, the SVIHM has not yet been published by the USGS and remains a preliminary product without available documentation as of the publication of this HBA Update.

8.1 HYDROLOGIC BENEFITS

The Salinas Valley has experienced an overall increase in the amount of fresh groundwater in storage in the Basin aquifers due to the presence of the Projects. This has manifested as increased groundwater head and decreased seawater intrusion from Monterey Bay. Higher head values have resulted in reduced pumping lift in wells and reduced energy use. Groundwater pumping has also been reduced in the CSIP area due to the provision of recycled water and diverted Salinas River flow to this area. The hydrologic benefits of the Projects are discussed in Chapter 3.

The Projects result in higher head values in the study area aquifers. Higher heads were concentrated in two portions of the study area: the area between Castroville and Salinas and along the Salinas River from about Bradley to Gonzales. By the end of the model period (September 2018), head was as much as about 67 feet higher in the 400-Foot Aquifer of the Pressure Subarea in the area between Castroville and Salinas. Head along the Salinas River was up to about 15 feet higher by September 2018. Although head in much of the study area was lower at the end of the model period compared to the start even with the Projects, this decline was substantially smaller than it would have been without the Projects. Head declined by up to about 3.0 feet per year in the area between Castroville and Salinas with the Projects; the average annual head decline was about 3.3 feet per year in the same area without the Projects.

The increased groundwater heads reflect an increase in groundwater storage resulting from additional water entering the groundwater system. Groundwater budgets indicate that the Projects have resulted in about 72,000 afy more streamflow losses from the Salinas River and its tributaries to the study area aquifers; most of the increase has occurred in the Upper Valley Subarea (about 44,000 afy) and the Forebay Subarea (about 20,000 afy). The resulting higher head values have resulted in about 45,000 afy more discharge to agricultural drains and about 14,000 afy less net recharge, also mostly focused in the Upper Valley and Forebay Subareas. The Projects have also resulted in about 10,000 afy less agricultural pumping, with most of the reduction taking place in the Pressure Subarea. Although storage declined (by an average of about 11,000 afy) with the Projects, this storage loss would have been substantially greater (about 31,000 afy) without the Projects.

Although the SVIHM cannot be used in its current state to directly simulate the intrusion of seawater into the freshwater aquifers of the study area, model results indicate that seawater intrusion has been about 1,000 afy lower with the Projects than it would have been without the Projects.

Surface water budget information indicates that the increase in streamflow losses (about 72,000 afy) caused by the Projects has resulted in a decrease in Salinas River outflow to Monterey Bay of about 51,000 afy. The Projects have also resulted in about 21,000 afy less inflow along the Nacimiento and San Antonio Reservoirs, likely reflecting evaporation from the reservoir surfaces and the provision of water to San Luis Obispo County and lakeside users from Nacimiento Reservoir. Increased head values due to the Projects have resulted in about 45,000 afy more land surface runoff in the study area.

The Projects have resulted in little difference in the ability of groundwater wells to operate (for example, due to lowered groundwater head values). However, the Projects have led to substantially less agricultural pumping, especially in the Pressure Subarea, where there has been about 299,000 af less pumping than would have occurred without the Projects. Smaller reductions in agricultural pumping have taken place in the Upper Valley (about 104,000 af) and Forebay (about 76,000 af) Subareas.

The above changes to the groundwater and surface water systems demonstrate how the Projects have benefited the Salinas Valley over the past 50 years. The Nacimiento and San Antonio Reservoirs have held back high winter flows for release during the summer period and during dry years to recharge the aquifers of the Basin. Less water has flowed out to Monterey Bay, and therefore been kept within the Basin. Streamflow losses have been substantially larger during dry and normal years. The implementation of the CSIP west of Salinas has maintained substantially higher heads in the area between Castroville and Salinas and reduced agricultural pumping in this area, as well as decreased the rate of seawater intrusion into the Basin; these changes can be attributed to the operation of CSIP because their onset coincides with the beginning of CSIP operation in 1998.

8.2 FLOOD CONTROL BENEFITS

The Projects have resulted in a decrease in the frequency and magnitude of major inundation events in the floodplain of the Salinas River. The Nacimiento and San Antonio Reservoirs have provided this benefit by storing high flows during wet winter periods and releasing flows during drier parts of the year. The reservoirs act to attenuate flood peaks generated in the Nacimiento and San Antonio River watersheds rather than passing them directly to the Salinas River. The flood control benefits of the Projects are discussed in Chapter 4.

The operation of the reservoirs has resulted in smaller floods in the system. This is shown in the Flood Frequency Curves for the Salinas River at Bradley with and without the Projects, which quantify the magnitude of events of various return periods. These curves indicate that the 100-year flood event is about 115,000 cfs with the Projects in place, versus about 159,000 cfs without the Projects (a reduction of about 44,000 cfs, 28 percent of the No Projects 100-year flood). For more frequent events, the Projects have resulted in larger proportional reductions in the magnitude of the peak flows; for example, the 10-year event (about 28,000 cfs with the Projects and about 68,000 cfs without) has a 58 percent decrease in magnitude. The larger proportional decreases in peak flow magnitudes for smaller events reflects the fact that the reservoirs cannot necessarily capture the entirety of the highest flow events because reservoir capacity may not be sufficient to fully store the event inflow.

The reduced magnitude of peak flow events has resulted in less inundation of the Salinas River floodplain than would have occurred had the Projects not been in place. The 100-year flood without the Projects would result in about 65,000 acres inundated, versus about 60,000 acres for the 100-year flood with the Projects. Larger decreases in inundated area are estimated for more frequent events; for example, the 10-year event would result in about 48,000 acres inundated without the Projects and about 32,000 acres inundated with the Projects.

In addition to decreasing the extent of inundation, the Projects, by reducing the magnitude of peak flows, result in lower streamflow velocities in the Salinas River floodplain. This results in decreased potential for erosion in the floodplain; for the 100-year flood, the area of high potential for erosion was about 11,000 acres with the Projects and about 17,000 without.

These results indicate that the Projects have led to less flooding in the Salinas River floodplain, protecting both agricultural resources (crops and soils) and structural resources (buildings).

8.3 ECONOMIC BENEFITS

The economic benefit provided by the Projects can be estimated from the other types of benefits described in this HBA Update, but this report does not provide a quantification of the monetary benefits; instead, these are being prepared separately for MCWRA based on the results of this study. The economic benefits analysis will be published under separate cover.

8.4 OTHER BENEFITS

The Projects provide additional benefits other than the hydrologic and flood control benefits that are difficult or impossible to quantify. These include recreational and tourism benefits, environmental benefits, improved system reliability, and insurance against uncertain future conditions. Other benefits are described briefly in Chapter 6.

CHAPTER 9
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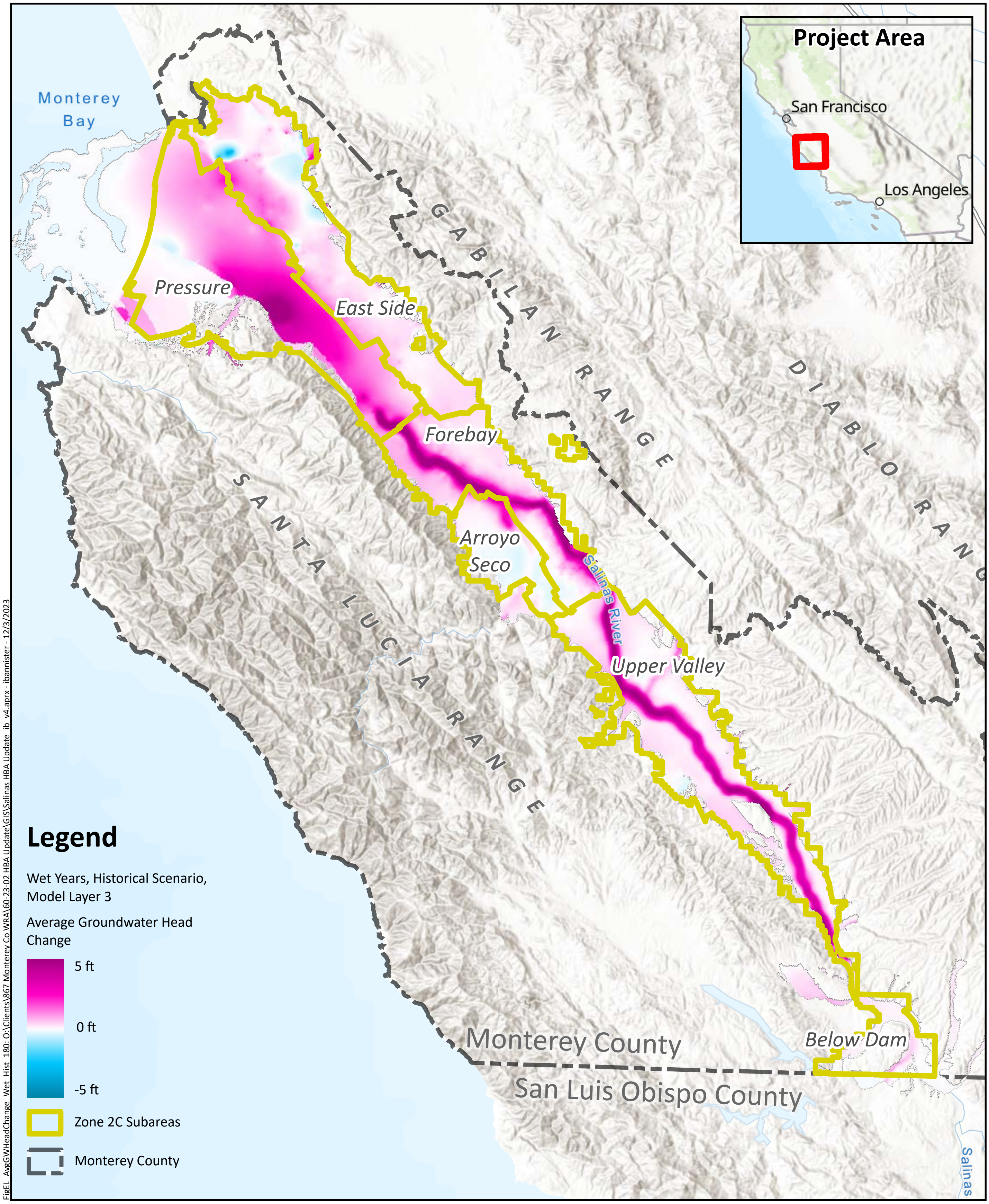
Appendix A

Additional Simulated Groundwater Head Maps

LIST OF FIGURES

FigEL AvgGWHeadChange Wet Hist 180: O:\Clients\867 Monterey Co WRA\60-23-02 HBA Update\GIS\Salinas HBA Update ib v4.aprx - ibannister - 12/3/2023



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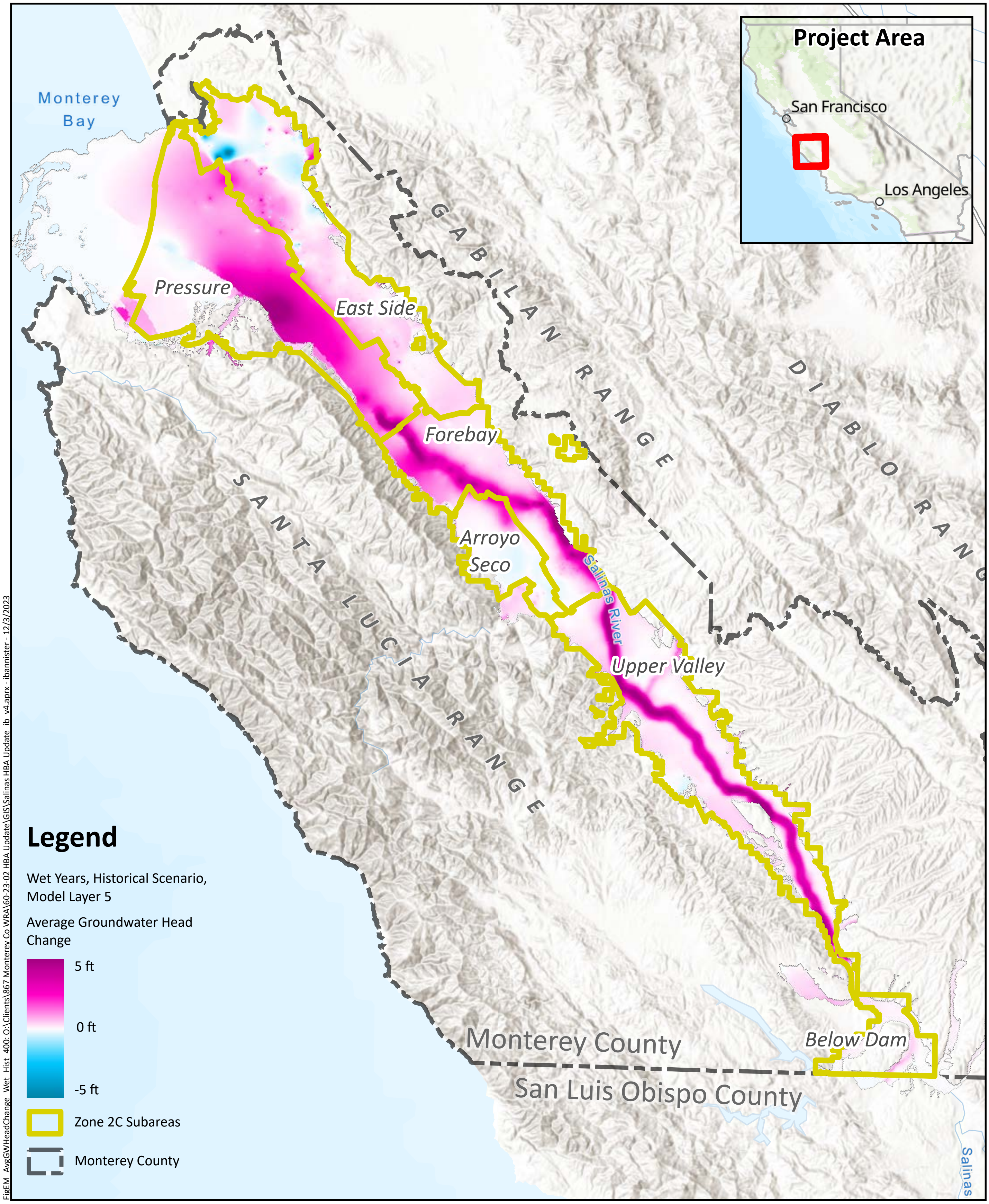
April 2025

Average Annual Groundwater Head Change Historical Scenario, Wet Years
180-Foot Aquifer & Equivalent

Figure A1



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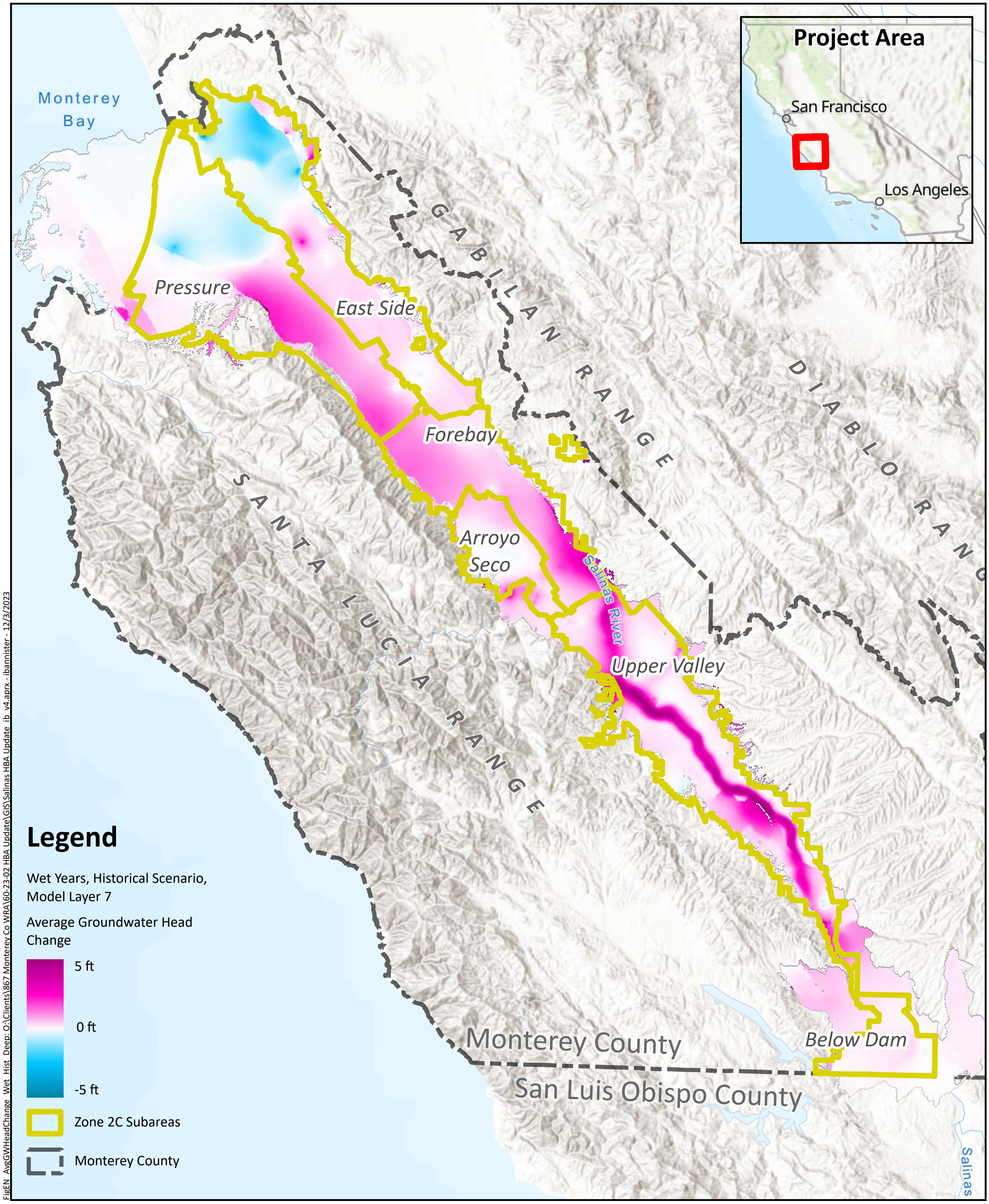
April 2025

Average Annual Groundwater Head Change Historical Scenario, Wet Years
400-Foot Aquifer & Equivalent

Figure A2



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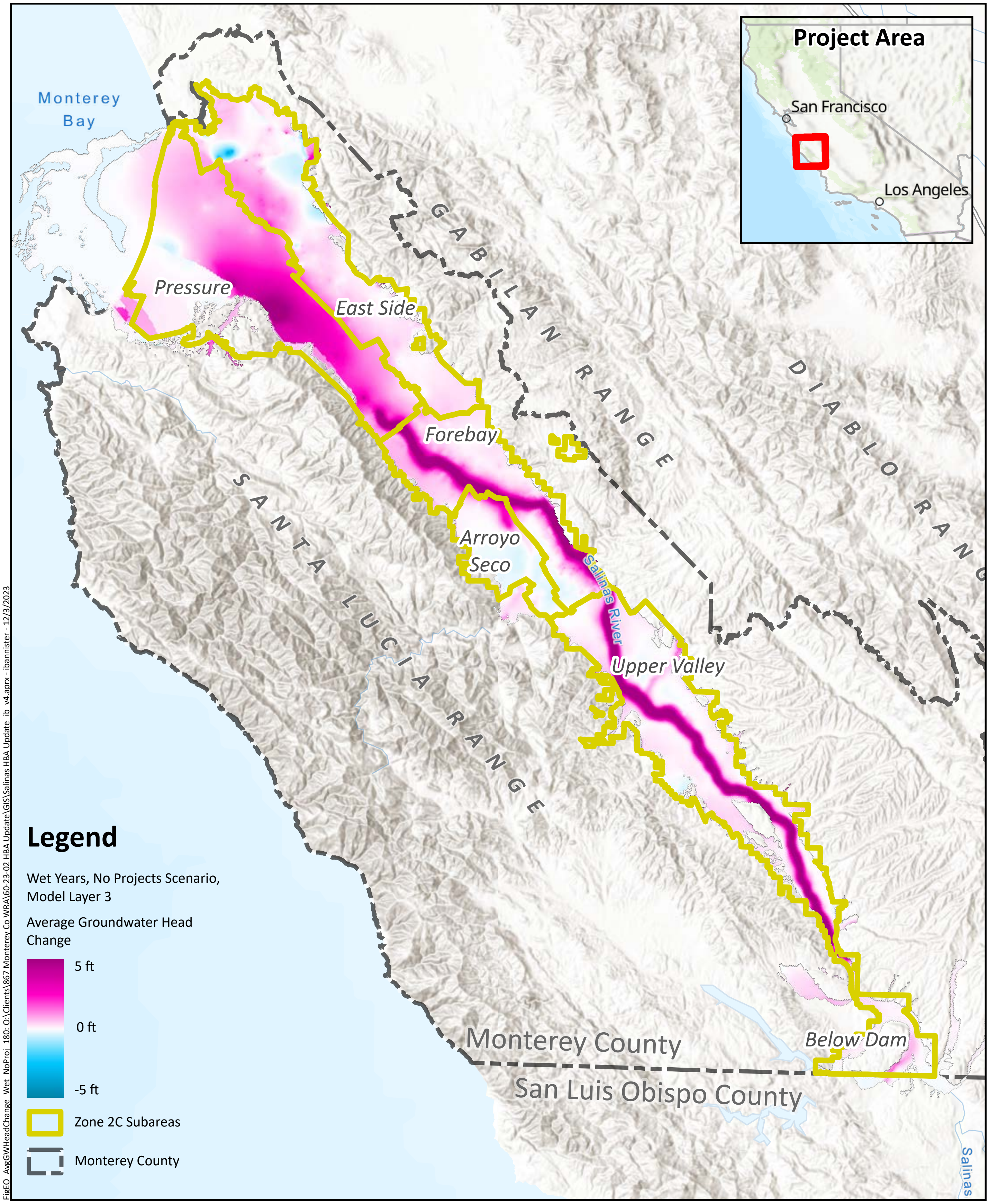
April 2025

Average Annual Groundwater Head Change Historical Scenario, Wet Years
Deep Aquifer

Figure A3



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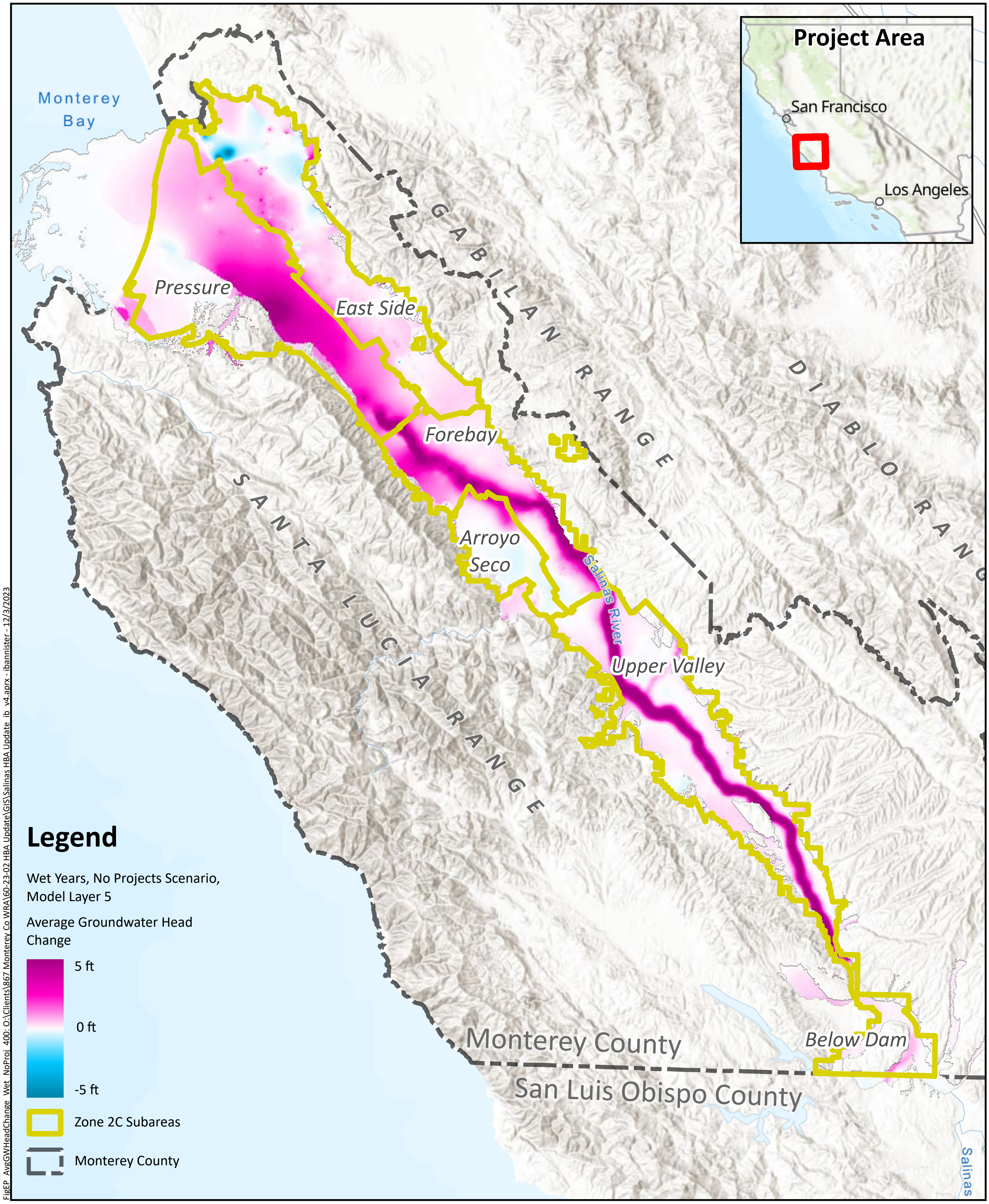
Average Annual Groundwater Head Change No Projects Scenario, Wet Years
180-Foot Aquifer & Equivalent

Figure A4



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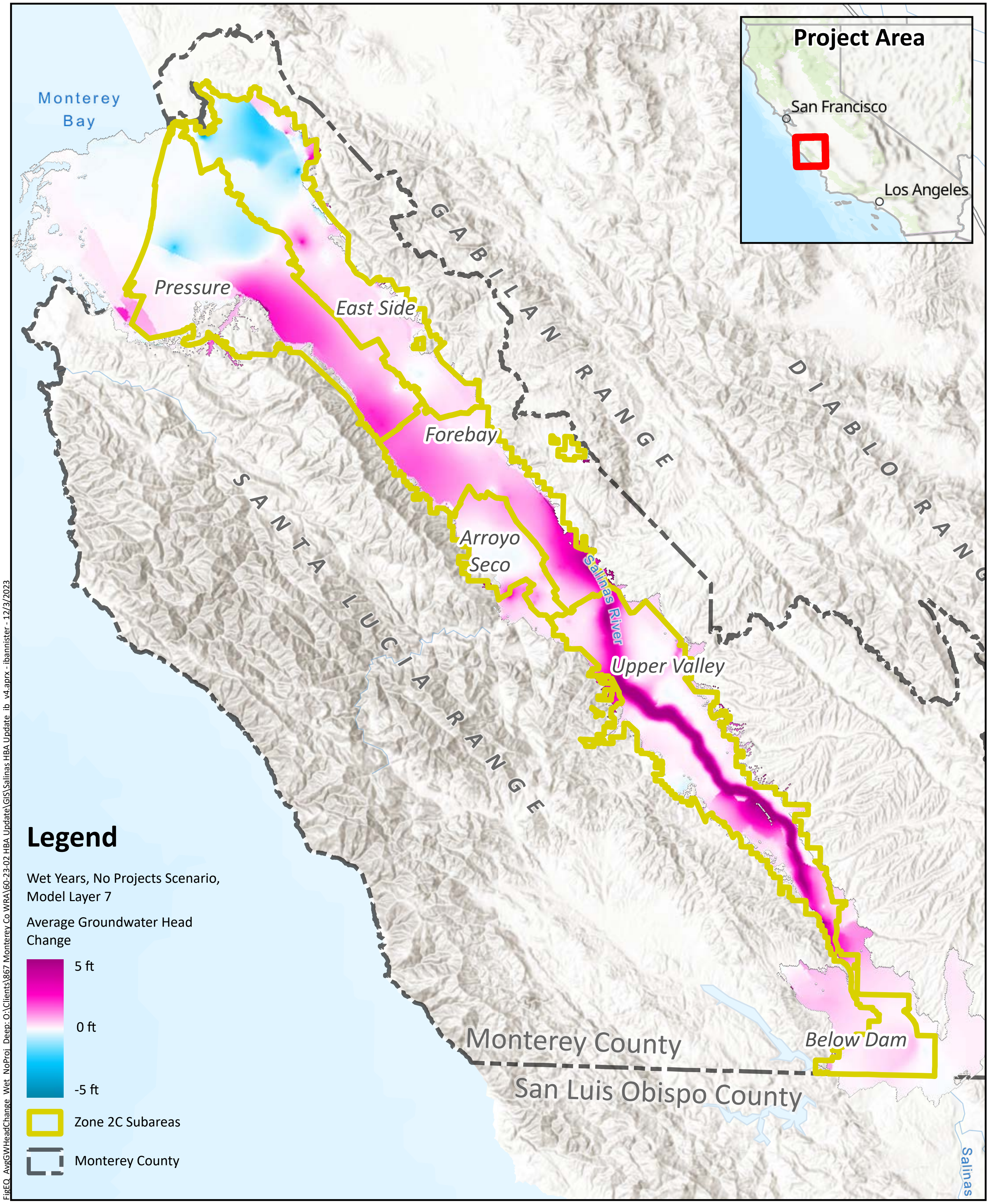
April 2025

Average Annual Groundwater Head Change No Projects Scenario, Wet Years

400-Foot Aquifer & Equivalent

Figure A5



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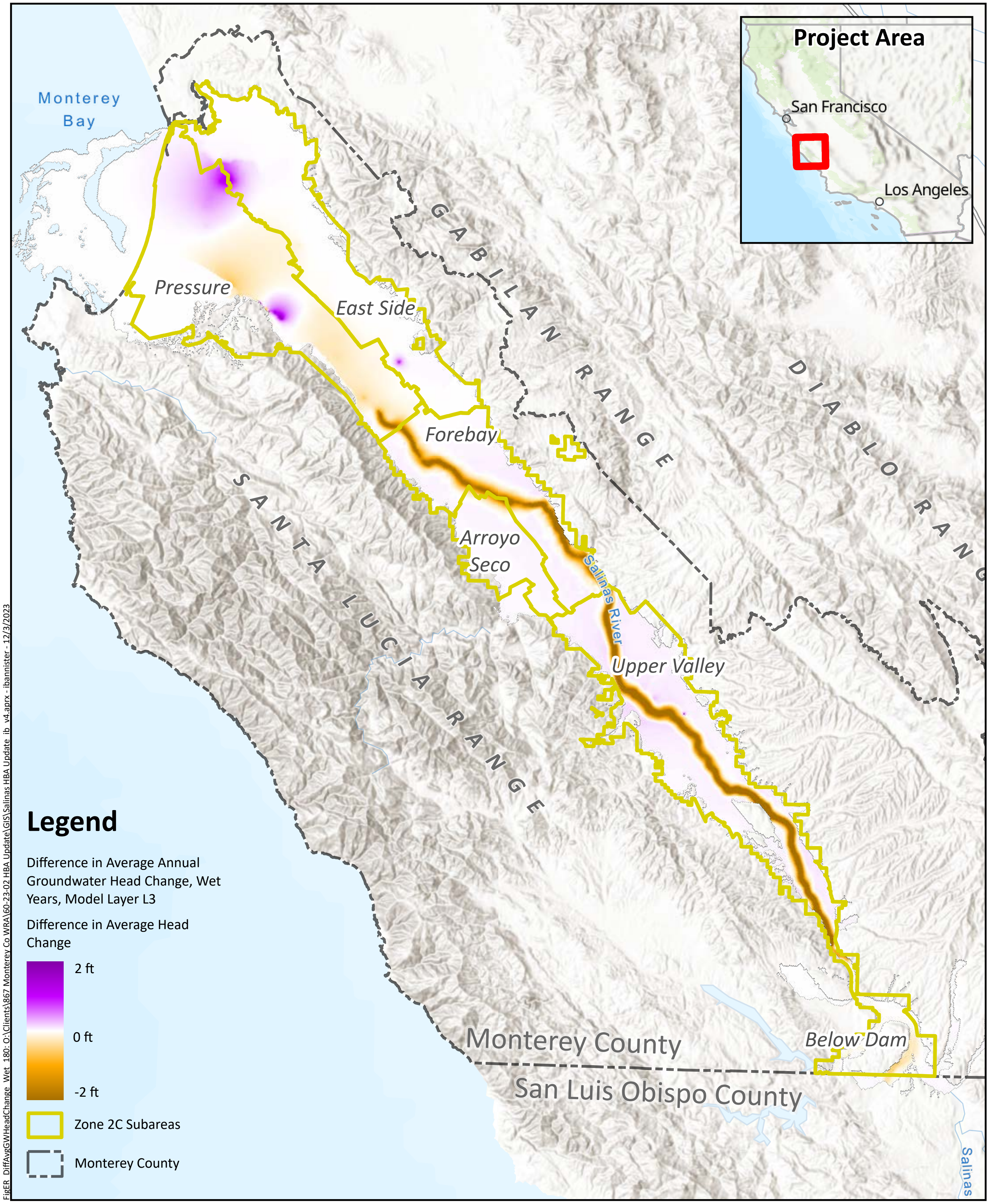
April 2025

Average Annual Groundwater Head Change No Projects Scenario, Wet Years
Deep Aquifer

Figure A6



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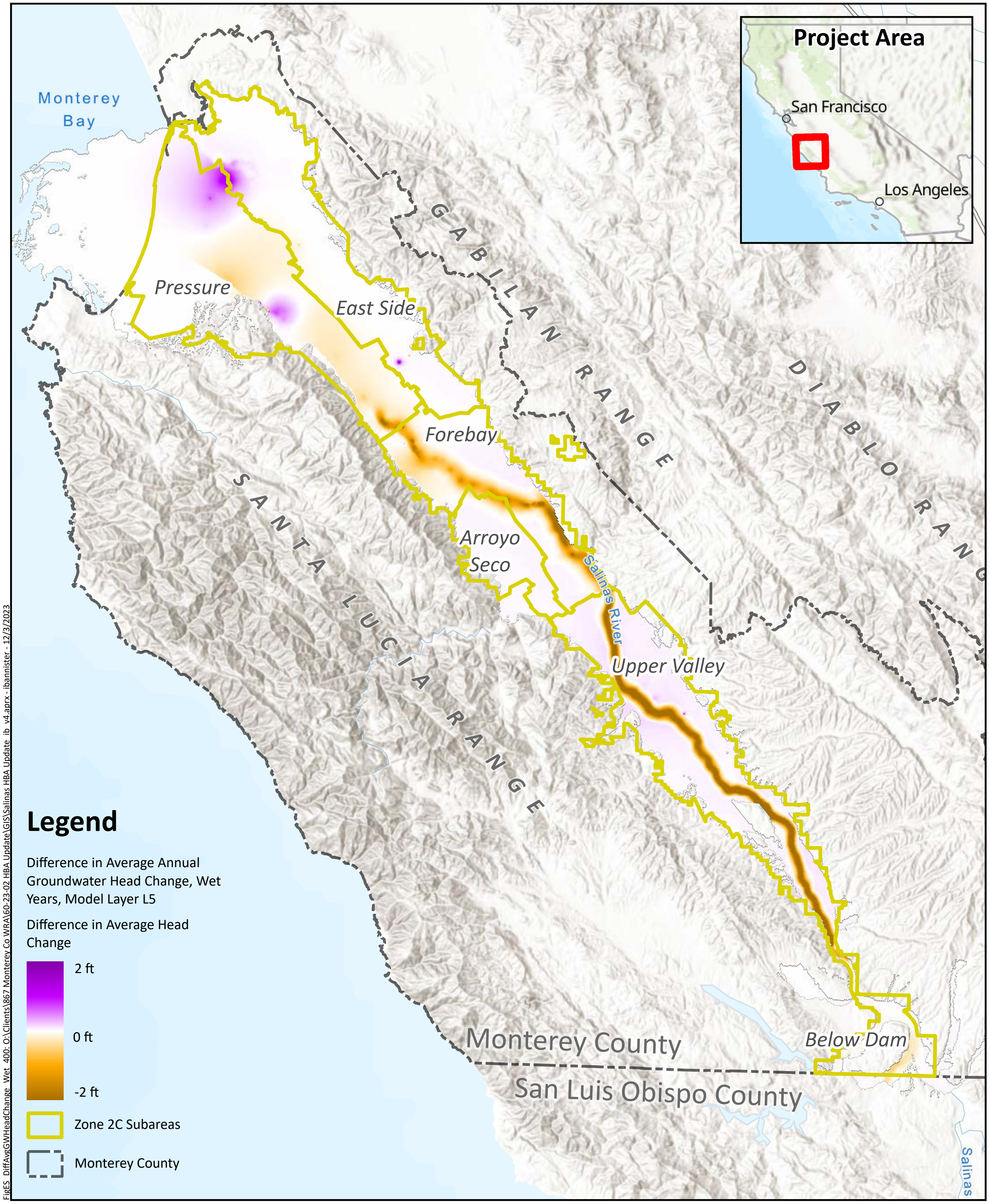
April 2025

Difference in Average Annual Groundwater Head Change Wet Years
180-Foot Aquifer & Equivalent

Figure A7



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WEST YOST

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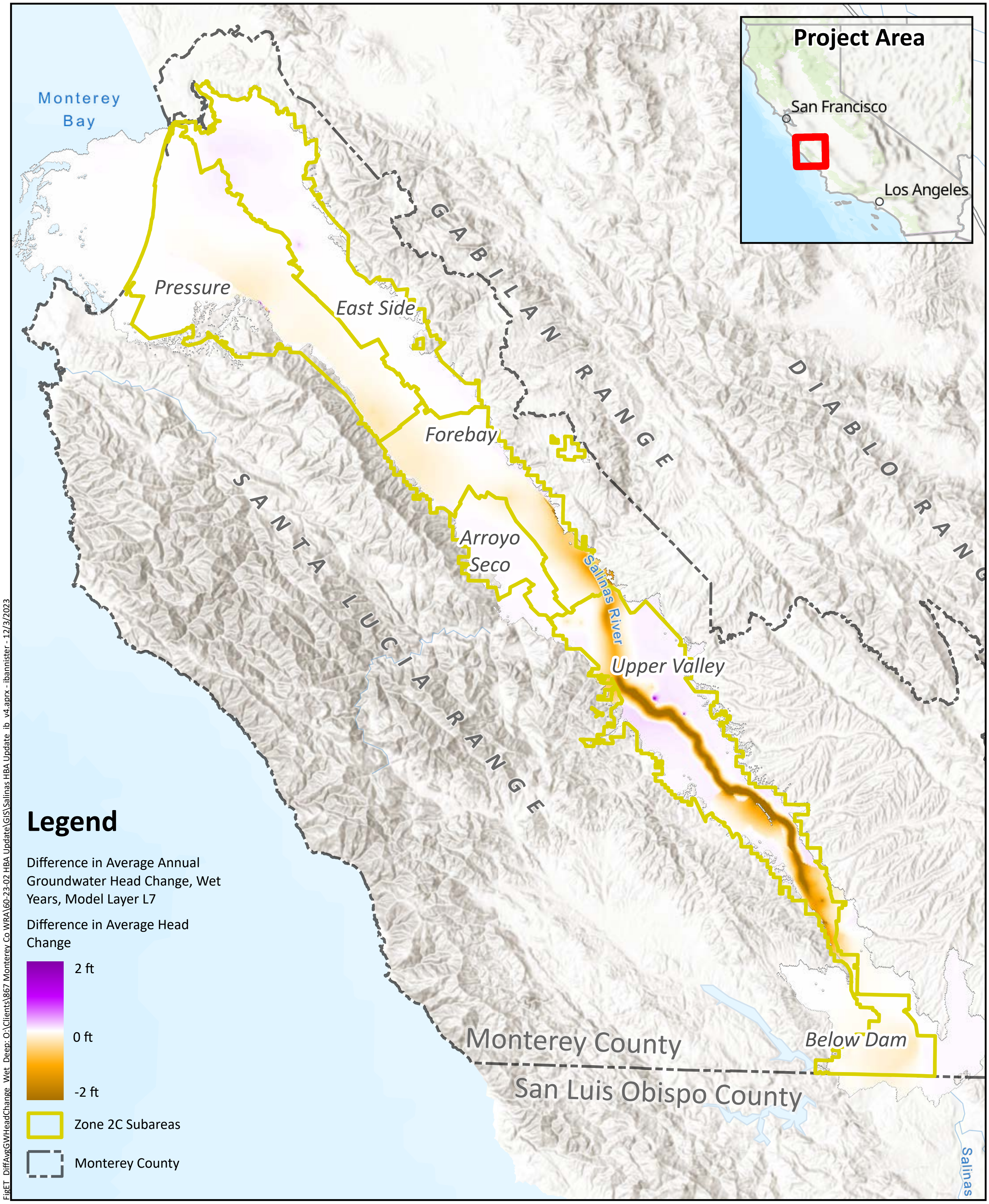
April 2025

Difference in Average Annual Groundwater Head Change
Wet Years
400-Foot Aquifer & Equivalent

Figure A8



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Difference in Average Annual Groundwater Head Change Wet Years

Deep Aquifer

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WEST YOST

0 5 10 Miles

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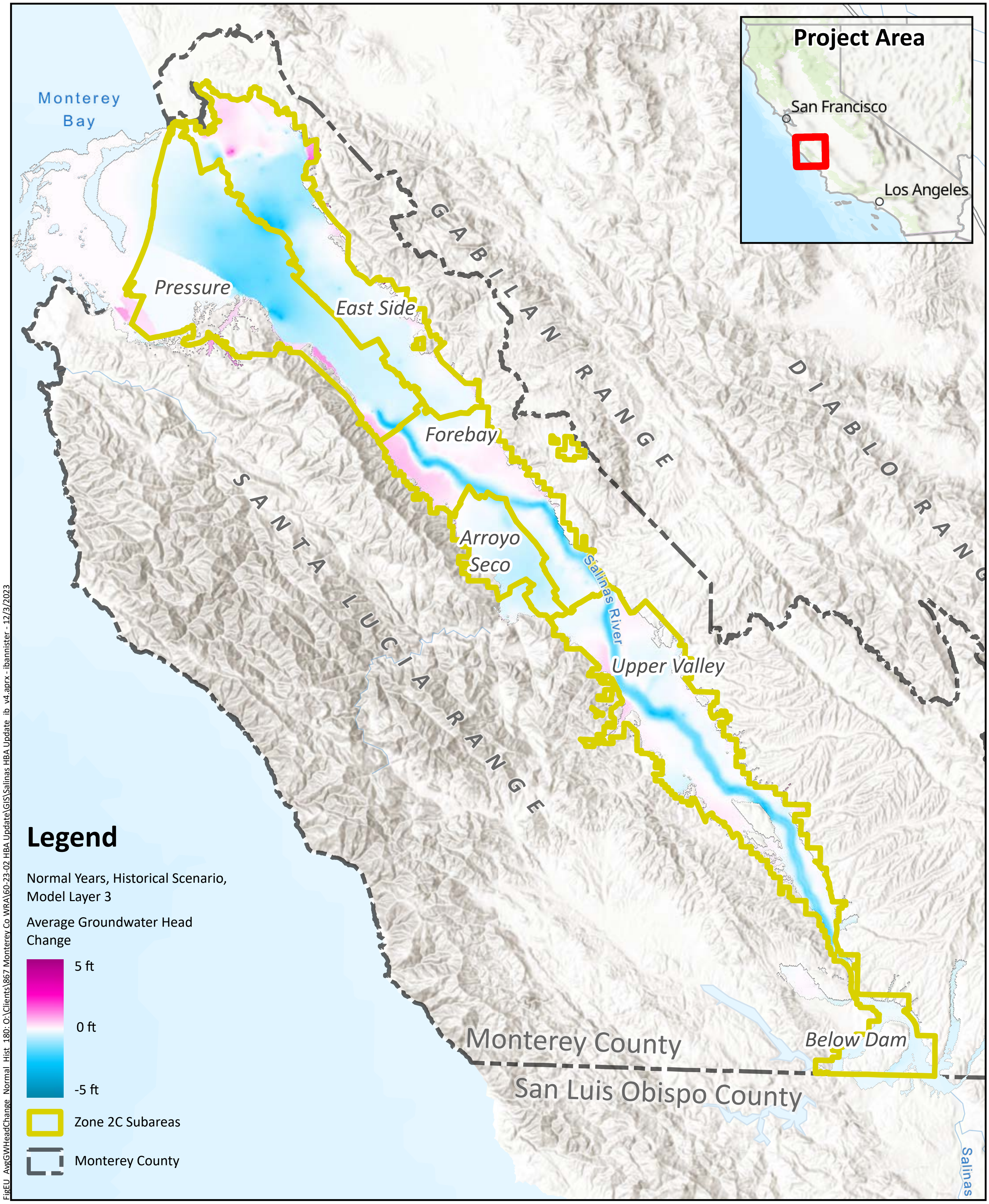
Salinas Valley HBA Update

April 2025

Figure A9



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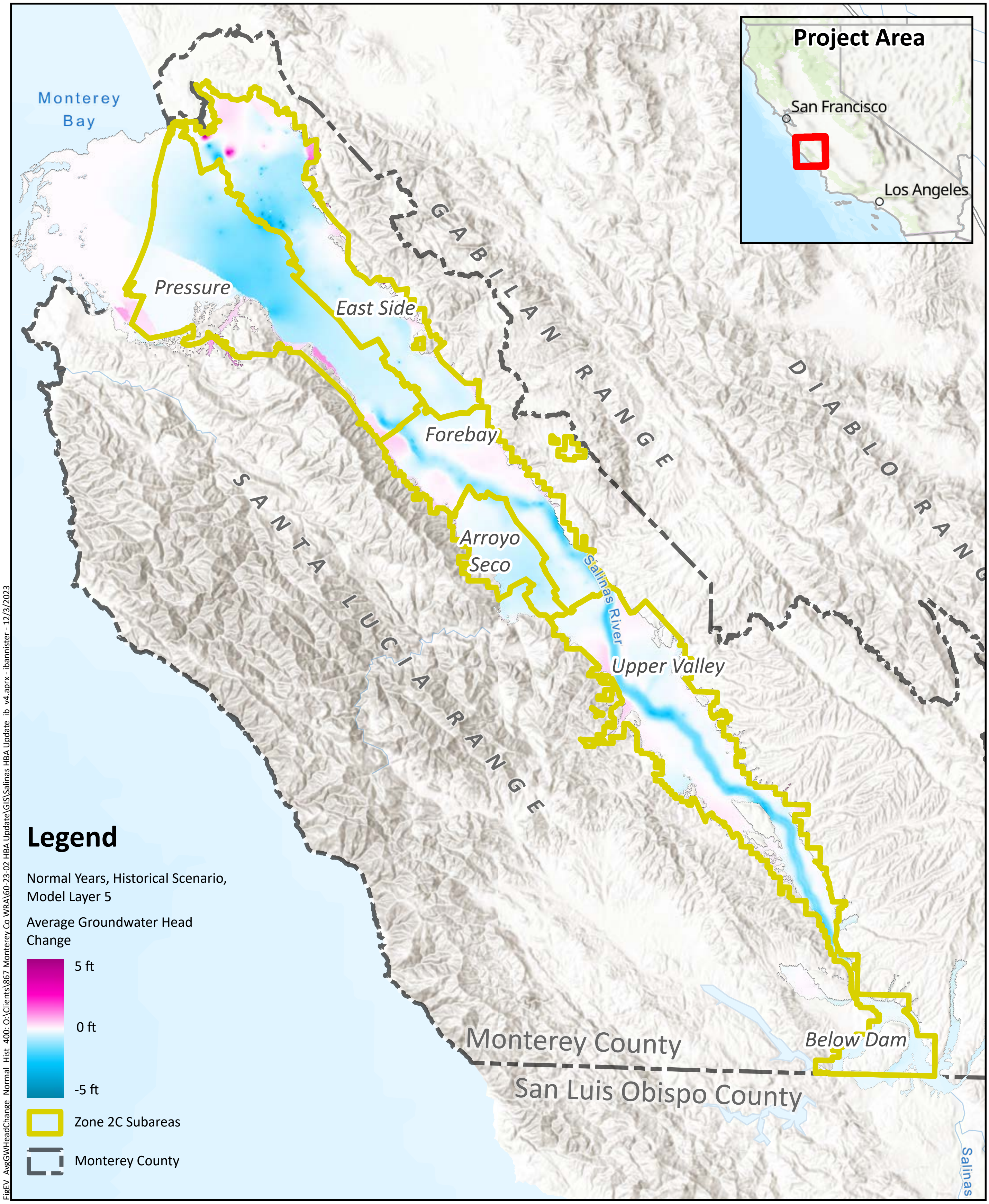
April 2025

Average Annual Groundwater Head Change Historical Scenario, Normal Years
180-Foot Aquifer & Equivalent

Figure A10



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WEST YOST

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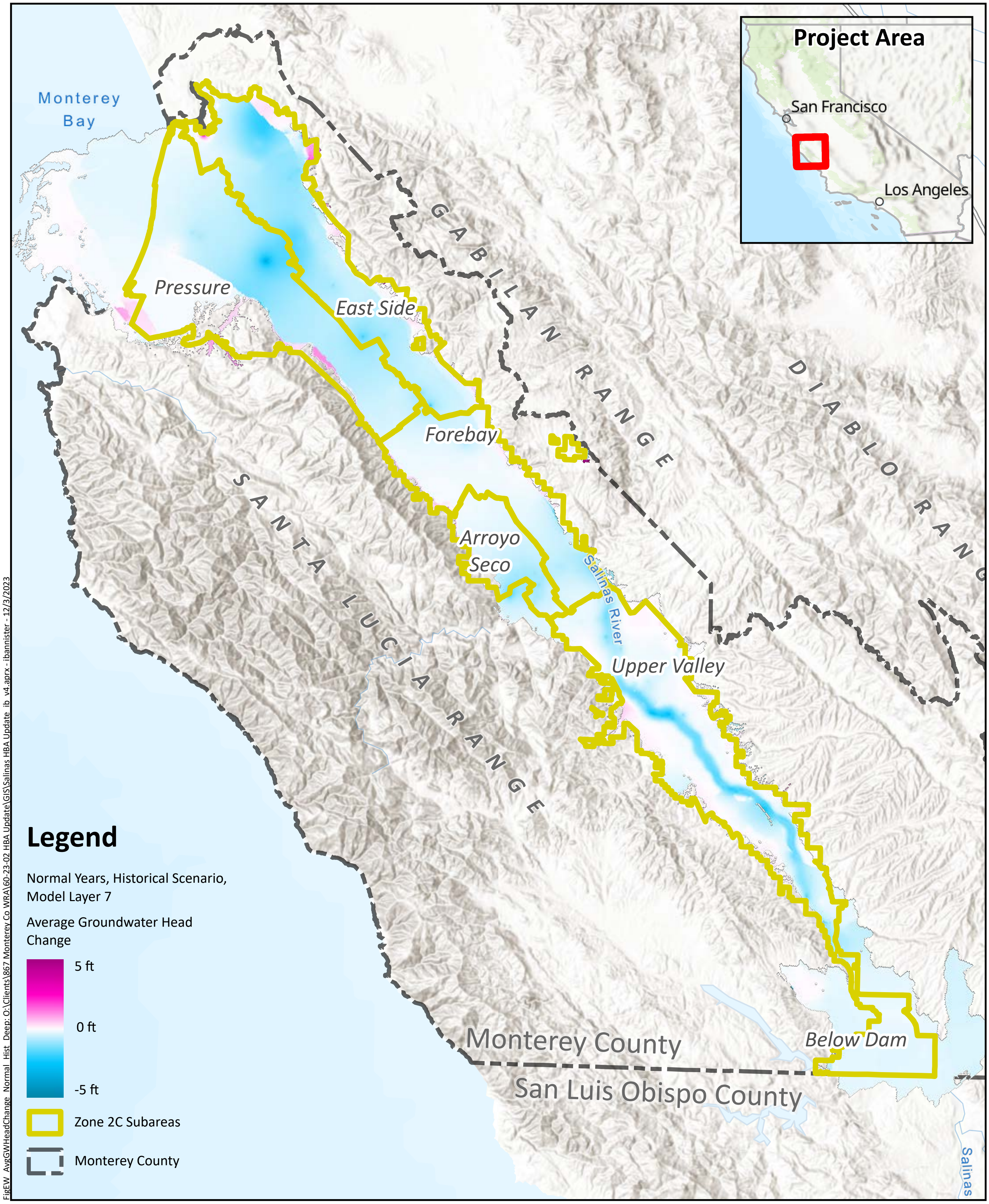
Salinas Valley HBA Update
April 2025

Average Annual Groundwater Head Change Historical Scenario, Normal Years
400-Foot Aquifer & Equivalent

Figure A11



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Average Annual Groundwater Head Change Historical Scenario, Normal Years

Deep Aquifer

Figure A12

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WEST YOST

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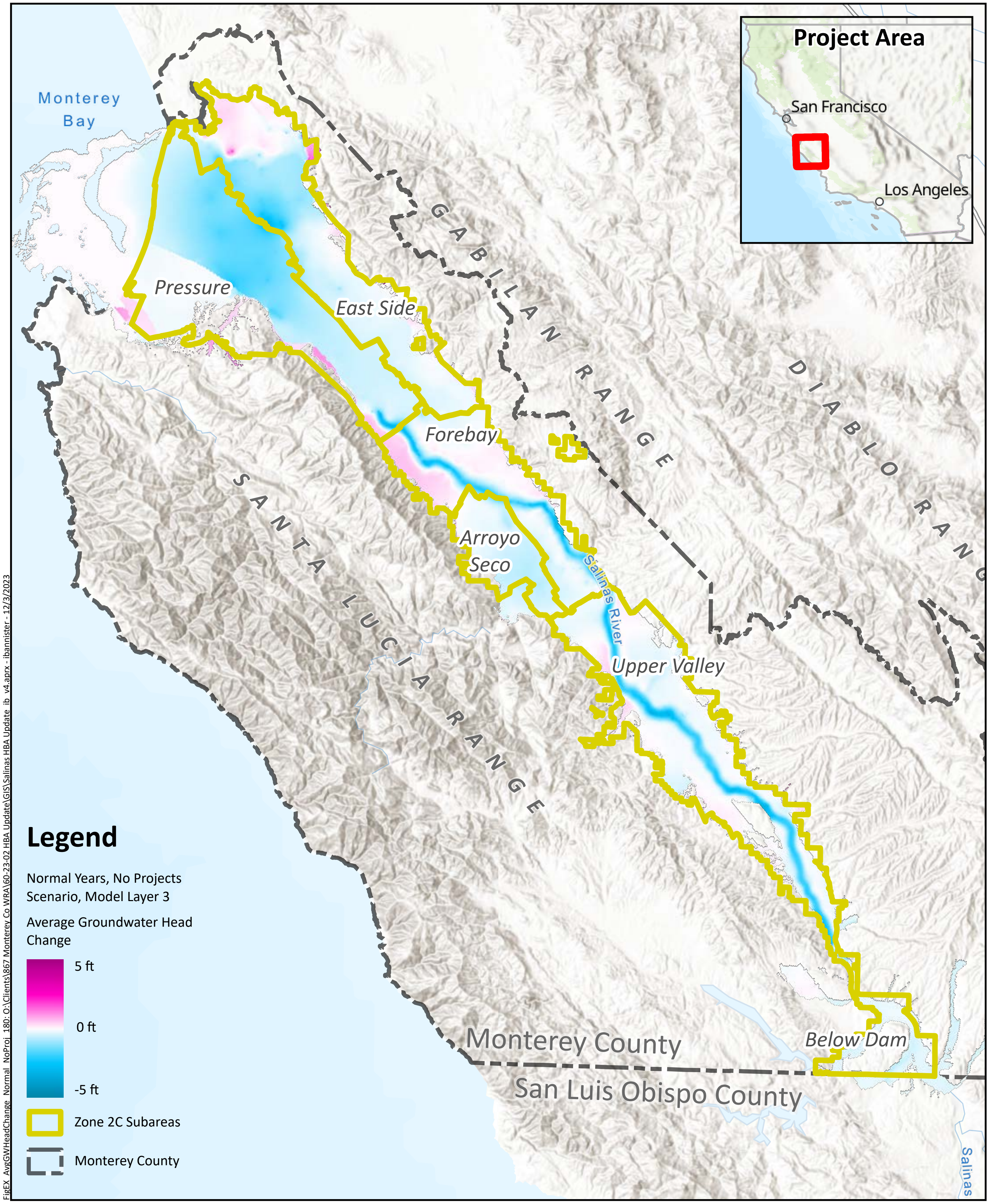
Salinas Valley HBA Update

April 2025

MONTEREY COUNTY WATER RESOURCES AGENCY 1947



Average Annual Groundwater Head Change, No Projects Scenario, Normal Years

180-Foot Aquifer & Equivalent

Figure A13

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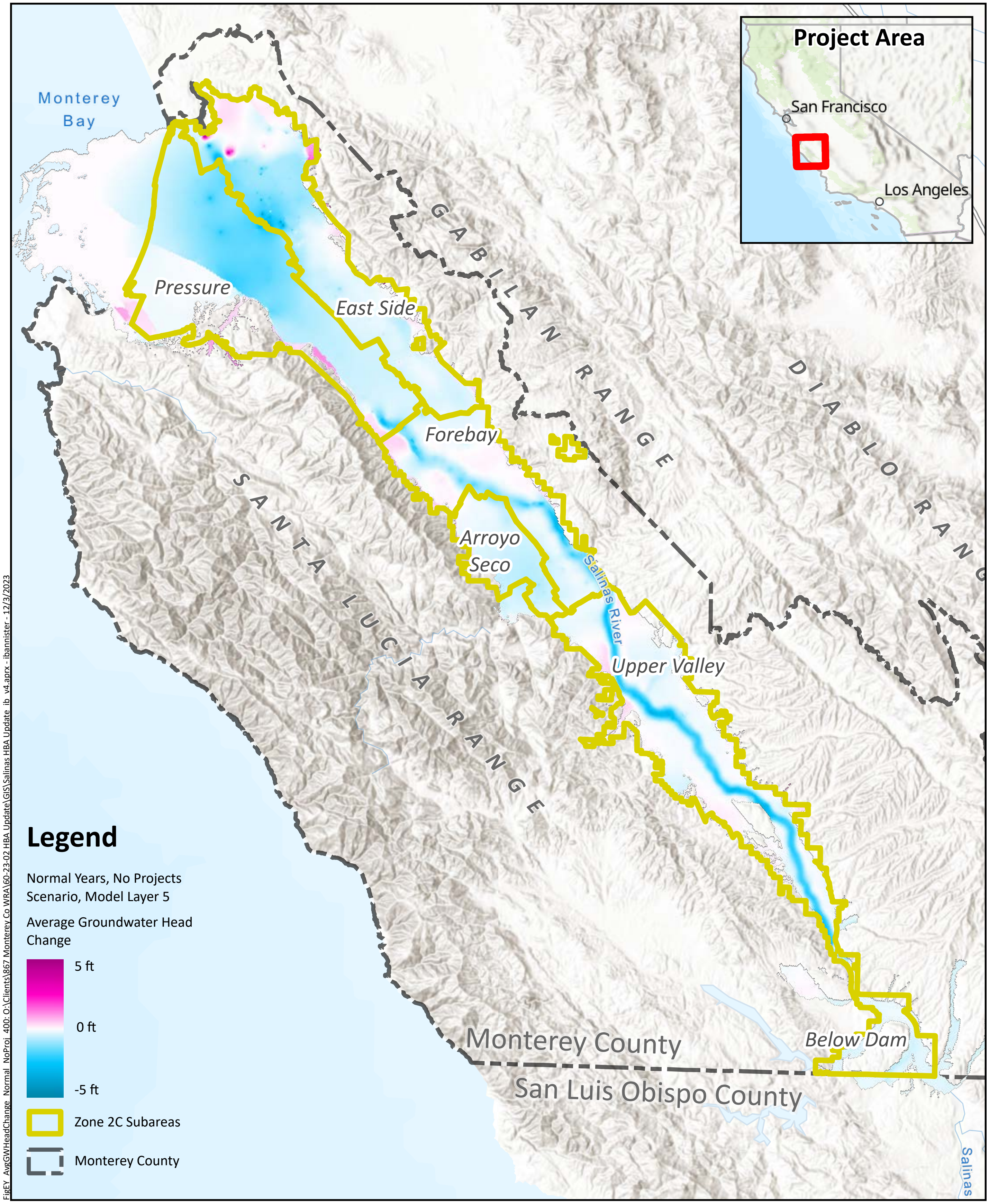
Salinas Valley HBA Update

April 2025



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Average Annual Groundwater Head Change, No Projects Scenario, Normal Years

400-Foot Aquifer & Equivalent

Figure A14

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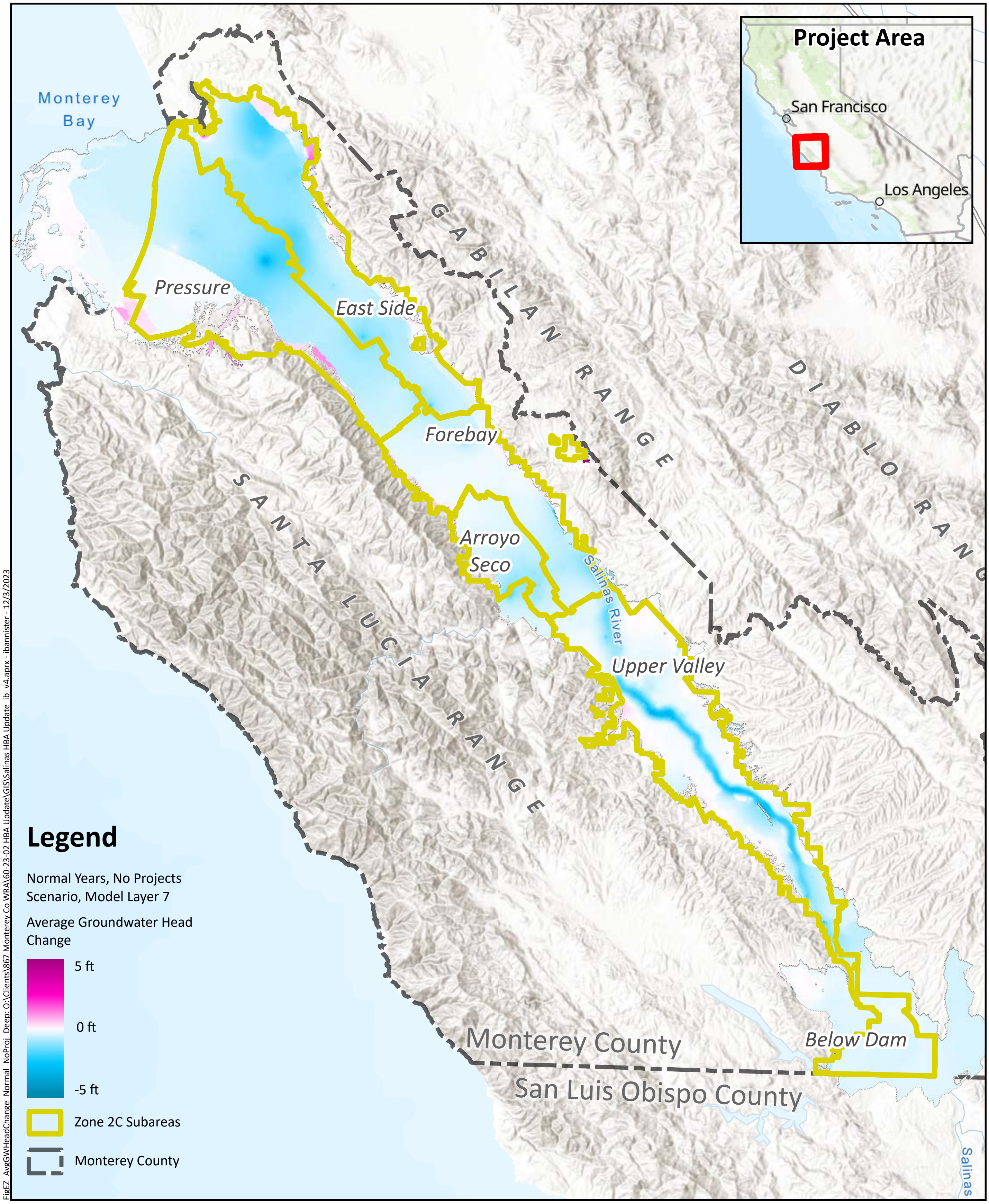
Salinas Valley HBA Update

April 2025



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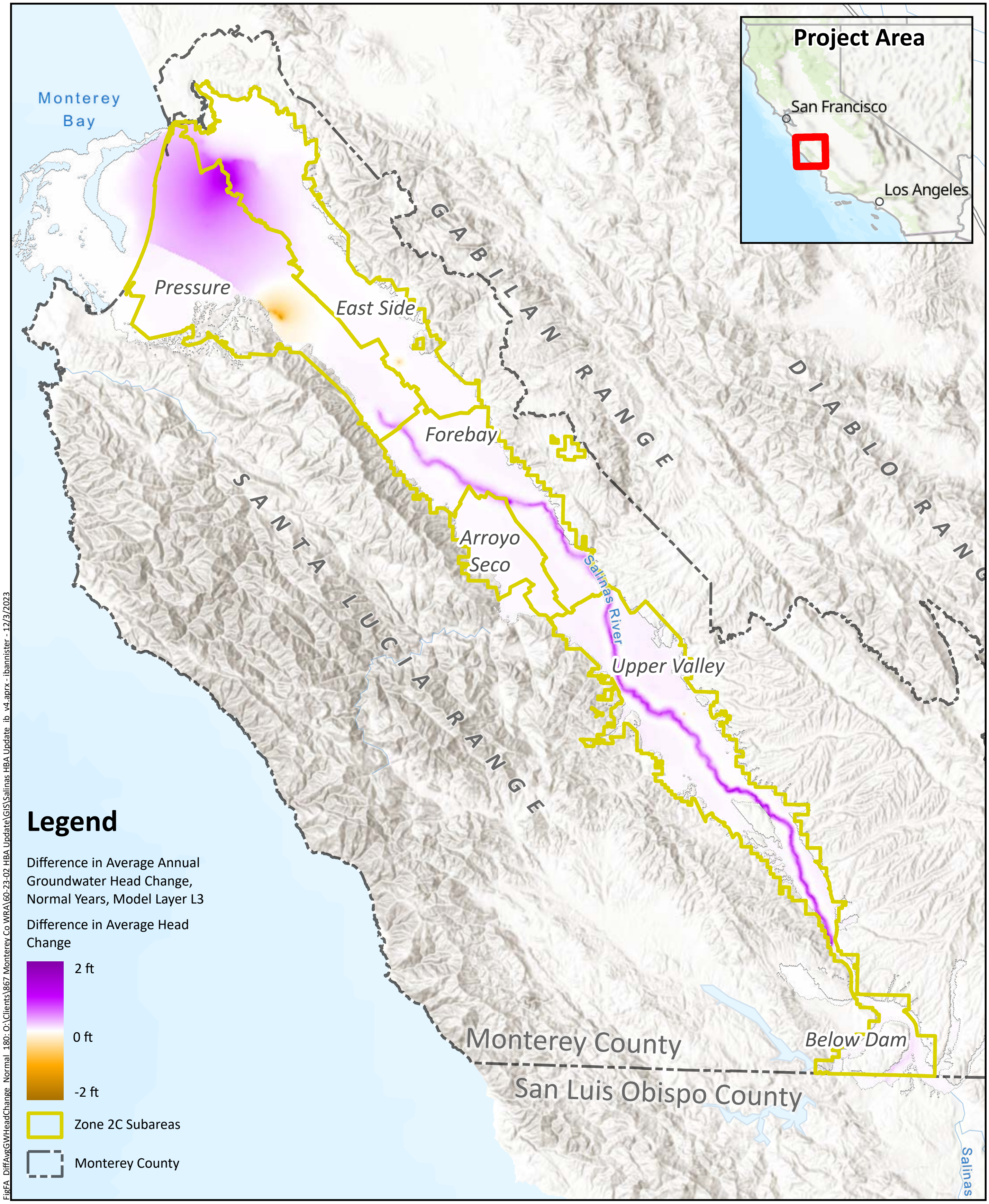
Salinas Valley HBA Update

April 2025

Average Annual Groundwater Head Change, No Projects Scenario, Normal Years

Deep Aquifer

Figure A15



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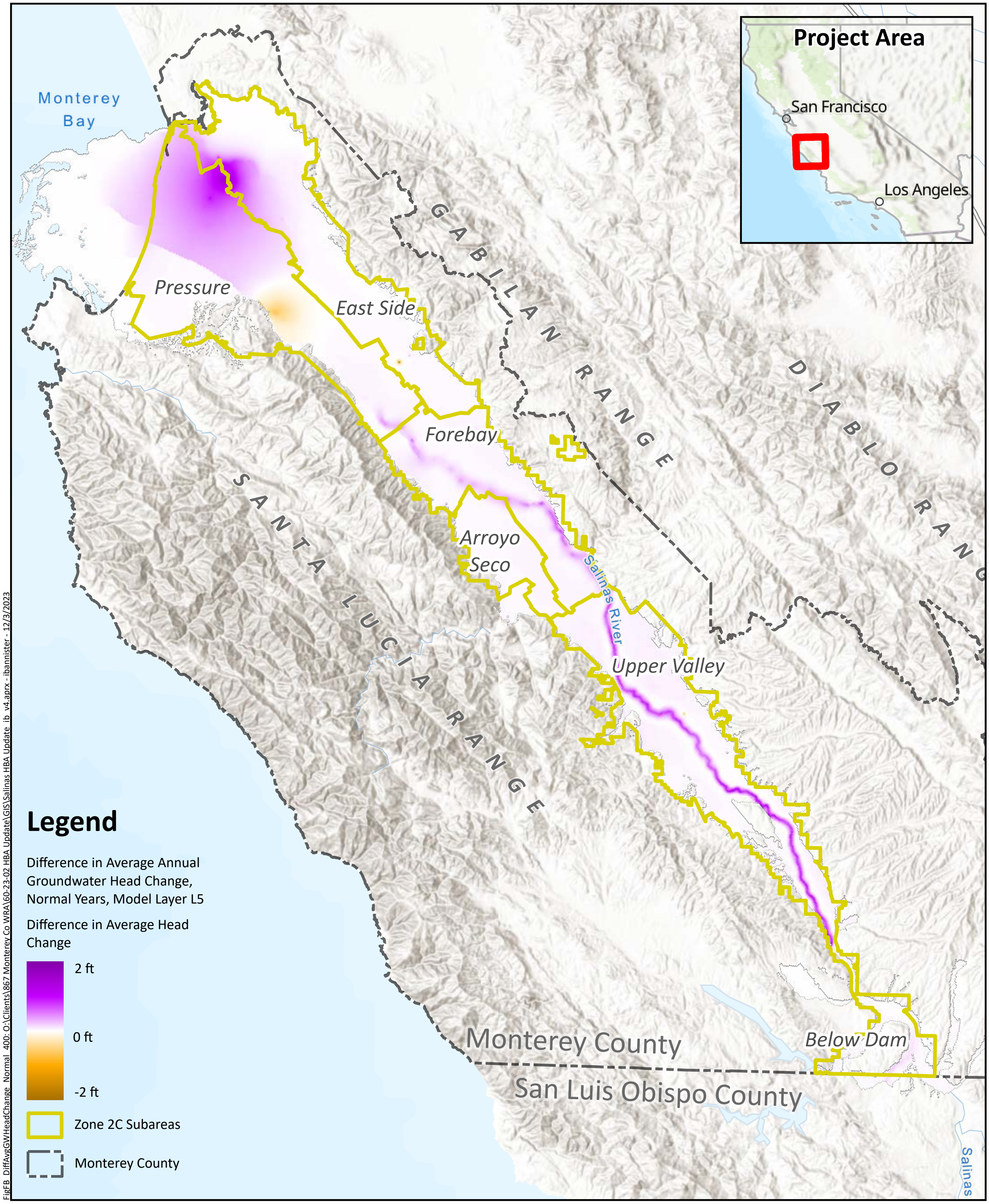
Salinas Valley HBA Update

April 2025

Difference in Average Annual Groundwater Head Change Normal Years

180-Foot Aquifer & Equivalent

Figure A16



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Difference in Average Annual Groundwater Head Change Normal Years

400-Foot Aquifer & Equivalent

Figure A17

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WEST YOST

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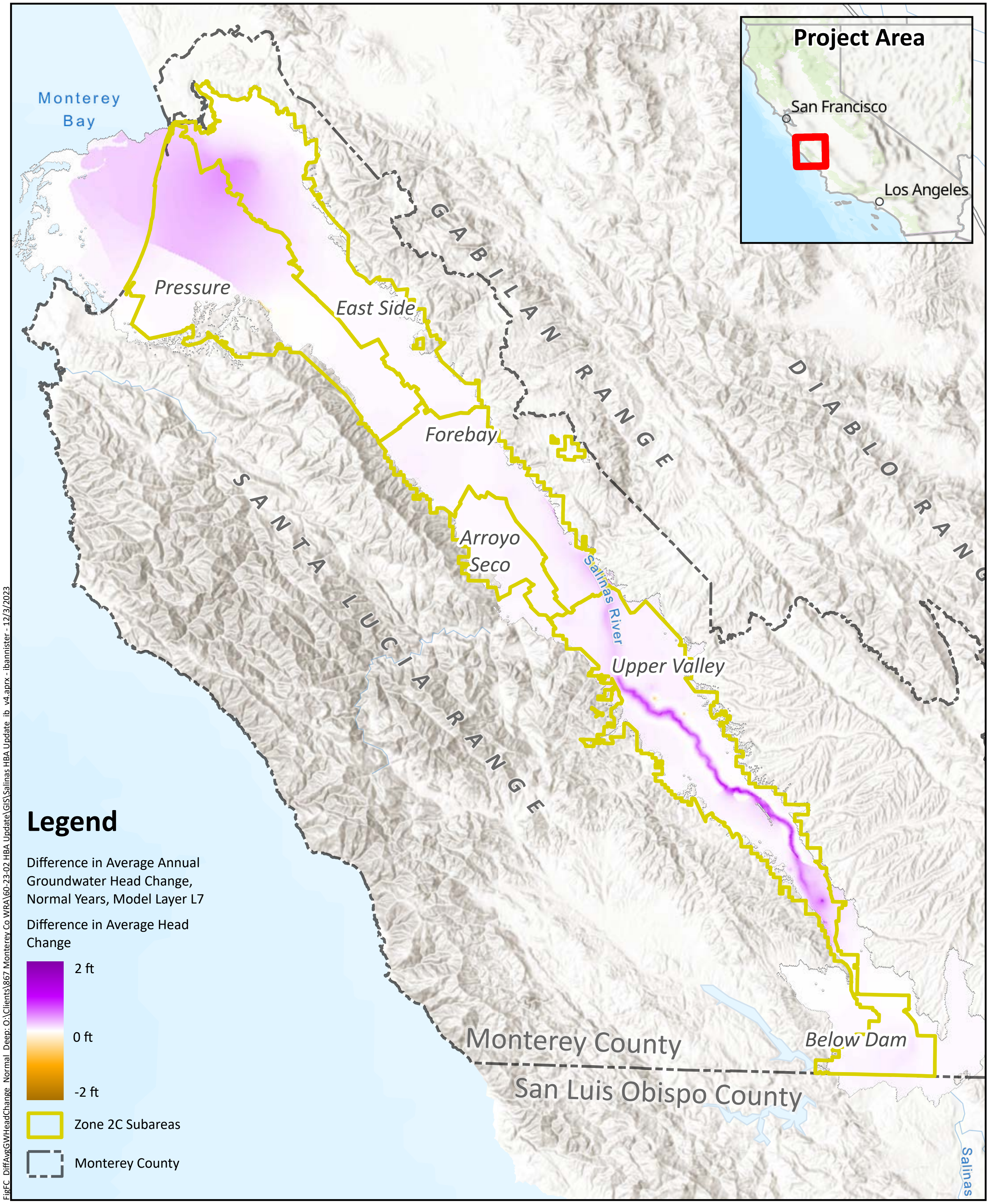

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Difference in Average Annual Groundwater Head Change Normal Years
Deep Aquifer

Figure A18

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WEST YOST

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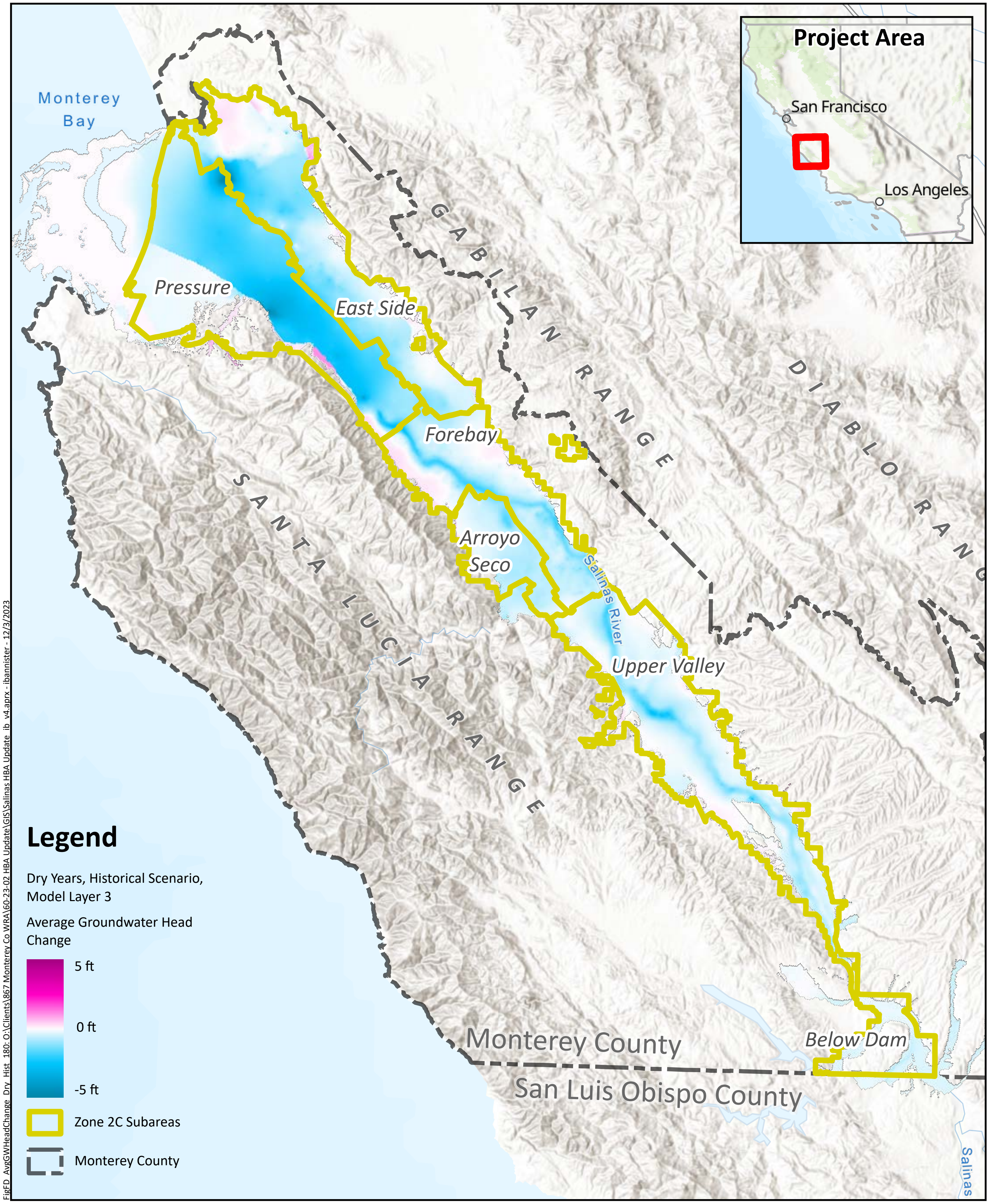
April 2025

MONTEREY COUNTY WATER RESOURCES AGENCY 1947



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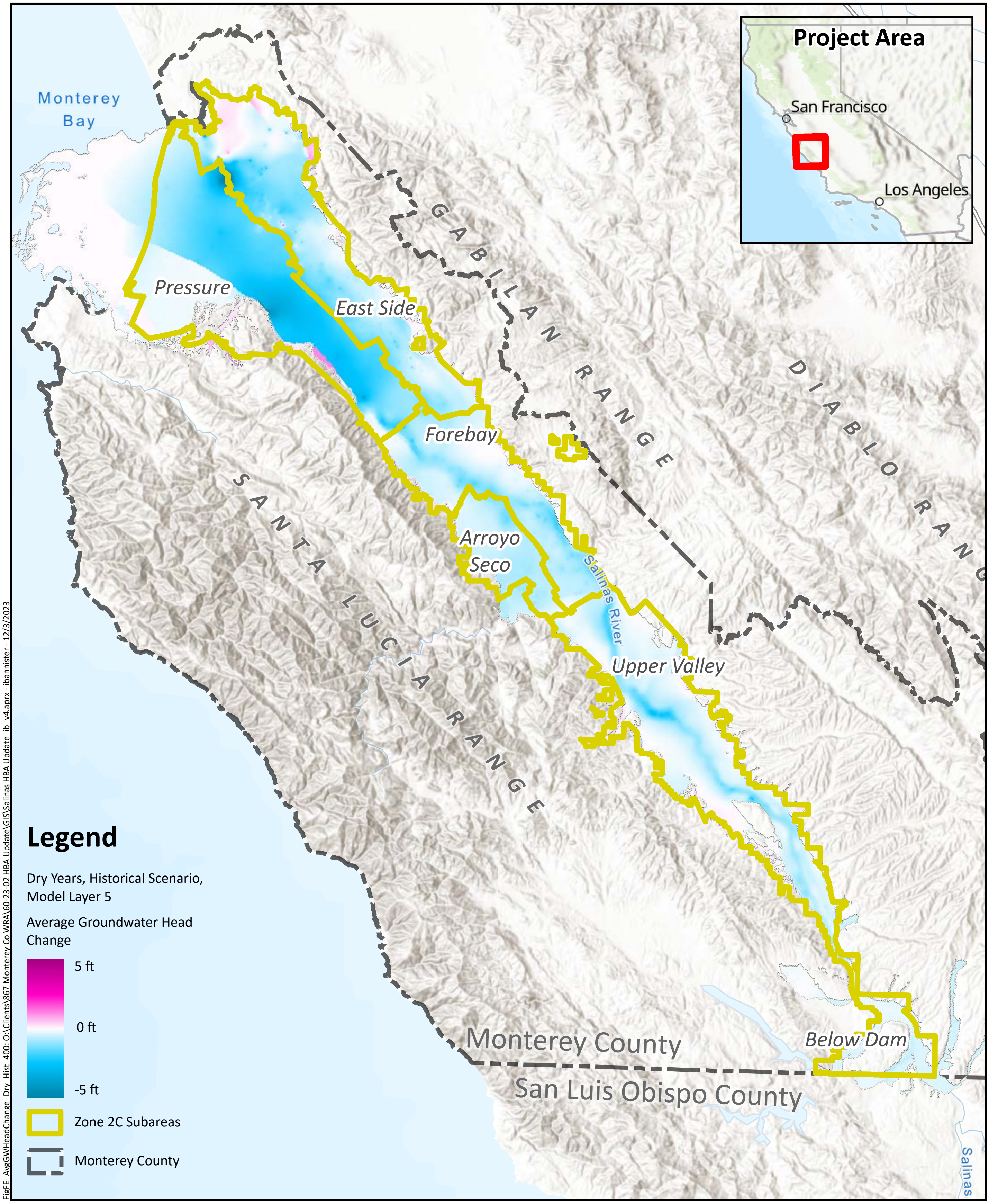
April 2025

Average Annual Groundwater Head Change Historical Scenario, Dry Years
180-Foot Aquifer & Equivalent

Figure A19



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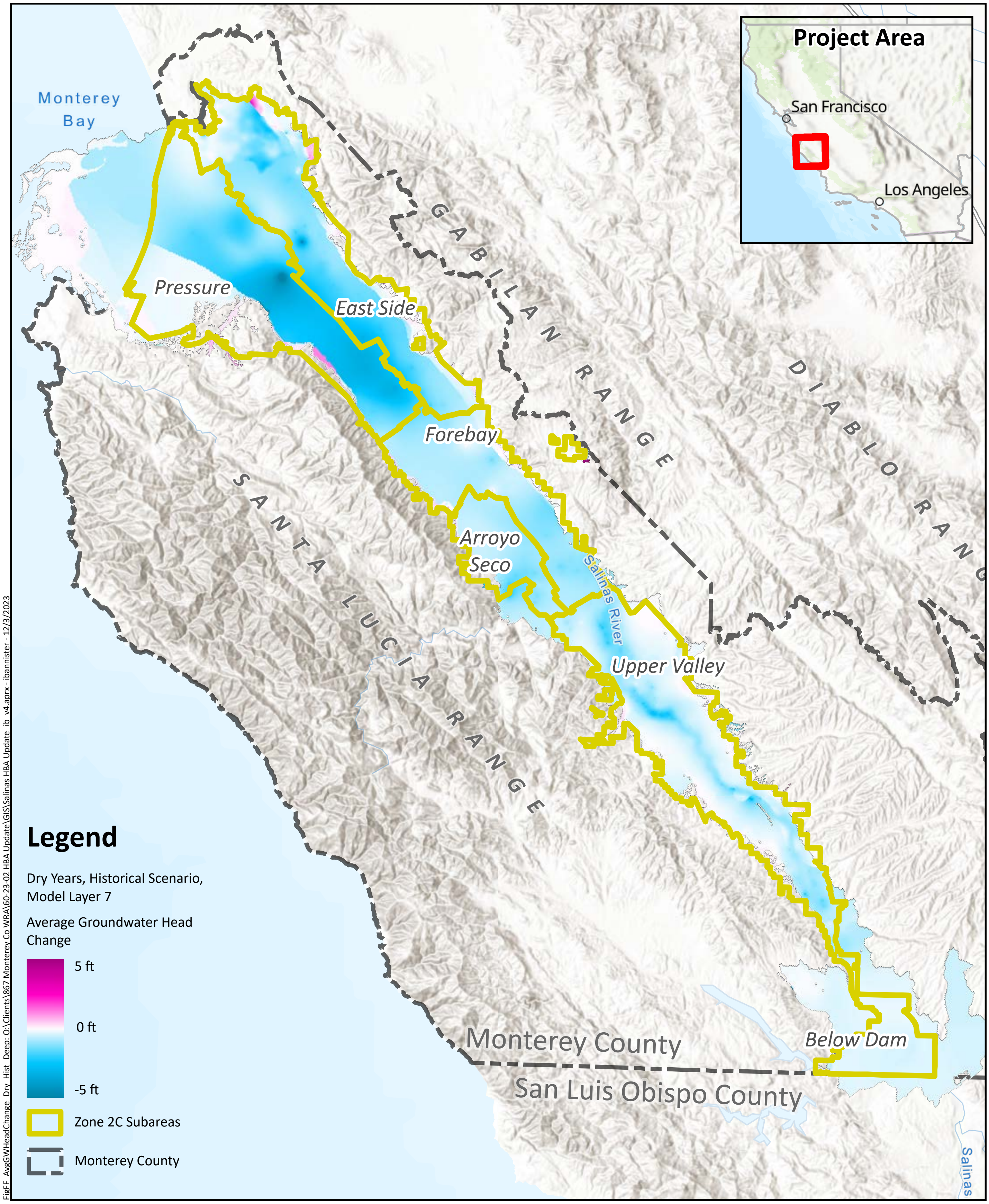
April 2025

Average Annual Groundwater Head Change Historical Scenario, Dry Years
400-Foot Aquifer & Equivalent

Figure A20



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Average Annual Groundwater Head Change Historical Scenario, Dry Years

Deep Aquifer

Figure A21

Prepared by:

WEST YOST

0 5 10 Miles

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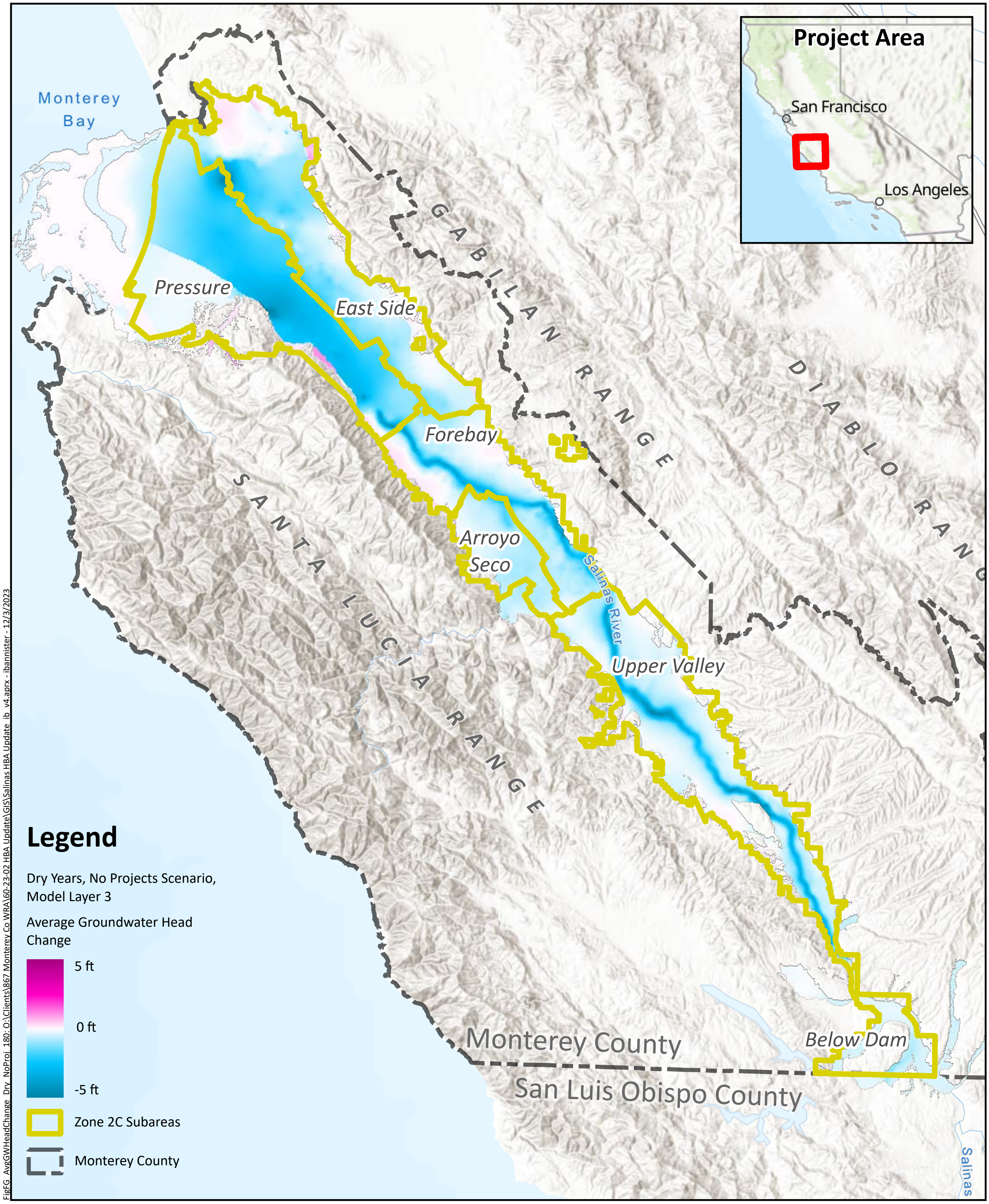
Salinas Valley HBA Update

April 2025



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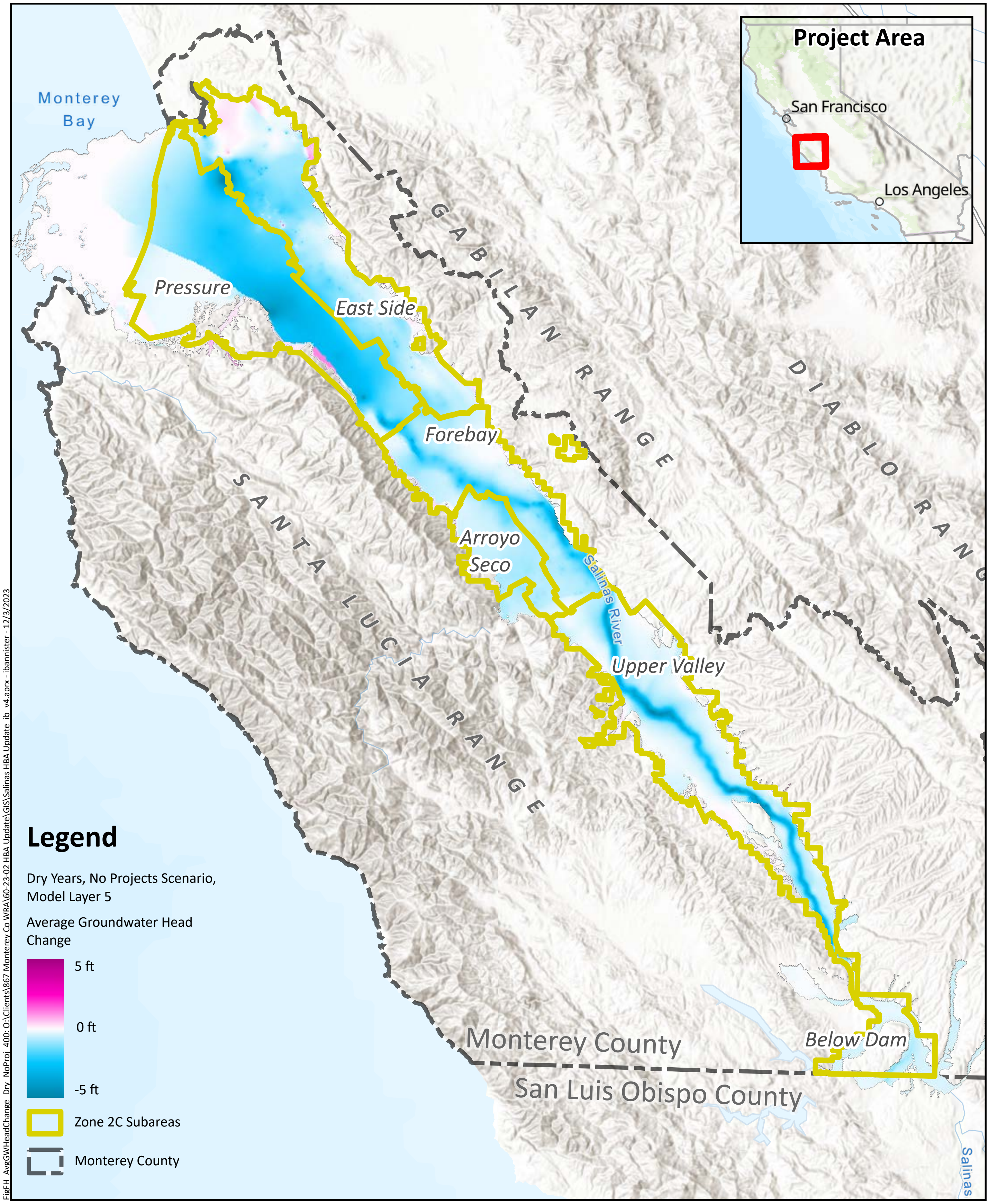
April 2025

Average Annual Groundwater Head Change No Projects Scenario, Dry Years

180-Foot Aquifer & Equivalent

Figure A22



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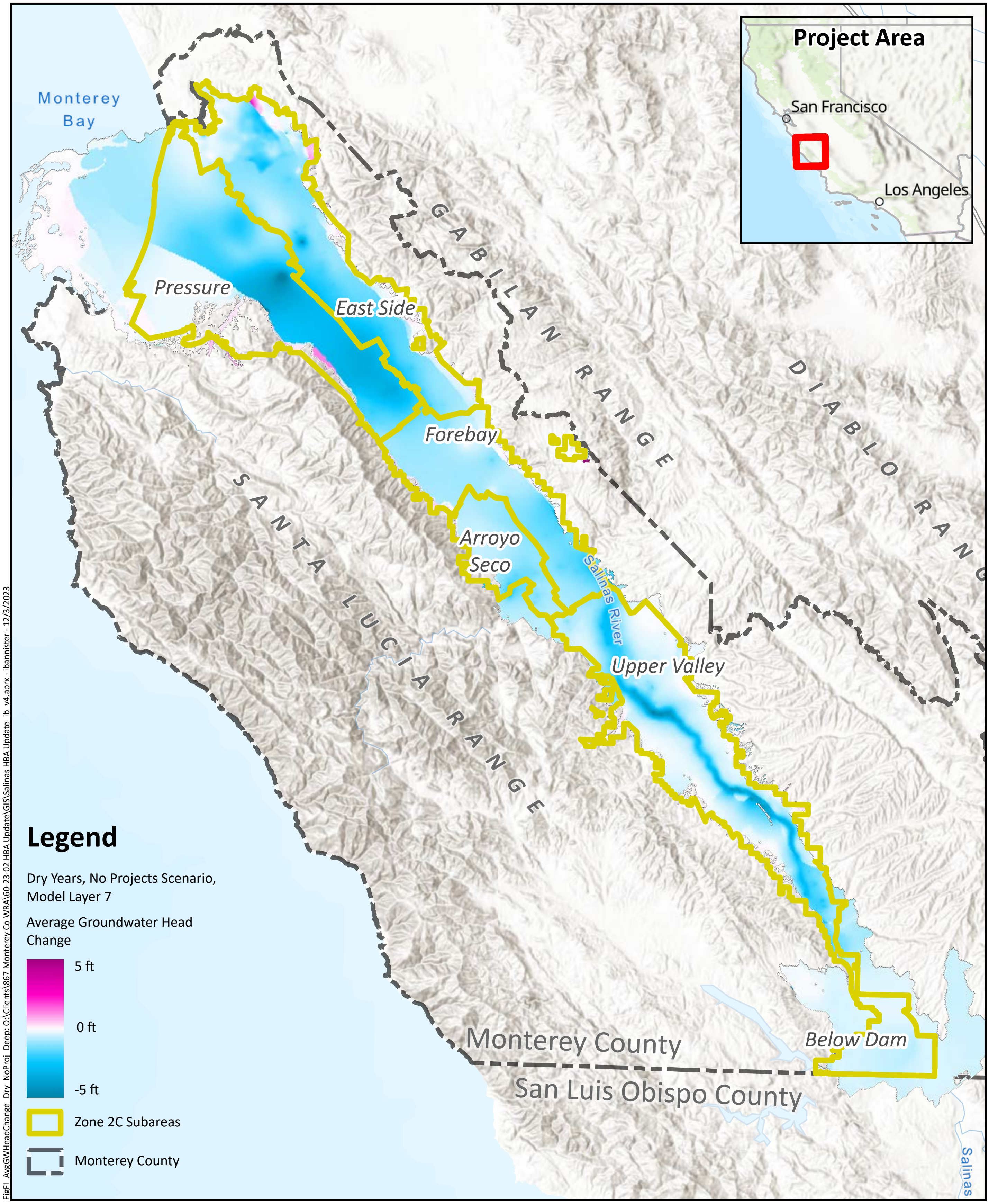
April 2025

Average Annual Groundwater Head Change No Projects Scenario, Dry Years
400-Foot Aquifer & Equivalent

Figure A23



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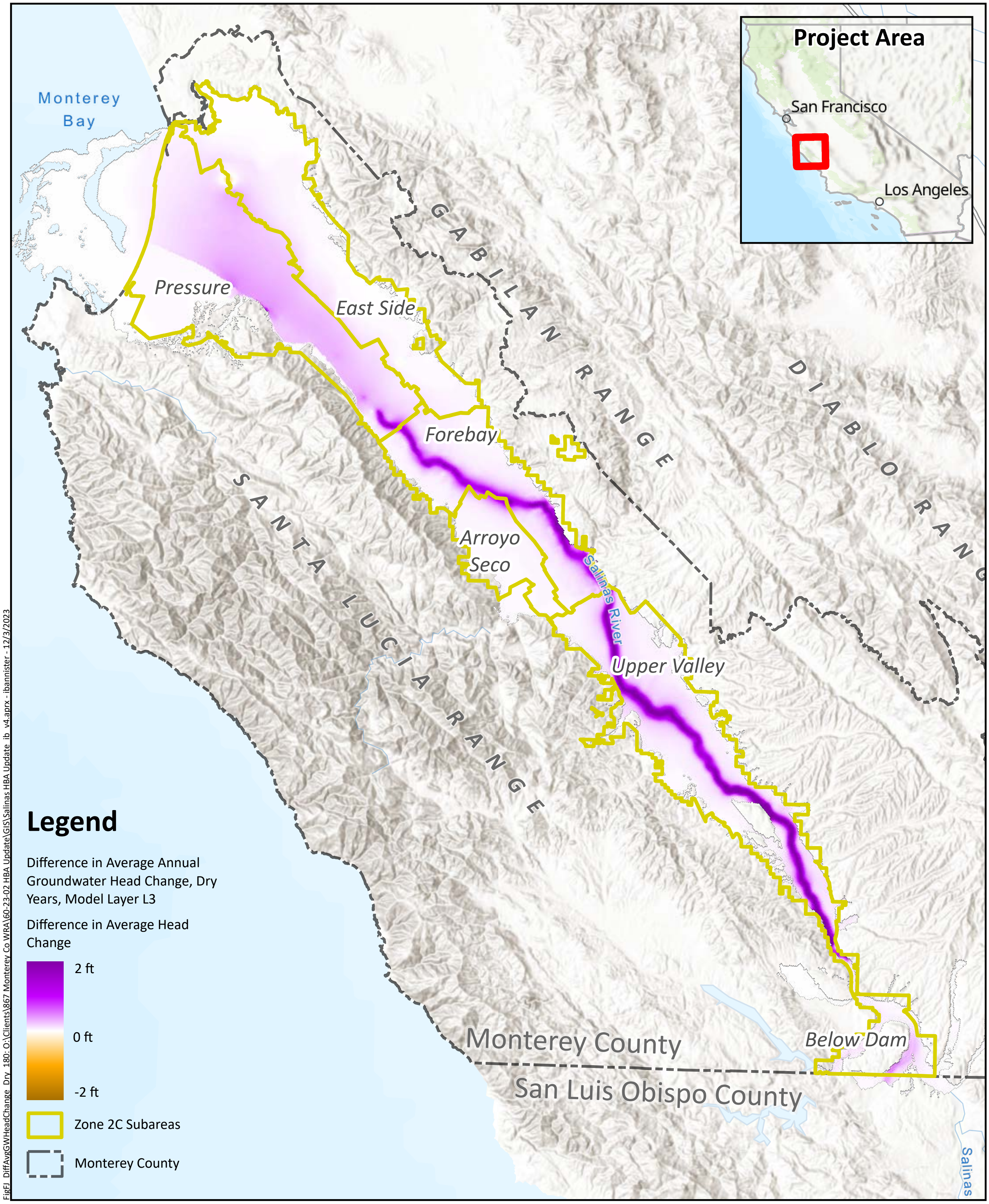
April 2025

Average Annual Groundwater Head Change No Projects Scenario, Dry Years
Deep Aquifer

Figure A24



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Difference in Average Annual Groundwater Head Change
Dry Years
180-Foot Aquifer & Equivalent

Figure A25

Prepared by:
WEST YOST

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0 8 16 Km

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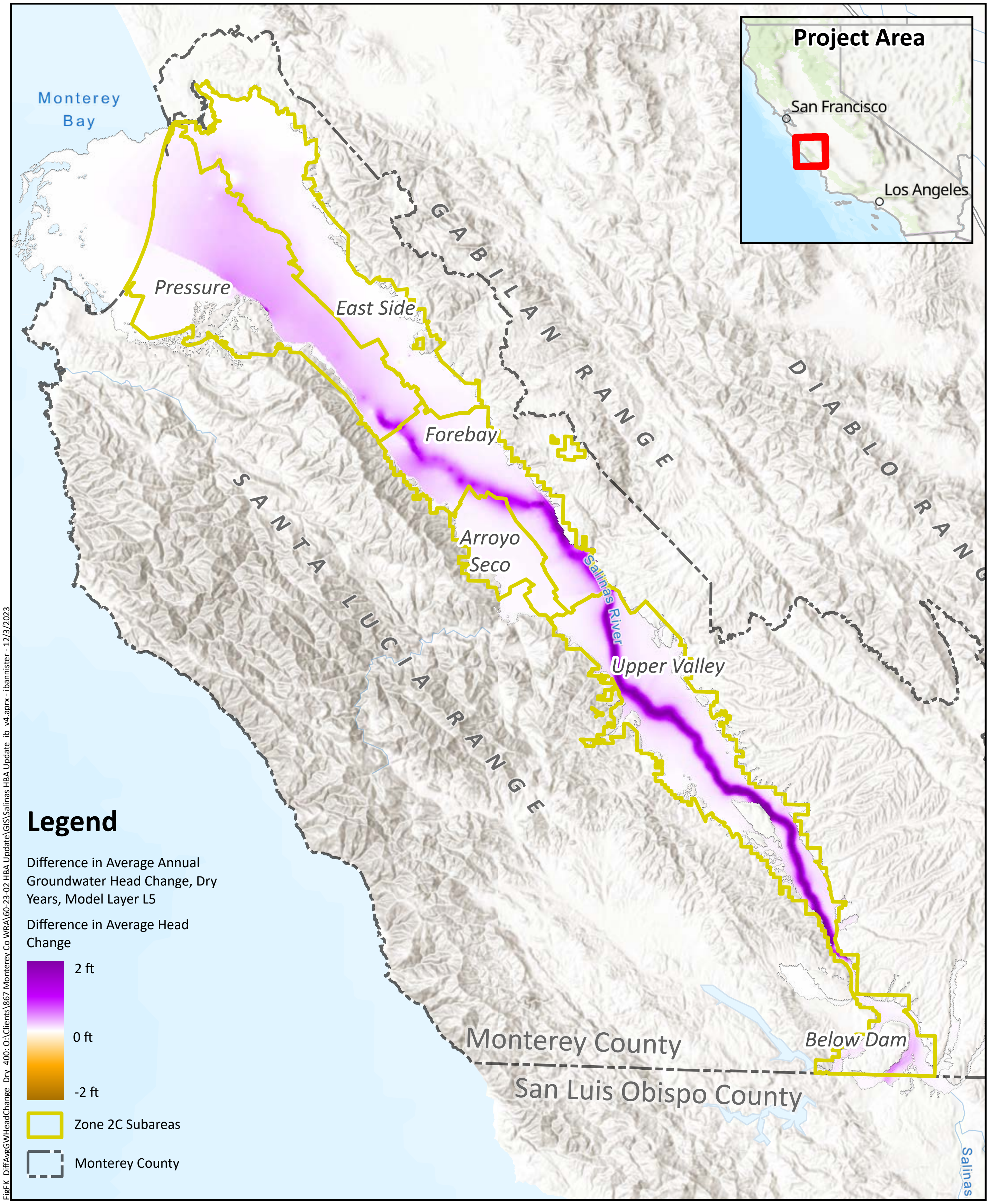

Prepared by:

WEST YOST

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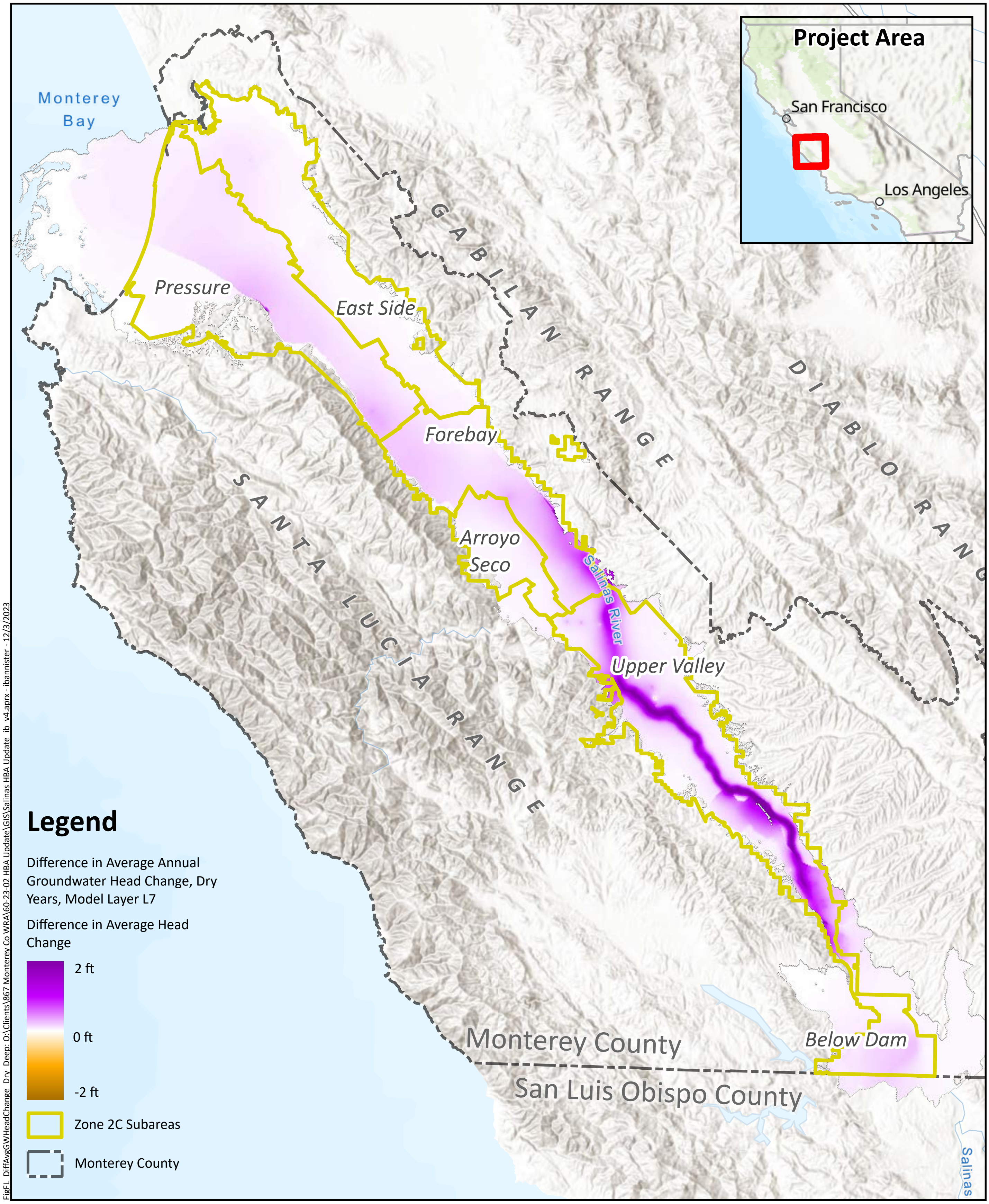
April 2025

Difference in Average Annual Groundwater Head Change Dry Years
400-Foot Aquifer & Equivalent

Figure A26



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Difference in Average Annual Groundwater Head Change Dry Years

Deep Aquifer

Figure A27

Prepared by:

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0 5 10 Miles

0 8 16 Km

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Monterey County Water Resources Agency

Salinas Valley HBA Update

April 2025

Appendix B

Streamflow Estimation Approach

One major finding of the 1998 HBA (MW, 1998) was that the reservoirs have reduced the extent of severe flooding occurring along the Salinas River from Bradley to Monterey Bay. That study developed a statistical description of flood flow magnitudes with and without the Nacimiento and San Antonio Reservoirs using a combination of observed and simulated streamflow and accounts of historical flood events. The 1998 HBA presented the extents of the 100-year floods with and without the reservoirs to demonstrate the benefit that stakeholders in the Basin have received due to the reservoirs' flood control operations.

For this HBA Update, some modifications to the 1998 HBA approach were required because of differences in the modeling tools available. The Salinas Valley Integrated Hydrologic Model (SVIHM) was the main tool used to simulate conditions in the Basin for the HBA Update, and simulated streamflow in the SVIHM is only calculated once per 5- to 6-day timestep, with temporal variation in streamflow highly influenced by the use of monthly streamflow values at the stream inflow points along the edges of the SVIHM (i.e., there is little variation in simulated streamflow within each month in the SVIHM). While the SVIHM is useful for understanding seasonal and annual variations in streamflow, it is not appropriate for characterizing the magnitude of peak flows resulting from, for example, individual storm events.

This appendix describes an alternative approach that was created for this HBA Update to develop an estimate of peak flow magnitudes analogous to those analyzed in the 1998 HBA. This approach relies on a combination of observed streamflow data, simulated mean daily streamflow from the USGS Salinas Valley Watershed Model (SVWM), measured daily reservoir outflow, estimated mean daily reservoir inflow, and simulated groundwater-surface water interaction from the SVIHM. The goal of this approach was to estimate the magnitude of peak flows with the information available. The finest temporal resolution available for most of the data sources used for the streamflow estimation is daily (total or average daily flow); instantaneous peak streamflows were estimated from mean daily streamflows based on linear regressions.

The portion of the study area over which this streamflow estimation was performed consists of the active model domain of the SVIHM above the location of the U.S. Geological Survey's Salinas River at Bradley stream gauge along the Salinas River and its tributaries, the Nacimiento and San Antonio Rivers (see Figure 4-3 in the HBA Update). Other tributaries to the Salinas River in this area (e.g., Vineyard Canyon) are relatively minor and are not considered here.

This Appendix includes discussion of results from the SVIHM, which is a preliminary model that has not yet been published and documented by the USGS. Results from the SVIHM until publication are considered preliminary; any use of the SVIHM results before publication of the model must be accompanied by the following disclaimer:

> *Historical SVIHM Model: Unoffical [sic] Collaborator Development Version of Preliminary Model. Access to this repository and use of its data is limited to those who are collaborating on the model development. Once the model is published and recieved [sic] full USGS approval it will be archived and released to the public. This preliminary data (model and/or model results) are preliminary or provisional and are subject to revision. This model and model results are being provided specifically to collaborate with agencies who are contributing to the model development and meet the need for timely best*

science. The model has not received final approval by the U.S. Geological Survey (USGS). No warranty, expressed or implied, is made by the USGS or the U.S. Government as to the functionality of the model and related material nor shall the fact of release constitute any such warranty. The model is provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the model.

SIMULATED STREAMFLOW IN SVIHM

The SVIHM simulates the routing of streamflow within a defined stream network based on a simplified mass balance approach. The SVIHM takes inflow where streams intersect the edges of the active model domain, or where stream headwaters are located within the active model domain; together, there are about 150 such locations in the SVIHM.

Inflow to the model domain at these locations is provided as an average monthly flow, corresponding to the temporal discretization of the SVIHM. Although model calculations are made on a slightly finer discretization of 5 to 6 days, the values of streamflow within the model depend strongly on the monthly structure of the inflow time series. Figure B-1 shows an example time series of simulated streamflow in the Salinas River at Bradley for the Historical and No Projects Scenarios run for the HBA Update. Although this historical period experienced a very high peak streamflow (observed daily mean streamflow in the Salinas River at Bradley reached a maximum of 14,000 cfs on 3 Jan 1997), streamflow simulated by the SVIHM does not approach the magnitude of the peak daily streamflow.

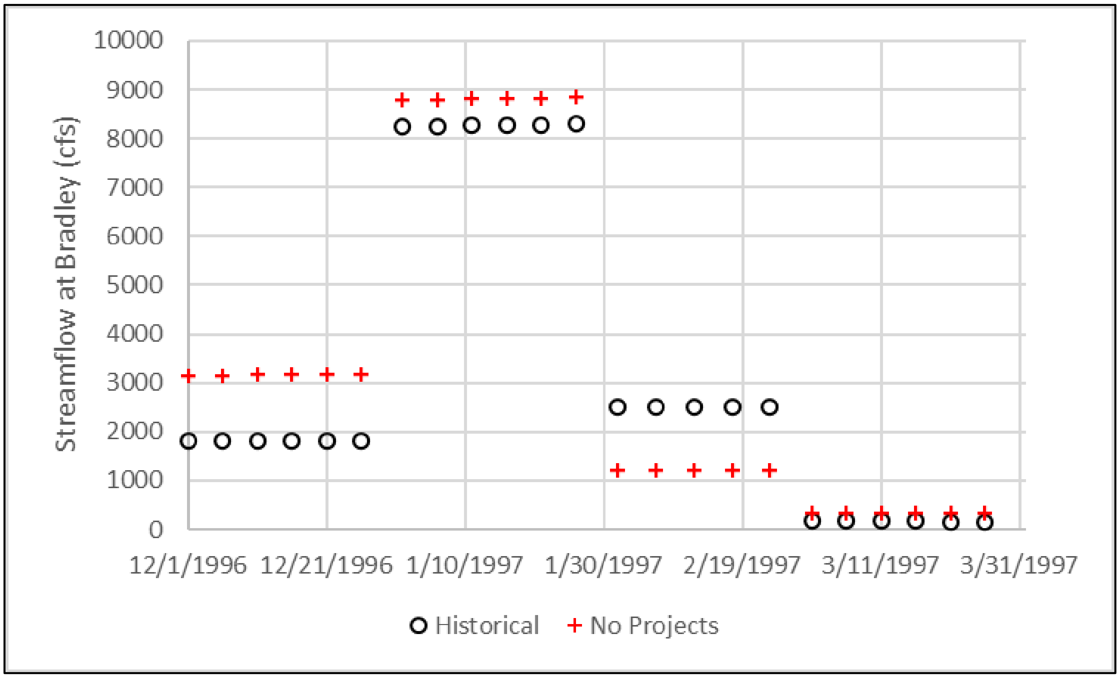

Figure B-1. SVIHM-Simulated Streamflow in the Salinas River at Bradley Showing Monthly Pattern of Streamflow

The monthly structure of simulated streamflow in the SVIHM means that the model results cannot be used directly to quantify the magnitude of peak flow events. Instead, an alternative approach to peak flow estimation was developed that utilized available data sources that could be combined to produce reasonable estimates of instantaneous peak flow magnitudes in the Salinas River at Bradley for the Historical and No Projects Scenarios.

AVAILABLE DATA SOURCES

Streamflow data in the Salinas River and its tributaries, either observed or simulated, are available from various sources. These data sources include:

- Measured mean daily streamflow at the Salinas River at Bradley stream gauge from the USGS (1 Oct 1948 to present)
- Measured instantaneous streamflow (15-minute intervals) at the Salinas River at Bradley stream gauge from the USGS (1 Oct 1988 to present)
- Measured daily release from Nacimiento Reservoir from MCWRA (1 Oct 1958 to present)
- Measured daily release from San Antonio Reservoir from MCWRA (1 Oct 1966 to present)
- Estimated daily inflow to Nacimiento Reservoir from MCWRA (1 Oct 1958 to present)
- Estimated daily inflow to San Antonio Reservoir from MCWRA (1 Oct 1966 to present)
- Simulated mean daily streamflow in the Salinas River near San Miguel (where the Salinas River enters the SVIHM) from the SVWM (1 Oct 1967 to 30 Sep 2018)
- Simulated groundwater-surface water interaction from the SVIHM for the Historical and No Projects Scenarios (1 Oct 1967 to 30 Sep 2018)

Throughout this document, streamflow measurements taken at the USGS gauge at Bradley and dam releases are referred to as “observed” or “measured,” direct model outputs from the SVIHM and SVWM are referred to as “simulated,” and reservoir inflows as well as outputs from the streamflow estimation approach are referred to as “estimated.”

STREAMFLOW ESTIMATION APPROACH

For this HBA Update, the data sources listed above were used to develop time series of estimated mean daily streamflow, annual peak mean daily streamflow, and annual peak instantaneous streamflow for the Salinas River at Bradley under the Historical and No Projects Scenarios. This approach relies on a simple mass balance of the streamflows within the estimation area:

$$S_{Br} = S_{Na} + Q_{Na} + S_{SA} + Q_{SA} + S_S + Q_S \quad (1)$$

where:

- S_{Br} = Mean daily streamflow at the Salinas River at Bradley gauge
- S_{Na} = Mean daily streamflow below Nacimiento Dam (measured, estimated, or simulated)
- Q_{Na} = Simulated groundwater-surface water interaction flux along Nacimiento River between the point where it enters the SVIHM domain and its confluence with the Salinas River (simulated)
- S_{SA} = Mean daily streamflow below San Antonio Dam (measured, estimated, or simulated)
- Q_{SA} = Simulated groundwater-surface water interaction flux along San Antonio River between the point where it enters the SVIHM domain and its confluence with the Salinas River (simulated)
- S_S = Mean daily streamflow in the Salinas River where it enters the SVIHM domain (simulated, from SVWM)
- Q_S = Simulated groundwater-surface water interaction flux along the Salinas River between where it enters the SVIHM domain and the location of the Salinas River at Bradley gauge (simulated)

In this equation, all streamflow variables (S_{Br}, S_{Na}, S_{SA}, and S_S) are available as mean daily flows, whereas all groundwater-surface water interaction flux variables (Q_{Na}, Q_{SA}, and Q_S) are single values for each 5- to 6-day SVIHM timestep. The source of the values of S_{Na} and S_{SA} varies depending on the model scenario being considered. For the Historical Scenario, measured reservoir releases are used. For the No Projects Scenario, the estimated reservoir inflow is used. The equation can be used to estimate streamflow at Bradley for any period where reservoir outflow and Salinas River inflow are known or can be estimated.

Observed versus Estimated Streamflow

Equation 1 was used to calculate an estimated mean daily streamflow for the Salinas River at Bradley for the period of the SVIHM, 1 Oct 1967 to 30 Sep 2018. Figure B-2 shows a time series comparing the observed and estimated mean daily streamflow throughout this period. This figure shows a strong agreement in the overall pattern of streamflow, including the timing of peak flows, between the observed and estimated streamflows. However, the figure also shows that the estimation method under-predicts the magnitudes of many of the highest peaks.

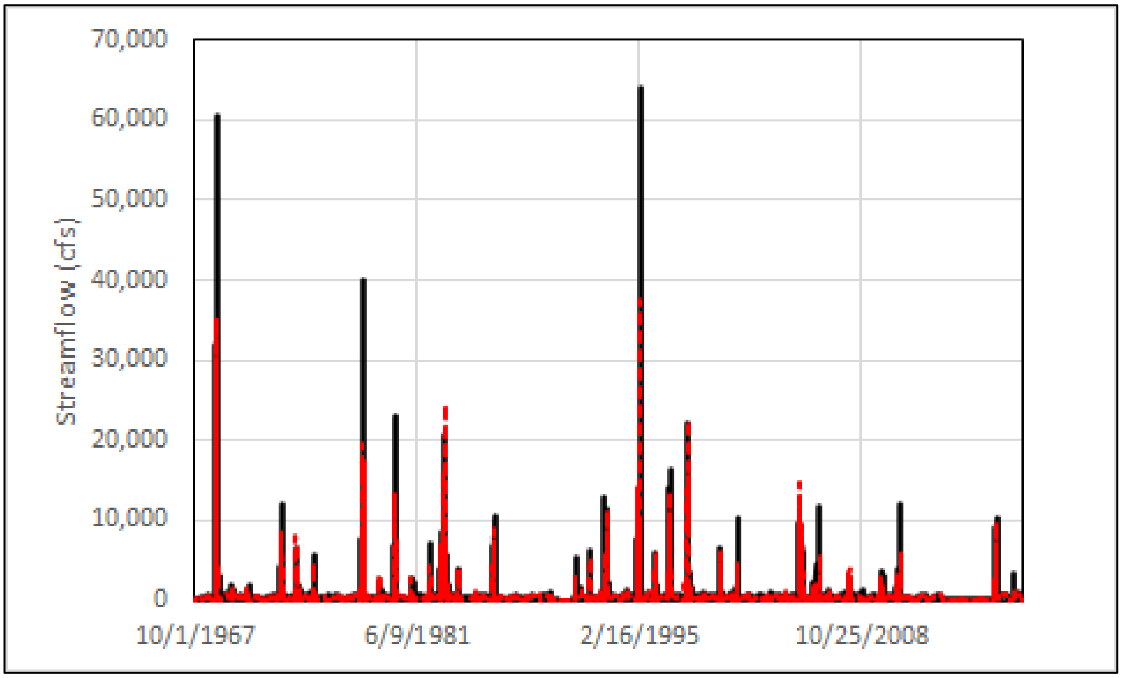

Figure B-2. Observed (black) and Estimated (red) Streamflow in the Salinas River at Bradley

Figure B-3 shows a scatterplot of the observed and estimated mean daily streamflows in the Salinas River at Bradley. Although this plot shows a generally good agreement between observed and estimated mean daily streamflow (as shown by a regression slope of 0.8768 and a regression coefficient, r^2, of 0.8860)[1], the quality of the relationship is noticeably poorer for observed mean daily streamflows above about 32,000 cfs, which are substantially under-predicted by the estimation method.

[1] All linear regressions presented in this document use a forced intercept of (0,0).

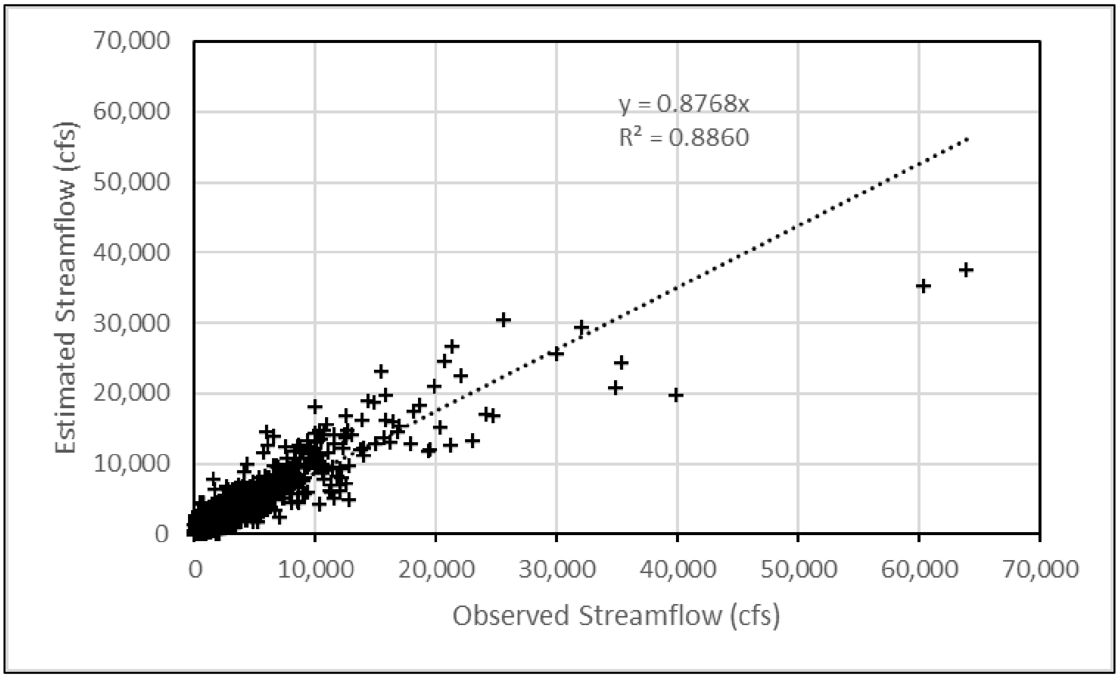

Figure B-3. Scatterplot of Observed Versus Estimated Streamflow Values in the Salinas River at Bradley with Linear Regression

Because the HBA Update is chiefly concerned with the magnitude of peak flows, this regression indicates that the basic streamflow estimation approach cannot be used as-is, and must be modified to provide a more reasonable estimate of mean daily streamflow.

To better understand the under-prediction of the highest streamflows, we looked closer at how well the estimation method matches observed mean daily streamflows above 10,000 cfs (Figure B-4). The linear regression (black line) for the >10,000 cfs events (black circles on Figure B-4) has a slope of 0.7850 and an r^2 of 0.9054. This is not substantially different from the parameters of the linear regression for all of the data (Figure B-3). Figure B-4 further divides the >10,000 cfs mean daily streamflow events into one dataset without the five highest-flow events (green plusses) and another with just the five highest-flow events (purple x's). Each of these subsets exhibits an r^2 significantly closer to a value of 1. For the first subset, the regression (green line) has a slope of 0.9180 and an r^2 of 0.9318. For the second subset, the regression (purple line) has a slope of 0.5859 and an r^2 of 0.9932. The fact that both of these regressions have r^2 values quite close to one indicates that 1) the estimation approach performs very well for flows below 32,000 cfs and 2) the under-prediction of observed mean daily streamflows above 32,000 cfs is fairly systematic, meaning that the degree of under-prediction varies in a predictable way with observed streamflow.

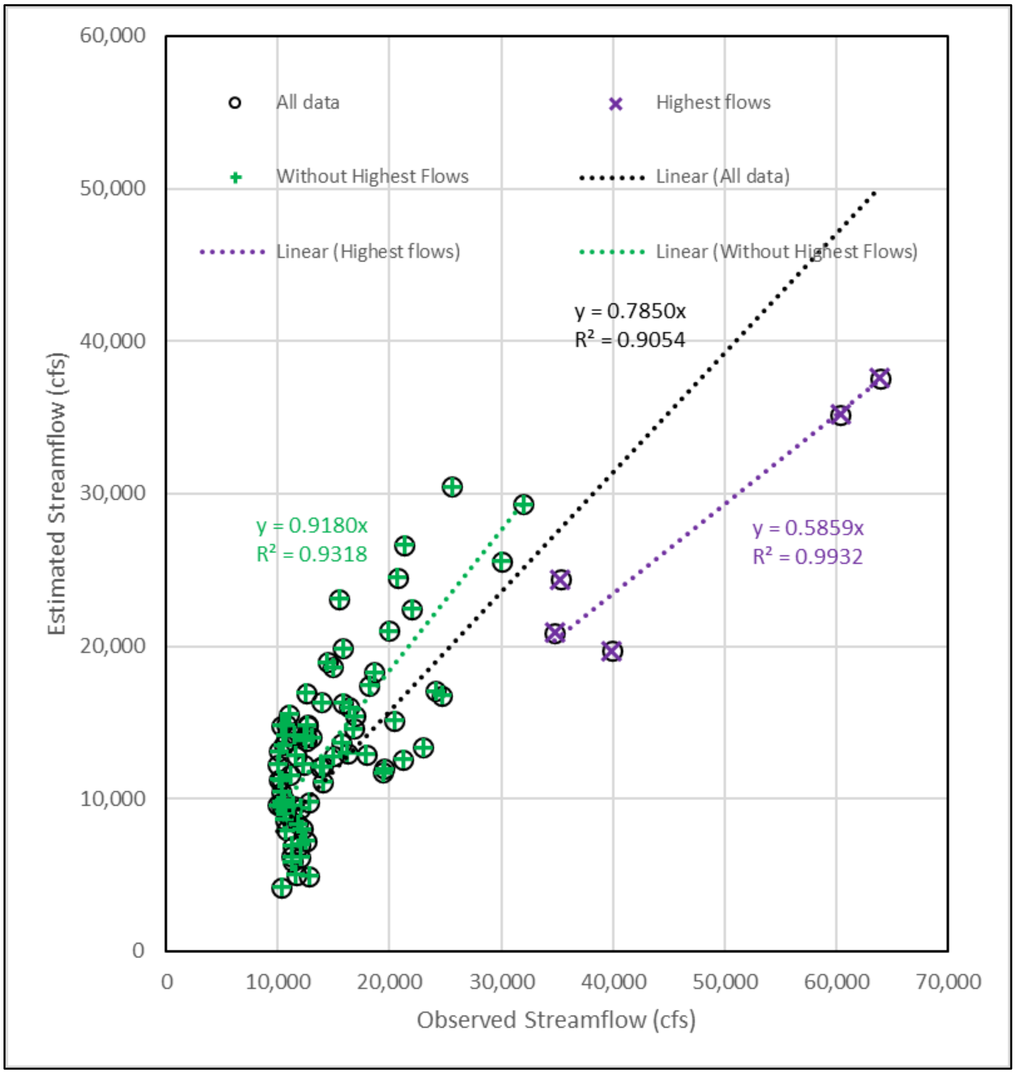

Figure B-4. Scatterplot of Observed Versus Estimated Daily Mean Streamflow in the Salinas River at Bradley for Observed Streamflows of 10,000 cfs or More

Because the sample of observed mean daily streamflows above 32,000 cfs is quite limited, we can take a closer look at those events individually and attempt to ascertain the reason that each is under-predicted. Table B-1 provides the values of all Equation 1 variables for the five highest observed streamflow events, along with the historical date of each streamflow. This table makes it clear that the inflow along the Salinas River (S_S) is by far the largest contributor to the estimated mean daily streamflow in the Salinas River at Bradley for the largest events. This is a strong indication that the under-estimation of these highest peak streamflows may result from under-prediction of the Salinas River inflow for these five events.

Date	S_{Na}	Q_{Na}	S_{SA}	Q_{SA}	S_s	Q_s	S_{Br}	Observed	Est/Obs
2/24/69	2,605	-26	0	-1	18,330	-14	20,893	34,800	0.600
3/10/1995	800	-17	10	-1	23,609	-12	24,388	35,000	0.691
2/10/1978	2,580	-25	5	-1	17,158	-11	19,706	39,900	0.494
2/25/1969	5,466	-26	0	-1	29,784	-14	35,208	60,400	0.583
3/11/1995	1,000	-17	10	-1	36,600	-12	37,578	63,900	0.588

Table B-1. Estimated Mean Daily Streamflow (cfs) in the Salinas River at Bradley for Five Highest Flow Days, with Corresponding Observed Mean Daily Streamflow for Comparison

Table B-1 also includes the ratio between the estimated (Est) and observed (Obs) streamflow values for these five events, which ranges from 0.494 to 0.691 and average 0.591, quite close to the slope of the linear regression through the five highest-flow events (0.5859).

As stated above, the Salinas River inflow used to estimate mean daily streamflow in the Salinas River at Bradley is derived from the USGS' SVWM, which simulates the generation of streamflow throughout the Salinas River watershed. The SVWM, like the SVIHM, is a preliminary model that has not been published as of the date of publication of this HBA Update, and was not available for assessment as part of this update. This means that any inability for the SVWM to match observed streamflows cannot be investigated or corrected at this stage; the SVWM-simulated streamflow at the Salinas River inflow point represents the best available quantification of streamflow at this location.

Considering the above, the next step in the streamflow estimation approach was to assess the effect of scaling the Salinas River inflow for the five highest-flow events on the match between observed and estimated streamflows.

Modification of SVWM Salinas River Inflows

To improve the ability of the streamflow estimation approach to produce an accurate representation of observed streamflow values, the Salinas River inflow for the five highest-flow events (as measured in the Salinas River at Bradley) was scaled by a factor. Values for the scaling factor of 0.1 to 1.0 were tested and assessed based on the slope and regression coefficient for a linear regression fitted through all observed and estimated streamflow values, as well as the mean and absolute mean residuals for the five highest-flow events (Table B-2; a scaling factor of 1.0 represents no scaling).

Table B-2. Assessment of Application of Scaling Factor for Modification of Highest-Flow Events in the Salinas River Inflow				
Scaling Factor	Regression Slope	Regression Coefficient	Residual Mean, cfs	Absolute Residual Mean, cfs
0.1	2.1229	0.5349	206,561	206,561
0.2	1.4306	0.7512	81,080	81,080
0.3	1.1999	0.8680	39,253	39,253
0.4	1.0845	0.9172	18,339	18,339
0.5	1.0153	0.9815	5,791	7,005
0.54	0.9948	0.9320	2,073	4,304
0.55	0.9901	0.9310	1,228	4,020
0.56	0.9856	0.9613	413	3,814
0.565	0.9834	0.9314	17	3,715
0.57	0.9813	0.9312	-373	3,648
0.575	0.9792	0.9310	-756	3,664
0.5859	0.9747	0.9305	-1,568	3,877
0.6	0.9691	0.9296	-2,574	4,505
0.7	0.9362	0.9209	-8,550	8,550
0.8	0.9114	0.9095	-13,031	13,031
0.9	0.8922	0.8976	-16,517	16,517
1.0	0.8768	0.8860	-19,305	19,305

From Table B-2, it is clear that a range of scaling factors between about 0.5 and 0.6 provide a marked improvement in the overall fit compared to the unscaled estimation. Although various different statistics can be used to identify the optimal scaling factor, the absolute residual[2] mean was relied on most heavily because it provides an indication of the magnitude of the mismatch between observed and estimated streamflows (compared to the residual mean, which can be near the ideal value of zero if large positive and negative residuals balance each other). Based on the absolute residual mean, a scaling factor of 0.57, when applied to the five highest-flow events, provides the best match between observed and estimated mean daily streamflows in the Salinas River at Bradley.

[2] Residual is defined as the difference between an observed and estimated value and is equal to the estimated streamflow minus the observed streamflow. The absolute residual is the absolute value of the residual.

Table B-3 provides the values of the Equation 1 variables for the five highest-flow events (as in Table B-1), with S_S scaled (i.e., divided by 0.57). This table shows that the modified (i.e., scaled) estimated streamflow values produce a much closer match to the observed highest flows compared to using the unscaled flow values.

Table B-3. Estimated Mean Daily Streamflow in the Salinas River at Bradley for Five Highest Flow Days, Using Scaled Values of Salinas River Inflow, with Corresponding Observed Mean Daily Streamflow for Comparison

Date	S_{Na}	Q_{Na}	S_{SA}	Q_{SA}	S_s	Q_s	S_{Br}	Observed	Est/Obs
2/24/69	2,605	-26	0	-1	31,285	-14	33,848	34,800	0.973
3/10/1995	800	-17	10	-1	40,295	-12	41,075	35,000	1.164
2/10/1978	2,580	-25	5	-1	29,285	-11	31,833	39,900	0.798
2/25/1969	5,466	-26	0	-1	50,835	-14	56,259	60,400	0.931
3/11/1995	1,000	-17	10	-1	62,468	-12	63,447	63,900	0.993

Figure B-5 shows the time series of observed and modified estimated streamflow values in the Salinas River at Bradley. Comparison with Figure B-2 demonstrates that the highest peak flows are much better matched with the scaled Salinas River inflows compared to the unscaled inflows. Figure B-6 provides a scatterplot of all observed and modified estimated mean daily streamflows in the Salinas River at Bradley; comparison with Figure B-3 shows that the modification to the Salinas River inflow for the highest-flow events results in a substantially better (i.e., closer to the desired 1:1 line) match to the observed data. A linear regression through these data results in a regression slope of 0.9813 (compared to 0.8768 without scaling) and an r^2 of 0.9312 (compared to 0.8860 without scaling). This scaling factor has no physical meaning, a limitation of this approach. But, because we do not have access to the SVWM to better understand why it may be under-predicting the highest peak flows (and correct the issue), this scaling is considered the best way to reproduce observed streamflow conditions in the Salinas River at Bradley with the available information.

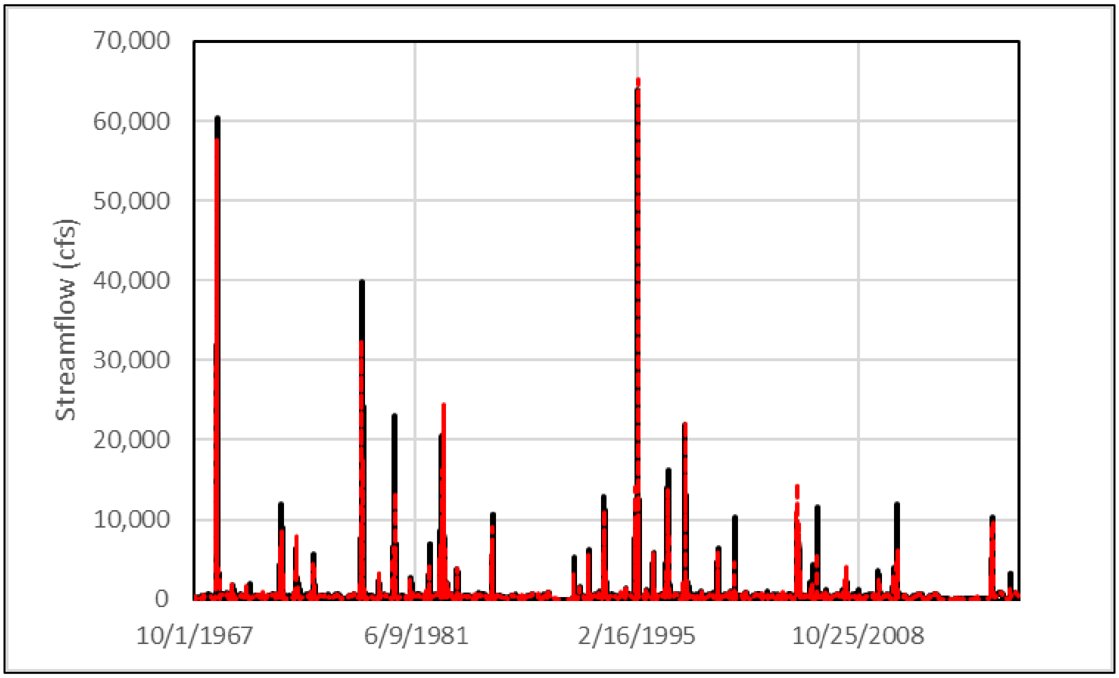

Figure B-5. Observed (black) and Modified Estimated (red) Streamflow in the Salinas River at Bradley, Using Modified Values of Salinas River Inflow for Highest-Flow Events

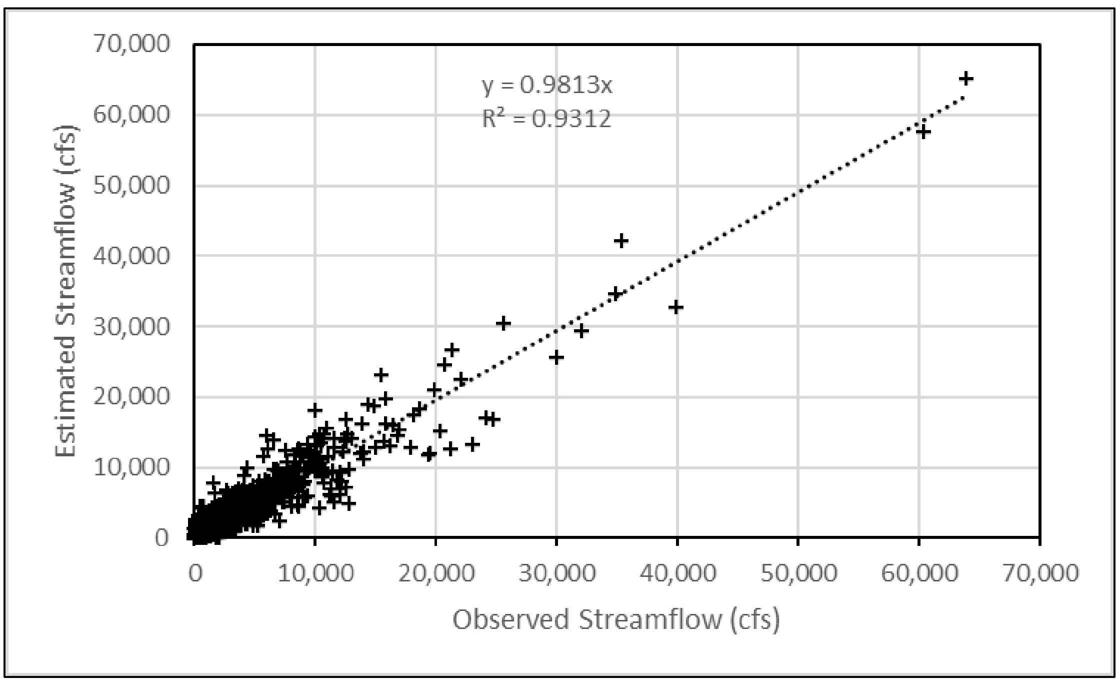

Figure B-6. Scatterplot of Observed Versus Modified Estimated Streamflow Values in the Salinas River at Bradley, Using Modified Values of Salinas River Inflow for Highest-Flow Events (Scaling Factor = 0.57), with Linear Regression

Throughout the remainder of this document, the scaled Salinas River inflows are used to provide the values of S_S to Equation 1 for the characterization of annual peak streamflow in the Salinas River at Bradley.

Modified Estimated Streamflows

Two time series of streamflow were developed using the modified estimation described previously, one representative of historical conditions in the study area and another approximating conditions as if the Nacimiento and San Antonio Reservoirs (and certain related projects and programs; see Section 1.2.4 of the HBA Update). Each uses Equation 1 to calculate mean daily streamflow in the Salinas River at Bradley; the difference lies in the inputs used to calculate the data for each time series.

For the Historical Scenario, the input variables for Equation 1 are as follows:

- S_{Na} = Measured daily releases from Nacimiento Dam (provided by MCWRA)
- Q_{Na} = Simulated groundwater-surface water interaction flux along the Nacimiento River under the SVIHM Historical Scenario
- S_{SA} = Measured daily releases from San Antonio Dam (provided by MCWRA)
- Q_{SA} = Simulated groundwater-surface water interaction flux along the San Antonio River under the SVIHM Historical Scenario
- S_S = Modified estimated mean daily Salinas River inflow
- Q_S = Simulated groundwater-surface water interaction flux along the Salinas River above Bradley under the SVIHM Historical Scenario

This time series of mean daily streamflow is presented in Figure B-5, and the comparison between this time series and the observed mean daily streamflow time series in the Salinas River at Bradley is discussed in the previous section.

For the No Projects Scenario, the input variables for Equation 1 are as follows:

- S_{Na} = Estimated daily inflow to Nacimiento Reservoir (provided by MCWRA)
- Q_{Na} = Simulated groundwater-surface water interaction flux along the Nacimiento River under the SVIHM No Projects Scenario
- S_{SA} = Estimated daily inflow to San Antonio Reservoir (provided by MCWRA)
- Q_{SA} = Simulated groundwater-surface water interaction flux along the San Antonio River under the SVIHM No Projects Scenario
- S_S = Modified estimated mean daily Salinas River inflow
- Q_S = Simulated groundwater-surface water interaction flux along the Salinas River above Bradley under the SVIHM No Projects Scenario

For the No Projects Scenario mean daily streamflow time series, the use of reservoir inflows rather than releases as the inputs to the Nacimiento and San Antonio Rivers approximates the flows along those rivers that would have occurred had the reservoirs not existed. There is no equivalent observed time series against which these streamflow estimates can be compared for verification.

Without the reservoirs in place, one would expect the streamflow in the Salinas River at Bradley to be somewhat more variable compared to the observed streamflows, as flood events in the Nacimiento and San Antonio River watersheds would be passed directly into the Salinas River without the possibility of storage within the reservoirs. Table B-4 provides a selection of statistics for the observed and estimated mean daily streamflow time series. The statistics for the Historical Scenario time series compare very favorably with those of the observed dataset. The average No Projects Scenario mean daily streamflow is very similar to that of the observed data, but the median streamflow is substantially lower, the maximum streamflow is higher, and the standard deviation is larger, a demonstration of the increased variability of streamflow without the reservoirs.

Table B-4. Statistics of Streamflow Time Series for Observed and Estimated Mean Daily Streamflow in the Salinas River at Bradley, cfs

	Observed Streamflow	Historical Scenario Modified Estimated Streamflow	No Projects Scenario Modified Estimated Streamflow
Average	502	506	536
Standard Deviation	1,479	1,506	2,547
Minimum	0	-20	-30
10th Percentile	32	26	-1
1st Quartile	76	66	-1
Median	299	293	16
3rd Quartile	498	489	178
90th Percentile	661	648	891
Maximum	63,900	65,190	105,374

This table indicates that the estimation method described in this appendix results in many negative streamflow estimates. This is obviously not representative of reality; negative streamflow is physically meaningless. Negative mean daily streamflow values in the estimated streamflow time series demonstrate the uncertainties involved in the streamflow estimation, and in part result from the fact that the simulated groundwater-surface water interaction fluxes from the SVIHM are averaged over a 5- to 6-day timestep, while the stream inflow time series have a daily timestep. The simulated groundwater-surface water fluxes also take into account land surface runoff and tributary inflow that enter the stream network between where the stream inflow points are located and the location of the Salinas River at Bradley gauge. When considering the effect of these negative estimated streamflows, it is worth keeping in mind that the flood flow frequency analysis built from these streamflow estimates is largely focused the highest flows in the system and is insensitive to the accuracy of estimates of low flows.

Annual Peak Flows

For a sufficiently long period of record, the characterization of peak flow magnitudes for different return periods (e.g., the 100-year flood) can rely solely on a time series of annual[3] peak flows (i.e., the largest streamflow observed during the year). The 1998 HBA utilized datasets of:

- instantaneous peak flow (i.e., the largest observed or estimated streamflow that occurred each year),
- 1-day flow (i.e., the highest mean daily streamflow each year),
- 3-day flow (i.e., the highest 3-day average of mean daily streamflows each year), and
- 5-day flow (i.e., the highest 5-day average of mean daily streamflows each year).

For this HBA Update, equivalent datasets were developed. The annual peak 1-day flows were derived directly from the results of the streamflow estimation approach, as described above. The annual peak 3-day and 5-day flows were calculated from the time series of estimated mean daily flow by calculating the running 3-day and 5-day average streamflow in each streamflow time series (observed, Historical Scenario modified estimated, and No Projects Scenario modified estimated) and identifying the highest value occurring each year.

Figure B-7 shows the time series of annual peak mean daily streamflow for the observed and Historical Scenario modified estimated streamflow data. Figure B-8 shows a scatterplot of the same data; a linear regression between the annual peak mean daily observed and modified estimated streamflow has a slope of 0.9346 and an r^2 of 0.9742 (compared to a slope of 0.9813 and an r^2 of 0.9312 for all of the streamflow data), demonstrating that the streamflow estimation approach does at least as good a job of replicating the subset of annual peak flows as it does with the entire mean daily streamflow dataset.

[3] For this study, annual peaks are identified based on the water year (WY), which lasts from 1 October to 30 September.

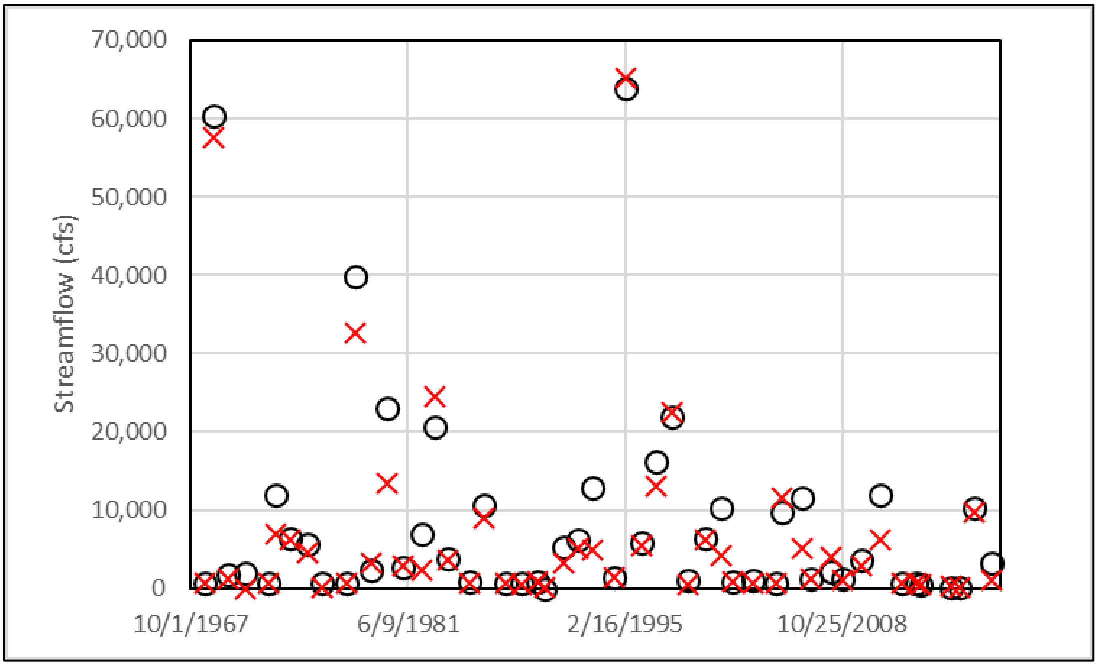

Figure B-7. Observed (black) and Modified Estimated (red) Annual Peak Mean Daily Streamflow in the Salinas River at Bradley

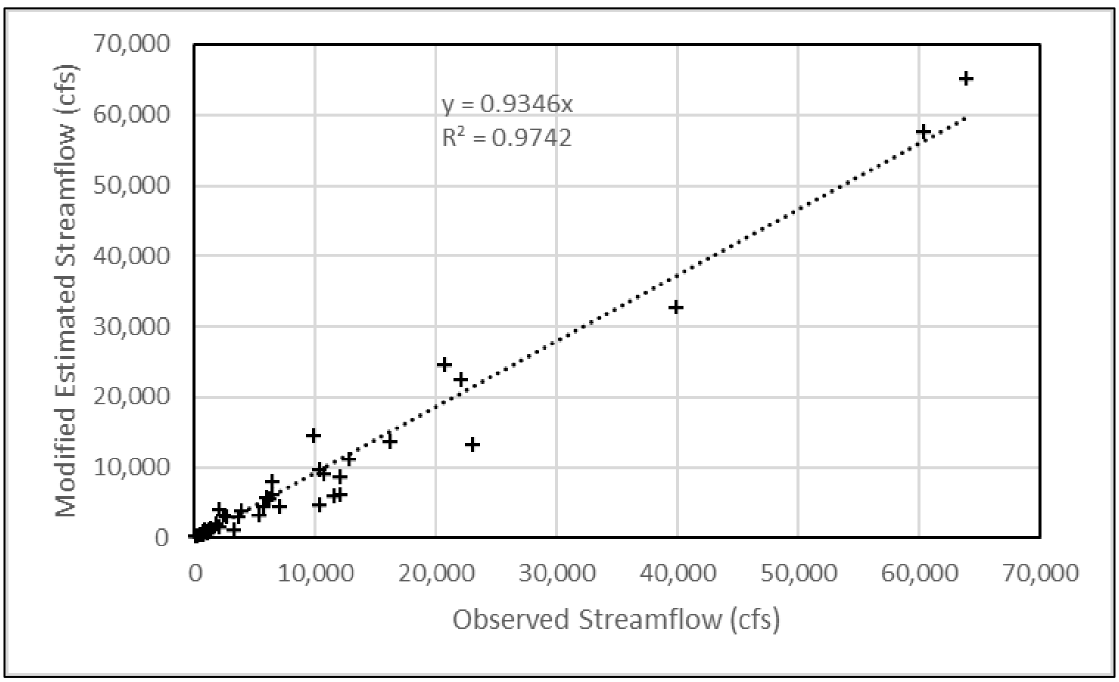

Figure B-8. Scatterplot of Observed Versus Modified Estimated Annual Peak Mean Daily Streamflow Values in the Salinas River at Bradley with Linear Regression

Identification of the annual instantaneous peak flow requires streamflow data on a sub-daily temporal resolution. The USGS makes available streamflow measurements on a 15-minute interval for the Salinas River at Bradley gauge for a limited portion of the study period (i.e., WY 1989 to 2022). However, sub-daily streamflow data are not available for any of the inputs to Equation 1, meaning that the estimation method cannot be used directly to develop a time series of annual instantaneous peak streamflow.

Next, we consider the relationship between annual peak 15-minute streamflow and annual peak mean daily streamflow for the Salinas River at Bradley gauge over the 34-year period when 15-minute data are available. Figure B-9 shows a scatterplot of the annual peak instantaneous streamflow against the annual peak mean daily streamflow for the Salinas River at Bradley over the period from WY 1989 to 2022. A linear regression through these data has a slope of 1.7515 and an r^2 of 0.9819.

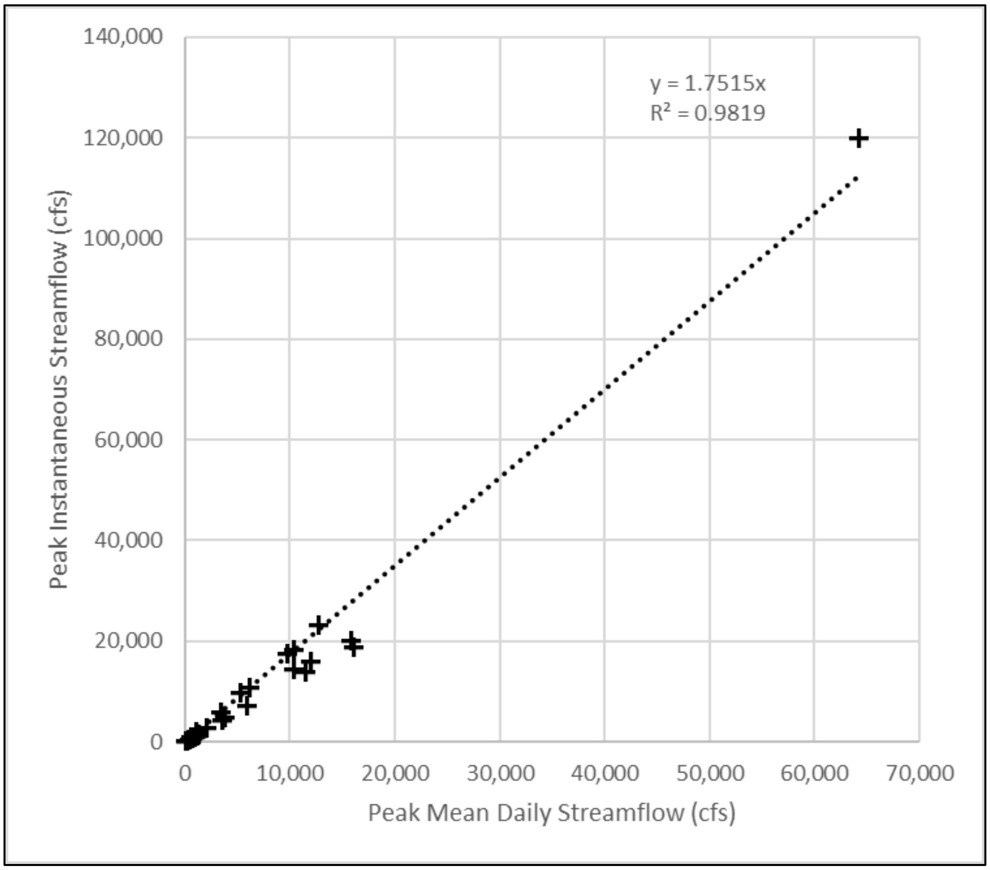

Figure B-9. Scatterplot of Annual Peak Mean Daily Streamflow Versus Annual Peak Instantaneous Streamflow in the Salinas River at Bradley with Linear Regression

The quality of the fit between these two datasets suggests that the annual peak mean daily streamflow time series developed for the entire period of the analysis (WY 1968 to 2018) can be used to calculate an equivalent annual peak instantaneous flow for each year. The slope of the regression (1.7515) can be used to scale the annual peak mean daily streamflows derived from the streamflow estimation approach. Table B-5 provides the annual peak instantaneous, 1-day, 3-day, and 5-day streamflows in the Salinas River at Bradley for the observed, Historical Scenario modified estimated, and No Projects Scenario modified estimated datasets.

Table B-5. Annual peak streamflow values for observed and estimated streamflow datasets (in cfs)

WY	Observed				Historical Scenario Modified Estimated				No Projects Scenario Modified Estimated			
	Instant	1-Day	3-Day	5-Day	Instant	1-Day	3-Day	5-Day	Instant	1-Day	3-Day	5-Day
1968	1,131	646	621	609	1,174	670	666	649	3,148	1,797	1,172	849
1969	105,791	60,400	40,267	29,440	101,021	57,677	40,957	31,136	120,139	68,592	55,496	40,423
1970	3,240	1,850	1,750	1,622	3,438	1,963	1,721	1,536	25,865	14,767	7,520	5,307
1971	3,485	1,990	1,322	848	2,910	1,661	1,402	1,167	17,493	9,988	6,057	5,213
1972	1,279	730	691	675	1,655	945	703	639	9,668	5,520	4,155	3,296
1973	21,018	12,000	8,667	6,700	15,072	8,605	6,953	6,799	38,845	22,178	15,716	13,873
1974	11,192	6,390	6,140	5,630	13,963	7,972	6,971	6,193	39,872	22,764	13,946	10,226
1975	10,071	5,750	5,387	4,778	7,965	4,547	4,431	4,185	41,150	23,494	12,819	8,745
1976	1,130	645	638	632	1,103	629	628	628	1,783	1,018	861	669
1977	1,193	681	680	673	1,229	702	700	698	1,426	814	405	343
1978	69,885	39,900	25,133	23,380	57,187	32,650	22,118	19,823	72,925	41,635	33,892	28,434
1979	4,151	2,370	2,367	2,276	5,755	3,286	3,126	2,939	13,195	7,533	5,469	4,274
1980	40,285	23,000	21,200	18,760	23,410	13,366	12,669	12,571	48,061	27,440	26,980	24,642
1981	4,729	2,700	2,617	2,001	5,152	2,941	2,739	2,253	11,548	6,593	4,568	4,055
1982	12,261	7,000	6,067	5,424	7,821	4,465	3,605	3,339	45,355	25,895	14,763	10,771
1983	36,256	20,700	18,167	15,270	42,883	24,484	20,809	18,393	83,525	47,688	37,065	28,954
1984	6,761	3,860	3,780	3,708	6,715	3,834	3,825	3,817	19,005	10,851	6,378	4,543
1985	1,356	774	757	743	1,946	1,111	783	657	8,303	4,741	3,321	2,286
1986	18,741	10,700	9,730	7,756	15,793	9,017	7,818	6,573	41,590	23,745	19,594	18,198
1987	1,119	639	614	602	1,047	598	598	598	13,534	7,727	3,387	2,192
1988	1,142	652	628	603	1,266	723	661	628	5,708	3,259	2,153	1,547
1989	1,664	950	928	926	1,578	901	901	901	9,057	5,171	2,517	1,730

Table B-5. Annual peak streamflow values for observed and estimated streamflow datasets (in cfs)

WY	Observed				Historical Scenario Modified Estimated				No Projects Scenario Modified Estimated			
	Instant	1-Day	3-Day	5-Day	Instant	1-Day	3-Day	5-Day	Instant	1-Day	3-Day	5-Day
1990	51	29	27	25	474	270	128	86	2,838	1,620	1,134	807
1991	9,353	5,340	4,377	2,825	5,603	3,199	2,917	2,353	32,767	18,708	8,216	6,265
1992	10,772	6,150	4,923	4,398	9,753	5,568	4,962	4,755	25,091	14,325	9,654	10,121
1993	22,419	12,800	9,727	8,598	19,661	11,225	9,248	8,414	63,238	36,105	21,840	18,350
1994	2,365	1,350	1,347	1,278	2,430	1,387	1,387	1,327	9,491	5,419	3,399	2,624
1995	111,921	63,900	40,167	27,306	114,180	65,190	44,673	32,955	184,563	105,374	74,868	51,024
1996	10,404	5,940	5,567	5,472	10,232	5,842	5,472	5,281	23,972	13,687	11,575	9,147
1997	28,374	16,200	14,000	12,426	23,928	13,661	12,646	11,389	37,972	21,680	18,630	15,020
1998	38,533	22,000	17,400	14,600	39,344	22,463	20,426	17,918	85,785	48,978	31,840	26,356
1999	1,979	1,130	1,007	954	1,744	995	970	907	7,590	4,333	2,727	2,058
2000	11,210	6,400	5,660	4,822	10,783	6,156	5,945	5,305	28,595	16,326	10,755	8,479
2001	18,040	10,300	7,657	5,380	8,294	4,736	3,841	3,033	26,261	14,993	10,649	8,323
2002	1,461	834	827	826	1,682	960	936	918	11,612	6,630	3,822	2,569
2003	1,874	1,070	726	636	1,396	797	628	625	18,697	10,675	5,367	4,499
2004	1,223	698	693	686	1,819	1,038	781	689	15,318	8,746	5,763	4,008
2005	17,147	9,790	7,457	7,028	25,609	14,621	13,640	11,734	53,909	30,779	19,843	18,278
2006	20,317	11,600	10,100	8,386	10,305	5,883	5,358	5,052	22,279	12,720	11,016	8,876
2007	2,154	1,230	1,170	1,044	2,172	1,240	1,240	1,120	3,465	1,978	1,037	718
2008	3,661	2,090	1,690	1,415	7,165	4,091	3,507	3,087	18,166	10,372	9,505	8,370
2009	2,102	1,200	1,180	1,168	1,725	985	985	985	8,139	4,647	2,936	2,198
2010	6,288	3,590	2,907	2,093	5,210	2,974	2,589	2,119	24,383	13,921	11,097	9,031
2011	21,018	12,000	7,920	6,496	10,804	6,168	5,520	4,713	40,700	23,237	14,197	12,473

Table B-5. Annual peak streamflow values for observed and estimated streamflow datasets (in cfs)

WY	Observed				Historical Scenario Modified Estimated				No Projects Scenario Modified Estimated			
	Instant	1-Day	3-Day	5-Day	Instant	1-Day	3-Day	5-Day	Instant	1-Day	3-Day	5-Day
2012	1,124	642	614	614	1,223	698	637	634	5,806	3,315	2,201	1,677
2013	1,287	735	716	707	1,368	781	690	676	16,464	9,400	5,272	3,880
2014	870	497	500	499	915	522	520	517	2,773	1,583	1,246	937
2015	361	206	186	171	730	417	232	208	6,843	3,907	3,131	2,279
2016	254	145	135	124	726	415	341	283	12,936	7,386	5,152	3,598
2017	18,040	10,300	9,337	8,410	17,169	9,802	9,131	8,451	37,792	21,577	15,868	14,648
2018	5,780	3,300	1,772	1,296	2,194	1,253	947	812	20,132	11,494	6,148	4,306

Figures B-10 through B-13 show time series of the annual peak instantaneous, 1-day, 3-day, and 5-day streamflows, respectively, for the observed, Historical Scenario modified estimated, and No Projects Scenario modified estimated datasets. These figures show the excellent agreement between the observed and Historical Scenario modified estimated peak flows, as well as the noticeable difference form the No Projects modified estimated peak flows, which tend to be substantially higher.

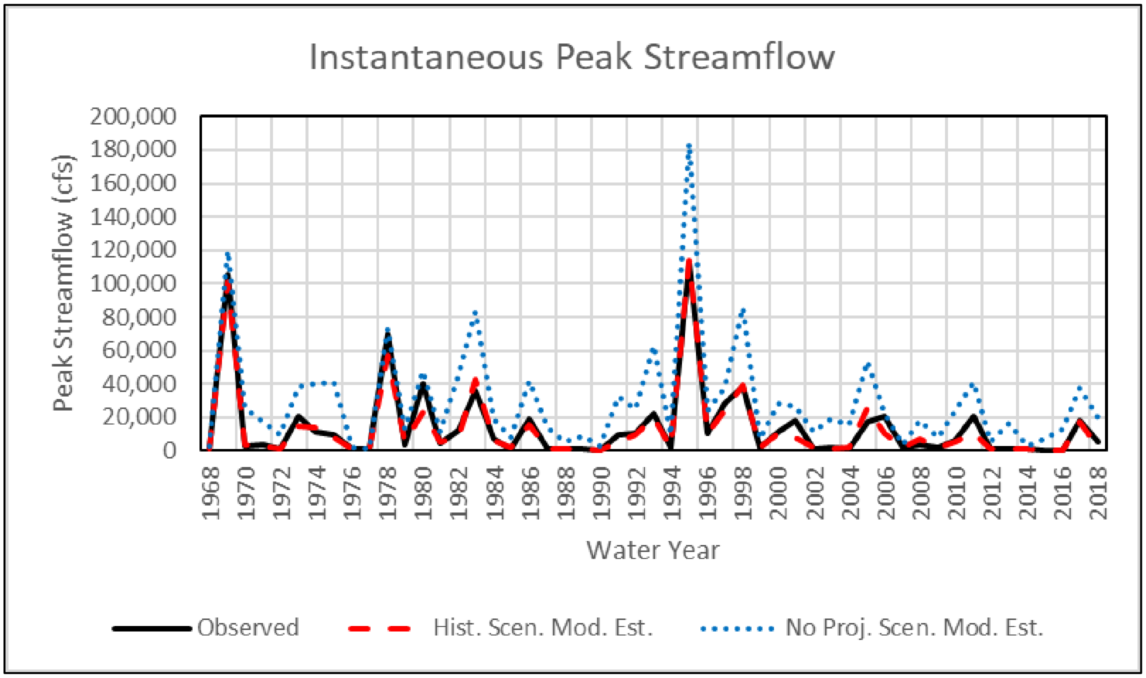

Figure B-10. Annual Peak Instantaneous Streamflow (in cfs) for Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated Datasets

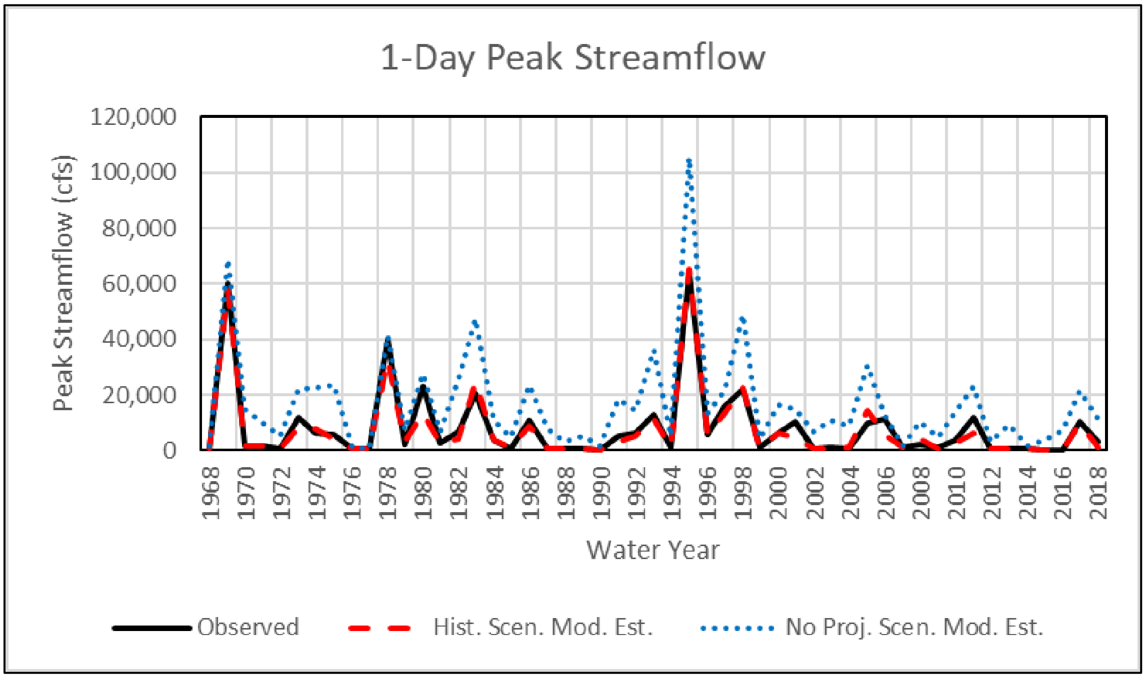

Figure B-11. Peak 1-Day Streamflow (in cfs) for Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated Datasets

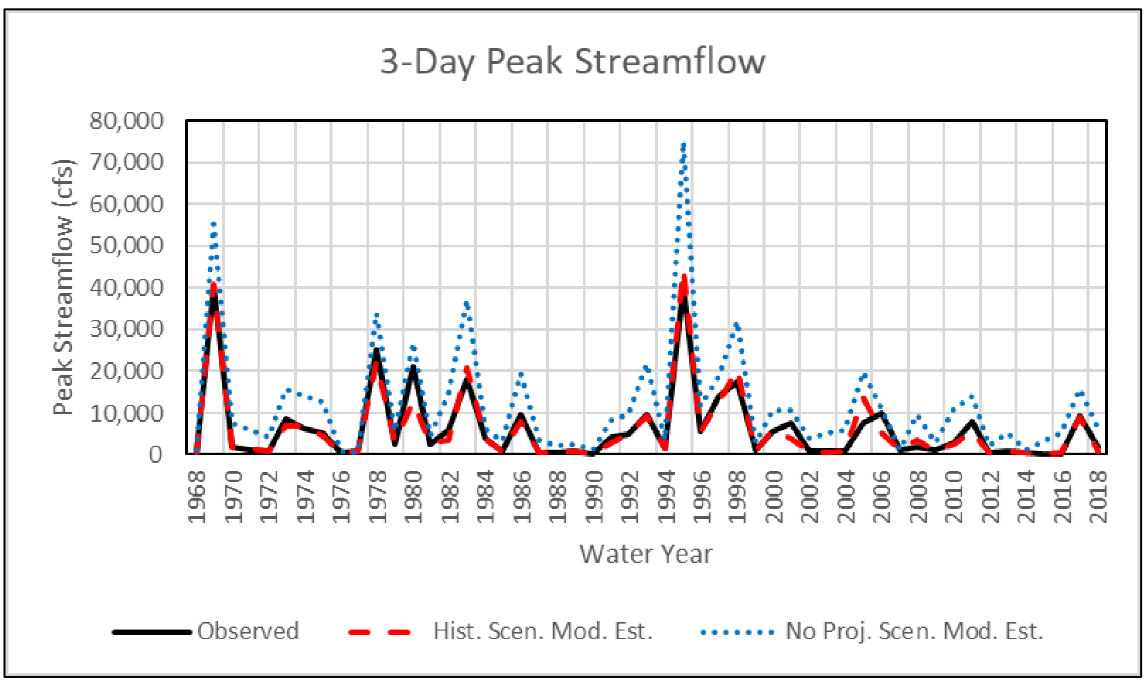

Figure B-12. Peak 3-Day Streamflow (in cfs) for Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated Datasets

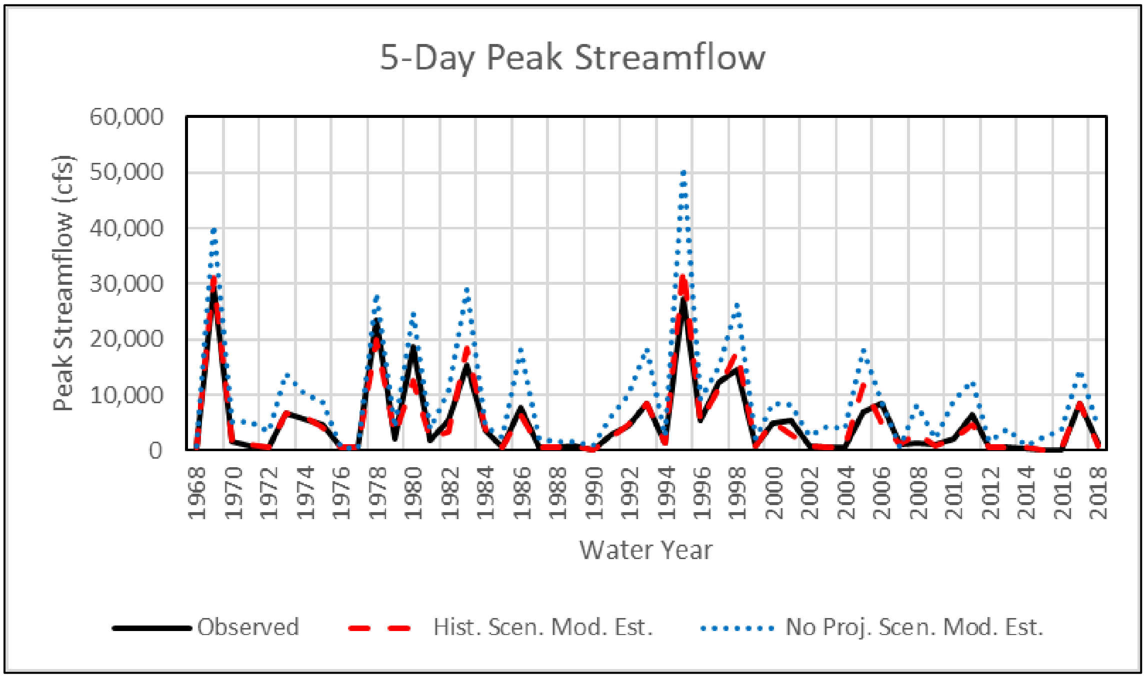

Figure B-13. Peak 5-Day Streamflow (in cfs) for Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated Datasets

FLOOD FLOW FREQUENCY ANALYSIS

As stated at the beginning of this appendix, one important conclusion of the 1998 HBA was that the reservoirs have substantially reduced the magnitude of the 100-year flood in the system. This was determined by characterizing the statistical distribution of annual peak flows with and without the reservoirs, then simulating of the effects of these peak flows on the system using a hydraulic model of the Salinas River. This HBA Update reproduces the analysis of the benefits that the reservoirs and related projects and programs have had in terms of their effect on the magnitude of peak flows in the system. Following the approach used for the 1998 HBA, we developed a statistical characterization of the distribution of peak flows in the Salinas River at Bradley, and used a selection of peak flows to investigate the extent of inundation in the Salinas River floodplain using an existing HEC-RAS 2D model of the Salinas River and its floodplain (FlowWest, 2015).

The characterization of the magnitude of peak streamflows relies on the fact that annual peak streamflows in natural systems generally follow a well-defined statistical distribution. England et al. (2019) describe the approach employed here for performing a flood flow frequency analysis using time series of annual peak flows. In brief, the flood flow frequency analysis relies on fitting a log-Pearson Type III distribution to the annual peak flow data. The probability distribution function of a log-Pearson Type III distribution is defined based on certain parameters (location parameter, shape parameter, and scale parameter) the values of which can be estimated for a flood flow frequency analysis from the values of the moments (mean, standard deviation, and skew coefficient) of the dataset of annual peak flows (England et al., 2019).

Various automated programs have been developed for performing flood flow frequency analyses; this study utilizes the USGS software PeakFQ (Flynn et al., 2006). Based on user inputs, PeakFQ estimates the parameters of the statistical distribution for an annual peak flow dataset; it can automatically identify and remove outliers and other problematic data.

In PeakFQ, the third moment of the probability distribution (the skew coefficient) can be calculated directly from the dataset of annual peak flows, but England et al. (2019) recommend using a regional skew coefficient determined independently. For this analysis, California-specific skew coefficients (Parrett et al., 2011) were consulted to identify an appropriate value of the skew coefficient. Although skew coefficients are not published for stream gauges that are highly impacted by surface water regulation (such as the Salinas River at Bradley), other nearby gauges located within the Salinas River watershed from Paso Robles north have skew coefficients ranging from -0.442 to -0.577 (Parrett et al., 2011); a skew coefficient of -0.5 was selected for this study to fit within the range published for nearby gauges.

PeakFQ can also provide confidence limits on the estimation of the flood flow frequency curve if the skew coefficient is accompanied by an estimate of the mean standard error. Parrett et al. (2011) indicated a mean standard error of 0.13 for all of the gauges in the Salinas River watershed.

The output from PeakFQ is a set of flow magnitudes corresponding to various annual exceedance probabilities (AEPs), which is the probability that the corresponding peak flow magnitude will be exceeded each year. For example, a peak flow with an AEP of 0.1 has a 10 percent chance of being exceeded each year. In standard parlance, the inverse of the AEP is referred to as the return period; for example, a peak flow with an AEP of 0.01 is generally referred to as the 100-year flood. The return period should not be taken as an indicator that a given flood should be expected to occur once during the duration of the return period (i.e., that the 100-year flood will happen once per century). In reality, the 100-year flood can happen several times during a given 100-year period, or not at all. The AEP is a more precise way of describing the expected frequency of floods in a system but, because the return period is the more typical way of discussing floods among the general public (e.g., this is the terminology used in flood insurance studies), this study presents peak flows along with their corresponding AEPs and return periods.

Flood Flow Frequency Curves

For this study, flood flow frequency curves were developed for the observed streamflow, Historical Scenario modified estimated streamflow, and No Projects modified estimated streamflow time series (all covering the 51-year period from WY 1968 to 2018). Although observed annual peak streamflows are available for the Salinas River at Bradley from WY 1949 to 2022, the time series analyzed was limited to the same period simulated by the SVIHM. This avoids the complication of analyzing a dataset that is highly non-stationary (because of the construction of the reservoirs).

Table B-6 provides the magnitude of peak flows (instantaneous, 1-day, 3-day, and 5-day) for each of the datasets (observed, Historical Scenario modified estimated, No Projects Scenario modified estimated) for a selection of AEPs and return periods. Figures B-14 through B-16 present the flood flow frequency curves for the observed streamflow, Historical Scenario modified estimated streamflow, and No Projects Scenario modified estimated streamflow, respectively. These data demonstrate the reduction in the magnitude of flood flow events in the Basin that has occurred due to the presence of the reservoirs (and related projects and programs).

Table B-6. Peak Flow Magnitudes (in cfs) for the Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated Streamflow Time Series for Selected AEPs

Annual Exceedance Probability	0.5	0.2	0.1	0.04	0.02	0.01
Return Period, Years	2	5	10	25	50	100
Observed Data (WY1968-2018)						
Instantaneous	5,423	19,330	35,650	65,900	96,020	132,900
1-Day	3,096	11,040	20,350	37,620	54,810	75,850
3-Day	2,700	8,956	15,840	27,920	39,390	52,920
5-Day	2,388	7,566	13,060	22,400	31,050	41,050
Historical Scenario Modified Estimated Streamflow (WY1968-2018)						
Instantaneous	5,007	15,740	28,480	53,360	79,880	114,600
1-Day	2,858	8,985	16,260	30,470	45,610	65,450
3-Day	2,526	7,856	13,980	25,510	37,370	52,430
5-Day	2,308	7,028	12,290	21,940	31,600	43,600
No Projects Scenario Modified Estimated Streamflow (WY1968-2018)						
Instantaneous	19,360	45,170	67,600	100,900	128,800	158,700
1-Day	11,050	25,790	38,600	57,640	73,530	90,630
3-Day	7,283	17,740	27,250	41,960	54,670	68,730
5-Day	5,669	14,220	22,180	34,660	45,590	57,780
Difference Between Scenarios (No Projects Scenario minus Historical Scenario)						
Instantaneous	14,353	29,430	39,120	47,540	48,920	44,100
1-Day	8,192	16,805	22,340	27,170	27,920	25,180
3-Day	4,757	9,884	13,270	16,450	17,300	16,300
5-Day	3,361	7,192	9,890	12,720	13,990	14,180

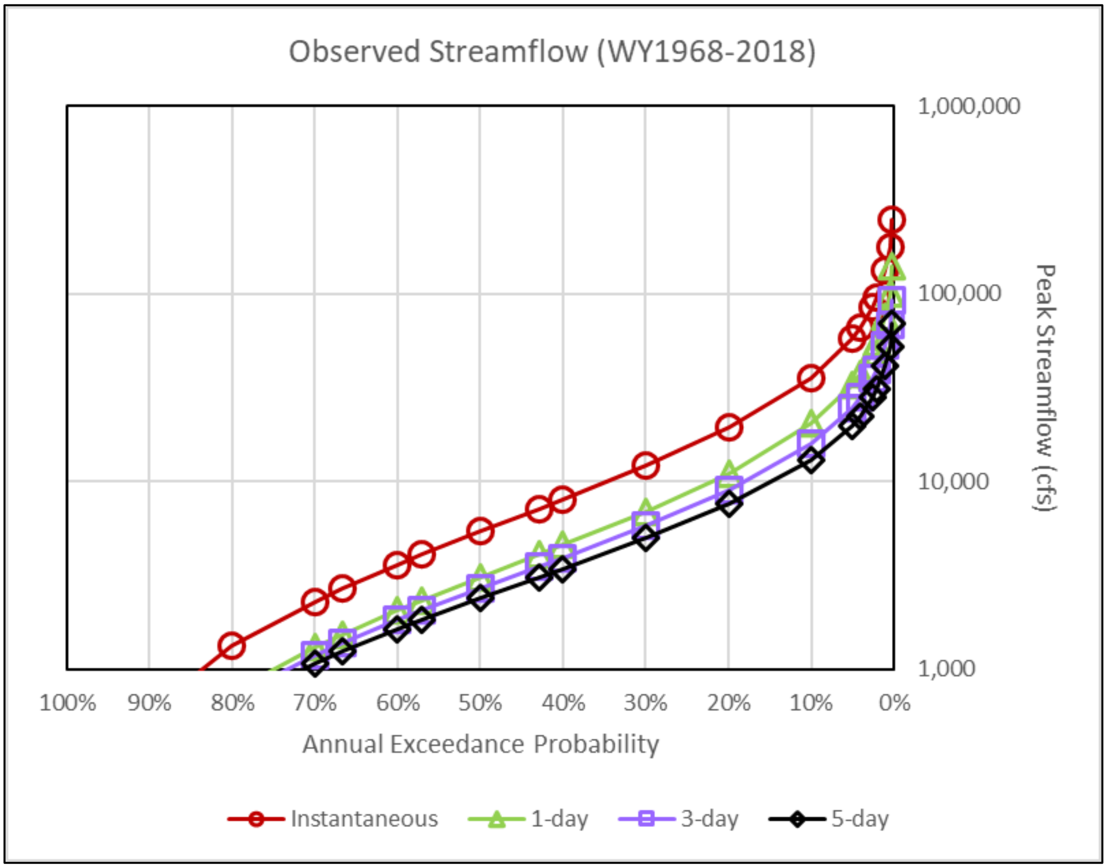

Figure B-14. Flood Flow Frequency Curves for Observed Streamflow for the Salinas River at Bradley

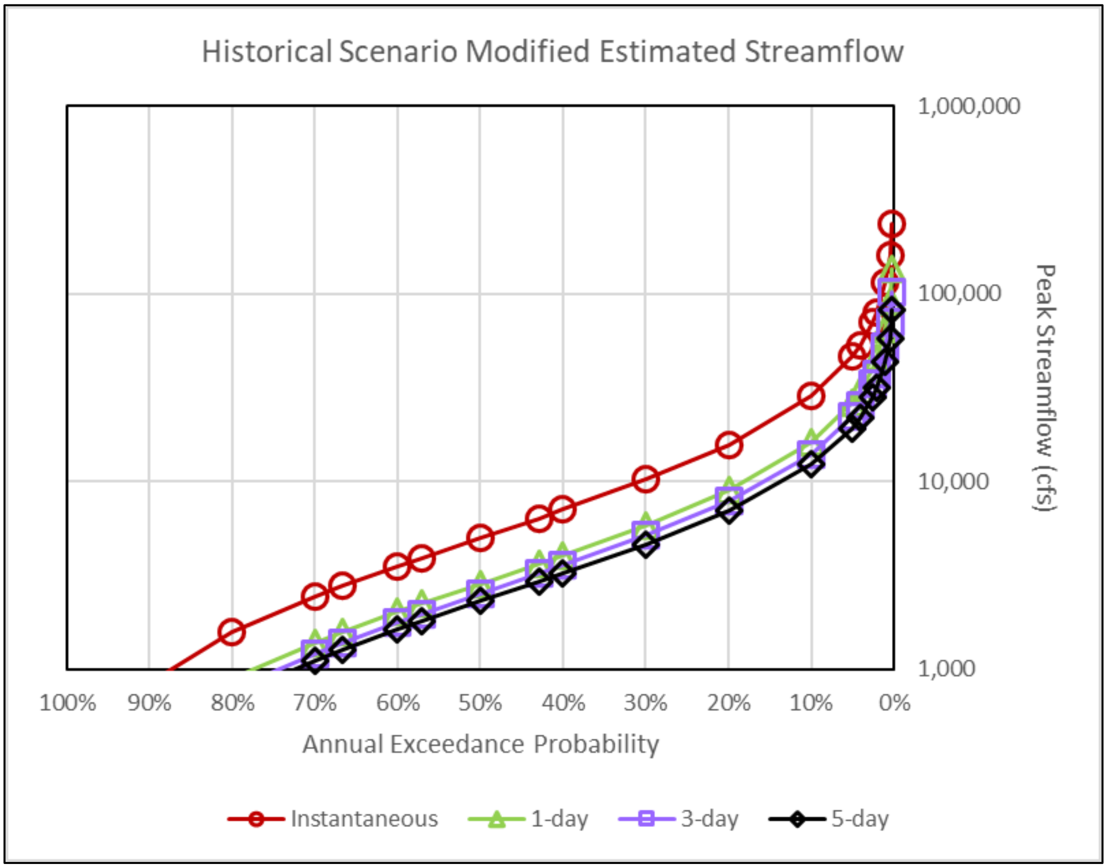

Figure B-15. Flood Flow Frequency Curves for Historical Scenario Modified Estimated Streamflow for the Salinas River at Bradley

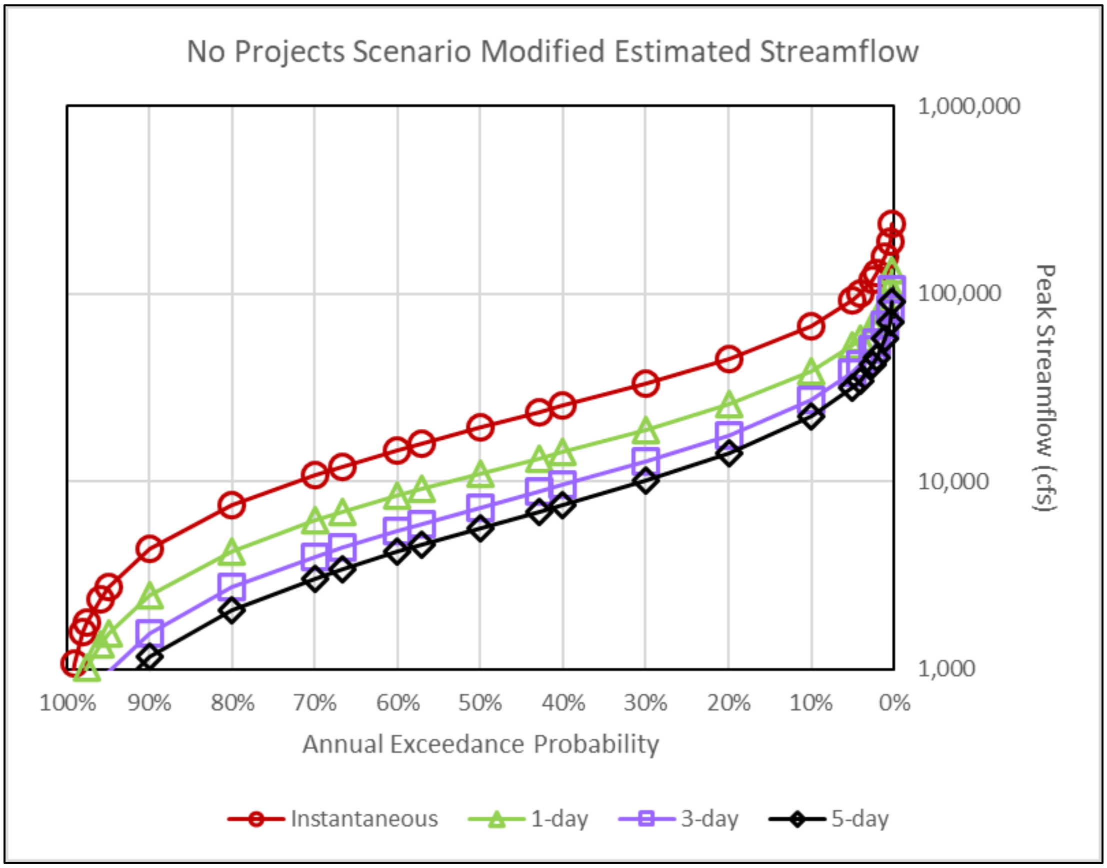

Figure B-16. Flood Flow Frequency Curves For No Projects Scenario Modified Estimated Streamflow for the Salinas River at Bradley

Figure B-17 shows the difference in the flood flow frequency curves between the Historical and No Projects Scenario modified streamflow time series (calculated as the No Projects Scenario curves minus the Historical Scenario curves; this is opposite to the approach used for the groundwater head maps, and is done to avoid negative differences when plotting on logarithmic axes); these differences are also tabulated in Table B-6. These data indicate that the Projects result in a reduction of about 44,000 cfs for the 100-year flood event (AEP = 0.01).

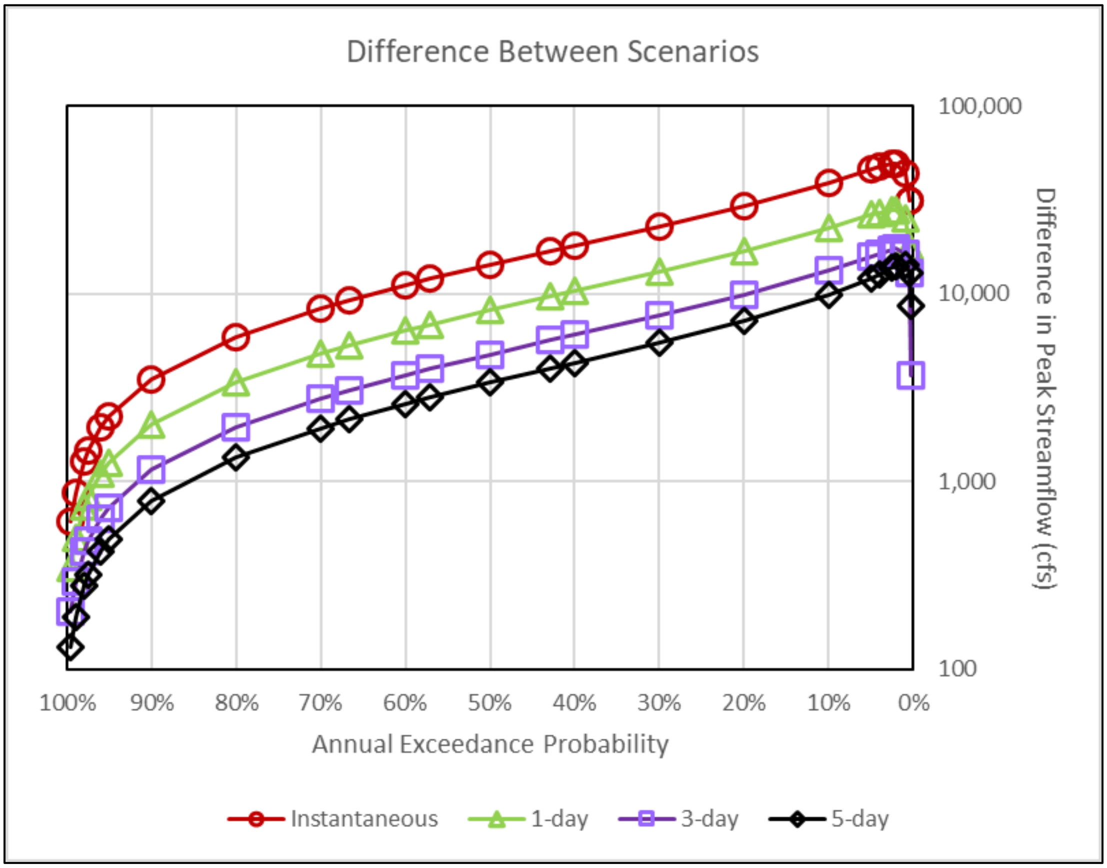

Figure B-17. Difference Between Flood Flow Frequency Curves for Historical and No Projects Scenario Modified Estimated Streamflow

An alternative view providing a more direct comparison between the flood flow frequency curves is provided in Figures B-18 through B-21. Each figure presents the flood flow frequency curves for the observed, Historical Scenario modified estimated, and No Projects Scenario modified estimated streamflows for instantaneous (Figure B-18), 1-day (Figure B-19), 3-day (Figure B-20), and 5-day (Figure B- 21) peak streamflows. These figures show the substantial differences between the flood flow frequency curves estimated for the Historical and No Projects Scenarios.

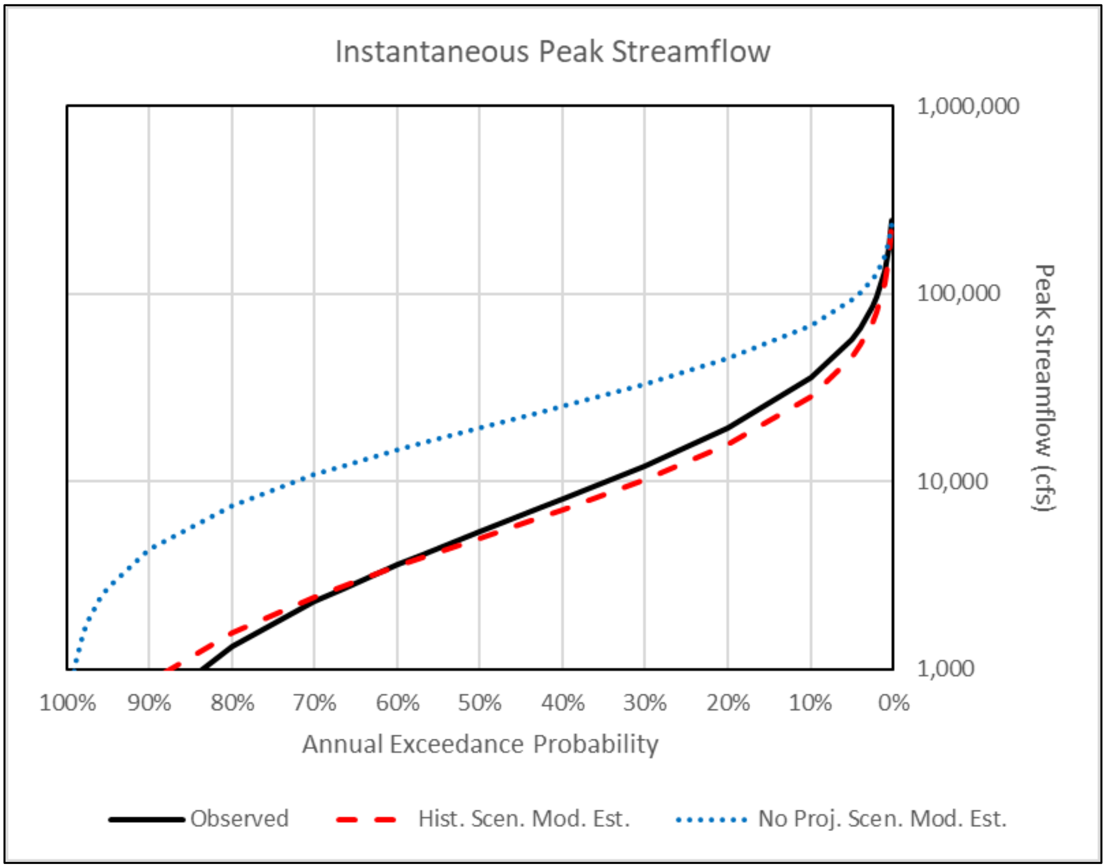

Figure B-18. Flood Flow Frequency Curves for Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated Instantaneous Peak Streamflows

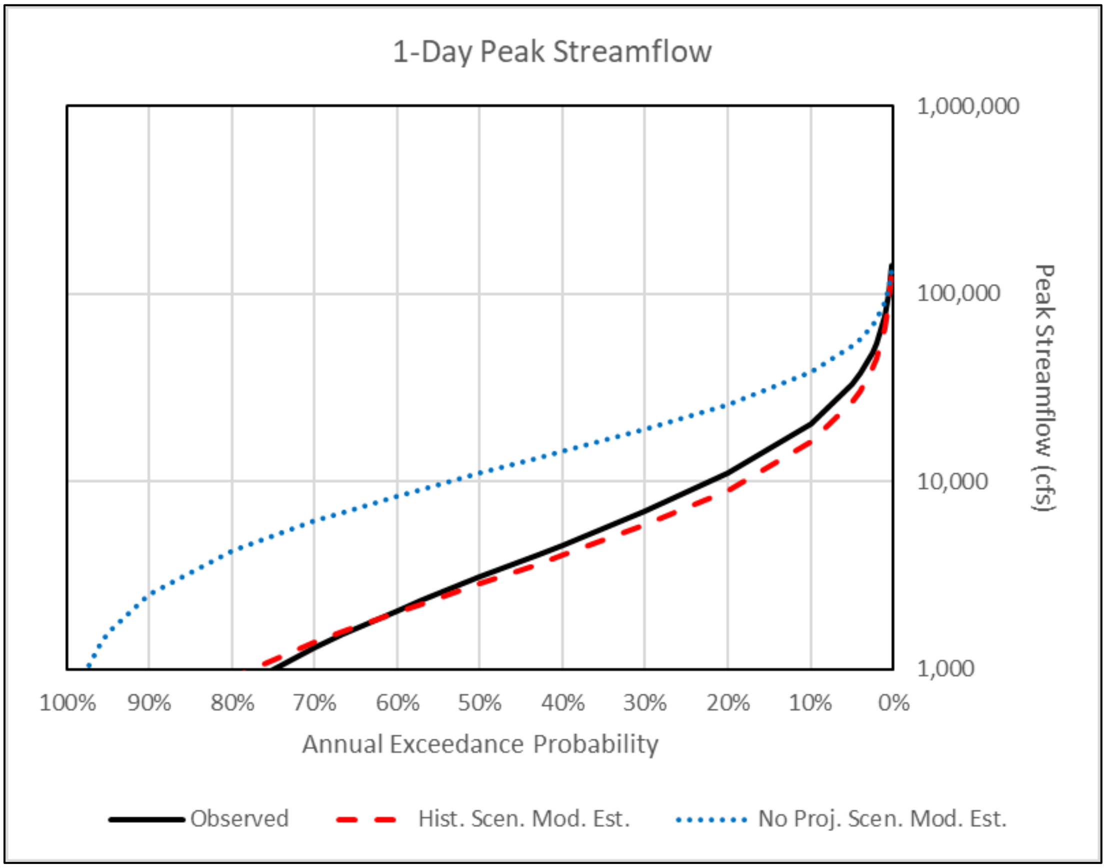

Figure B-19. Flood Flow Frequency Curves for Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated 1-Day Peak Streamflows

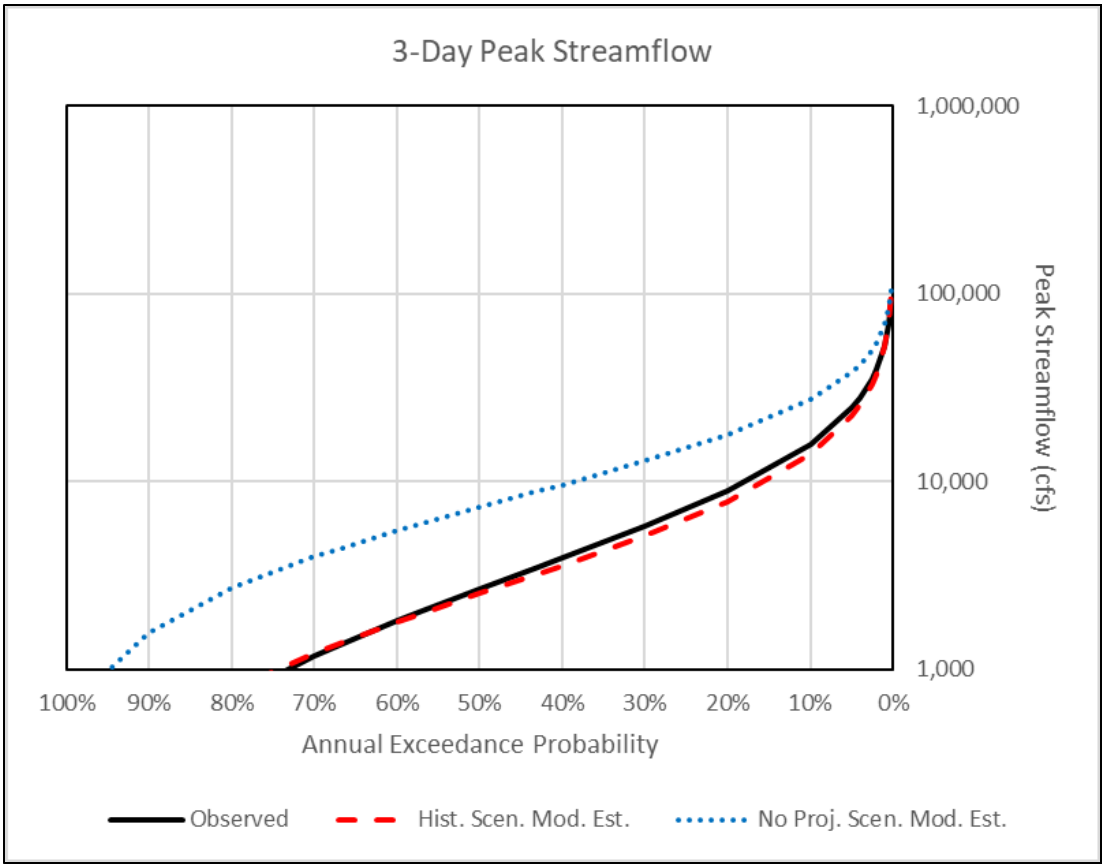

Figure B-20. Flood Flow Frequency Curves for Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated 3-Day Peak Streamflows

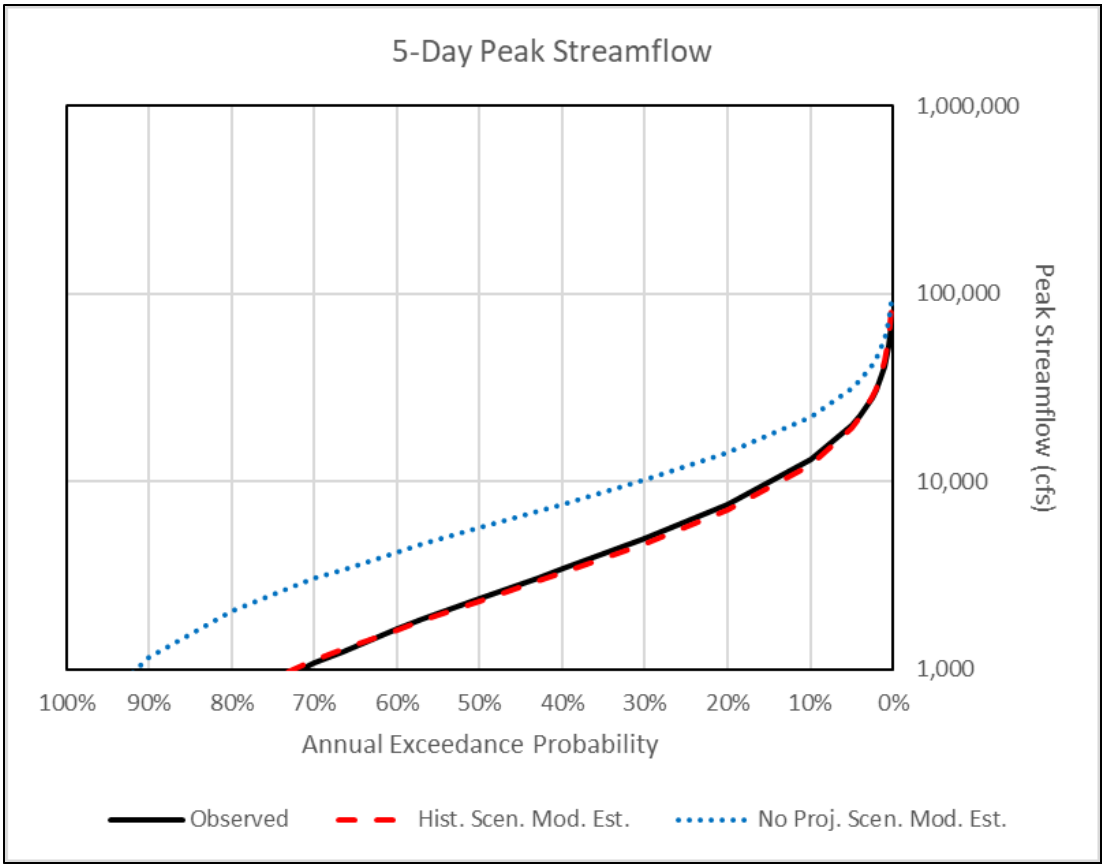

Figure B-21. Flood Flow Frequency Curves for Observed, Historical Scenario Modified Estimated, and No Projects Scenario Modified Estimated 5-Day Peak Streamflows

The peak flow estimates listed above were used as inputs to an existing HEC-RAS 2D model of the Salinas River floodplain (FlowWest, 2015). This model takes as input streamflow in the Salinas River at Bradley and simulates the movement of this flow through the system to Monterey Bay. The model ignores groundwater-surface water interaction. Tributary inflows are limited to Arroyo Seco and San Lorenzo Creek, which are the major gauged tributaries to the Salinas River below Bradley.

Tributary Inflows for HEC-RAS Model

With peak flow values calculated for the Salinas River at Bradley, equivalent tributary inflows had to be developed for Arroyo Seco and San Lorenzo Creek. The Arroyo Seco below Reliz Creek near Soledad gauge (#11152050) has been measuring streamflow since 1 Oct 1994; the San Lorenzo Creek below Bitterwater Creek near King City gauge (#11151300) has been measuring streamflow since 1 Oct 1958. Although the historical record for the USGS gauge present on each tributary could be used to develop flood flow frequency curves, these could only be used as tributary inflows for the HEC-RAS model if it can be shown that the tributary flood with a specific AEP coincides in time with the flood of the same AEP in the Salinas River at Bradley. Instead, peak annual mean daily streamflows in the Salinas River at Bradley were compared to the mean daily streamflow in Arroyo Seco and San Lorenzo Creek for the same dates. Because it can take multiple days for water to flow through the stream network from Bradley to Monterey Bay, the tributary flows for up to two days before and two days after the date of the peak mean daily streamflow at Bradley were also investigated to determine which results in the strongest statistical relationship.

Table B-7 presents the slopes and regression coefficients for the observed peak mean daily streamflow in the Salinas River at Bradley against the mean daily streamflow in Arroyo Seco and San Lorenzo Creek for dates falling two days before to two days after the date of the peak streamflow at Bradley. These results indicate that a strong correlation exists between peak flows at Bradley and streamflow observed in Arroyo Seco and San Lorenzo Creek on the day before the peak flow was observed at Bradley. This indicates that Salinas River tributaries within the study area may react more quickly to storm events compared to the Salinas River at Bradley.

Table B-7. Regression statistics for streamflow in Arroyo Seco and San Lorenzo Creek against annual peak mean daily streamflow in the Salinas River at Bradley

	Arroyo Seco		San Lorenzo Creek	
	Regression Slope	Regression Coefficient	Regression Slope	Regression Coefficient
-2 Days	0.0734	0.3552	0.0109	0.4677
-1 Day	0.2733	0.9166	0.0780	0.8928
Same Day	0.1723	0.7481	0.0333	0.5422
+1 Day	0.0898	0.7148	0.0125	0.6322
+2 Days	0.0658	0.7050	0.0099	0.6123

The high correlation of the observed tributary streamflows to the annual peak mean daily streamflows in the Salinas River at Bradley indicate that observed and estimated streamflows at Bradley could be used to estimate equivalent tributary flows in Arroyo Seco and San Lorenzo Creek. Based on the slopes of the linear regressions, streamflow in Arroyo Seco is about 27 percent of the peak flow at Bradley, and streamflow in San Lorenzo Creek is about 8 percent of the peak flow at Bradley. The peak flows contained in Table B-6 were multiplied by these factors to estimate the equivalent tributary inflows. Note that tributary inflows for No Project Scenario peak flows use the tributary inflows for the Historical Scenario peak flows for the same AEP (e.g., the 100-year flow for the No Projects Scenario uses the tributary inflows from the 100-year flow for the Historical Scenario) because the presence or absence of the Projects has no impact on the amount of flow entering the Salinas River from unregulated tributaries like Arroyo Seco and San Lorenzo Creek.

UNCERTAINTIES AND LIMITATIONS

The analyses presented in this appendix relies on a large number of assumptions and limitations, and they are subject to various uncertainties. This section lists a number of the uncertainties and limitations affecting the estimation of peak flow values in the Salinas River at Bradley and the simulation of the effects of these peak flows. This discussion is not intended to be exhaustive, nor does it cover assumptions inherent to some of the modeling software utilized for this study, except as they may have specific bearing on this analysis.

Any numerical model is an imperfect representation of a natural system, with assumptions and approximations required to simulate conditions within the modeled system with current computing resources. The SVWM and SVIHM, each of which plays a role in developing the estimated streamflows, are both preliminary, unpublished models that are still under development by the USGS (see above for the disclaimer that must accompany the use of any results from the SVIHM prior to publication of its documentation).

As described in this appendix, the development of mean daily streamflows in the Salinas River at Bradley for the Historical and No Projects Scenarios relies on a simplified mass balance approach for calculating streamflow at Bradley. It combines time series of observed, simulated and estimated streamflow from multiple different sources together; each time series has its own associated uncertainty. This approach assumes no lag between the inflow locations (the Salinas River near San Miguel, the Nacimiento River below Nacimiento Dam, and the San Antonio River below San Antonio Dam) and the location of the Salinas River at Bradley gauge. The use of estimated reservoir inflow time series as inputs to Equation 1 further assumes that no lag or interaction would occur between the Nacimiento and San Antonio Rivers and their surrounding environments from the location where the reservoir inflow is estimated (taken to be approximately equivalent to the upstream end of each reservoir) to the location of the reservoir releases.

Equation 1 further utilizes groundwater-surface water fluxes that were simulated based on SVIHM-simulated streamflow conditions which, as described in the HBA Update, are highly affected by the monthly stream inflow boundary conditions. The groundwater-surface water fluxes may be under-predicted during peak flows, as the corresponding SVIHM streamflow (which determines the rate of groundwater-surface water flux) generally represents an average monthly streamflow.

Several components of this analysis rely on linear regressions between different datasets. While many of the regressions demonstrate a high degree of correlation, none is perfect and each regression introduces some error. The regressions are not sophisticated treatments of the data, they do not represent in any meaningful way the complicated physical processes that determine the timing and amount of streamflow, and they cannot be taken to indicate causation.

Similarly, the modification to the streamflow estimation approach described above assumes that the highest-flow events can be scaled in a way that is more representative of actual conditions in the Salinas River. The scaling factor used has no obvious physical meaning, and is included simply to address a clear limitation of the SVWM in terms of its ability to reproduce the highest observed flows. Scaling these high flows was necessitated by the fact that the SVWM itself was not accessible for this study, and therefore the cause of the high-flow mismatch could not be understood or addressed. Although the scaling results in an excellent fit for the linear correlation between the observed and Historical Scenario modified estimated annual peak streamflows, it must be acknowledged as a limitation of the analysis.

The flood flow frequency analysis rests on a number of assumptions. The application of a statistical distribution (the log-Pearson Type III distribution) to the peak flow data assumes that the data are random (that is, a random sampling of the “true” distribution of peak flow events), stationary (i.e., the parameters of the distribution do not change over time), and representative (England et al., 2019). The randomness of the sample can be affected by the presence of extended wet and dry cycles. The stationarity of the peak flow sample is affected by changes to the stream or its watershed above the location of the gauge, including changes in land use and regulation.

The flood flow frequency analysis is not designed for use in settings where regulation of surface water flow (e.g., by reservoirs) substantially alters flood flows (England et al., 2019). This is clearly the case for the Salinas River at Bradley, and it is important to understand that the flood flow frequency analysis is not strictly designed for settings such as the study area. However, the 1998 HBA used the same type of analysis to estimate the magnitude of large peak flows with and without the reservoirs, and its use for this HBA Update provides continuity and comparability with the 1998 HBA.

In terms of stationarity, the period of the flood flow frequency analysis did not include any major changes to the watershed above Bradley, as both Nacimiento and San Antonio Reservoirs were operating at the start of the analytical period (WY 1968). However, there have been various smaller changes that affect the stationarity of the dataset, including the modification of the Nacimiento Dam spillway as part of the Salinas Valley Water Project and various operational changes that have been implemented by MCWRA at the reservoirs over the past decades. The flood flow frequency analysis, as implemented here, assumes that any operational or structural changes that took place during the period of the analysis have been relatively inconsequential to the parameters of the statistical distribution of peak flows. It should be noted that the analytical period used for the 1998 HBA[4] includes periods before and after San Antonio Reservoir began operating, meaning that the sample for that study included a substantial change to the watershed regulation.

Finally, as noted in England et al. (2019), the period chosen for a flood flow frequency analysis has an effect on the results. In a system that is stationary, a longer analytical period theoretically provides a more “representative” sample, with shorter analytical periods potentially impacted by the occurrence (or lack) of very large peak flows. As noted above, the analytical period used for the 1998 HBA was shorter (30 years for the with-dams conditions in the Salians River at Bradley) than the period used for this HBA Update (51 years). While a longer analytical period does not guarantee a “better” result (i.e., closer to the “real” peak flow distribution), it is generally desirable to have a larger sample size than a smaller one.

[4] It is not clearly stated in the 1998 HBA what analytical period was used for characterizing the flood flow frequency curves for the Salinas River at Bradley. However, Figure 15 of Appendix B of the 1998 HBA indicates that the curves were built using 30 years of record, which implies that the analytical period could not have been limited to the period when both reservoirs were operating, as San Antonio Reservoir had been operating for only 27 years by the end of the period of the SVIHM (i.e., WY 1968 to 1994).

SUMMARY

This Appendix presents the analyses that were undertaken to support the development of peak flow estimates in the Salinas River at Bradley for the HBA Update's analysis of the benefits that the Projects have provided in terms of inundation-related damage in the study area. Because the available modeling tools for the HBA Update are not well-suited to directly quantifying the short-term variability in streamflow that would be necessary for characterizing the magnitude of peak flows resulting from storm events, an alternative approach had to be developed that could quantify the expected peak flow magnitudes associated with different return periods (e.g., the 100-year flood). This was done through a simple mass balance approach incorporating various datasets of observed, estimated, and simulated streamflow and groundwater-surface water flux, combined with linear regressions between related datasets.

The results of this analysis indicate that the Projects have substantially reduced the magnitude of flood events passing through the Salinas River at Bradley. This is true for various AEPs (or return periods). For example, the estimated 100-year flood (AEP = 0.01) under the Historical Scenario was about 114,600 cfs, compared to about 158,700 cfs under the No Projects Scenario, a difference of about 44,100 cfs. The difference between the scenarios is slightly larger for the estimated 25-year (about 47,540 cfs) and 50-year (about 48,920 cfs) flood events. This may reflect the fact that the reservoirs are most effective at regulating mid-size floods that they have the available capacity to store fully.

The peak flow magnitudes estimated as outlined in this appendix were used as inputs to a HEC-RAS 2D model of the Salinas River and its floodplain (including tributary inflows from Arroyo Seco and San Lorenzo Creek). The simulation of the effects of these peak flows on the Salinas River floodplain are discussed in the main text of the HBA Update.

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