Byron Alan Clark, P.E.

1976-2021

Biggs-West Gridley Water District, Butte Water District, Richvale Irrigation District, Sutter Extension Water District and Western Canal Water District would like to dedicate the 2020 update of the Feather River Regional Agricultural Water Management Plan (FRRAWMP) to Byron Clark. During his too-short lifetime, Byron contributed greatly to water management in not only the Feather River region, but the entire Sacramento Valley and the state of California as a whole. The Sacramento Valley was always a special place to him. Byron's connection to the valley began in his youth as he grew up in the small farming town of Willows, California, and it continued throughout his life, both professionally and personally. Byron became an Eagle Scout, was Valedictorian of the Willow's High School class of 1994, and graduated from UC Davis with a degree in Biosystems Engineering.

As an engineer, Byron maintained an incredibly high standard of work. He was able to focus in on technical details while also maintaining a clear vision of the big picture and why each project or task was important. He was always dedicated to thoughtful data analysis and dissemination, helping clients and the community in making sound resource management decisions. He had an unmistakable passion for his work, and his leadership in agricultural water management will be missed.

As a person, Byron was a warm, generous, and thoughtful man. He was appreciative and thankful of others, noting their unique skills and contributions. The people he worked with in the Sacramento Valley trusted not only the quality of his work, but also that he truly valued them and held their best interests in mind. He was considerate and respectful at all times and did everything with a deep kindness and consideration of others.

The FRRAWMP was originally conceived, designed, and developed by a team at Davids Engineering led by Byron and his unique drive and vision. He was also involved in preparing a 2015 update to the Plan, and most recently, in this 2020 update as well. The FRRAWMP has been a guide for water management in the Feather River region since its inception and will continue to be so into the future. It is one of many monuments that Byron leaves behind marking his impact not only on wise water management and responsible stewardship of our natural resources, but on the resource managers who had the opportunity to work with him and know him during his lifetime.

Byron's contributions to water management in the Sacramento Valley will long outlive him, but his calm and kind presence is already greatly missed.

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Preface

This Feather River Regional Agricultural Water Management Plan (FRRAWMP) was originally prepared by the Northern California Water Association (NCWA) and participating Feather River agricultural water users under a Proposition 204 grant awarded by the California Department of Water Resources (DWR) in 2014. The plan was prepared in accordance with the requirements of the Water Conservation Act of 2009 (SBx7-7), which modifies Division 6 of the California Water Code (CWC or Code), adding Part 2.55 (commencing with §10608) and replacing Part 2.8 (commencing with §10800). SBx7-7 requires all qualifying agricultural water suppliers to prepare and adopt an AWMP as set forth in the CWC and the California Code of Regulations (CCR) by December 31, 2012. Plans must be updated by December 31, 2015 and then every 5 years thereafter (§10820 (a)). Additionally, the CWC requires suppliers to implement certain efficient water management practices (EWMPs).

DWR released a Guidebook to Assist Agricultural Water Suppliers to Prepare a 2012 Agricultural Water Management Plan (Guidebook) on October 24, 2012 (DWR 2012a). The Guidebook was relied upon in the preparation of the FRRAWMP to ensure that applicable sections of the CWC were addressed. Some differences in the specific formatting of the FRRAWMP from the template provided in the Guidebook exist due to this plan being a regional AWMP, as compared to an individual supplier AWMP, and in the interest of conciseness and readability.

Development of the plan included coordination among the following Feather River water suppliers and users:

- Joint Water Districts
    - Biggs – West Gridley Water District (BWGWD)
    - Butte Water District (BWD)
    - Richvale Irrigation District (RID)
    - Sutter Extension Water District (SEWD)
- Western Canal Water District (WCWD)
- Lower Feather Water Users
    - Feather Water District (FWD)
    - Garden Highway Mutual Water Company (GHMWC)
    - Plumas Mutual Water Company (PMWC)
    - Tudor Mutual Water Company (TMWC)
    - Sutter Bypass-Butte Slough Water Users Association (SBBSWUA)

Additionally, development of the FRRAWMP included consultation with representatives of the Butte County Department of Water and Resource Conservation, the California Department of Fish and Wildlife (CDFW[1]), the U.S. Fish and Wildlife Service (USFWS), and DWR. These consultations do not necessarily denote endorsement of the plan.

[1] Formerly the California Department of Fish and Game (CDFG).

The FRRAWMP is structured in two volumes. Volume I includes regional AWMP components, and Volume II includes individual supplier AWMP components. Per the requirements of the CWC, the individual supplier AWMP components in Volume II were updated in 2015. For this next iteration of the AWMP, both Volumes I and II have been updated. Volume I was updated to reflect current water management and hydrologic conditions within the Feather River region as of 2020. Volume II has been updated for the following districts: Western Canal Water District, Richvale Irrigation District, Biggs – West Gridley Water District, and Butte Water District. Butte Water District serves less than 25,000 acres and voluntarily elected to update their Plan; therefore, they are exempt from the requirements set forth by DWR.

Plans have been updated in accordance with the requirements of the Water Conservation Act of 2009 (SBx7-7), the recently passed 2018 Water Management Planning Legislation (Assembly Bill 1668, or AB 1668), and Agricultural Water Measurement Requirements under Title 23 of the California Code of Regulations (CCR), §597 et seq., 2011 referencing the 2020 AWMP Guidebook and relevant sections of the CCR.

AB 1668 modifies Water Code §531.10 *et seq.* and Water Code §10820 *et seq.* to address water conservation issues more adequately and to improve the management and evaluation of agricultural water suppliers' systems. Specifically, AB 1668 requires updated AWMPs to:

(1) Include an annual water budget (CWC §10826(c)),

(2) Identify water management objectives (CWC §10826(f)),

(3) Quantify water use efficiency (CWC §10826(h)), and

(4) Revise the supplier's Drought Plan to describe both drought resilience planning and drought response planning (CWC §10826.2).

AB 1668 also modifies AWMP submittal and compliance requirements, requiring the updated AWMP to be submitted to DWR on or before April 1, 2021 (and no later than 30 days after adoption), and thereafter on or before April 1 in the years ending in six and one.

Sections in the second volume of the regional AWMP for agricultural water suppliers serving over 10,000 acres include a cross-reference identifying the location(s) in the AWMP within which each of the applicable requirements of SBx7-7, AB 1668 and the corresponding sections of the CWC or CCR are addressed. This cross-reference is intended to support efficient review of the AWMP to verify compliance with the CWC.

This document represents the second AWMP for the Feather River region and is an update of the first regional AWMP prepared to satisfy the requirements of SBx7-7. It is anticipated that this AWMP will be updated every five years, as required by the CWC. The next update will occur in 2025 and is expected to include updated descriptions of hydrology and water management within the region, additional detail describing regional water management objectives and opportunities, and updated descriptions of projects with the potential to further enhance water management capabilities for individual suppliers and for the region collectively.

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Acronyms and Abbreviations

AB3030	Assembly Bill 3030
ac	acre
ACWA	Association of California Water Agencies
af	acre-foot
AFRP	Anadromous Fish Restoration Program
ASC	Agriculture Stakeholder Committee
AWMC	Agricultural Water Management Council
AWMP	Agricultural Water Management Plan
BBWUA	Butte Basin Water Users Association
BCD	Butte Creek near Durham
BCG	Butte Creek near Gridley
BCWC	Butte County Water Commission
BCWP	Butte Creek Watershed Project
BMO	Basin Management Objective
BSM	Butte Slough near Meridian
BWD	Butte Water District
BWC	Butte Creek near Western Canal
BWGWD	Biggs-West Gridley Water District
CALFED	CALFED Bay-Delta Program
CASGEM	California Statewide Groundwater Elevation Monitoring Program
CCR	California Code of Regulations

CCUF	Crop Consumptive Use Fraction
CDEC	California Data Exchange Center
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife
CDM	Camp Dresser McKee
CDMP	Customer Delivery Measurement Program
cfs	cubic feet per second
CFWC	California Farm Water Coalition
CIMIS	California Irrigation Management Information System
CNRA	California Natural Resources Agency
CRC	California Rice Commission
CVHM	Central Valley Hydrologic Model
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CVRWQCB	Central Valley Regional Water Quality Control Board
CWA	California Waterfowl Association
CWC	California Water Code
DD100	Drainage District 100
DD200	Drainage District 200
DE	Davids Engineering
DF	Delivery Fraction
DFG	California Department of Fish and Wildlife, formerly the Department of Fish and Game
DWR	Department of Water Resources
ECDMO	Evaluation of Customer Delivery Measurement Options
EQIP	Environmental Quality Incentives Program
ET	Evapotranspiration
ET_{aw}	Evapotranspiration of applied water
ET_o	Reference Evapotranspiration
ET_{pr}	Evapotranspiration of precipitation
EWMP	Efficient Water Management Practice
FRRAWMP	Feather River Regional Agricultural Water Management Plan
FSA	Farm Service Agency
FWD	Feather Water District
GAR	Groundwater Assessment Report
GGS	Giant Garter Snake
GHMWC	Garden Highway Mutual Water Company
GLWA	Gray Lodge Wildlife Area
GLWAWSP	Gray Lodge Wildlife Area Water Supply Project
GMP	Groundwater Management Plan
GPS	Global Positioning System
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
GW	Groundwater
hp	Horsepower
IDC	IWFM Demand Calculator
ILRP	Irrigated Lands Regulatory Program
IPCC	Intergovernmental Panel on Climate Change
IWFM	Integrated Water Flow Model
Joint Districts	Joint Water Districts Board
LAFCO	Local Agency Formation Commission
M&I	Municipal and Industrial
MPR	Mid-Pacific Region
MWC	Mutual Water Company
NAWMP	North American Waterfowl Management Plan
NCWA	Northern California Water Association
NRCS	Natural Resource Conservation Service

NSVIRWMP	Northern Sacramento Valley Integrated Regional Water Management Plan
O&M	Operations and Maintenance
OWD	Oswald Water District
PG&E	Pacific Gas & Electric Company
PMWC	Plumas Mutual Water Company
QO	Quantifiable Objective
R&Rs	Rules and Regulations
RD1004	Reclamation District 1004
RD1500	Reclamation District 1500
RD2054	Reclamation District 2054
RD2056	Reclamation District 2056
RD777	Reclamation District 777
RD833	Reclamation District 833
RID	Richvale Irrigation District
SB1938	Senate Bill 1938
SBCC	Sutter Butte Canal Company
SBBSWUA	Sutter Bypass-Butte Slough Water Users Association
SBFCA	Sutter Butte Flood Control Agency
SBx7-7	Senate Bill x7-7
SCADA	Supervisory Control and Data Acquisition
SEBAL	Surface Energy Balance Algorithm for Land
SEWD	Sutter Extension Water District
SGMA	Sustainable Groundwater Management Act
SRSC	Sacramento River Settlement Contractors
STATSGO	State Soil Geographic Database
SVIRWMP	Sacramento Valley Integrated Regional Water Management Plan
SVRWMP	Sacramento Valley Regional Water Management Plan
SWP	State Water Project
SWRCB	State Water Resources Control Board
SWSF	Surface Water Supply Fraction
TB	Targeted Benefits
TMWC	Tudor Mutual Water Company
UCB	University of California at Berkeley
UCCE	University of California Cooperative Extension
USBR	United States Bureau of Reclamation
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VFD	Variable Frequency Drive
WCWD	Western Canal Water District
WD	Water District
WDL	California Water Data Library
WMA	Wildlife Management Area
WMF	Water Management Fraction
WMO	Water Management Objective
WUE	Water Use Efficiency

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1 Introduction

1.1 *Overview and Purpose*

This Feather River Regional Agricultural Water Management Plan (FRRAWMP) has been funded by a Department of Water Resources (DWR) Proposition 204 grant awarded to the Northern California Water Association (NCWA). The plan has been developed for the irrigation water suppliers along the Feather River, including those receiving water from Thermalito Afterbay. The region relies on substantial amounts of surface water and groundwater, yet water supplies, consumptive uses, and water management have generally not been comprehensively documented historically. The region has been evaluated for its potential to expand conjunctive water management practices through groundwater management planning and other efforts; however, there remains interest in better understanding groundwater–surface water interactions in the region.

To address these needs, this regional AWMP includes an inventory of surface water and groundwater supplies and uses and through water balance analyses characterizes the interaction between irrigated lands, underlying groundwater systems, and the surrounding environment. Additionally, the AWMP provides an evaluation of opportunities to enhance water management and monitoring in the region to meet local, regional, and statewide water management objectives (described in greater detail in subsequent sections). The plan identifies and characterizes interdependencies between agricultural water suppliers and other water uses, including other agriculture in the region and important wetlands and aquatic ecosystems. Water use in the region can be described as "flow through" or "cascading" where water diverted and applied to an individual farm or within an individual supplier service area that is not consumed to produce crops or provide habitat flows through the system where it is available for other beneficial uses.

1.2 *Participating Entities*

Development of the plan included coordination among the following Feather River water suppliers and water users associations:

- Joint Water Districts
    - Biggs – West Gridley Water District (BWGWD)
    - Butte Water District (BWD)
    - Richvale Irrigation District (RID)
    - Sutter Extension Water District (SEWD)
- Western Canal Water District (WCWD)
- Lower Feather Water Users
    - Feather Water District (FWD)
    - Garden Highway Mutual Water Company (GHMWC)
    - Plumas Mutual Water Company (PMWC)
    - Tudor Mutual Water Company (TMWC)
    - Sutter Bypass-Butte Slough Water Users Association (SBBSWUA)

Additionally, development of the FRRAWMP included consultation with representatives of the Butte County Department of Water and Resource Conservation, the California Department of Fish and Wildlife (CDFW), the U.S. Fish and Wildlife Service (USFWS), and DWR. These consultations do not necessarily denote endorsement of the plan.

1.3 Scope

1.3.1 Plan Area

The plan area, herein referred to as the Feather River Region, is located on the east side of the Sacramento Valley in northern California. It is bounded on the east by Thermalito Afterbay and the Feather River and on the west by the Sacramento River, Butte Slough, and the west levee of the Sutter Bypass. It is bounded in the north by the northern boundary of WCWD and Rancho Llano Seco and by the confluence of the Feather River and Sacramento River in the south. A map of the region is provided as part of the Regional Description and Inventory of Water Supplies in Section 2 (Figure 2.1).

The region encompasses an overall area of approximately 740 square miles and includes portions of Butte, Glenn, Colusa, Sutter, and Yuba counties. It includes the cities of Yuba City, Live Oak, Gridley, and Biggs; approximately 324,000 acres of some of the Sacramento Valley's most productive agricultural land, a majority of which is irrigated through surface water diversions; the Sutter Buttes, a circular formation of volcanic rock rising above the other otherwise relatively flat terrain of the Sacramento Valley floor; several natural waterways, including Butte Creek, an important waterway for salmon and steelhead; and approximately 76,000 acres of important riparian habitat, managed wetlands, and wildlife areas and refuges, including Sutter National Wildlife Refuge, Gray Lodge Wildlife Area, Upper Butte Basin Wildlife Area, North Central Valley Wildlife Management Area, and Butte Sink Wildlife Management Area.

The area overlies portions of four groundwater subbasins as defined by the Department of Water Resources as part of its Bulletin 118: West Butte Subbasin (5-21.58), East Butte Subbasin (5-21.59), Sutter Subbasin (5-21.62), and South Yuba Subbasin (5-21.61).

Several maps of the region are provided in Section 2, which follows this section.

1.3.2 Plan Components

The individual components of the plan are driven by the objectives of the plan described in Section 1.1 above and by the requirements of the California Water Code (CWC) Sections 10608.48 and 10800-10853. The following components are included:

- Regional Components
    - Regional Description and Inventory of Water Supplies
    - Regional Water Balance
    - Water Management Activities, Objectives, and Opportunities

- Climate Change
- Recommendations
- Supplier Components
  - Cross-Reference to Requirements of CWC
  - Plan Preparation and Adoption
  - Background and Description of Service Area
  - Inventory of Water Supplies
  - Water Balance
  - Climate Change
  - Efficient Water Management Practices and Water Use Efficiency

1.3.3 Focus

1.3.3.1 Irrigation Season and Winter Water Use (Not Flood Operations)

Water is used in the region throughout the year for a combination of agricultural and environmental purposes. The primary growing season is from April or May of each year to September or October and is the period when irrigation to produce crops primarily occurs. During the remainder of the year from October through March, water is used to provide important wetlands and aquatic habitat for waterfowl and shorebirds in the Pacific Flyway as well as aquatic fish and reptile species such as salmon, steelhead, and the giant garter snake. Winter water use is also an integral part of rice production in the region, allowing for rice straw decomposition as an alternative to rice burning, which was phased out in the 1990's. Adequate flow and water quality in Butte Creek and the Sutter Bypass is additionally critical to support the migration of salmon and steelhead.

Accordingly, characterization of water use within the region requires a focus on both irrigation season and winter water use; however, analytically, this is complicated by large flood flows that pass through the region in certain years. Weirs along the Sacramento River allow flood flows to pass into the Sutter Bypass, which also collects flood flows originating the east of the Sutter Buttes. The bypass conveys water south where it re-enters the Sacramento River or flows to the Yolo Bypass via Fremont Weir near the confluence with the Feather River at Verona. These large flows pass quickly through the region yet can conceal management of winter water supplies for habitat and rice straw decomposition from a regional perspective due to their large influence on measured surface water outflows from the region. In order to overcome these analytical challenges, flood flows are isolated in the regional water balance analysis by examining the primary April to October irrigation season and by separating flood flows from other surface inflows when examining average monthly flow volumes. For individual supplier water balances, flood flows pose less of a challenge analytically, as the supplier distribution and drainage systems primarily perform irrigation and drainage functions, respectively, rather than a flood control role.

1.3.3.2 Evaluation of Existing Water Management and Opportunities

Existing water management and opportunities are examined in reference to Efficient Water Management Practices (EWMPs) defined in the CWC, but also in relation to the hydrology of the region and specific water management objectives, identified through prior efforts and through consultation with water managers in the region as part of preparation of this plan. The regional water balance and individual supplier balances provide the technical basis for identifying and evaluating water management objectives and specific actions that the suppliers could take to enhance water management capabilities (provide increased control over the timing and amount of flows in the system) and monitoring both within their service areas and, collectively, within the region.

Evaluation of opportunities to enhance water management considers both managed wetlands and Butte Creek flows and water quality. In particular, water needs for wetlands habitat, as documented by refuge managers are summarized. For Butte Creek, a review of creek flows at existing or historical monitoring locations within the region is provided and linked to potential surface water and groundwater inflows and outflows between monitoring sites.

Additionally, as noted above, the regional and supplier water balances characterize the spatially and temporally variable interactions between surface water and groundwater systems in the region, including quantification of groundwater pumping and deep percolation. Among a variety of possible uses, these quantified flow paths could be used to support enhanced calibration of existing and possible future regional groundwater models. Benefits of these efforts could include enhanced calibration of existing and possible future regional groundwater models used to evaluate potential water management activities under current or potential future conditions to evaluate potential benefits and tradeoffs.

The reviews of surface water and groundwater hydrology in Volume I, Section 2 include an evaluation and discussion of information gaps that pose challenges to optimization of water management in the region. In particular, additional information describing agricultural return flows and flows within the Butte Creek system would be valuable. Return flows could potentially be rerouted to meet a number of water management objectives, as discussed in Section 4 and throughout this plan. The evaluations of potential projects to enhance supplier water management capabilities included in Volume II include numerous projects that could help close gaps in knowledge or achieved water management objectives through flow re-routing.

1.4 Two-Part Document Structure

The FRRAWMP includes two volumes: Volume I. Regional Plan Components and Volume II. Supplier Plan Components. This introduction is included in each volume. In Volume II, a condensed table of contents is provided at the beginning of the volume, with a more detailed table of contents provided in the section corresponding to each major Feather River water supplier.

2 Regional Description and Inventory of Water Supplies

2.1 Overview

The plan area, herein referred to as the Feather River Region, is located on the east side of the Sacramento Valley in northern California. It is bounded on the east by Thermalito Afterbay and the Feather River and on the west by the Sacramento River, Butte Slough, and the west levee of the Sutter Bypass. It is bounded in the north by the northern boundary of Western Canal Water District and Llano Seco and by the confluence of the Feather River and Sacramento River in the south (Figure 2.1).

The region encompasses an overall area of approximately 740 square miles and includes portions of Butte, Glenn, Colusa, Sutter, and Yuba counties. It includes the cities of Yuba City, Live Oak, Gridley, and Biggs; approximately 324,000 acres of agricultural land, a majority of which is irrigated through surface water diversions; the Sutter Buttes, a circular formation of volcanic rock rising above the other otherwise relatively flat terrain of the Sacramento Valley floor; several natural waterways, including Butte Creek, an important waterway for salmon and steelhead migration; and approximately 76,000 acres of riparian habitat, managed wetlands, and wildlife areas and refuges, including Sutter National Wildlife Refuge, Gray Lodge Wildlife Area, Upper Butte Basin Wildlife Area, North Central Valley Wildlife Management Area, and Butte Sink Wildlife Management Area.

The primary industry in the region is agriculture, with over 180,000 acres of rice, approximately 90,000 acres of orchards, and 34,000 acres of other crops grown in recent years. Water for irrigation is the lifeblood of the region's economic engine. In 2012, the estimated gross value of crops grown in the region was over $700 million with a total contribution to the regional economy of between $1.5 and $1.9 billion[2].

The remainder of this section provides a description of the region and its water supplies. The following subsections are included:

- History – Brief history of agricultural water use in the region;
- Regional Subareas – Description of subareas defined for purposes of discussion of regional water management;
- Terrain and Soils – Description of the general terrain of the region and dominant soil characteristics;
- Climate – Summary of climatic conditions within the region;
- Inventory of Water Supplies – Description of surface water and groundwater supplies of the region, including water availability, hydrology, and water quality;
- Irrigation, Drainage, and Flood Control Facilities – Overview of water supplier irrigation facilities, drainage facilities, and flood control facilities;

[2] Estimated based on cropped acres, agricultural commissioner crop reports, and an economic multiplier of 2.0 to 2.5, representing the total contribution of agriculture to the region resulting from demands for goods and services resulting from agricultural production and employment.

- Rules and Regulations Affecting Water Availability – Overview of rules, regulations, and other agreements affecting the availability of water for irrigation in the region; and
- Water Measurement, Pricing, and Billing – Summary of measurement practices and pricing and billing policies of Feather River water suppliers.

2.2 *History*

Due to the Mediterranean climate of the Sacramento Valley, which is characterized by cool, wet winters and hot, dry summers, the first settlers in the Feather River Region grew grain crops such as wheat, barley, and oats without irrigation, typically planting in the late fall, allowing winter and spring rainfall to support crop growth, and harvesting in the summer; however, as early as the 1800's, forward-thinking settlers recognized the tremendous benefits irrigation could offer to the region. One of these was John Bidwell, who worked a gold-mining claim along the Feather River and owned agricultural land in what is now the city of Chico (approximately 8 miles to the north of Western Canal Water District). Bidwell is quoted as having said that "A well devised and extensive system of irrigation is the only thing that will ever enable the State to attain its highest development" (McGee 1980). It did not take long for John Bidwell's vision to become a reality.

Near the turn of the 20th century, a diversion structure was built along the Feather River at the Hazelbusch Ranch, and the construction of canals and conveyance systems for the diversion of water followed. In 1911, the Sutter-Butte Canal Company purchased the water rights and properties associated with the diversion and began diverting water to lands in present-day Butte and Sutter counties (McGee 1980). Rice was introduced around this same time, which is one of the only crops suited to the heavy clay soils that dominate much of the region and is consequently the primary crop grown today. Other crops include orchard crops such as walnuts, prunes, and almonds; a variety of field and truck crops; and pasture, grain, and hay crops.

As the century progressed, GHMWC, PMWC, TMWC, FWD, and Oswald Water District (OWD) were formed along the Feather River downstream of the Sutter-Butte Canal Company. RID, BWGWD, BWD, and SEWD were also formed. These four purchased the pre-1914 water rights and property of the Sutter-Butte Canal Company and formed the Joint Water Districts Board (Joint Districts), which remains in operation today. Reclamation District 1004 (RD1004) was formed along the eastern boundary of the Sacramento River during this period, as well as other, small water companies. WCWD, which historically diverted water from the Feather River and currently diverts water from Thermalito Afterbay along with the Joint Districts was formed in 1984 when its water rights and infrastructure were acquired from the Pacific Gas and Electric Company, who had acquired what was formerly known as the Western Canal Company from the Great Western Power Company in 1930.

The development of the California State Water Project (SWP) also influenced water management in the region. Water storage reservoirs were built along the Feather River upstream of the area in the 1960's, the largest being Lake Oroville, which is impounded by Oroville Dam and has a capacity of over 3.5 million acre-feet. Construction of Thermalito Afterbay, which lies below the dam, resulted in the need to replace the points of diversion for WCWD and the Joint Districts. The districts now divert water primarily from Thermalito Afterbay, with the exceptions of WCWD which receives a small portion of its supply from Butte Creek and SEWD which receives a portion of its supply from the Feather River at the Sunset Pumps.

Irrigation for agriculture is the primary developed water use in the region. Surface water from the Feather River is the most prominent source of water for irrigation. Groundwater is used in areas without access to surface water and generally throughout the region in the event of a surface water shortage due to drought. Groundwater is also increasingly chosen by individual water users as a source of supply for irrigation in some areas despite the availability of surface water due to potential water quality benefits, such as reduced filtration requirements, and increased flexibility in the timing and amount of water applied. This is particularly true for pressurized irrigation systems increasingly used to irrigate orchard and, in some cases, row crops. Other water uses in the region include municipal and industrial uses in urban and rural residential areas and environmental uses for managed wetlands and other wildlife habitat.

2.3 *Feather River Regional Subareas*

For discussion of the physical characteristics of the region and water management within it, five subareas have been defined. The five subareas are described in this section and include the following:

1. WCWD and Joint Districts
2. West of Butte Creek
3. Butte Slough and Sutter Bypass
4. Sutter Buttes
5. Lower Feather

The subarea boundaries are shown in Figure 2.1, along with water supplier service areas and regional hydrography.

2.3.1 WCWD and Joint Districts

The WCWD and Joint Districts subarea includes the service area for WCWD and each of the Joint Districts and comprises a total area of approximately 220,000 acres. The communities of Richvale, Biggs, Gridley, and Live Oak additionally lie within the subarea, which extends from the northern boundary of WCWD to the southern boundary of SEWD as it meets the Sutter Bypass.

The primary crop grown in the WCWD and Joint Districts subarea is rice. Other irrigated crops include walnuts, almonds, and a variety of field and truck crops. Other land uses include native vegetation, including managed wetlands. Publicly managed wetlands in the subarea include portions of the Upper Butte Basin Wildlife Area, Gray Lodge Wildlife Area, and Sutter National Wildlife Refuge.

The largest source of surface water is diversion from Thermalito Afterbay by the districts. There are also inflows from Butte Creek, Little Dry Creek, and Cherokee Canal. Water generally flows north to south through the subarea, around the west side of the Sutter Buttes via Butte Creek and

Cherokee Canal and around the east side of the Sutter Buttes via Snake Creek, the Wadsworth Canal, and drains in SEWD. Outflows from water supplier service areas are available for use downstream within the subarea or other subareas in the region. Drainage to Butte Creek and the Cherokee Canal originates primarily in WCWD, RID, and BWGWD. Drainage to Snake Creek, the Wadsworth Canal, and Sutter Bypass originates primarily in BWGWD, BWD, and SEWD.

The amount of groundwater pumping for irrigation varies within the subarea and is generally limited, although increased pumping has occurred in recent years as orchards are converted to pressurized irrigation. Substantial private pumping capacity exists and is relied upon mainly to augment surface water supplies when shortages occur. BWD and SEWD own and operate groundwater wells that are operated in some years to support groundwater substitution water transfers. Gray Lodge Wildlife Area uses a combination of surface water and groundwater for environmental purposes, with increased reliance on groundwater during years of surface water shortage. Groundwater pumping in the region for domestic use occurs in the cities of Biggs, Gridley, and Live Oak, as well as in smaller communities and rural homes throughout the subarea.

2.3.2 West of Butte Creek

The West of Butte Creek subarea is comprised of approximately 86,000 acres and includes lands within the region to the west of Butte Creek to its confluence with the Sacramento River at the Butte Slough Outfall Gates, with the exception of the portion of the WCWD service area west of Butte Creek. It includes the RD1004 service area; other agricultural water suppliers such as Sartain MWC and Colusa Properties; and portions of the Sacramento River National Wildlife Refuge, North Central Valley Wildlife Management Area (including the Llano Seco Unit), and Upper Butte Basin Wildlife Area. Water management by RD1004 is described in detail in the Sacramento Valley Regional Water Management Plan (SVRWMP) prepared by the Sacramento River Settlement Contractors (SRSC 2006) and is not described in this plan, which focuses on the management of Feather River water supplies.

The primary crop grown in the subarea is rice. Other irrigated crops include walnuts, almonds, and a variety of field and truck crops. Other land uses include managed wetlands. Publicly managed lands within the subregion include those described above.

The largest source of surface water is diversion from the Sacramento River. There are also diversions from Butte Creek and Angel Slough. Water tends to flow north to south through the subarea, leaving as return flow to the Sacramento River at the Butte Slough Outfall Gates or to the Sutter Bypass subarea via Butte Slough.

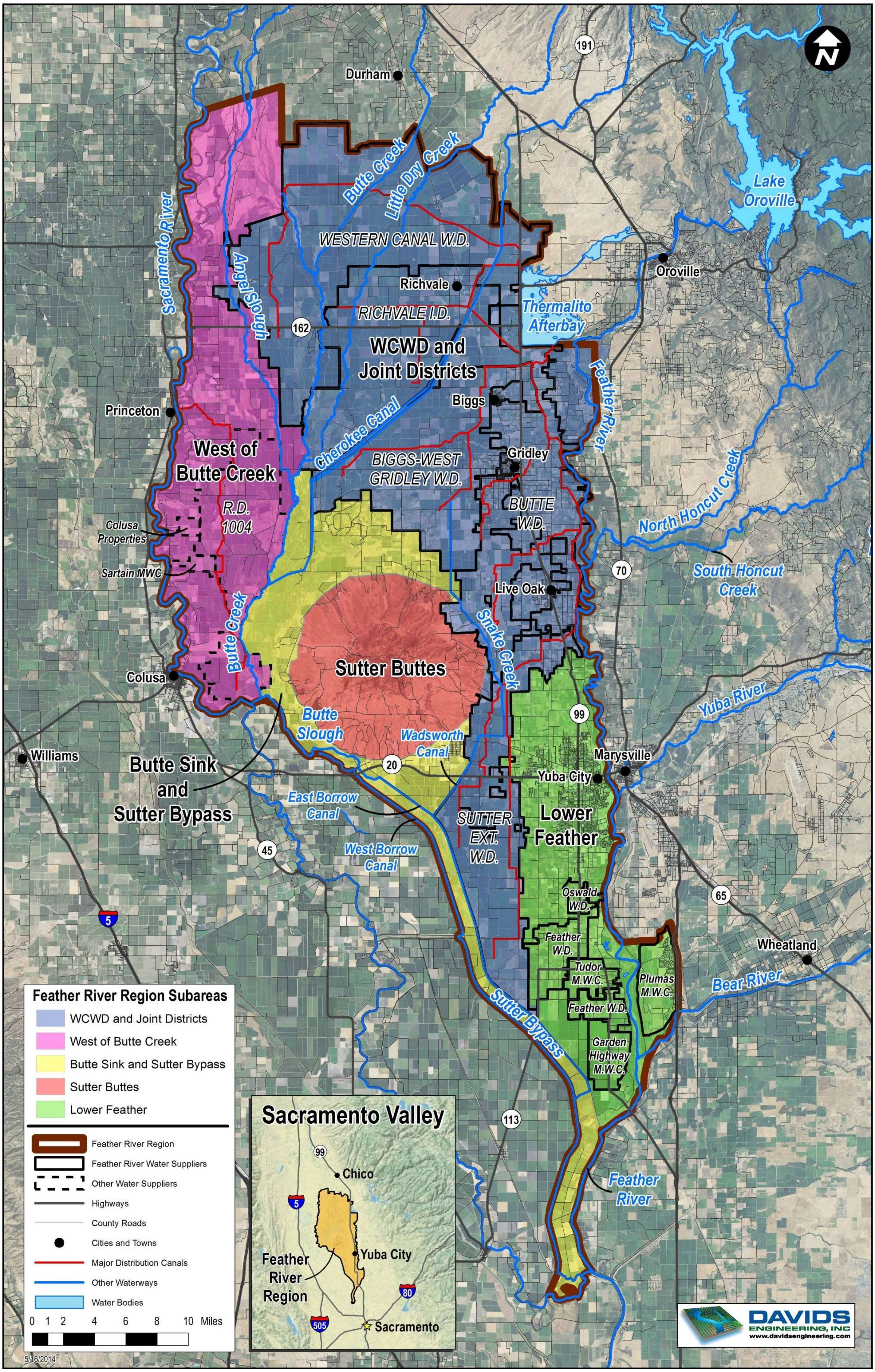

Figure 2.1. Feather River Region Subareas.

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Groundwater pumping for irrigation varies within the subarea. Pumping is generally limited, although there are areas of orchard crops in both Glenn and Colusa counties along the Sacramento River that rely exclusively on groundwater for irrigation. Substantial private pumping capacity exists and is relied upon as a primary source of supply or to augment surface water supplies when shortages occur. Groundwater pumping for rural residential use occurs in the subarea as well.

2.3.3 Butte Sink and Sutter Bypass

The Butte Sink and Sutter Bypass subarea includes the land east of Butte Creek and south or southwest of the Joint Districts, excluding the Sutter Buttes. The subarea extends around the west and south sides of the Sutter Buttes and extends south through the Sutter Bypass to its confluence with the Feather River and to the Feather's confluence with the Sacramento River near Verona. The total area of the subarea is approximately 56,000 acres and includes the community of Sutter and portions of the Gray Lodge Wildlife Area, Butte Sink Wildlife Management Area, and Sutter National Wildlife Refuge. There are several individual water users in the subarea, a portion of which is devoted to agricultural production. The individual water users in and around Butte Slough and Sutter Bypass have organized to form the SBBSWUA in order to pursue collective interests and protect water rights (see Volume II, Section 8).

The leading crop grown in the subarea is rice; other crops include orchard crops such as walnuts and almonds. Other land uses include managed wetlands. Managed wetlands include portions of Gray Lodge Wildlife Area, Butte Sink Wildlife Management Area, and Sutter National Wildlife Refuge, as described above.

The primary sources of surface water are Butte Creek and Butte Slough, which is partially supplied by outflows from WCWD and the Joint Districts. Other inflows include flow through the Wadsworth Canal and DWR Pumping Plants 1, 2, and 3 along the Sutter Bypass[3] (DWR 1976). Water generally flows from north to south through the subarea. Flows through the subarea during the winter and spring are primarily comprised of flood flows from the Sacramento River and are dependent on precipitation and timing; flows during the summer and fall are primarily comprised of outflows from upstream water users resulting from groundwater accretion and surface drainage. Outflows from the subarea typically enter the Sacramento River at Sacramento Slough, near Verona.

Groundwater pumping for irrigation within the subarea is generally limited. Gray Lodge Wildlife Area uses a combination of surface water and groundwater to maintain seasonal and permanent wetland habitat, with increased reliance on groundwater during periods of surface water shortage. Groundwater pumping for domestic use occurs in the community of Sutter, as well as in rural homes within the subarea.

[3] Flow into the Sutter Bypass through DWR Pumping Plants 1, 2, and 3 can be either gravity flow or pumped, depending on water levels in the Sutter Bypass and in drains and sloughs on the opposite side of the levee. In some instances, reverse gravity flows from the Sutter Bypass into drains and sloughs on the east side of the levee occur.

2.3.4 Sutter Buttes

The Sutter Buttes subarea is comprised of approximately 43,000 acres and includes the Sutter Buttes, a roughly circular formation of volcanic rock approximately 10 miles in diameter rising about 2,000 feet above the surrounding Sacramento Valley floor. A majority of the land is privately owned, although California Department of Parks and Recreation owns a portion of land along the north side of Buttes. There is little developed water use in the Sutter Buttes, with most of the land being used to graze cattle and sheep. Water entering the Sutter Buttes subarea consists of precipitation and limited groundwater pumping (where available) to meet domestic, stock water, and irrigation needs. The primary outflow is the runoff of precipitation to the surrounding lands occurring during the winter and spring.

2.3.5 Lower Feather

The Lower Feather subarea includes the service areas for FWD, GHMWC, OWD, PMWC, TMWC, and the city of Yuba City as well as agricultural lands outside of water supplier service areas. It extends east to west from to the eastern boundary of SEWD and the Sutter Bypass to the Feather River (also including the PMWC service area to the east of the Feather River), and from north to south from the SEWD boundary to where the Sutter Bypass and Sacramento River meet near Verona. The subarea is comprised of approximately 69,000 acres.

The primary crops grown in the subarea are orchard crops such as walnuts, peaches, and prunes. Other irrigated crops include rice, alfalfa, and a variety of row and truck crops. Other land uses include managed wetlands.

The largest source of surface water is the Feather River; however, there are also inflows from SEWD through drains and sloughs. Water generally flows from north to south through the subarea, leaving to the south via the Sutter Bypass and Feather River.

Groundwater pumping for agriculture varies within the region. Groundwater provides a relatively small portion of total irrigation supply in in the water supplier service areas in the southern portion of the subarea moving west of the Feather River due to the availability of surface water and relatively poor groundwater quality in some wells due to elevated salinity. Areas developed for agriculture in the northern portion of the subarea outside of supplier service areas rely exclusively on groundwater. FWD, TMWC, and GHMWC own and operate groundwater wells in the Sutter groundwater subbasin that are operated to meet a portion of demands. Additionally, GHMWC has historically participated in groundwater substitution transfers to increase statewide water supplies. PMWC also owns and operates groundwater wells in the South Yuba subbasin, east of the Feather River to meet a portion of demands. The groundwater subbasins underlying the region are described in greater detail in Section 2.6.2.

Yuba City's primary water source for domestic, municipal, and industrial uses is surface water diversions from the Feather River, although the surface water supply can be augmented with groundwater. Groundwater pumping for domestic uses also occurs in smaller communities and rural homes.

2.4 Terrain and Soils

With the exception of the Sutter Buttes, the terrain in the region is nearly flat with the land surface elevation gradually decreasing towards the south. Land surface elevation is approximately 150 feet above mean sea level in the northern part of the region and approximately 30 feet above mean sea level in the southern part of the region, resulting in a fall of approximately 0.1 feet per thousand feet (0.01 %). Accordingly, drainage occurs from north to south, with some drainage to the west towards Butte Creek and Butte Slough, primarily in the northern portion of the WCWD and Joint Districts subarea and in the West of Butte Creek and Butte Slough and Sutter Bypass subareas. Some drainage to the east occurs as well, primarily in the southern portion of the WCWD and Joint Districts subarea and in the Lower Feather subarea.

The surface soils in the region consist of alluvial deposits from historic flooding of the Sacramento and Feather Rivers. The soils tend to be heavier, clays and clay loams, in areas of rice production. There are also areas of coarser, loamy soils found along the west side the Feather River in areas of orchard production. Soils within WCWD, the Joint Districts, and Lower Diverter service areas are described in greater detail in the individual water supplier descriptions (see Volume II, Sections 3 through 8).

The region is comprised of 13 general soil associations, as characterized by the Natural Resource Conservation Service (NRCS) for the State Soil Geographic (STATSGO) database (Figure 2.2). Nine of these associations cover over 95 percent of the region. The 13 soil associations and corresponding coverage for each subarea are listed in Table 2.1. Each association is made up of one or more individual soil series. The dominant soil series are described for the nine associations making up 95 percent of the region. Soils within WCWD, the Joint Districts, and lower diverter service areas are described in greater detail elsewhere in this plan as noted above. Shaded cells in Table 2.1 indicate that the association is not found in the subarea.

2.4.1 Stockton-Clear Lake-Capay

The Stockton-Clear Lake-Capay map unit represents approximately 40 percent of the region and is located in the WCWD and Joint Districts, West of Butte Creek, and Butte Sink and Sutter Bypass subareas. The map unit is dominated by the Clear Lake (39%), Capay (26%), and Stockton (10%) soil series, with the remaining area (25%) composed of other soils.

The Clear Lake series consists of very deep, poorly drained soils that formed in fine textured alluvium derived from sandstone and shale and is found in basins and in swales of drainageways. Slopes are 0 to 2 percent. The water table is at depths of 4 to 10 feet in the late summer and in some areas is very near the surface during winter. Some areas are artificially drained.

The Capay series consists of very deep, moderately well drained soils that formed in moderately fine and fine textured alluvium derived from mostly sandstone and shale. Capay soils are found on alluvial fans, alluvial flats, interfan basins and basin rims. Slopes are 0 to 9 percent. Some locations have a water table between depth of 4 and 6 feet.

The Stockton series consists of deep to duripan, somewhat poorly drained soils that formed in alluvium from mixed rock sources. Stockton soils are found in basins and in swales of drainageways with slopes of 0 to 2 percent. Most areas are artificially drained.

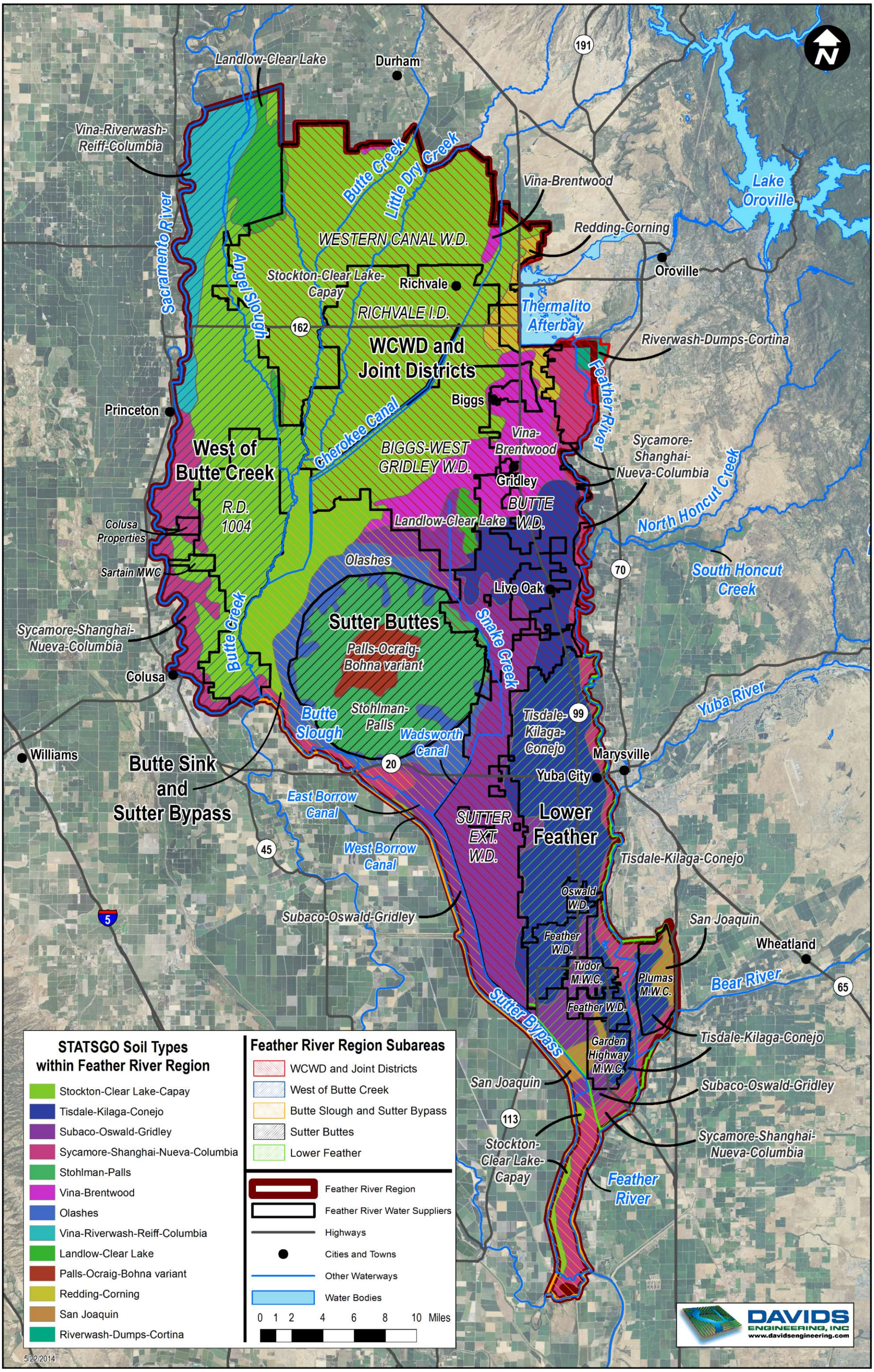

Figure 2.2. Regional Subareas and General Soil Associations.

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Table 2.1. Regional and Subarea Soil Distribution (Percent by Area).

Soil Map Unit	Subarea					Feather River Region
	WCWD and Joint Districts	West of Butte Creek	Butte Sink and Sutter Bypass	Sutter Buttes	Lower Feather	
Vina-Riverwash-Reiff-Columbia		17%				3%
Landlow-Clear Lake	1%	9%				2%
Vina-Brentwood	10%		1%			5%
Riverwash-Dumps-Cortina	1%					0.3%
Redding-Corning	3%					1%
Stockton-Clear Lake-Capay	55%	58%	33%			40%
San Joaquin			2%		5%	1%
Sycamore-Shanghai-Nueva-Columbia	4%	15%	17%		16%	9%
Subaco-Oswald-Gridley	16%		25%		15%	13%
Tisdale-Kilaga-Conejo	10%				64%	14%
Stohlman-Palls	1%			73%		7%
Palls-Ocraig-Bohna variant				15%		1%
Olashes			22%	12%		4%

2.4.2 Tisdale-Kilaga-Conejo

The Tisdale-Kilaga-Conejo map unit represents approximately 14 percent of the region and is located in the WCWD and Joint Districts and Lower Feather subareas. The map unit is dominated by the Conejo (40%), Tisdale (22%), and Kilaga (10%) soil series, with the remaining area (28%) composed of other soils.

The Conejo series consists of very deep, well drained soils that formed in alluvium from basic igneous or sedimentary rocks and is found on alluvial fans and stream terraces. Slopes range from 0 to 9 percent. Conejo soils are well drained with slow to medium runoff. Some areas are subject to occasional flooding.

The Tisdale series consists of moderately deep, well drained soils that formed in alluvium from mixed sources and is found on low terraces and have slopes of 0 to 2 percent. Tisdale soils are well drained with very slow runoff and moderately slow permeability.

The Kilaga series consists of deep and very deep, well drained soils formed in alluvium from mixed rock sources. These soils are found on terraces with slopes of 0 to 9 percent. Kilaga soils are well drained with slow to medium runoff and slow permeability. Some areas are subject to rare or occasional flooding.

2.4.3 Subaco-Oswald-Gridley

The Subaco-Oswald-Gridley map unit represents approximately 13 percent of the region and is located in the WCWD and Joint Districts, Butte Sink and Sutter Bypass, and Lower Feather subareas. The map unit is dominated by the Oswald (35%), Gridley (20%), and Subaco (17%) soil series, with the remaining area (28%) composed of other soils.

The Oswald series consists of moderately deep, poorly drained soils that formed in alluvium from mixed sources. Oswald soils are found in basins and on basin rims and have slopes of 0 to 2 percent. Some areas of this soil are subject to periods of flooding in December through April. A perched water table is at a depth of 18 to 36 inches from December through April.

The Gridley series consists of moderately deep, moderately well drained soils formed in alluvium from mixed sources. These soils are found on low terraces and basin rims and have slopes of 0 to 1 percent. Gridley soils are moderately well drained with slow runoff and slow permeability. A perched water table is at a depth of 5 inches or more from December through April.

The Subaco series consists of moderately deep, somewhat poorly drained soils that formed in alluvium from mixed sources. These soils are found on basin rims and in basins and have slopes of 0 to 2 percent. There is a perched water table between depths of 18 to 42 inches in December to April.

2.4.4 Sycamore-Shanghai-Nueva-Columbia

The Sycamore-Shanghai-Nueva-Columbia map unit represents approximately 9 percent of the region and is located within the WCWD and Joint Districts, West of Butte Creek, Butte Sink and Sutter Bypass, and Lower Feather subareas. The map unit is dominated by the Columbia (29%), Shanghai (18%), Nueva (15%), and Sycamore (11%) soil series, with the remaining area (27%) composed of other soils.

The Sycamore series consists of poorly drained soils that formed in alluvium from mixed sources. These soils are found on flood plains and have slopes of 0 to 2 percent. Some areas are artificially drained.

The Shanghai series consists of very deep, somewhat poorly drained soils that formed in alluvium from mixed sources. They are found on flood plains and have slopes of 0 to 2 percent. Unless drained, in low lying areas and areas adjacent to levees, a water table is present at a depth of 30 to 60 inches in December through April and below a depth of 48 inches in May to November. In other areas, the water table is at 36 to 60 inches in December through April.

The Nueva series consist of very deep somewhat poorly drained soils formed in alluvium from mixed sources. These soils are on floodplains and have slopes of 0 to 2 percent. The water table occurs at depths of 48 to 60 inches from December through April and below 60 inches the rest of the year.

The Columbia series consists of very deep, moderately well drained soils formed in alluvium from mixed sources. These soils are on flood plains and natural levees and have slopes of 0 to 8 percent.

2.4.5 Stohlman-Palls

The Stohlman-Palls map unit represents approximately 7 percent of the region and is located primarily within the Sutter Buttes subarea, although it can also be found in the WCWD and Joint Districts subarea. The map unit is dominated by Stohlman (40%) and Palls (40%) soil series, with the remaining area (20%) composed of other soils. The Stohlman series consists of shallow, well drained soils that formed in residuum from extrusive igneous rock. Stohlman soils are on hills and have slopes of 9 to 50 percent. The Palls series consists of moderately deep, well drained soils that formed in material weathered from extrusive igneous rock. Palls soils are on hills and mountains and have slopes of 9 to 60 percent.

2.4.6 Vina-Brentwood

The Vina-Brentwood map unit represents approximately 5 percent of the region and is located within the WCWD and Joint Districts and Butte Sink and Sutter Bypass subareas. The map unit is dominated by Brentwood (39%) and Vina (31%) soil series, with the remaining area (30%) being composed of other soils. The Vina series consists of very deep, well drained soils on alluvial fans and flood plains with slopes of 0 to 9 percent. The soils developed in recent alluvium derived from mixed sources. The Brentwood consists of well to moderately well drained soils that formed in valley fill from sedimentary rocks.

2.4.7 Olashes

The Olashes map unit represents approximately 4 percent of the region and is located within the Butte Sink and Sutter Bypass and Sutter Buttes subareas. The map unit is dominated by the Olashes (95%) soil series, with the remaining area (5%) being composed of other soils. The Olashes series consists of very deep well drained soils that formed in alluvium weathered from mixed sources. Olashes soils are found on alluvial fans and fan terraces and have slopes of 0 to 5 percent.

2.4.8 Vina-Riverwash-Reiff-Columbia

The Vina-Riverwash-Reiff-Columbia map unit represents approximately 3 percent of the region and is located within the West of Butte Creek subarea. The map unit is dominated by Columbia (35%), Vina (18%), Reiff (13%), and Riverwash (12%) soil series, with the remaining area (22%) being composed of other soils. The Columbia and Vina series are as described above. The Riverwash series consists of barren alluvial areas with unstabilized sandy, silty, clayey, or gravelly sediment exposed along streams and waterways at low water and subject to shifting during normal high water. The series is frequently flooded, washed, and reworked by water flows. The Reiff series consists of very deep, well drained soils formed in coarse to medium textured alluvium weathered from mixed sources. Reiff soils are found on flood plains and alluvial fans and are nearly level to moderately sloping with slopes are 0 to 9 percent.

2.4.9 Landlow-Clear Lake

The Landlow-Clear Lake map unit represents approximately 2 percent of the region and is located within the WCWD and Joint Districts and West of Butte Creek subareas. The map unit is dominated by Clear Lake (58%) and Landlow (25%) soil series, with the remaining area (17%) composed of other soils. The Clear Lake series is as described above. The Landlow series consists of somewhat poorly drained soils formed in alluvium and found on nearly level basins of valley plains.

2.5 *Climate*

The region experiences a Mediterranean climate, typical of the eastern Sacramento Valley, with mild winters and mild to moderate precipitation and warm to hot, dry summers. The climate statistics presented in this section are based on the Durham CIMIS station (#12) for the period October 1984 to September 2020. The station is located approximately one mile north of the region and is generally representative of the climate of the entire Feather River region. Regional climate statistics are summarized in Table 2.2.

Table 2.2. Mean Daily Weather Parameters by Month at Durham CIMIS Station.

Month	Total ET_o (in)	Total Precip. (in)	Average Daily Temperature (F)			Average Relative Humidity (F)			Average Wind Speed (mi/hr)
			Avg.	Min.	Max.	Avg.	Min.	Max.	
January	1.2	4.0	45.6	37.2	55.6	80	62	93	4.4
February	2.0	3.7	49.8	39.4	61.4	70	49	89	5.0
March	3.4	3.1	54.1	42.3	66.5	67	44	89	5.0
April	4.8	1.5	59.1	45.6	72.9	61	37	88	4.8
May	6.5	1.2	66.5	52.1	80.5	58	36	87	4.6
June	7.4	0.6	72.5	57.8	86.9	57	34	86	4.3
July	7.7	0.1	75.8	60.3	91.3	60	37	89	3.5
August	6.7	0.1	73.8	58.3	90.3	61	37	90	3.3
September	5.0	0.4	69.8	54.7	87.1	58	33	87	3.5
October	3.4	1.4	61.6	48.0	78.0	60	35	87	3.7
November	1.7	2.7	51.3	40.5	64.3	73	50	92	3.9
December	1.1	3.9	45.0	36.5	54.9	79	61	93	4.5
Annual	**50.8**	**22.7**	**60.4**	**47.7**	**74.1**	**65**	**43**	**89**	**4.2**

Average annual reference evapotranspiration (ET_o) is approximately 51 inches, ranging from a low of one inch in December and January to a high of over seven inches in June and July. Approximately three quarters of the annual ET_o occurs in the six-month period from April through September. Average monthly ET_o for the period 1985 to 2020 is shown in Figure 2.3.

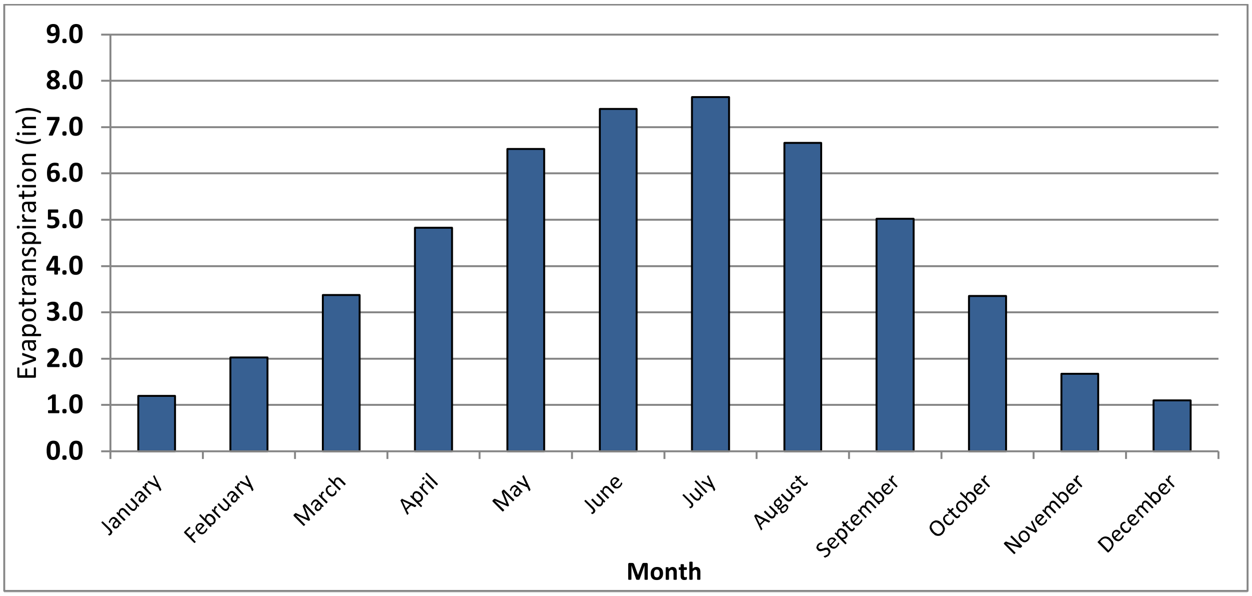

Figure 2.3. Average Monthly ET_o.

Average annual precipitation is approximately 22.7 inches, with 17.4 inches or slightly more than three quarters occurring in the five-month period from November through March. Significantly more precipitation occurs as both rain and snow in the Sierra Nevada Mountains east of the region, which represent the primary source of regional surface water supplies. Average monthly precipitation for the period 1985 to 2020 is shown in Figure 2.4.

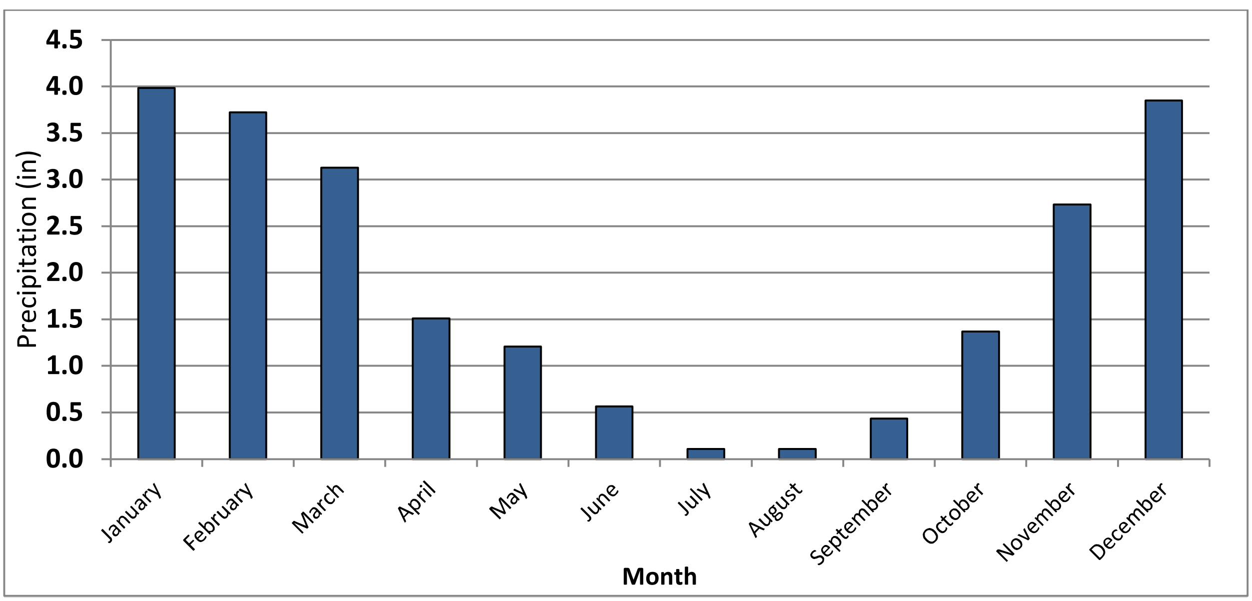

Figure 2.4. Average Monthly Precipitation.

Maximum average daily temperatures range from a low of about 55°F in December to a high of approximately 91°F in July. Minimum average daily temperatures range from a low of approximately 37°F in December and January to a high of about 60°F in July. Average daily temperatures range from a low of about 45°F in December to about 75°F in July.

Even during the peak summer period, the average maximum relative humidity reaches between 80 and 90 percent, which is indicative of irrigation in the area. Minimum relative humidity ranges between approximately 30 to 40 percent during the summer and 50 to 60 percent during the wet winter months. Similar to average maximum relative humidity, average minimum relative humidity is influenced by irrigation in the vicinity of the weather station and surrounding region and is thus quite high even during summer months.

Average wind speed is lowest in August (3.3 miles per hour) and greatest during late winter and early spring, about five miles per hour, on average. Winds tend to blow from the north and south through the Feather River Region due to its location within the Sacramento Valley, which is bordered by mountains on the east and west.

There are no significant microclimates within the region that affect water management or operations. Climate change and its potential impacts on water resources in the region are described in Section 5.

2.6 *Water Supplies and Hydrology*

This section describes surface water and groundwater supplies and hydrology in the region, including both water availability and water quality. Regional sources of surface water include the Feather River, Sacramento River, Butte Creek, and other, small streams. Surface water users within the region hold various rights and agreements to divert available surface water, and surface water is of good quality for irrigation. Groundwater is generally available throughout the region, with the exception of the Sutter Buttes subarea, and its use for irrigation is not regulated. Groundwater quality varies within the region, affecting its suitability in some areas, but is generally of good quality for irrigation.

2.6.1 Surface Water

2.6.1.1 *Overview*

The primary source of surface water within the region is the Feather River. A brief description of surface water rights is provided in this section; for a more detailed description of water rights and historical diversions, see the individual supplier descriptions developed as part of this plan (Volume II, Sections 3 through 8).

The remainder of this section includes the following subsections:

- Surface Water Supplies – Description of available surface water supplies and water rights,
- Surface Hydrology – Discussion of regional surface water inflows and outflows, as well as surface water connections among water use areas within the region,
- Surface Water Quality – Discussion of regional surface water quality and monitoring initiatives,

- Information Gaps – Discussion of opportunities to enhance understanding of surface water flows within the region.

2.6.1.2 *Surface Water Supplies*

Water is diverted from the Feather based on a combination of pre-1914, riparian, and appropriative water rights and based on diversion agreements between Feather River settlement contractors (water suppliers with water rights established prior to construction of the State Water Project) and the State. WCWD and the Joint Districts hold pre-1914 water rights on the Feather River and, as a result, have a relatively reliable surface water supply. The Joint Districts entered into an agreement for diversion of water from the Feather River with the State in 1969 following the construction of Lake Oroville stating that they have the right to the diversion of up to 555,000 af of natural flow from the Feather River, subject to reduction during drought. Under a similar agreement entered into between the State and WCWD in 1986, WCWD has a right to the diversion of up to 150,000 af of natural flow from the Feather River, subject to reduction during drought, and a right to 145,000 af of upstream stored water on the North Fork of the Feather River, not subject to reduction. Water from the Feather River is delivered by the State to WCWD and the Joint Districts through Thermalito Afterbay with the exception of SEWD, which can also divert water from the Feather River at the Sunset Pumps. WCWD also has an adjudicated water right on Butte Creek.

Under the agreement with the State, diversions can be reduced under the following conditions:

- DWR forecasted April to July unimpaired runoff into Lake Oroville is less than 600,000 ac-ft[4], or
- Total current year predicted and prior year actual deficiencies in unimpaired runoff (as compared to 2,500,000 ac-ft) exceed 400,000 ac-ft for one or more successive prior water years with less than 2,500,000 ac-ft of runoff.

When a reduction is allowed, WCWD and the Joint Districts supplies subject to reduction can be reduced by up to 50 percent in any one year, but not more than 100 percent in any seven years, cumulatively. Additionally, reductions in any given year cannot exceed the percent reduction experienced for agricultural use by SWP contractors. Historically, reductions have occurred in 1977, 1991, 1992, and 2015. In each year, the diversions were reduced by 50 percent.

GHMWC, PMWC, TMWC, and OWD hold similar diversion agreements with the State and are subject to reductions under the same conditions as WCWD and the Joint Districts. GHMWC, PMWC, and TMWC additionally hold riparian rights on the Feather River that are not subject to reduction.

FWD diverts water under a combination of riparian water rights and agreements with the State and the U.S. Bureau of Reclamation (USBR, or Bureau). The agreement with the Bureau represents the primary surface water supply and was originally entered into in 1977 and renewed in 2005. Water diverted by FWD under its agreement with USBR is replaced with water from the Central Valley Project (CVP) at the confluence of the Feather River and the Sacramento River. Under the terms of

[4] The final, official forecast must be made by April 10 of each year.

the agreement, FWD is subject to water availability under the same conditions as other CVP contractors in the Sacramento Valley.

Water is diverted from the Feather River by Yuba City for municipal and industrial use under a combination of water rights and project supply from the SWP.

Water is diverted into the region from the Sacramento River through a combination of riparian and appropriative water rights and through CVP contracts. The primary Sacramento River water user in the region is RD1004, which entered into a settlement contract with USBR following construction of Shasta Dam. Additional information describing water supplies from the Sacramento River for irrigation in the region is provided in the SVRWMP (SRSC 2006).

In addition to the surface water resources described above, there exist within the region several individual water rights holders with licenses and permits to divert water from the Feather River, Sacramento River, Butte Creek, and other streams, sloughs, and drains for irrigation and other purposes. Information describing these water rights is available from the State Water Resources Control Board.

2.6.1.3 Surface Hydrology

The surface water hydrology of the region can be characterized as a cascading or flow through system, where water entering an area of water use within the region as a diversion, natural inflow, or flood flow is consumed through the processes of evapotranspiration, enters the groundwater system, or returns to the surface water system and can be reused downstream. Water not consumed within the region is available for reuse downstream or may provide beneficial recharge of the groundwater system.

Locations of boundary inflows and outflows to and from the region, respectively, have been identified to support evaluation of regional surface hydrology. Inflow and outflow locations and selected existing and historical publicly available flow measurement sites for the region are shown in Figure 2.5. For development of this plan, available flow data were compiled for each site for the period of October 1984 through September 2012 from the United States Geological Survey (USGS), California Data Exchange Center (CDEC), and California Water Data Library (WDL). In the figure, measurement sites are labeled using the site ID for the agency responsible for the site and color-coded based on the availability of flow data for the full 1984 to 2012 period. These markers indicate the following:

- Red – Measurement records available for less than 25 percent of the period,
- Orange – Measurement records available for 25 to 50 percent of the period,
- Green – Measurement records available for 50 to 75 percent of the period, and
- Blue – Measurement records available for 75 to 100 percent of the period.

In order to further understand and evaluate opportunities for and implications of water management actions aimed at meeting water management objectives, a schematic depicting the surface hydrology within the region was developed (Figure 2.6). The schematic identifies local water use areas within each subarea and identifies linkages and flow routing (i.e., direction) to and from adjacent water use areas, natural waterways, and other water sources (i.e., Thermalito Afterbay). These specific water use areas have been shaded in the color of the subarea within which they are located for consistency with Figure 2.1. In the figure, natural waterways are differentiated from canals and drains. Additionally, the Butte Creek system, which includes Butte Creek, Butte Slough, and the East and West Borrow Canals of the Sutter Bypass, is differentiated from other natural waterways due to its importance as a migratory route for salmon and steelhead. Unique symbology is used to identify flood control waterways (weirs and bypasses) along the Sacramento River and to identify other, minor flow paths.

Additional symbols in Figure 2.6 indicate instances where flows have been measured and quantified during the period from October 1984 through September 2012. The color coding of the symbols is consistent with that of Figure 2.5, indicating the percent of time data was available for the period of interest. As described previously, much of the data is available publicly and can be obtained from USGS, CDEC, and WDL. Other data is available through SWP and CVP operations reports or is collected internally for management and accounting purposes by the water suppliers in the region. These data were used to prepare regional and water supplier water balances describing historical water management and are included in Volume I, Section 3 and Volume II, Sections 3 through 8 of this AWMP.

2.6.1.4 Surface Water Quality

Comprehensive water quality monitoring is conducted within the region and allows for assessment of the quality of water for agricultural and habitat uses. Most agricultural water suppliers do not actively monitor surface water quality due to the nature of their responsibilities and authorities. Surface water quality monitoring in the region has been performed in the past by the USGS, DWR, Yuba City, wildlife management agencies, and through water quality coalitions.

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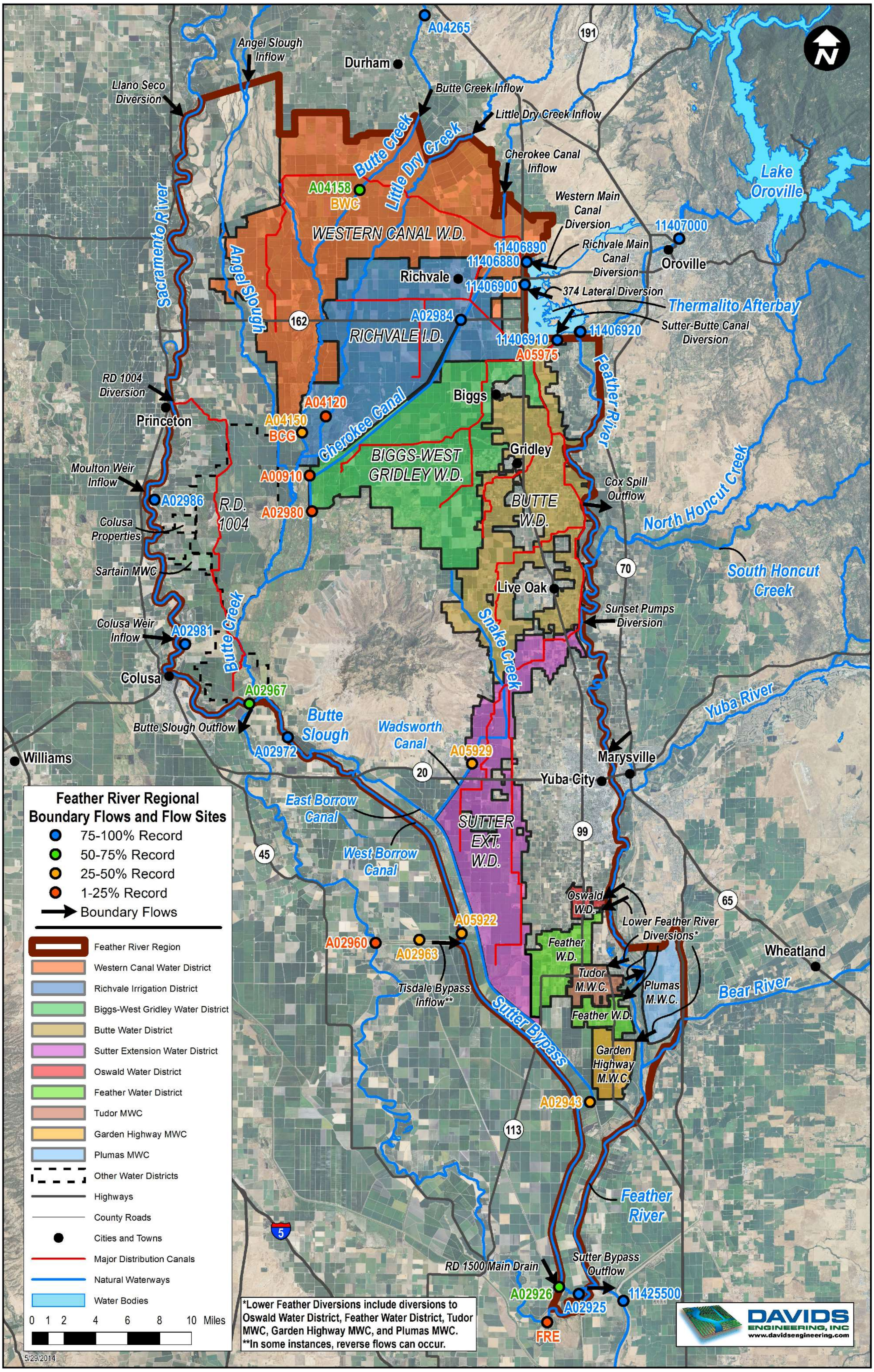
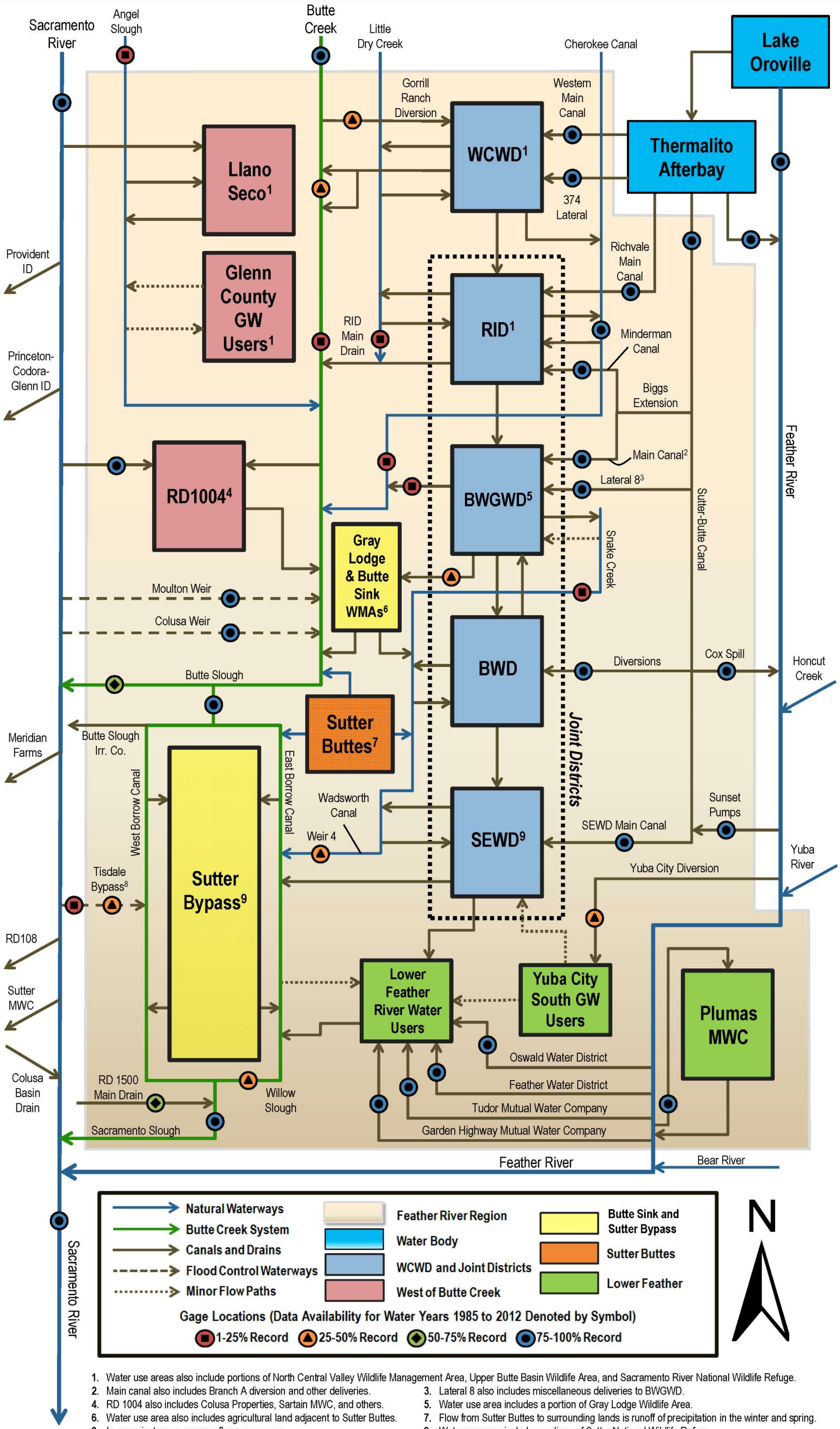


Figure 2.5. Regional Boundary Flows, Water Suppliers, and Flow Measurement Sites.



1. Water use areas also include portions of North Central Valley Wildlife Management Area, Upper Butte Basin Wildlife Area, and Sacramento River National Wildlife Refuge.
2. Main canal also includes Branch A diversion and other deliveries.
3. Lateral 8 also includes miscellaneous deliveries to BWGWD.
4. RD 1004 also includes Colusa Properties, Sartain MWC, and others.
5. Water use area includes a portion of Gray Lodge Wildlife Area.
6. Water use area also includes agricultural land adjacent to Sutter Buttes.
7. Flow from Sutter Buttes to surrounding lands is runoff of precipitation in the winter and spring.
8. In some instances, reverse flows can occur.
9. Water use area includes portions of Sutter National Wildlife Refuge.

Figure 2.7. Feather River Region Surface Hydrology and Water Use Areas.

Based on available data, water from the Feather River and other natural waterways within the Feather River region is generally of good to excellent quality for irrigation and habitat. Total dissolved solids values are typically low, although their average values tend to increase somewhat in sloughs and drains due to agricultural use and reuse. Nutrient concentrations are also typically low across the region.

The USGS performed a water quality assessment of the Feather River (source water for majority of region) near Nicolaus (indicative of inflows to the region) and Sacramento Slough (primary surface outflow from region) between 1996 and 1998 that included testing for a variety of parameters (USGS 2002). These included temperature, electrical conductivity, dissolved oxygen, pH, hardness, suspended sediment, inorganic constituents, trace elements, mercury, and pesticides. In general, drainage from the region displayed slightly increased temperature, reduced dissolved oxygen, increased sediment, increased electrical conductivity and total dissolved solids, and increased nitrogen and phosphorous as a result of application and reuse; however, the water remained of good quality for agricultural and environmental uses.

Between 1992 and 1997, bimonthly samples were collected from Lake Oroville by DWR and analyzed as part of the Lake Oroville relicensing process (DWR 2001). As one would expect, the quality was found to be similar to that documented by USGS for the Feather River near Nicolaus as described in the previous paragraph.

Yuba City diverts surface water from the Feather River for domestic use and performs regular testing. Yuba City historically has not had difficulty meeting State or Federal drinking water health standards.

Surface water quality monitoring is conducted by CDFW as part of management of the Gray Lodge Wildlife Area. Monitoring of water received by Gray Lodge has also been conducted by the Central Valley Regional Water Quality Control Board (CVRWQCB 1989), including deliveries of Feather River water by BWGWD, agricultural drain water, and groundwater. The monitoring results indicate that the water quality of these three sources is good for irrigation and does not limit the beneficial use of water for wildlife habitat.

Growers within the region participate in the Sacramento Valley Water Quality Coalition and/or the California Rice Commission Coalition, which conduct monitoring of surface water quality in compliance with the CVRWQCB's Irrigated Lands Regulatory Program (ILRP). The monitoring program includes sampling and testing of a host of parameters for hundreds of samples collected annually from sites strategically distributed throughout the Sacramento River basin, which includes the Feather River region.

BWGWD, RID, and WCWD are a party to a settlement agreement with DWR that addresses yield losses from lower water temperatures resulting from the operation of Lake Oroville, as compared to pre-reservoir conditions. As part of the process to develop the settlement agreement, the districts and DWR developed and implemented a method to estimate rice yield reductions through detailed monitoring of water temperatures and yields. Water quality impacts of reservoir operations are monitored annually.

Water quality in portions of the Feather River and other water bodies in the region was identified as being impaired by copper, mercury, toxicity, and over than 15 pesticides such as diazinon, chlorpyrifos, and lindane in the 2006 Clean Water Act Section 303(d) list of impaired water quality segments (SWRCB 2006). Through the efforts of various stakeholders within the watershed, these waters were delisted for diazinon in 2010. These efforts provide an example of the effectiveness of collaborative, proactive efforts to improve water quality by the water quality coalitions established under the ILRP, public agencies, and others. Efforts to improve water quality continue.

2.6.1.5 Information Gaps

Review of Figure 2.6 indicates that while information describing inflows to and outflows from the region is relatively abundant and complete, limited information is available describing surface flows between water use areas within the region. In particular, information describing inflows to and flows along the Butte Creek system[5] are limited. Several stream gage sites were established on Butte Creek as part of the Central Valley Project Improvement Act (CVPIA) Anadromous Fish Restoration Program (AFRP) in the late 1990s, but some have been discontinued or are no longer maintained. As a result, current hydrologic conditions and system responses to water management activities are not adequately monitored. The supplier water balance analyses described in Volume II, Sections 3 through 7 of this AWMP provide insight into return flows to the system from irrigation but are estimated and subject to substantial uncertainty. Improved understanding of flows in the Butte Creek/Sutter Bypass system is important for multiple operational and analytical purposes.

From an operational perspective, improved knowledge of return flows can help support improved water management by water suppliers to increase local water supply reliability or to support other local, regional, or statewide water management objectives. Additionally, better knowledge of flows can help wildlife managers better respond to changes in instream flows and water quality and to ensure that adequate conditions exist. Migration of salmon and steelhead into the Butte Creek watershed is typically from the Sacramento River to the East Borrow Canal of the Sutter Bypass and then up through Butte Slough to Butte Creek. Improved monitoring of inflows along the primary migratory route would enable increased effectiveness of water management actions by wildlife managers and water suppliers.

From an analytical perspective, improved knowledge of flows in the Butte Creek system and agricultural return flows to the system would lead to increased understanding of system responses to changing water management and natural hydrologic conditions. Additionally, this improved knowledge would support the development of plans aimed at meeting water management

[5] For purposes of this discussion, the Butte Creek system includes Butte Creek from the northern boundary of WCWD to Butte Slough and the East Borrow Canal and West Borrow Canal of the Sutter Bypass to Sacramento Slough, which discharges to the Sacramento River near Verona.

objectives through more precise information describing system behavior. Potential objectives are discussed in greater detail in Section 4.

Regionally, the greatest benefit would likely be achieved by first increasing information describing flows within the migratory "backbone" of the Butte Creek system. Historically, flow measurement sites existed at several locations but are now discontinued or remain operational but are no longer being maintained. As a first step, it would be beneficial to re-establish these sites while identifying additional sites to be added. In particular, it would be beneficial to establish a monitoring site on the East Borrow Canal below the bifurcation of Butte Slough to improve understanding of the division of flows entering the bypass. Additional sites to characterize reaches of the system located near major inflow locations could be identified and established as a next step. Increased knowledge of flows in the system could enhance management capabilities of both wildlife managers and agricultural water suppliers.

As part of this plan, projects to improve monitoring of boundary outflows have been evaluated for each of the participating Feather River water suppliers. Identified outflow locations are typically on drains where they cross district boundaries. The suppliers are in the process of implementing these improvements and seeking to identify funding opportunities and prioritize outflow measurement relative to other potential water management activities. The potential outflow improvement projects are described in greater detail in Volume II, Sections 3 through 8 of this plan. Information describing anticipated improvements and associated costs for outflow monitoring could be used to develop initial estimates of costs for flow measurement improvements along the Butte Creek system, given that the types of devices and associated costs will be similar in many cases, although additional environmental permitting and mitigation would likely be required to accurately measure flows in natural channels.

2.6.2 Groundwater

2.6.2.1 Overview

The region is located within the Sacramento Valley groundwater basin (Basin 5-21), as described in DWR Bulletin 118 (DWR 2003), which spans the valley floor from approximately Red Bluff in the north to the Cosumnes River and southernmost extent of the Sacramento River in the south and encompasses an area of over 5,800 square miles. The Feather River Region overlies portions of the Butte (5-21.70), Sutter (5-21.62), South Yuba (5-21-61), and Colusa (5-21.52) subbasins (Figure 2.8). The subbasin boundaries originally published in 2003 as part of Bulletin 118 were refined by DWR in 2018. The updated boundaries can be found on DWR SGMA Data Viewer.[6]

Areas in the region that rely on groundwater for irrigation generally fall outside of water supplier service areas, although pumping by agricultural water suppliers and growers within supplier service areas does occur in some cases. Pumping by districts has typically been to make water available for transfer to other water users through groundwater substitution, through district-facilitated private pumping programs to enhance groundwater production during surface water

[6] SGMA Data Viewer: https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#boundaries

shortages, or in order to reduce water costs[7]. Water transfers meet agricultural, environmental, and urban needs locally and in other areas of the State. Groundwater is also preferred by growers in some cases due to water quality and flexibility considerations. Increased reliance on groundwater has and continues to occur within many water supplier service areas where orchard crops are grown. In particular, groundwater pumping is preferred over surface water by many growers irrigating orchards using pressurized irrigation systems due to reduced filtration requirements and the ability to irrigate on demand with the relatively small flow rates required as compared to surface irrigation. Another primary driver of private pumping is surface water shortages, which are infrequent within water supplier service areas but can result in substantial pumping in years of reduced surface water availability.

Groundwater is replenished through deep percolation of applied irrigation water and precipitation, canal seepage, and stream losses. Recharge via subsurface inflow is relatively small in proportion to the other sources.

The California Statewide Groundwater Elevation Monitoring (CASGEM) program's groundwater basin prioritization process has resulted in the designation of the West Butte subbasin as a medium priority basin with respect to the need to help identify, evaluate, and determine the need for additional groundwater level monitoring (DWR 2014). The West Butte subbasin has since been combined with portions of the East Butte subbasin, and other areas, into the Butte Subbasin, which has also been designated as medium priority basin (DWR 2020). The basin prioritization process considers eight data components: population, population growth, number of public supply wells, irrigated acreage, groundwater reliance, documented impacts (overdraft, subsidence, saline intrusion, and other groundwater quality issues), and other information determined to be relevant.

The remainder of this section includes the following subsections:

- Hydrogeology – General description of the water-bearing formations of regional subbasins;
- Groundwater Well Locations and Development – Review of the distribution and development of irrigation and monitoring wells in the region;
- Groundwater Elevations, Flow, and Storage – Discussion of the spatial distribution of observed groundwater levels within the region, flow direction, and estimated storage;
- Groundwater Quality – Discussion of regional groundwater quality and monitoring initiatives; and
- Information Gaps – Discussion of opportunities to enhance understanding of surface-groundwater interactions within the region.

[7] In particular, FWD blends groundwater pumped from district-owned wells with Feather River diversions to reduce water costs due to the combined cost of purchasing and pumping CVP water exceeding groundwater pumping costs.

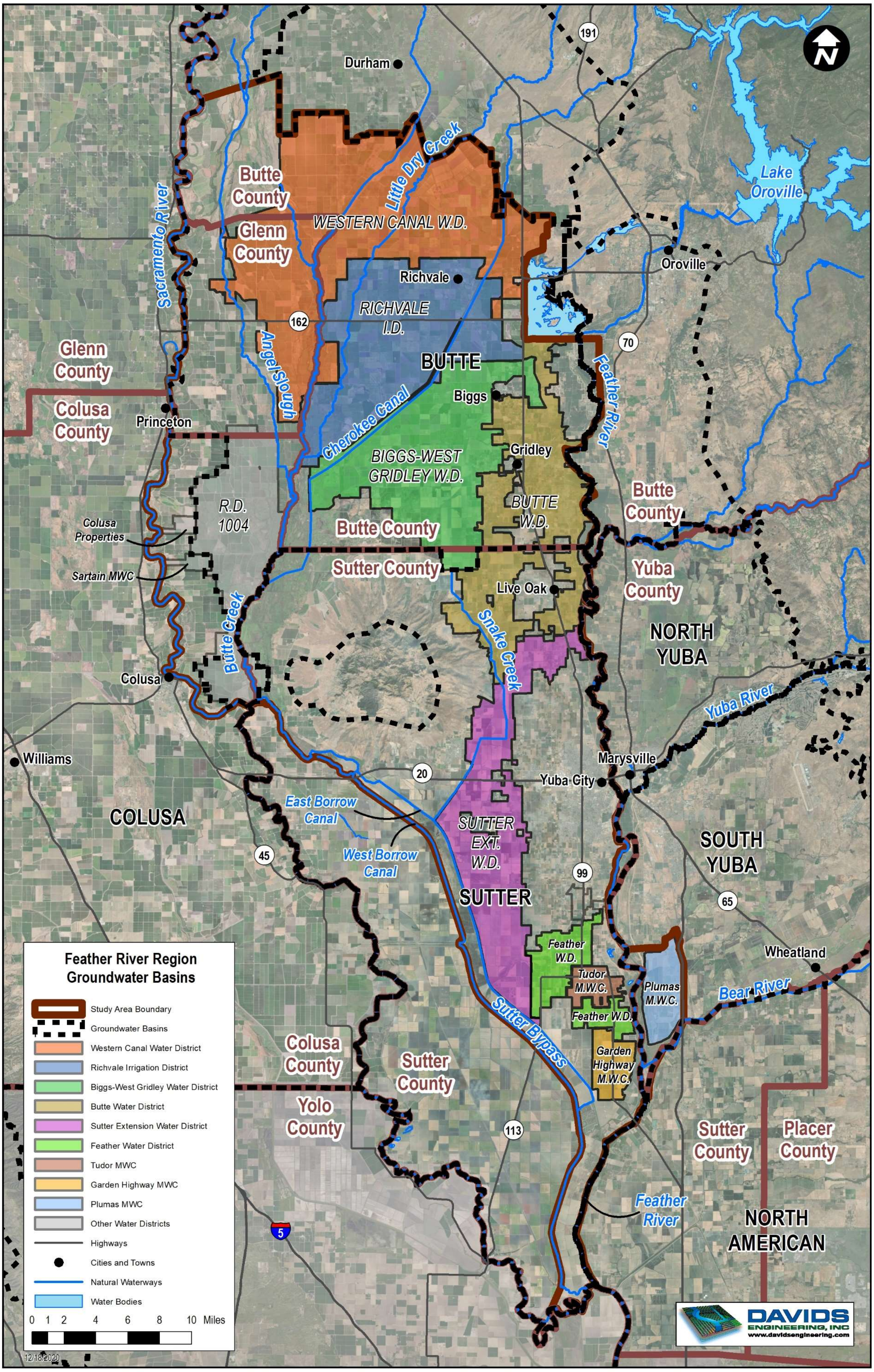


Figure 2.8. Feather River Region Groundwater Basins.

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2.6.2.2 *Hydrogeology*

The materials making up the Sacramento Valley groundwater basin and its subbasins consist of sediments deposited in both marine and terrestrial environments. The marine deposits are older and typically contain water with elevated salinity. The overlying terrestrial deposits conversely contain fresh water. Underlying these deposits are metamorphic and granitic rocks. The base of fresh water has been defined as the depth at which saline water is found, with water having a specific conductivity of 3 millisiemens per centimeter or a total dissolved solids (TDS) content of approximately 2,000 mg/l being considered saline (DWR 1978). The base of fresh water varies from over 1,000 feet below sea level in the northern portion of the region to approximately 400 feet below sea level surrounding the Sutter Buttes. Saline water at relatively shallow depths in some locations is believed to result from uplifted marine sediments around the Buttes. The water-bearing formations of each subbasin are described below. Additional information describing the hydrogeology of the region is available from the following sources:

- California's Groundwater. Update to DWR Bulletin 118. (DWR 2018)
- Evaluation of Groundwater Resources: Sacramento Valley. DWR Bulletin 118-6. (DWR 1978)
- Butte County Groundwater Management Plan (GMP). (BCDWRC 2004)
- Butte County Groundwater Inventory Analysis. (DWR 2005)
- Sutter County GMP. (Wood Rogers 2013)
- Yuba County Water Agency Groundwater Management Plan[8]. (YCWA 2010)

In addition to the sources listed above, the majority of water suppliers in the region have prepared and adopted GMPs, as described in Volume II, Sections 3 through 7 of this AWMP. Groundwater Sustainability Plans (GSPs) for the Butte and Sutter subbasins that will address hydrogeology are also currently in development; they are scheduled to be complete by January 2022. The GSP for the South Yuba subbasin was adopted in December 2019 and submitted to DWR in January 2020.

2.6.2.2.1 Butte Subbasin

The water-bearing formations of the Butte subbasin consist of a combination of Holocene, Pleistocene, and Pliocene deposits and alluvium. The formations include the following:

- Holocene Stream Channel Deposits – Moderately to highly permeable unconsolidated gravel, sand, silt, and clay derived from erosion of adjacent alluvial deposits with thickness of 1 to 80 feet representing the upper part of the unconfined aquifer.
- Holocene Basin Deposits – Low permeability and low yield silts and clays with locally interbedded stream channel deposits in some areas derived from sediment-laden floodwaters with thickness to 150 feet and typically poor water quality.

[8] Includes the South Yuba Subbasin, a portion of which is included in the Feather River region, as defined within this AWMP.

- Pleistocene Modesto Formation – Friable gravel and cobbles with sand, silt, and clay derived from reworking of other formations with thickness of 50 to 150 feet and surface exposure west of the Feather River extending south from Thermalito Afterbay to the Sutter Buttes.
- Pleistocene Riverbank Formation – Poorly to highly permeable deposits of pebble and gravels interlensed with clay sands and silt with thickness from 50 to 200 feet and surface exposure south and west of Thermalito Afterbay.
- Pleistocene Sutter Butte Alluvium – Fan deposits surrounding the Sutter Buttes consisting largely of gravel, sand, silt, and clay with a thickness of up to 600 feet and extending up to 15 miles north of the Buttes and westerly beyond the Sacramento River.
- Pliocene Tuscan Formation – A series of volcanic mudflows, tuff breccia, tuffaceous sandstone and volcanic ash layers with thickness of up to 800 feet described as four separate but lithologically similar units found throughout the subarea.
- Pliocene Laguna Formation – Compacted, low to moderately permeable interbedded alluvial sand, gravel, and silt deposits with maximum thickness estimates ranging from 180 to 1,000 feet yielding moderate amounts of water to wells and with surface exposure in the vicinity of Thermalito Afterbay.

2.6.2.2.2 Sutter Subbasin

The water-bearing formations of the Sutter subbasin consist of a combination of Holocene, Pleistocene, Pliocene, Miocene-Pliocene, and Oligocene-Miocene deposits and alluvium. The formations include the following:

- Holocene Stream Channel and Floodplain Deposits – Highly permeable coarse sand and gravel alluvial material providing groundwater recharge within the subbasin along stream channels of Yuba, Feather, and Sacramento Rivers with thickness up to 100 feet.
- Pleistocene Floodplain Deposits – Gravelly sand, silt, and clay from flood events along the Feather River and its tributaries with thickness up to 100 feet that provide a good medium for groundwater recharge.
- Pleistocene Victor Formation (Old Alluvium) – Loosely compacted silt, sand, and gravel from Sierran alluvial fan deposits with thickness up to 100 feet which occur as lenticular beds with decreasing thickness and grain size with increasing distance from the Yuba River and the foothills. Hardpan and claypan soils have developed to form a generally impermeable surface, but below this the formation is moderately permeable and provides for most of the groundwater from domestic and shallow irrigation wells.
- Pliocene Laguna Formation – Low permeability compacted layers of sand, silt, and clay with hardpan in surface soils with typical thickness of about 300 feet but maximum thickness of up to 1,000 feet along Sacramento Valley axis.
- Miocene-Pliocene Mehrten Formation – Volcanic and volcaniclastic rocks ranging in thickness from about 200 feet to over 1,000 feet along axis of Sacramento Valley with one unit of gray to black well-sorted fluvial andesitic sand, andesitic stream gravel lenses, and brown to blue clay and silt beds that are highly permeable and a second unit of andesitic tuff-breccia that acts as a confining layer between sand intervals.

- Obligocene-Miocene Valley Springs Formation – Low permeability gravel, sand, silt, and clay, siltstone, and tuffaceous beds which all contain rhyolitic material and have a maximum thickness of about 200 feet and yield only small quantities of water to wells.

2.6.2.2.3 South Yuba Subbasin

The water-bearing formations of the South Yuba subbasin consist of a combination of Holocene, Pleistocene, Pliocene, and Miocene-Pliocene, deposits and alluvium. The formations include the following:

- Holocene Dredger Tailings – Highly permeable coarse gravels and cobbles that can be up to 125 feet thick and occur along the Yuba and Bear Rivers within the eastern region of the South Yuba subbasin.
- Holocene Stream Channel and Floodplain Deposits – Highly permeable coarse sand and gravel alluvial material providing groundwater recharge within the subbasin along stream channels of Yuba, Feather, and Bear Rivers with thickness up to 110 feet.
- Pleistocene Victor Formation – Loosely compacted silt, sand, and gravel from Sierran alluvial fan deposits with thickness up to 100 feet which occurs primarily in the North Yuba subbasin but is also found in floodplain deposits along stream channels in the South Yuba subbasin.
- Pleistocene Floodplain Deposits – Gravelly sand, silt, and clay from flood events along the Feather River and its tributaries with thickness ranging from 5 to 15 feet that provide a good medium for groundwater recharge.
- Pleistocene Alluvium – Loosely compacted silt, sand, and gravel with lesser amounts of clay deposits from Sierran alluvial fan deposits with varying thickness that occur as lenticular beds with decreasing thickness and grain size with increasing distance from the Yuba River and the foothills. Hardpan and claypan soils have developed to form an impermeable surface, but below this the formation is moderately permeable and provides for most of the groundwater from domestic and shallow irrigation wells.
- Pliocene Laguna Formation – Low permeability silt to sandy silt with abundant clay and minor lenticular gravel beds that range in thickness from 400 feet near the Yuba River up to 1,000 feet in the southwest portion of Yuba County.
- Miocene-Pliocene Mehrten Formation – Volcanic rocks ranging in thickness from about 200 feet near the eastern margin of the subbasin to over 5000 feet near the Feather River with one unit of gray to black well-sorted fluvial andesitic sand, andesitic stream gravel lenses, and brown to blue clay and silt beds that are highly permeable and a second unit of andesitic tuff-breccia that acts as a confining layer between sand intervals.

2.6.2.3 Groundwater Well Locations and Development

DWR records of groundwater well construction were compiled to evaluate the density and distribution of wells constructed for irrigation and monitoring within the region. DWR maintains a database of well completion reports for all water wells in California. Well completion reports include information describing the location, type, depth, and other characteristics of wells constructed throughout the State, including monitoring wells. Counts of well completion reports by township, range, and section were compiled for the Feather River region based on information provided by the Northern Region and North Central Region offices of DWR located in Red Bluff and West Sacramento, respectively. Locations of irrigation and monitoring wells are shown in Figures 2.9 and 2.10, respectively.

Based on DWR records, there are approximately 1,800 irrigation wells within the region. Irrigation wells tend to be concentrated in areas of crop production without dedicated surface water supplies. These areas include the area east of the Sacramento River south of Rancho Llano Seco and outside of RD1004 and the area west of the Feather River between Thermalito Afterbay and GHMWC. As indicated in Figure 2.9, a relatively large number of irrigation wells exist within BWD and PMWC, despite the availability of surface water[9]. This results from relatively shallow depths to groundwater, resulting in relatively low pumping costs; relatively good groundwater quality; and the availability of groundwater on demand, which is well-suited to pressurized irrigation systems for orchards which require frequent, low-flow irrigation. Reliance on groundwater for irrigation in BWD results in increased groundwater extraction and reduced recharge from surface irrigation, as discussed in Volume II, Section 4 of this AWMP; however, the use of surface water within BWD results in net recharge of the groundwater system in any given year and over the course of several years, despite occasional extraction of groundwater for water transfers. Such transfers by BWD and others in the region increase statewide water supplies without significantly reducing water availability within the region.

Also based on DWR records, there are approximately 460 dedicated monitoring wells within the region. The completion reports are filed for each boring of multiple completion monitoring wells; thus the number of locations with monitoring wells is less than 460. Also, groundwater levels and quality can be monitored in irrigation, domestic, and other wells, which are not included in the estimated 460 monitoring wells. As indicated in Figure 2.10, dedicated monitoring wells are generally distributed across the region, with increased concentration in populated areas.

Development of irrigation and monitoring wells in the region between 1977 and 2013 is shown in Figure 2.11. As indicated, over 100 irrigation wells were developed in 1977 in response to drought conditions with more than 40 irrigation wells completed annually, on average, through 1982. Irrigation well completion again increased in 1991 and 1992 in response to drought, with more than 80 wells completed each year. More than 40 wells were completed in 2009, the third in a series of dry or critically dry years.

[9] PMWC owns and operates several wells to conjunctively use surface water and groundwater supplies, increasing overall water supply reliability.

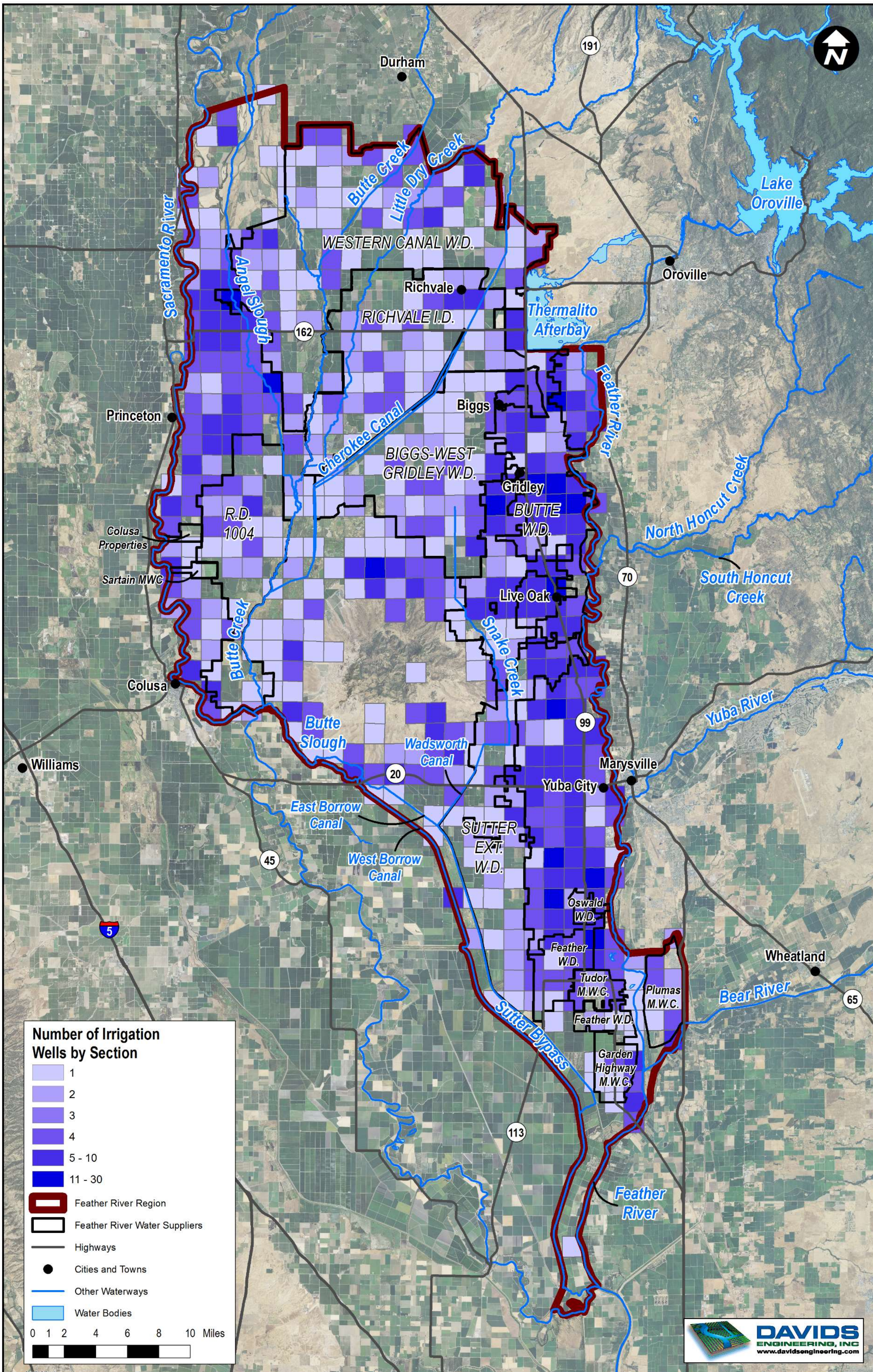


Figure 2.9. Feather River Region Irrigation Wells.

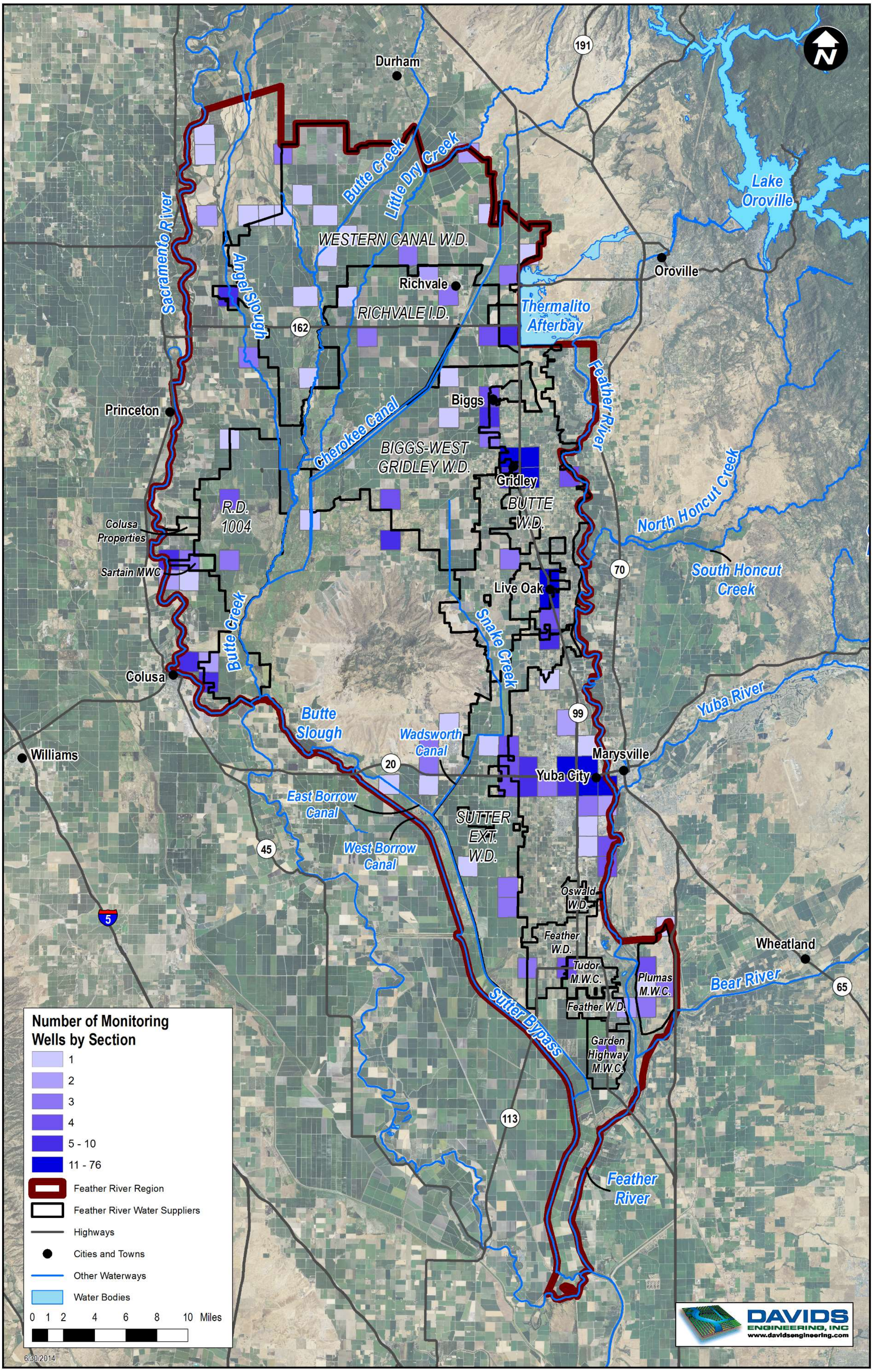


Figure 2.10. Feather River Region Monitoring Wells.

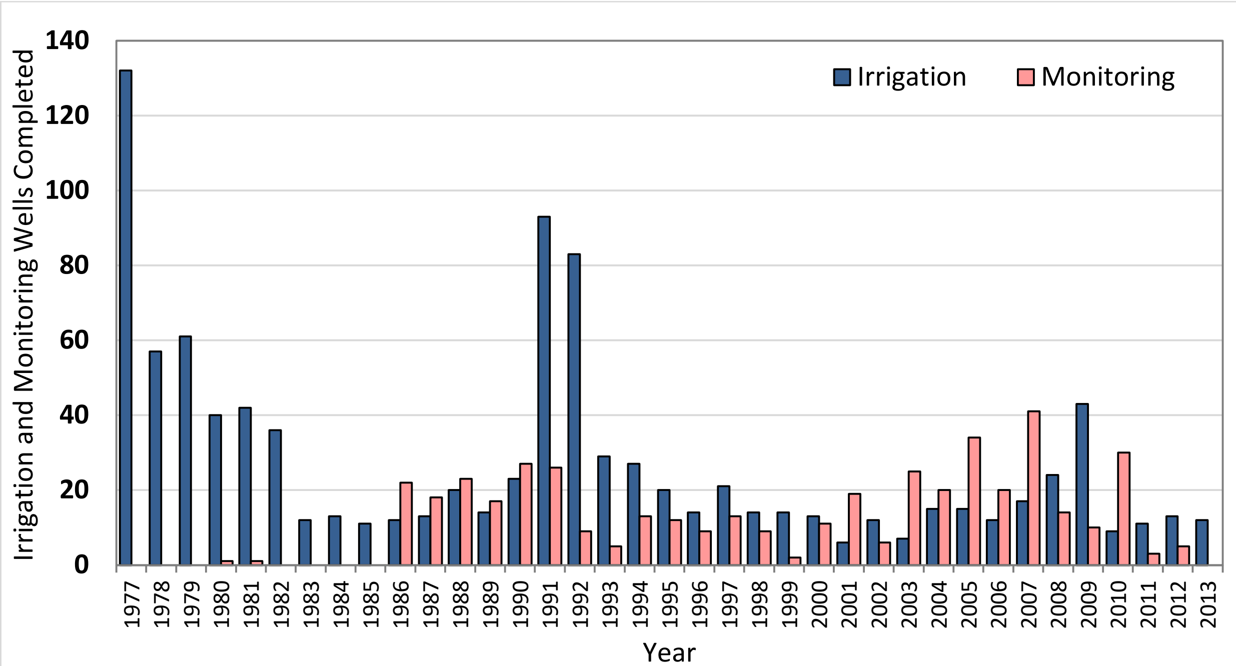


Figure 2.11. Feather River Region Irrigation and Monitoring Wells.

Dedicated monitoring well construction between 1977 and 2013 was limited prior to 1986, during which more than 20 monitoring wells were completed. Similar construction activity occurred through 1991. Installation of monitoring wells during this period may have resulted from funding available through the Groundwater Protection Act of 1983. Between 1992 and 2000, approximately 10 monitoring wells were completed each year, on average. Construction generally increased between 2001 and 2007, and approximately 30 monitoring wells were completed in 2010. Many of these wells may have been installed due to funding provided through the Groundwater Quality Monitoring Act of 2001.

2.6.2.4 *Groundwater Elevations, Flow, and Storage*

2.6.2.4.1 <u>Elevations and Flow</u>

Groundwater levels fluctuate within a given year and across years. Intra-annual variability occurs as groundwater is extracted from the underlying groundwater system for irrigation during the summer months and recharged during times of precipitation in the winter and spring months. In rice growing areas, shallow groundwater levels often increase during the irrigation season in response to irrigation using surface water. Historically, inter-annual groundwater levels within the region have declined during periods of drought but recovered to pre-drought levels subsequently during wetter periods. In some areas, such as some western portions of the Butte subbasin, there are indications of persistent declines in groundwater levels.

Groundwater levels within the region are currently being monitored through the CASGEM program, and the upcoming Butte and Sutter subbasin GSPs will identify and describe a monitoring network for the subbasin. Monitoring entities in the region include the following:

- Butte Subbasin
    - Butte County Department of Water and Resource Conservation
    - Glenn County Department of Agriculture
- Sutter Subbasin
    - Feather Water District
    - Sutter Extension Water District
- South Yuba Subbasin
    - Yuba Water Agency

Figure 2.12 displays average recent spring groundwater levels in the region between 2013 and 2018. The figure includes groundwater contours demonstrating the general movement of groundwater from north to the south and west through the region (groundwater moves perpendicular to the contours, from higher elevations to lower elevations). Figure 2.13 displays average recent fall groundwater levels in the region between 2013 and 2018 and also includes groundwater contours. Regional groundwater levels are typically lower in the fall following groundwater pumping for the irrigation season in some areas and preceding the recharge that occurs during winter and spring precipitation. The data used to develop these figures are from over 400 wells in the underlying and surrounding groundwater subbasins, which are monitored multiple times annually by DWR and others. Groundwater elevation data from the selected wells were interpolated to represent the entire region.

Depth to groundwater varies across the region from less than five feet in much of RID and WCWD to more than 15 feet in the groundwater only area around Yuba City. In areas that are in rice production, (notably in WCWD, RID, and BWGWD) there is typically a groundwater table within five to ten feet of the ground surface. Irrigation wells in the region range from a depth of 35 ft to over 900 ft with an average of approximately 300 ft (DWR 2003).

2.6.2.4.2 Storage

Estimates of groundwater storage are highly sensitive to assumptions of specific yield, which is uncertain and highly simplified when applied at large scales such as a groundwater subbasin. Instead, there is greater certainty in estimating the change in storage in the groundwater system through water balance analysis. The regional water balance analysis provided in the following section and individual supplier water balance provided in Volume II of this plan describe estimated surface water – groundwater interactions over time. The following estimates of total groundwater storage are provided as suggested by DWR (2012a) based on DWR's Bulletin 118 (2018) but are uncertain as described above:

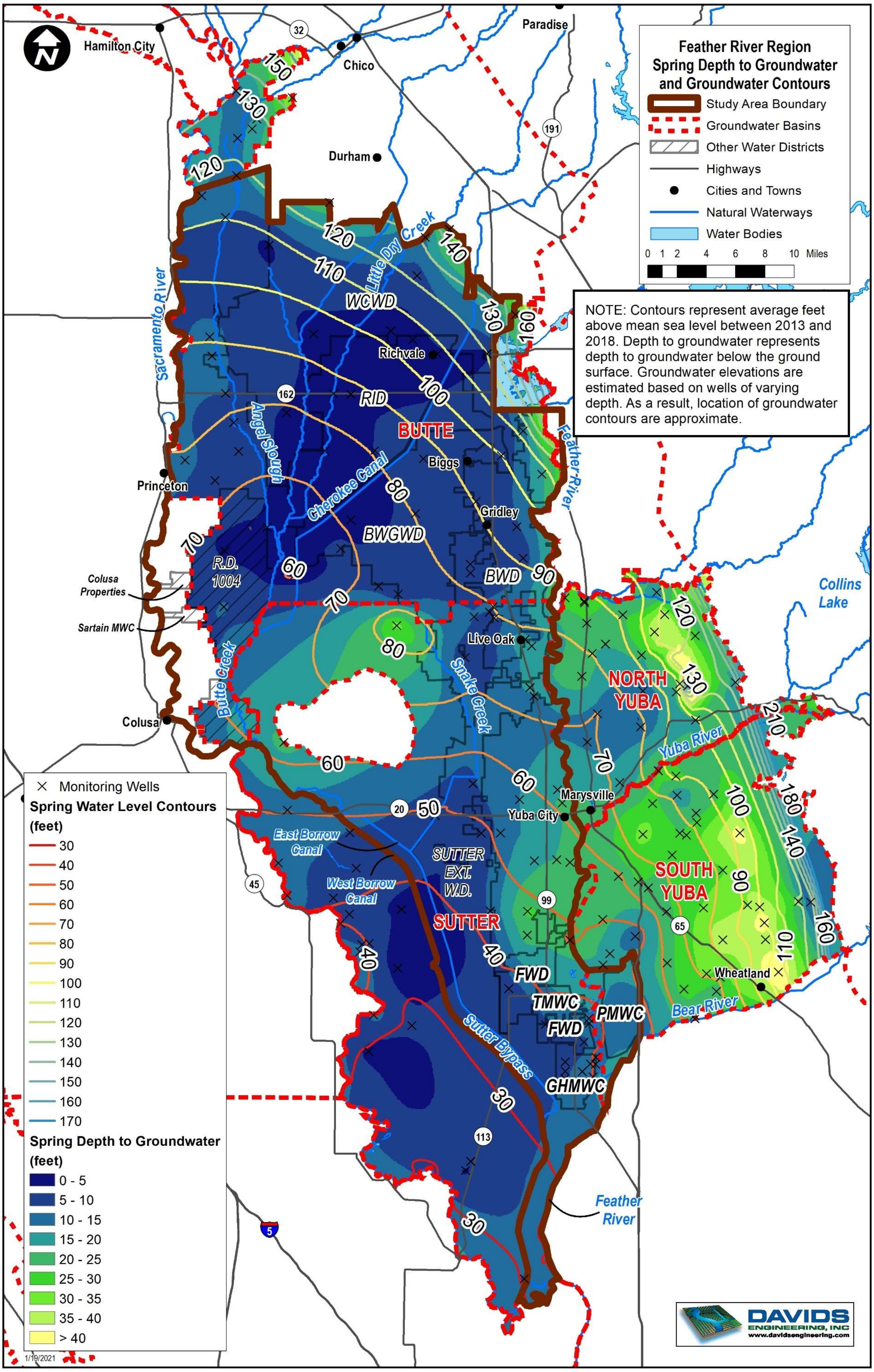


Figure 2.12. Average Spring Groundwater Levels and Contours for Feather River Region from 2013 to 2018.

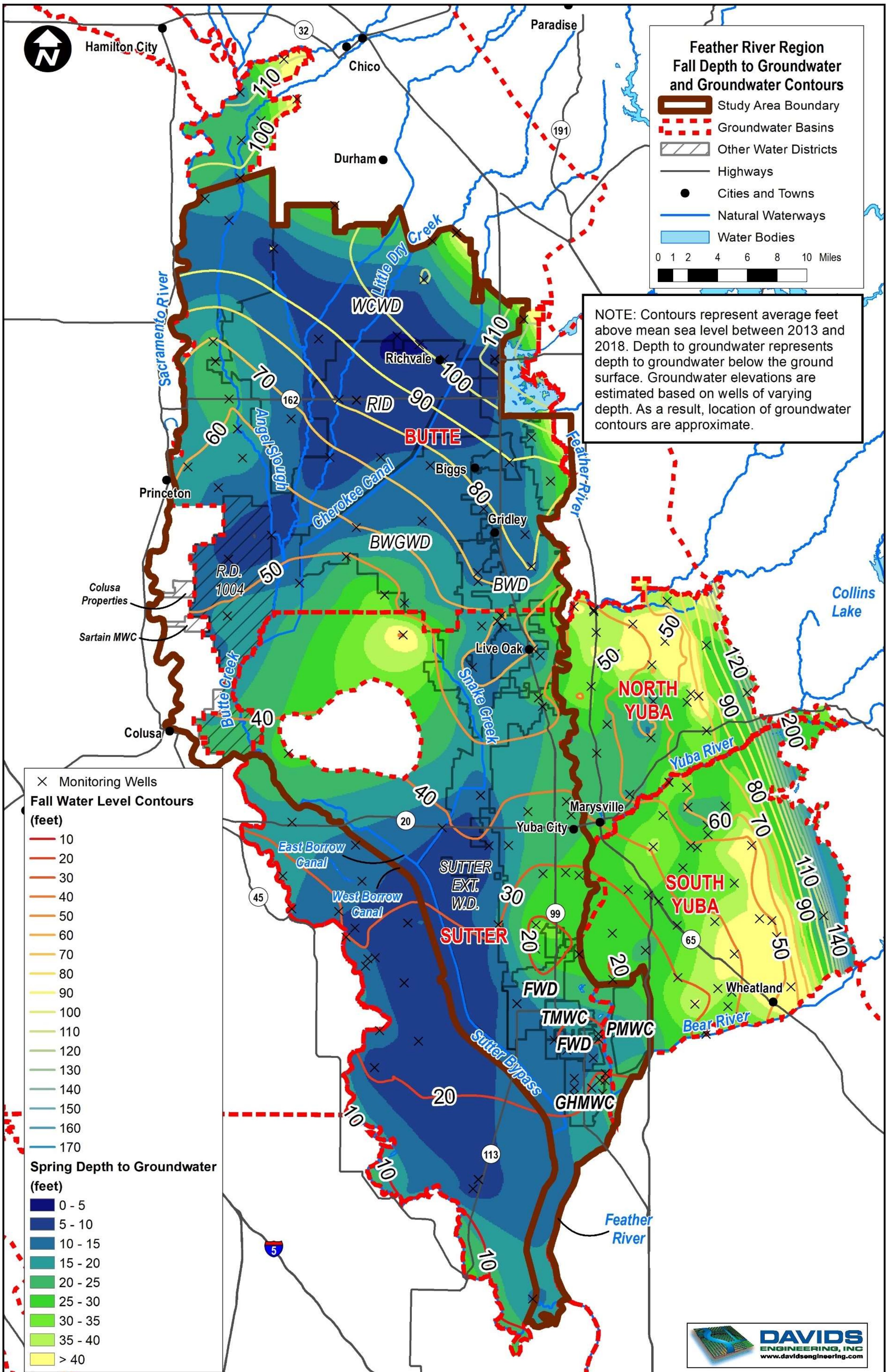


Figure 2.13. Average Fall Groundwater Levels and Contours for Feather River Region from 2013 to 2018.

- The Butte subbasin has an estimated storage capacity to a depth of 200 feet of approximately 5.9 million af. The estimate is based on estimated specific yield of 6.8 percent for the subbasin.
- The Sutter subbasin has an estimated potential useable storage of 5 million af. There are no existing published reports providing an estimate of actual groundwater storage.
- The South Yuba subbasin has an estimated storage capacity to a depth of 200 ft of approximately 1.1 million af. The estimate is based on an estimated specific yield of 6.9 percent.

2.6.2.5 *Groundwater Quality*

Most agricultural water suppliers in the region do not actively monitor groundwater quality; however, water quality monitoring is conducted within the region by others and allows for assessment of the quality of water for agricultural and environmental uses. Groundwater quality monitoring in the region has been performed in the past by DWR, the USGS, Butte County, individual water suppliers, wildlife management agencies, and municipalities.

The following characterizations of groundwater quality are from DWR Bulletin 118 (2003):

- Butte Subbasin
  - TDS ranging from 120 to 680 mg/L, averaging approximately 260 mg/L
  - Localized elevated manganese, iron, magnesium, TDS, calcium, conductivity, boron, TDS, and adjusted sodium adsorption ratio
- Sutter Subbasin
  - TDS ranging from 130 to 1,660 mg/L
  - Localized exceedances of drinking water quality and aesthetic standards in some locations
  - Naturally occurring levels of minerals presenting concerns in some locations
- Yuba Subbasin
  - TDS ranging from 140 to 690 mg/L, with a median of 220 mg/L
  - No documented impairments to water quality
  - Localized exceedances of drinking water quality and aesthetic standards in some locations
  - Naturally occurring levels of minerals presenting concerns in some locations

The USGS sampled 31 wells in the southeastern Sacramento Valley in 1996 (USGS 2001). The study area encompassed the Feather River region and evaluated temperature, electrical conductivity, dissolved oxygen, pH, hardness, suspended sediment, inorganic constituents, trace elements, and pesticides. Groundwater quality in the study area was found suitable for most uses.

Butte County monitors groundwater quality at a network of 13 wells distributed among county subinventory units. Monitoring is conducted as part of implementation of the Butte County GMP adopted in 2004, though monitoring actually began in 2002. Water quality parameters monitored include temperature, pH, and electrical conductivity.

Groundwater quality monitoring is conducted by CDFW as part of management of the Gray Lodge Wildlife Area. Monitoring of water received by Gray Lodge has also been conducted by the CVRWQCB (1989), including groundwater. The monitoring results indicate that the water quality of these three sources is good for irrigation and does not limit the beneficial use of water for wildlife habitat.

In 2014, NCWA prepared the Sacramento Valley Water Quality Coalition Groundwater Quality Assessment Report to evaluate the sources of salt and nitrate loads and potential long-term effects on surface water and groundwater resources. This information supported understanding of sustainable management of surface water and groundwater supplies, including conjunctive management opportunities and limitations. The primary objectives of the assessment were to (1) identify known groundwater quality impacts, (2) prioritize high vulnerability areas, and (3) evaluate opportunities to incorporate existing groundwater monitoring efforts to achieve water management objectives. Based on available data, groundwater in the region is generally of good quality, with few isolated exceptions.

2.6.2.6 Information Gaps

Groundwater levels within the region are currently being monitored through the CASGEM program and provide frequent and spatially representative information to characterize groundwater depths. Water quality is being monitored on an ongoing basis by water suppliers within the region under existing GMPs, by Butte County, and by municipalities relying on groundwater for municipal supplies. Additionally, GSPs for the Butte and Sutter subbasins will include monitoring networks that may provide additional information about groundwater levels and quality than what is currently available.

Primary information gaps are related to interactions between the surface and groundwater systems. Exchanges between the surface water and groundwater systems include flows to the groundwater system through deep percolation, seepage, and stream losses and flows from the groundwater system through pumping and shallow groundwater interception (including shallow groundwater uptake by vegetation and accretions in drains and streams). These fluxes cannot be practically directly measured in most cases. Results of the water balances developed as part of this AWMP and described for the region in this volume and for supplier service areas in Volume II indicate that net recharge of the groundwater system occurs in the region. Improved understanding of these interactions would enhance the evaluation of conjunctive management opportunities to increase local water supplies to meet local and regional water management objectives. The primary value of additional information would be to better understand net exchange between the surface and groundwater systems and the individual fluxes contributing to net exchange.

The approach to improve confidence in estimates of interactions between the surface water and groundwater systems is complementary with objectives for closing information gaps related to surface hydrology. By increasing information describing surface water outflows from water use areas, water balances could be refined to allow for improved estimation of net recharge. The primary sources of uncertainty in estimating surface water-groundwater exchange are surface water outflows at the supplier and regional scales. Following improvements to the estimates of net recharge, the contributions of individual surface water-groundwater fluxes could be refined through investigations of canal seepage and gains and losses in streams and drains and through field-scale water balances to better estimate deep percolation resulting from irrigation and precipitation.

2.7 *Irrigation, Drainage, and Flood Control Facilities*

2.7.1 Irrigation Facilities

Water diversion and conveyance infrastructure in the region tends to be relatively similar in nature, although there are some notable differences between the water suppliers in the northern part of the region that receive the water through the Thermalito Afterbay and facilities and in the southern part of the region that divert water directly from the Feather River. Water delivered to suppliers from Thermalito Afterbay is exclusively via gravity flow with no pumping required and no direct influence on Feather River flows downstream of Lake Oroville. Diversions along the Feather River use pumps to lift water from the river for conveyance through distribution systems via gravity.

Within water supplier distribution systems, a majority of the water diverted is conveyed via gravity, although some suppliers lift water using pumps where necessary to deliver water to higher elevation portions of their service areas. Most of the canals in the region are unlined due to relatively low permeability soils that limit seepage. FWD, TMWC, and GHMWC in the Lower Feather subarea deliver water by gravity through concrete pipelines and lined ditches to varying extents.

Canal automation exists to varying degrees among water suppliers within the region. Deliveries to individual fields are typically made through laterals constructed to allow for gravity flow wherever possible with pumping used to provide deliveries only when gravity flow is infeasible. Measurement of deliveries to individual fields has increased in recent years with the three largest Feather River water suppliers already implementing or in the process of implementing measurement plans to allow for measurement of all individual deliveries to meet CWC requirements.

Local irrigation and drainage facilities are described in greater detail in Volume II, Sections 3 through 8 of this AWMP.

2.7.2 Drainage Facilities

Extensive networks of drains in the region convey direct precipitation, runoff of precipitation and tailwater, and shallow groundwater interception away from fields. The majority of the drains are managed by reclamation districts, drainage districts, or private growers, although some drains are maintained by water suppliers. Suppliers and individual water users take measures to recapture drainwater for reuse through a combination of gravity flow where possible and pumped flow where required. Water in drains that is not recaptured either seeps into the ground in certain locations and at certain times to recharge the underlying aquifer or is available for use by downstream water users. Reuse is extensive throughout the region. Some water users, particularly in the southern subareas of the region, are heavily dependent on drain flows from upstream water use areas. Water supplier irrigation and drainage facilities are described in detail in Volume II, Sections 3 through 8 of this AWMP.

2.7.3 Flood Control Facilities

Flood control within the region is accomplished through operation of Lake Oroville, the Sutter Bypass, and related facilities by DWR and others. Regional drainage networks operated by drainage districts, reclamation districts, and others provide localized flood control and also provide drainage of surface runoff from irrigation and shallow groundwater relief. A detailed evaluation of flood control within the region is not included as part of this regional AWMP. A detailed assessment of flood management priorities within the region and the Central Valley as a whole is provided in the Draft Feather River Regional Flood Management Plan (YCWA et al. 2014) and the 2012 Central Valley Flood Protection Plan (DWR 2011).

Lake Oroville is operated by DWR to reserve storage for collection of storm runoff from the upper Feather River watershed to allow for measured releases to prevent downstream damage. Reservoir operators must balance the need to anticipate potential storm inflows while retaining stored water to meet demands by Feather River water suppliers and SWP contractors.

The Sutter Bypass was built in the 1920's by the State of California to provide an overflow for Sacramento River flood flows during the winter and to provide a source of irrigation water for agriculture during the growing season (DWR 1976). The bypass conveys the majority of Sacramento River flood flows north of Sacramento during flood years, while also collecting and conveying flood flows originating in the Butte Basin north of the Sutter Buttes via Butte Creek and the Wadsworth Canal. The bypass and associated facilities include canals, levees, borrow pits, weirs, and pumping plants that have been improved over time to continue to provide intended functions while also providing improved habitat conditions for migratory fish. As originally built, facilities within the bypass were detrimental to fish migration.

During flood years, winter flows into the bypass from the Sacramento River are large relative to other flows through the region, masking the effects of water management for agriculture and managed habitat. In order to evaluate water management within the region, these effects are minimized in the water balance analysis described in Section 4 of this volume by focusing on the primary irrigation season (April – September) and years without substantial flood flows.

Flood control in PMWC east of the Feather River is provided by Reclamation District 784 (RD784). RD784 was established in 1908 and provides flood protection east of the Feather River from the Yuba River in the north to the Bear River in the South. RD784's eastern boundary is the Western Pacific Interceptor Canal east of Highway 70.

2.8 Rules and Regulations Affecting Water Availability

Each agricultural water supplier within the region possesses its own operating rules and regulations and/or bylaws, accompanied by associated policies. These protocols are described in greater detail for Feather River Water Suppliers in Volume II, Sections 3 through 8 of this regional AWMP. Additional information regarding water users diverting from the Sacramento River can be found in the SVRWMP (SRSC 2006).

In general, operating rules and regulations of the Feather River suppliers include policies on water allocation, water usage, required fees and charges, timing of water deliveries, and water transfers into or out of each supplier's service area. The operating rules and regulations vary to some extent based on the organization of individual suppliers. For example, water districts formed under Chapter 11 of the CWC have policies and procedures that are determined by a board of directors who require the districts to hold a certain amount of money in reserve, but mutual water companies have policies and procedures that are determined by a board of trustees.

The Feather River is the primary source of surface water in the region, and the SWP played a major role in development of reliable surface water supplies. Agreements with the State were made by those diverting water from the Feather River prior to construction of the SWP, and various institutional and regulatory actions have been taken following the construction of the project that affect operations of the Feather River by DWR and individual Feather River water users. Each has the right to divert certain amounts of water, subject to reduction under certain conditions.

In the event of a water shortage and reduced surface water availability, there is not a proportional decrease in irrigated acreage. A common response within areas of the region relying on surface water in reduction years is to increase groundwater production through private pumping to supplement reduced surface water supplies, to the extent possible. In water shortage years, groundwater well construction has historically increased, as described in Section 2.6.2.3. The most recent shortages occurred in 1991 and 1992 when surface water diversions from the Feather River were generally reduced by 50 percent; increased groundwater well development also occurred in 2009 after three successive years of dry or critically dry conditions. Butte Creek, which is another important waterway in the region, is adjudicated upstream of the WCWD siphon, and accounting for and measuring diversions under established water rights is mandatory and enforced by the DWR watermaster.

Groundwater is a critical source of water supply in the region for areas that rely exclusively on groundwater and important in areas that rely on groundwater as a supplemental water source. Historically, groundwater in California has been managed through locally-controlled programs instead of through statewide regulations. In general, groundwater use is not as strictly regulated as surface water use.

An important act of legislation regarding groundwater was Assembly Bill 3030 (AB3030), which was passed in 1992. AB 3030 authorized existing local water service agencies to develop groundwater management plans (GMPs) and encouraged cooperative groundwater management within basins. Then, in 2002, Senate Bill 1938 (SB1938) was passed to further advance groundwater management planning. SB1938 amended the CWC to require that GMPs include additional components to be eligible for DWR grant funding for construction of groundwater projects. Agencies within the Feather River region that have prepared and adopted GMPs include BWGWD, BWD, FWD, RD1004, RID, SEWD, and WCWD. Additionally, the counties of Butte, Colusa, Glenn, Sutter, and Yuba have prepared and adopted GMPs. All county plans and some supplier plans are compliant with SB1938. The GMPs identify management goals and basin management objectives (BMOs) and outline implementation plans. The counties in the region have also developed GMPs to manage groundwater in areas outside of the service areas of suppliers with adopted GMPs. In some cases, counties have adopted groundwater management ordinances that outline steps necessary to perform a transfer of groundwater or surface water forgone as a result of groundwater substitution. Topics considered in these ordinances include groundwater overdraft, land subsidence, and potential effects on long-term groundwater storage. Additional groundwater ordinances that address issues such as well spacing and health and safety issues have been adopted by some counties.

2.9 *Water Measurement, Pricing, and Billing*

2.9.1 Water Measurement

Water measurement is practiced throughout the region and varies depending on location and conditions. All water suppliers practice diversion measurement for water accounting and to manage available water supplies efficiently and effectively. Water measurement within supplier service areas typically occurs at the distribution system level (i.e. measurement of diversions at the head of the distribution system and/or key outflows from the system), at key operational sites (i.e. at lateral headings or division points), and/or at individual delivery locations to fields. Water measurement practices vary among suppliers and are influenced by factors including the type of distribution system, irrigation methods employed, cropping, contractual/regulatory measurement requirements, and operational benefits and costs associated with measurement intensity.

In 2009, California State Legislature passed Senate Bill x7-7 (SBx7-7) mandating new customer delivery measurement requirements for agricultural water suppliers. DWR was responsible for developing and adopting regulations pursuant to SBx7-7. In July 2012, DWR's agricultural water measurement regulation, enacted as California Code of Regulations Title 23 Division 2 Chapter 5.1 Article 2 Section 597 et seq. (CCR 23 §597), was approved. CCR 23 §597 requires that, on or before July 31, 2012, agricultural water suppliers subject to the law shall measure the volume of water delivered to customers with sufficient accuracy to:

- Enable reporting of aggregated farm-gate delivery data to the State and
- Adopt a pricing structure based at least in part on the quantity of water delivered.

This regulation has had a substantial influence on customer delivery measurement in the region, as WCWD, RID, and BWGWD are mandated by law to comply, regardless of the availability of funding. WCWD has historically implemented a customer delivery measurement program that satisfies the requirements. BWGWD and RID have performed an evaluation of customer delivery measurement options and have selected compliant measurement devices. BWGWD is the process of implementing their delivery measurement and a pricing structure based at least in part on the quantity of water delivered. The District is waiting on the necessary permits to begin construction to improve their delivery infrastructure allowing for measurement. Permitting is expected to be complete by summer 2021 with construction being complete in 2022. RID has measured farm deliveries since 2014. In 2017, the District adopted a rate structure and began billing based on the volume delivered thus satisfying the delivery measurement and volumetric billing requirement in the CWC. For further information see Volume II, Sections 3 and 5, respectively.

Table 2.3 summarizes measurement practices for each of the Feather River agricultural water suppliers, including measurement locations and methods. More detailed information describing each of the Feather River supplier's measurement practices can be found in Volume II, Sections 3 through 8 of this AWMP.

2.9.2 Water Pricing and Billing

Water pricing structures can be used to influence water usage, address issues or concerns, and promote management objectives; however, potential consequential effects within or downstream of water supplier service areas should be considered in developing pricing structures and rates.

Existing water supplier pricing structures within the region are influenced by several factors such as external influences on water pricing, operating costs, typical demands based on cropping and irrigation methods, and historical precedent. Water suppliers typically establish rates to recover administrative, O&M, and long-term capital improvement costs. Pricing structures often include a stand-by charge regardless of water usage, and one of the following additional charges:

- Per-acre: Rate per acre per season. This charge may be the same for all crops or vary by crop type and can vary between the primary irrigation season and winter water season.
- Per irrigation: Rate per acre per irrigation event. A charge may be applied to each scheduled irrigation event. Rates may be the same for all crops or vary by crop type. The rate may also vary by time of year or based on the number of irrigations requested. In some cases, the first irrigation event of the season has an initial cost followed by a lesser cost for subsequent irrigation events. In other cases, a pre-determined number of irrigation events have a lesser cost with additional irrigation events at a greater cost.
- Per acre-foot: Rate per af delivered. This charge applies directly to the measured volume of water delivered.

Feather River agricultural water suppliers use a combination of the water pricing structures outlined above. For example, a pricing structure could include a stand-by charge with an additional per af charge based on actual water usage. All of the three water pricing structures summarized above are currently used by Feather River water suppliers. Water pricing structures and water rates corresponding to individual Feather River suppliers are described in greater detail in Volume II, Sections 3 through 8 of this regional AWMP. As a result of CCR 23 §597, required suppliers who do not already have a pricing structure based in part on delivery amount are developing pricing structures based in part on the volume of water delivered to individual turnouts.

Table 2.3. Summary of Feather River Supplier Measurement Practices.

Water Supplier	Measurement Locations and Methods
BWGWD	Diversions to the main canal are measured by an acoustic Doppler flowmeter. Other diversions and lateral headings are typically estimated using gate position and stage. Key drain outflows and operational spills are measured using stage and weir geometry. Deliveries at field turnouts are in the process of being estimated, or measured using a portable flowmeter that records flow rate as of 2014.Pumped deliveries will have totalizing flowmeters.
BWD	Diversions are estimated by difference of inflows to the Sutter-Butte Canal and combined deliveries to others and return flows to the Feather River via Cox Spill. Lateral headings are typically estimated using gate position and stage. Deliveries at field turnouts are estimated. Groundwater wells and drainwater recovery pumps are typically metered.
RID	Diversions from Thermalito Afterbay to the Main Canal are measured at a USGS gaging station, which measures both flow rate and volume. Diversions through the Minderman Canal are measured by a flowmeter, which measures both flow rate and volume. Lateral headings are typically estimated using gate position and stage. Main Drain outflows are measured using stage and gate position. Deliveries at field turnouts are measured using a portable flowmeter that records flow rate as of 2014.Pumped deliveries have totalizing flowmeters installed.
SEWD	Diversions from Thermalito Afterbay are measured by a flowmeter that measures both flow rate and volume. Sunset Pump diversions are metered. Lateral headings are typically estimated using gate position and stage. Deliveries at field turnouts are typically estimated using gate position and stage. Groundwater wells and recovery pumps are metered or estimated. SEWD currently meters both district wells and recovery pumps. Recovery pumps are measured to comply with SB88.
WCWD	Diversions from Thermalito Afterbay are measured at USGS gaging stations, which measure both flow rate and volume. Key points along the Main Canal are typically measured using gate position and stage. Lateral headings are typically estimated using gate position and stage. Key drain outflows and operational spills are typically measured using stage and weir geometry. Deliveries at field turnouts are measured using propeller-type flowmeters that measure both flow rate and volume.
Feather WD	Diversions are measured by flowmeters that measure both flow rate and volume. Flows at key control points are typically estimated using stage. Groundwater wells and drainwater recovery pumps are metered or estimated based on power usage. Deliveries at field turnouts are measured using propeller flowmeters that report both flow rate and cumulative volume.
Garden Highway MWC	Diversions are measured by flowmeters that measure both flow rate and volume. Groundwater wells and drainwater recovery pumps are metered or estimated. Deliveries at field turnouts are typically estimated using gate position and stage. Some pumped deliveries are measured using flowmeters.
Plumas MWC	Diversions are measured by flowmeters that measure both flow rate and volume. Groundwater wells are metered or estimated based on power use. Deliveries at field turnouts are typically estimated using flow meters or gate position and stage.
Tudor MWC	Diversions are measured by flowmeters that measure both flow rate and volume. Groundwater wells are metered or estimated based on power usage. Deliveries at field turnouts are measured using flowmeters that record both flow rate and volume.

3 Regional Water Balance

3.1 *Overview*

This section describes the various uses of water within the Feather River Region between 1999 and 2012. The water balance quantifies all substantial inflows to and outflows from the region on a water year basis (October – September). The period from 1999 to 2012 depicts recent changes in water management within the region as well as current management conditions. Key drivers of water management variability across years include precipitation timing and amounts, which affect the amount of the surface water available; the potential for voluntary water transfers based on crop idling and/or groundwater substitution; and the amount of groundwater pumping occurring to meet demands. Limited supplies in surface water shortage years are a strong water management driver but occur infrequently for the primary water suppliers in the region, though none occurred during the 1999 to 2012 period. It is anticipated that the regional water balance will be updated to include recent years during the 2025 plan update.

The remainder of this section includes the following subsections:

- Analytical Approach – Description of mass balance approach for water balance analysis, methodologies for estimation of individual flow paths, and uncertainty in flow path estimates;
- Water Uses – Description of water use for agricultural, environmental and recreational, municipal and industrial, groundwater recharge, and transfer and exchange purposes;
- Drainage – Description of drainage occurring within and flowing from the region; and
- Water Accounting (Water Balance Summary) – Summary of annual and monthly inflows to and outflows from the region, including a discussion of existing water management and performance.

3.2 *Analytical Approach*

For the Regional water balance a total of 26 individual flow paths are estimated, along with the change in surface storage over time. A schematic of the water balance structure is provided in Figure 3.1.

3.2.1 Mass Balance

In general, flow paths are quantified on a monthly basis. Water volumes associated with certain flow paths are estimated independently based on measured data or calculated estimates, and the remaining flow is then calculated based on the principal of conservation of mass (Equation 3.1), which states that the difference between total inflows to and total outflows from the region for a given period of time is equivalent to the change in stored water within the region. For the region, the monthly change in storage varies, reflecting changes in the volume of water ponded in rice and managed wetlands areas as well as changes in soil moisture stored in the root zone. Over the course of a year the change in storage across the region is expected to be near zero.

$$Inflows - Outflows = Change\ in\ Storage\ (monthly\ time\ step) \qquad [3.1]$$

The flow path that is calculated using Equation 3.1 is referred to as the "closure term" because the mass balance equation is solved for or "closed" on the unknown quantity. The closure term is selected based on consideration of the availability of data or other information to support an independent estimate as well as the volume of water representing the flow path relative to the size of other flow paths. Generally speaking, the largest, most uncertain flow path is selected as the closure term.

3.2.2 Flow Path Estimation and Uncertainty

Individual flow paths were estimated based on direct measurements or based on calculations using measurements and other available data. As described previously, those flow paths not estimated independently were calculated as the closure term of each accounting center.

The analysis results for each flow path are reported with a high level of precision (nearest whole acre-foot) that implies a higher degree of accuracy than is actually justified. The estimated percent uncertainty (approximately equivalent to a 95 % confidence interval) in each measured or calculated flow path has been estimated as part of the water balance analysis. Based on the relative magnitude of each flow path, the resulting uncertainty in each closure term can be estimated by assuming that errors in estimates are random (Clemmens and Burt 1997). Errors in estimates for individual flow paths may cancel each other out to some degree, but the combined error due to uncertainty in the various estimated flow paths is ultimately expressed in the closure term.

For the regional water balance, shallow groundwater interception was calculated as the closure term. Groundwater level monitoring data and field observations suggest that the shallow groundwater system and regional aquifer are coupled within portions of the region at certain times (See Figures 2.12 and 2.13 and additional discussion in Section 3.3.4). Shallow groundwater interception includes shallow groundwater seeping into drains as well as evapotranspiration by native vegetation and to some extent non-ponded crops. Uncertainty in the absolute magnitude of shallow groundwater interception is relatively large due to being small as compared to other flow paths used to estimate it.

Table 3.1 lists each flow path included in the water balance indicating whether it is an inflow or an outflow; whether it was measured or calculated; the supporting information and assumptions used to determine it; the estimated uncertainty, expressed as a percent; and average values for the period of analysis. Results for both the full water year and for the primary irrigation season (April to September) are provided. As indicated, estimated uncertainties vary from 5 to 100 percent of the average volume for the irrigation season, with uncertainties generally being less for measured flow paths and greater for calculated flow paths.

The estimated uncertainty of the closure term is also shown. As indicated, the estimated uncertainty in shallow groundwater interception 170 percent for the water year as a whole and 72 percent for the irrigation season. The large uncertainty for the full water year results in large part from the inclusion of winter flood flows from the Sacramento River into and out of the region, which are approximately 2 million af, on average. By focusing on the irrigation season, the uncertainty is reduced to 72 percent, which remains relatively large due to uncertainties in other flow paths such as groundwater pumping, crop evapotranspiration, deep percolation, and surface outflows.

Despite the large calculated uncertainty in shallow groundwater interception, independent evidence supports the finding that there is shallow groundwater interception in the region. This evidence includes observations of accretions in streams, drains, and canals; observed groundwater levels in wells less than 10 feet below the surface over much of the region; and estimates from other modeling efforts such as the USGS Central Valley Hydrologic Model (CVHM) (Faunt 2009).

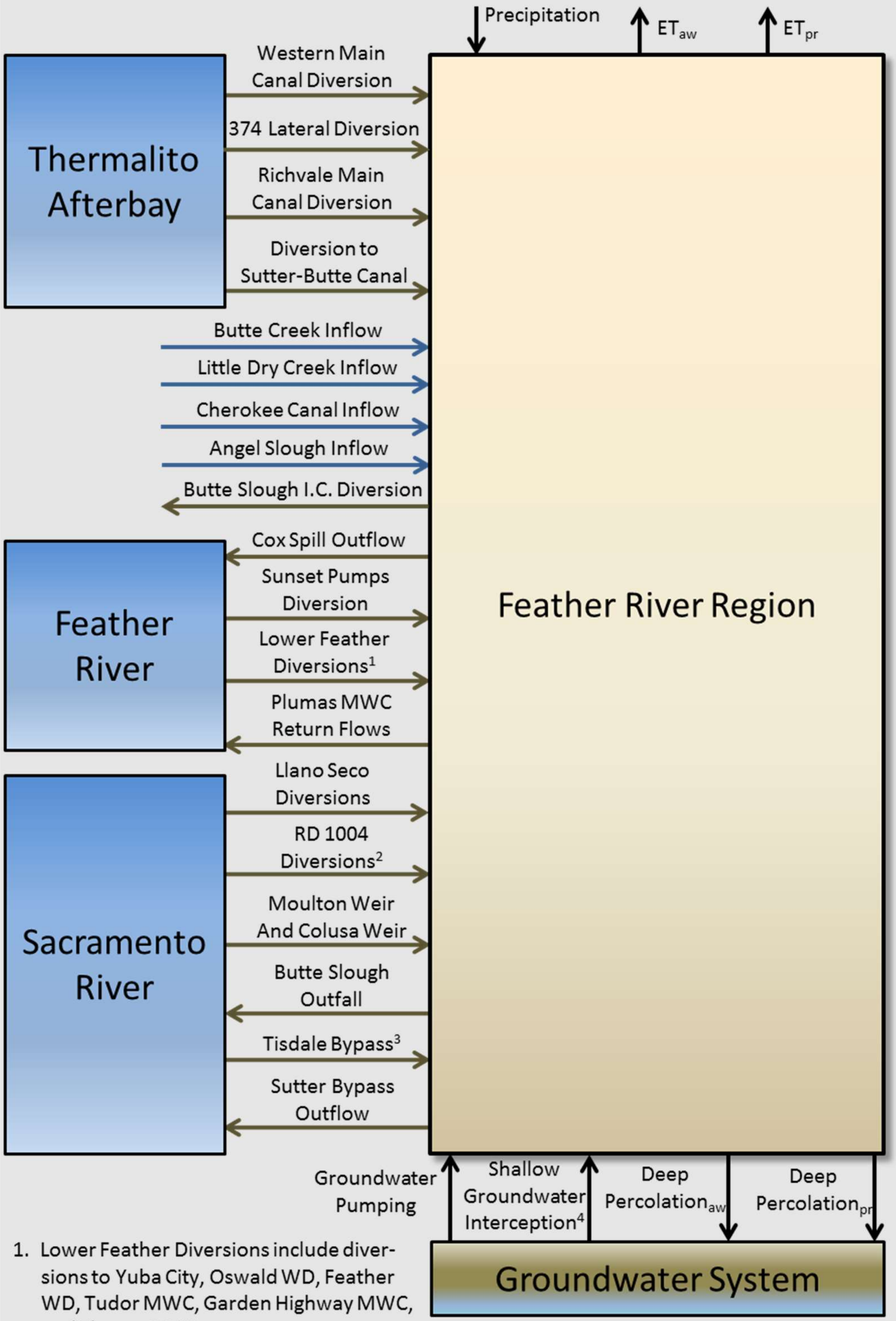
3.3 Water Uses

Water uses in the region include agricultural irrigation water; environmental uses to create, maintain, and enhance wetlands and aquatic habitat; and domestic use in developed and rural residential areas. These water uses are described in greater detail in the remainder of this section.

3.3.1 Agricultural

Between 1999 and 2012, there were an average of 306,000 cropped acres within the region, plus an average of 18,000 additional acres of fallow or idle land. Table 3.2 and Figure 3.2 present estimated agricultural acreages for this period. Total agricultural acreage varies somewhat from year to year due to changes in areas of native vegetation and rural residential and urban development.

The main crop grown in the region is rice, which was grown on an average of 183,000 acres between 1999 and 2012, representing 60 percent of the total cropped area or 57 percent of the irrigable area. Permanent orchard crops, primarily prunes and walnuts, were grown on an average of 88,000 acres or 29 percent of total cropped area during this period. A variety of other crops including assorted field and truck crops, pasture, hay, and grains were grown on the remaining land, accounted for an average of 34,000 acres or 11 percent of the total irrigable area. The acreage of these other crops has decreased over time from more than 40,000 acres in the early 2000’s to around 28,000 acres in recent years.



1. Lower Feather Diversions include diversions to Yuba City, Oswald WD, Feather WD, Tudor MWC, Garden Highway MWC, and Plumas MWC.
2. RD 1004 Diversions also includes diversions to Colusa Properties and Sartain MWC.
3. In some instances, reverse flows can occur in Tisdale Bypass.
4. Includes seepage from and accretions to canals, drains, and streams.

Figure 3.1. Water Balance Structure.

Table 3.1. Water Balance Flow Paths, Supporting Data, and Estimated Uncertainty.

Flow Path Type	Flow Path	Source	Supporting Data	Water Year (Oct. - Sept.)		Irrigation Season (Apr. - Sept.)	
				Average Volume (af)	Estimated Uncertainty (%)	Average Volume (af)	Estimated Uncertainty (%)
Inflow	Western Main Canal Diversion	Measurement	USGS Measurement Gage 11406880	304,192	5%	223,986	5%
	Richvale Main Canal Diversion	Measurement	USGS Measurement Gage 11406890	147,234	5%	96,232	5%
	374 Lateral Diversion	Measurement	USGS Measurement Gage 11406900	3,911	5%	3,179	5%
	Diversion to Sutter-Butte Canal	Measurement	USGS Measurement Gage 11406910	578,971	5%	423,162	5%
	Sunset Pumping Station Diversion	Measurement	SEWD Operational Data	6,631	10%	6,631	10%
	Yuba City Diversion	Measurement	Butte Basin Groundwater Model Documentation; Yuba City Urban Water Management Plan	16,199	15%	10,916	15%
	Oswald WD Diversion	Measurement	DWR Bulletin 132	831	5%	794	5%
	Feather WD Diversion	Measurement	USBR Reporting	9,575	5%	9,514	5%
	Tudor MWC Diversion	Measurement	DWR Bulletin 132	3,273	5%	3,179	5%
	Garden Highway MWC Diversion	Measurement	DWR Bulletin 132	14,910	5%	13,279	5%
	Plumas MWC Diversion	Measurement	DWR Bulletin 132	9,731	5%	9,194	5%
	Butte Creek Inflow	Calculation	California Water Data Library Butte Creek near Durham site A04265	244,621	10%	82,867	10%
	Little Dry Creek Inflow	Calculation	Correlation to Big Chico Creek near Chico based on Butte Basin Groundwater Model	6,251	25%	1,993	25%
	Cherokee Canal Inflow	Calculation	Correlation to Big Chico Creek near Chico based on Butte Basin Groundwater Model	51,723	25%	16,489	25%
	Angel Slough Inflow	Calculation	Correlation to Big Chico Creek near Chico based on Butte Basin Groundwater Model. Monthly pattern adjusted based on monthly flows at Butte Slough near Meridian.	40,922	25%	10,463	25%
	Llano Seco Diversions	Measurement	Butte Basin Groundwater Model average monthly diversions	6,141	25%	5,407	25%
	RD1004 Diversions	Measurement	USBR Central Valley Operations Monthly Delivery Reports. Winter diversions based on percent of Apr-Sept diversions by month and year for Feather districts.	96,149	5%	66,786	5%
	Moulton Weir	Measurement	Moulton Weir California Water Data Library Site A02986	33,124	15%	5,018	15%
	Colusa Weir	Measurement	Colusa Weir California Water Data Library Site A02981	679,016	15%	105,604	15%
	Tisdale Bypass	Measurement	Tisdale Weir California Water Data Library Site A02960	578,357	15%	101,239	15%
	Precipitation	Calculation	Area-weighted average of precipitation stations at Nicolaus, Marysville, Oroville, Chico University Farm, and Colusa.	769,795	15%	112,966	15%
	Groundwater Pumping	Calculation	Estimated demand for groundwater only area based on ET estimates, DWR land use surveys and groundwater use information from districts.	302,295	25%	246,751	25%
	Shallow Groundwater Interception	**Closure**	**Estimated based on closure of annual balance and distributed based on monthly trends.**	**244,711**	**170%**	**246,096**	**72%**
Outflow	Cox Spill Outflow	Measurement	Joint Water Districts Board Measurement Site	8,620	10%	7,458	10%
	Plumas MWC Return Flows	Calculation	Estimated as 15 percent of Plumas MWC diversions	1,460	35%	1,379	35%
	Butte Slough Irr. Co. Diversions	Calculation	Estimated based on service area west of Sutter Bypass, total water right, and monthly diversion pattern by RD1004.	17,361	20%	12,047	20%
	Butte Slough Outfall	Measurement	Prior to 2005, California Water Data Library Site A02967; 2005 – 2012 based on multivariate linear regression to surface inflows. Monthly pattern after 2005 adjusted to reflect minimized summer outflows to prevent fish attraction.	163,918	15%	32,806	15%
	Sutter Bypass Outflow	Measurement	California Water Data Library site A02925 (Sacramento Slough near Karnak) minus site A02926 (R.D. 1500 Drain to Sacramento Slough near Karnak). Data gaps and flagged values filled based on monthly linear regression to site A02972 (Butte Slough near Meridian). Adjusted to account for unmeasured flood flows from large storm events.	1,828,880	15%	430,167	15%
	ET of Applied Water	Calculation	CIMIS reference ET; estimated crop coefficients based on SEBAL 2009 analysis; crop acreages from District records, DWR land use surveys, and agricultural commissioner crop reports; Integrated Water Flow Model Demand Calculator (IDC) analysis to divide total ET into applied water and precipitation components	1,054,379	10%	811,606	10%
	ET of Precipitation	Calculation		319,094	10%	195,499	10%
	Deep Percolation of Applied Water	Calculation	IDC analysis, NRCS soils characteristics, CIMIS precipitation data, Integrated Water Flow Model Demand Calculator (IDC) analysis to divide total deep perc. into applied water and precipitation components	590,292	35%	328,326	35%
	Deep Percolation of Precipitation	Calculation		164,877	35%	54,804	35%
NA	Change in Storage	Calculation	IDC analysis	-317	100%	-72,348	50%

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Crop evapotranspiration (ET) was estimated using a crop coefficient approach similar to that described by Allen et al. (1998), whereby estimated crop- and time-specific water use coefficients were multiplied by reference ET (ET_o) to calculate the total consumptive use of water for the region over time. Crop coefficients specific to the Sacramento Valley were developed based on actual ET estimates from a remote sensing analysis using the Surface Energy Balance Algorithm for Land (SEBAL, Bastiaanssen et al. 2005) developed through a prior study conducted for DWR. The analysis used ground and satellite data to compute actual ET from March to September 2009 for individual 30-meter satellite pixels within Glenn and Colusa counties. Spatially distributed cropping data from DWR land use surveys for the counties developed for 2009 were combined with quality-controlled reference evapotranspiration (ET_o) from CIMIS to calculate crop coefficients representing actual ET over the course of the growing season[10]. A map showing growing season (March – September) ET estimates for the region from SEBAL for 2009 is provided in Figure 3.3. As shown, ET tends to be greatest in areas of rice production and wetland areas such as the Butte Sink and least in areas of upland native vegetation (such as the Sutter Buttes) and urban development.

Table 3.2. Regional Crop and Idle Acres, 1999-2012.

	Agricultural Acreage by Type					
Year	**Rice**	**Orchards**	**Other**	**Idle**	**Total Cropped**	**Total with Idle**
1999	178,930	92,785	48,390	12,739	320,105	332,844
2000	182,759	92,380	43,097	12,632	318,236	330,868
2001	173,852	86,855	42,182	25,774	302,890	328,664
2002	180,837	85,283	42,265	18,665	308,385	327,050
2003	175,806	85,543	38,256	26,241	299,604	325,845
2004	187,824	86,204	33,634	15,026	307,662	322,688
2005	183,834	84,486	33,247	21,140	301,567	322,708
2006	185,668	86,034	29,685	20,354	301,386	321,740
2007	186,938	86,782	30,139	17,866	303,859	321,725
2008	182,849	87,994	30,706	21,746	301,549	323,295
2009	188,824	87,215	27,748	15,749	303,788	319,537
2010	183,814	88,695	27,210	19,852	299,719	319,571
2011	190,157	87,534	27,745	11,914	305,436	317,350
2012	184,758	90,481	27,862	14,793	303,101	317,894
Average	**183,346**	**87,734**	**34,440**	**18,178**	**305,520**	**323,698**

[10] Ideally, the crop coefficient analysis would have included portions of Butte, Sutter, and Yuba counties within the region; however, DWR land use surveys were not available for 2009 for these counties. Crop coefficients developed for Glenn and Colusa counties are expected to be reasonably representative of the region as a whole.

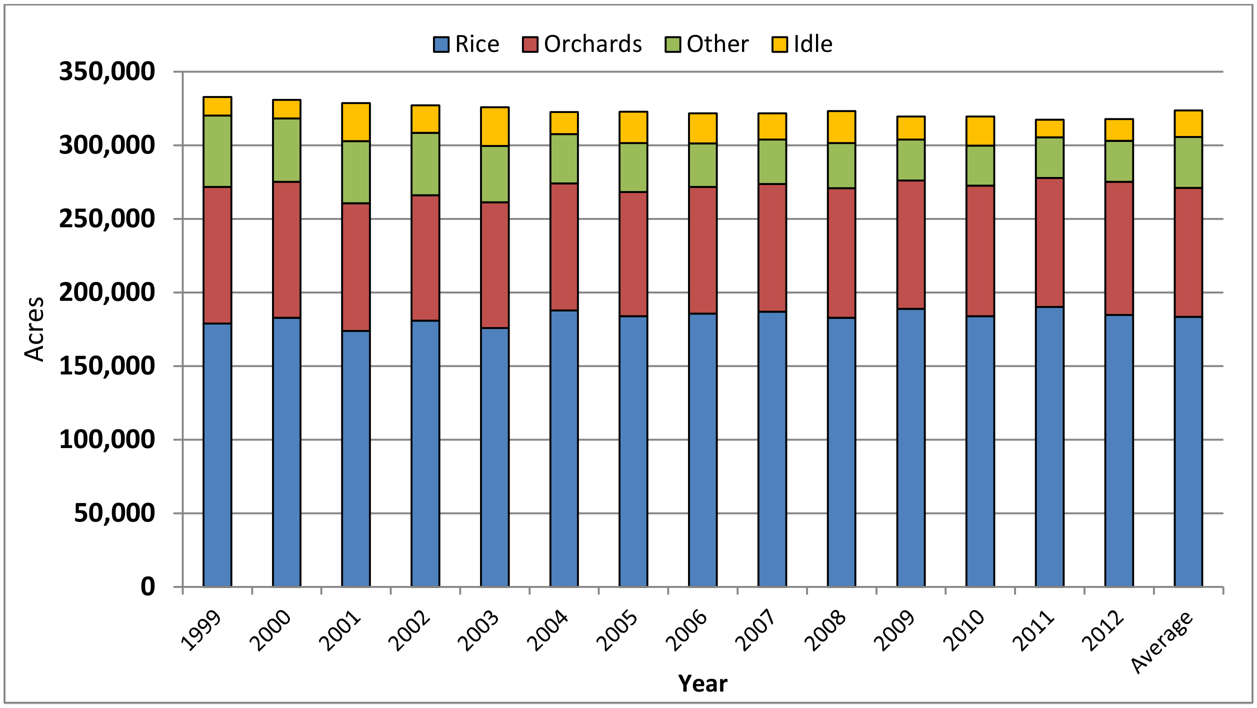

Figure 3.2. Crop and Idle Acres, 1999-2012[11].

A root zone water balance simulation was developed for each crop using the Integrated Water Flow Model (IWFM) Demand Calculator (IDC) Version 4.0 to estimate the portions of total ET derived from applied water (ET_{aw}) and from precipitation (ET_{pr}). ET values for each crop, expressed in units of acre-feet per acre were multiplied by the corresponding acreage in each year to compute total water volumes consumed for agricultural purposes. IDC was additionally used to estimate deep percolation, which was also divided into portions derived from applied water and precipitation.

As noted previously and discussed in detail later in this section, there is evidence of shallow groundwater interception in the region, which is manifest in accretions to streams, canals, and drains as well as consumption by crops and native vegetation. The estimates of ET_{aw} include shallow groundwater interception, to the extent that it occurs in agricultural areas.

[11] Total acres vary somewhat from year to year reflecting estimated changes in total irrigable acres resulting from rural development and changes in areas of native vegetation.

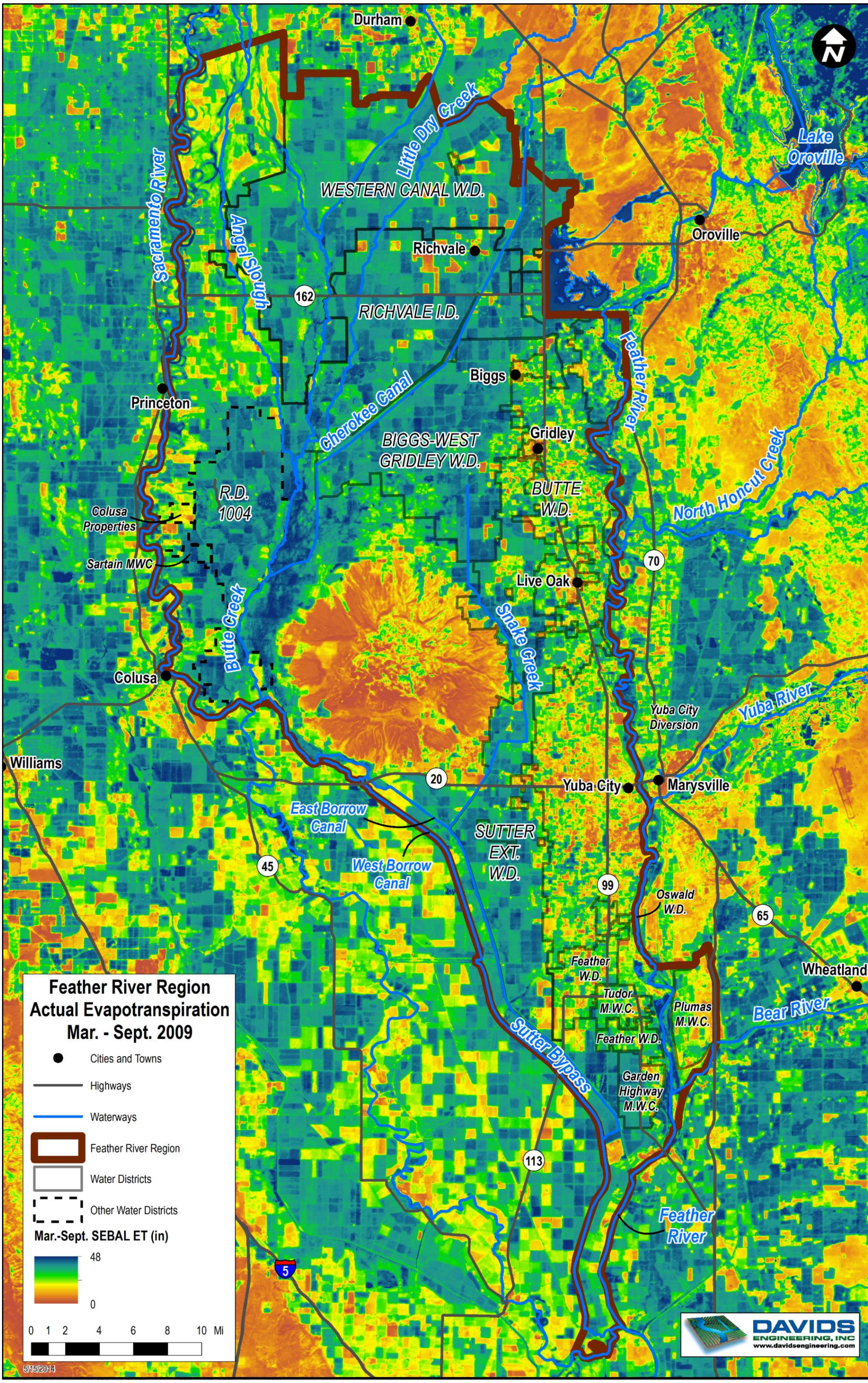

Figure 3.3. Regional March to September 2009 SEBAL Actual ET.

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For rice, precipitation occurring during the irrigation season runs off of the fields when fully ponded and is not available to contribute to crop ET. Rice ponds are typically maintained to allow some water flow through them, so there is little or no storage capacity to hold precipitation. Outside the growing season, precipitation that does not run off or deep percolate and is stored in the soil is available for extraction during the growing season. A summary of rice water management practices in the region is provided below under Rice Water Management (Section 3.3.1.1).

For non-ponded crops, precipitation entering the soil may be stored and available to support crop ET, or it may leave the root zone as deep percolation. One result of the differences in irrigation and cultural practices between rice and non-ponded crops is that ET_{pr} is significantly less for rice as a percentage of total ET. This results from the greater opportunity to utilize available precipitation to support crop growth for non-ponded crops. A summary of water management practices for other crops grown in the region is provided below under Other Crop Water Management (Section 3.3.1.2).

The monthly consumptive use of water for agricultural lands in the region ranges from approximately 1 inch of total ET in December and January to approximately 7 inches in June and July. A majority of ET is derived from applied water, and ET_{aw} ranges from approximately 1 inch in December and January to over 6 inches in July. The average monthly consumptive use of water is presented in Figure 3.4.

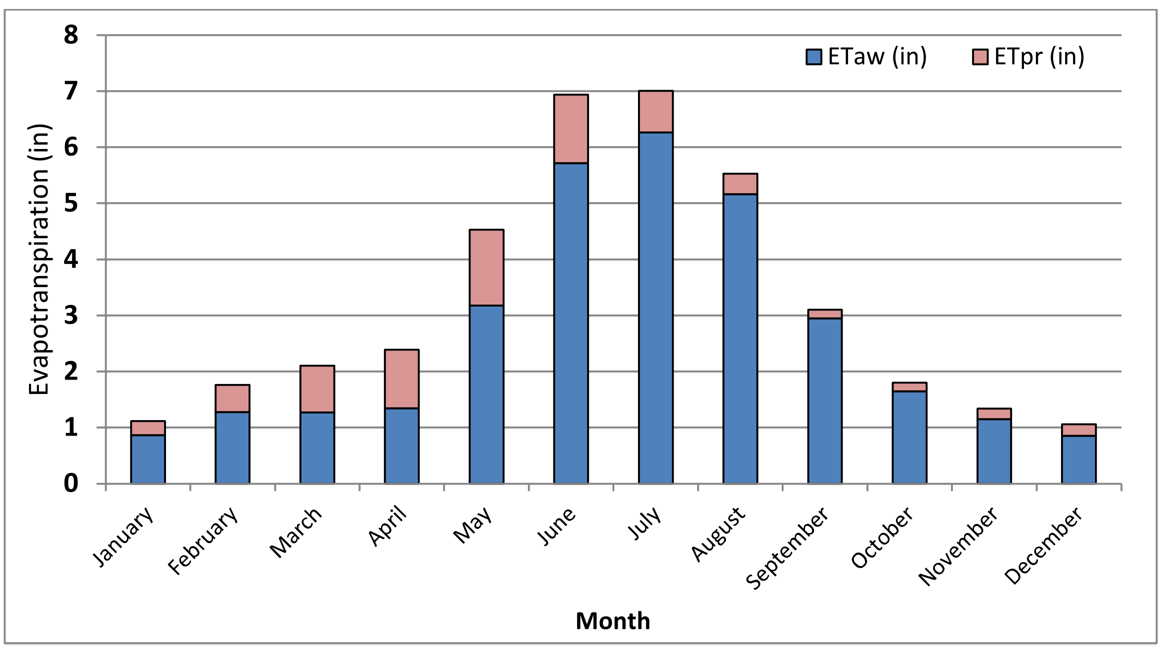

Figure 3.4. Average Monthly Consumptive Use of Water for Agricultural Lands.

The annual consumptive use of water by crops in the region is approximately 45 inches of total crop ET for rice, approximately 35 inches for orchard crops, and approximately 32 inches for other crops (Table 3.3). ET_{aw} ranges from approximately 20 inches to 40 inches for the cropped area. For rice, approximately 40 inches of the 44 inches of total ET are derived from applied irrigation water. For orchards and other crops, approximately 23 and 20 inches of total ET, respectively, are derived from applied irrigation water. On average, approximately 31 inches of 39 inches of total ET are derived from applied irrigation water.

Table 3.3. Average Acreages and Annual Evapotranspiration Rates for Agricultural Lands.

Crop	Average Acres	Average Evapotranspiration (in)		
		ET_c	ET_{aw}	ET_{pr}
Rice	183,346	44.9	40.4	4.5
Orchards	87,734	35.3	22.7	12.6
Other	34,440	31.5	20.3	11.2
Idle	18,178	10.9	0.0	10.9
Totals	**305,520**	**38.9**	**31.2**	**7.7**

ET_c and ET_{aw} vary from year to year primarily due to differences in atmospheric water demand (ET_o) and differences in the timing and amount of precipitation available to support crop growth and offset crop irrigation requirements. Changes in crop acreages also influence annual ET volumes over time.

The total annual volume of ET varied between approximately 1.30 million af and 1.44 million af during the 1999 to 2012 period, with an average annual volume of 1.37 million af. On average, approximately 1.05 million af of ET were derived from applied irrigation water (77% of total ET) and 0.32 million af of ET were derived from precipitation (23% of total ET).

Other, non-consumptive uses of applied irrigation water include rice decomposition; wildlife habitat for waterfowl, shorebirds, and other species; leaching of salts; and frost protection for orchard crops. Water use for rice decomposition and habitat is discussed in the following section. Due to the generally low salinity of groundwater in the region and the use of surface water where available, the required leaching fraction is small and has not been estimated as part of this plan. Water applied for frost protection is typically a minor use and has not been estimated at this time.

3.3.1.1 Rice Water Management

Water management practices for rice and other crops in the region are described in the report "Efficient Water Management for Regional Sustainability in the Sacramento Valley, prepared by NCWA in 2011 (NCWA 2011). This information is largely included herein to provide a more complete description of agricultural water use, including both consumptive and non-consumptive uses of water. Rice is discussed in this section, and other crops are discussed in Section 3.3.1.2.

Rice is grown on the low-lying, fine-textured "adobe" clay soils that formed over geologic time as floodwaters intermittently covered the valley, allowing fine sediments to settle. Early pioneers soon discovered that crops that thrived elsewhere in the valley either failed or did not produce well because the soils became "sticky when wet and bone hard when dry" (Richvale Writing Group and Ward, 2006). Groundwater tables were generally high and encroached into the root zone, and crop roots could not penetrate the heavy soil. It was eventually discovered that rice was uniquely well adapted to these conditions, to the near total exclusion of other crops. The initial experiments with long-season rice were not successful because available varieties required growing seasons longer than that of the Sacramento Valley. When a Japanese rice variety with a growing season matched to that of the valley was introduced in 1908, rice production took hold.

Rice is unique among Sacramento Valley crops for many reasons; however, from a water management perspective, rice is different mainly because it is grown under flooded conditions, which offers both crop production and environmental benefits. Flooding helps to control certain competitive weeds and enhances the availability of nutrients. Additionally, ponded water acts as a thermal buffer, gaining heat during the day and releasing it at night to protect against cool nighttime temperatures that can reduce rice yield at certain growth stages.

For non-rice crops, which are grown under aerated (non-flooded) conditions, the water requirement is composed mainly of ET; but for rice, the water requirement includes deep percolation of water through the root zone as well as ET. This reveals a major management distinction between rice and non-rice crops – the irrigation requirements for non-rice crops (based primarily on ET) can be calculated from weather conditions and published crop coefficients. For rice, although the ET component of the irrigation requirement can be calculated in a similar manner as for non-rice crops, the deep percolation component is not known. Deep percolation depends on field-specific soil and subsurface conditions that are naturally variable throughout the region and are practically impossible to predict. Thus, the irrigation requirements of rice fields must be empirically derived: a rice farmer knows how much water a rice field needs by visual observation of ponding. If ponding is maintained, the field is receiving enough water; if not, it needs more. Accordingly, if excessive tailwater occurs, the field needs less water.

Percolation rates through rice fields are typically very slow because of the fine texture and compacted structure of the soils where rice is typically grown, because of the formation of a compacted soil layer (or "plow pan") that results from years of shallow tillage and equipment traffic, and shallow groundwater conditions in many areas. The spatial variability of percolation rates among rice fields is high, depending on local soil and groundwater conditions.

Rice water management does not involve simply planting the crop into ponded conditions and maintaining that condition until harvest. Precise control of the depth and timing of ponding relative to rice growth stages and herbicide applications is critical from the standpoints of crop production and water use efficiency. Table 3.4 summarizes a schedule of water management objectives for a typical rice field in the region based on a generally accepted ideal plant date of May 1. The thousands of rice fields in the region cannot be planted all at once. Planting is typically spread over a period of several weeks between April and early June, leading to unique water management requirements for each field depending on its plant date, weed control practices, types of herbicides used, weather conditions, and other factors.

The most critical rice water management factor is controlling the ponded water depth over time. In the example described in Table 3.4, the pond is created and drained just once between planting and harvest, but some fields are drained two or sometimes even three times depending on weather conditions and the herbicide being used. To the extent that draining is accomplished by allowing ponds to drop as a result of percolation, the applied water requirement is not appreciably affected; however, to the extent that draining is achieved by releasing stored water, draining will increase the applied water requirement.

Another significant factor is the timing of the final drain-down before harvest. In the example, flow is cut off 15 days before the field is drained, during which time the stored pond water is used to meet crop ET and deep percolation requirements. In this way, only a portion of the pond is discharged when the boards are pulled to drain the field, and the applied water requirement is reduced accordingly. Traditionally, it was common for growers to continue water delivery to maintain the full up to 7-inch ponded depth up until the time boards were pulled for drain-down. That practice is gradually being phased out in favor of the water-conserving practice described above.

While controlling the pond depth to achieve desirable growing conditions (see Table 3.4), farmers must also pay attention to how much water flows through their rice fields. Ideally, water delivery to rice fields would exactly match the ET and percolation requirements; however, this is quite challenging to achieve in practice because ET requirements vary with weather changes and, in some cases, because of fluctuations in the delivery flow rate provided by the water supplier. A more practical and generally accepted approach is to allow a minimal rate of through-flow to serve as a buffer against ET and water delivery fluctuations and, where needed, to limit salinity buildup. Suppliers in the region have rules that prohibit excessive rice tailwater. There is an energy and cost savings to both the supplier and farmers when through-flow is reduced, especially where water supplies are pumped.

Table 3.4. Schedule of Water Management Objectives for a Typical Sacramento Valley Rice Field (NCWA 2011).

Time Period	Objective
May 1-3	Flood field to 1-inch minimum ponded depth; cut off water.
May 4-8	Fly on presoaked and germinated seed; seed sinks to soil surface and root attaches to soil. Pond drops gradually due to depletion by ET and deep percolation.
May 9	Drain remaining ponded water to promote deep root penetration.
May 16-19	Re-flood field to 4-inch depth.
May 20	Cut water off and apply weed-control herbicide. The 30-day “lockup” begins during which water cannot be discharged from the field because of pesticide label regulations.
May 20-30	Allow no inflow to ensure zero discharge from field. Pond level drops gradually due to depletion by ET and deep percolation.
May 31	Reintroduce low flow to prevent excessive drying while still maintaining zero discharge.
June 20	Increase flow to achieve 4-inch ponded depth and generate some outflow for maintaining ponded water quality (depending on several factors).
Late July	Increase flow to achieve up to a 7-inch ponded depth to act as thermal buffer. (Note: Average pond depth is about 5 inches.)
Late July - August 15	Continue small flow to maintain up to 7-inch ponded depth and minimal outflow. (Note: Average pond depth is about 5 inches.)
August 15	Turn water off.
August 15 - September 1	Pond drops gradually due to depletion by ET and deep percolation.
September 1	Pull boards to drain any remaining ponded water from field (typically 0 to 2 inches).
September 20 - mid to late October	Harvest rice.
Mid to late October	Replace boards and flood to a ponded depth of between 2 and 6 inches for rice straw decomposition and to provide waterfowl habitat.
Mid to Late October - December 31	Maintain ponded condition relying on precipitation supplemented by water delivery; ponded depth varies according to grower preference, surface water availability, precipitation, and other factors.
January	Capture seasonal precipitation to maintain water levels for rice straw decomposition. Water levels may subside as hunting season comes to a close and system is opened to allow flow-through.
February	Allow water levels to subside as ponds are drawn down and flow through the system. High precipitation levels prevent any tillage of the soil.
March	Allow systems to remain open to allow flow-through of seasonal precipitation and rice decomposition water.
April	Begin tillage of field to prepare for planting, construction of levee checks, and installation of rice boxes (weirs) to control water flow between basins.

There are locations and circumstances in the valley where water quality considerations become an important factor in managing through-flow. In situations where rice drainage water is recycled multiple times, salts contained in the water supply may become so concentrated by ET that rice growth is stunted and yields are affected. Rice is particularly sensitive to salinity during the seedling and pollination growth stages (UCCE 2009). Salinity must be managed by dilution with fresh water and maintaining sufficient tailwater to ensure a productive salt balance over the long term.

Over the more than 100 years that rice has been grown in the valley, all aspects of its production have steadily improved, including plant breeding, cultivation and weed-control techniques, harvesting, and water management. In particular, precision land leveling is now widely used to achieve nearly dead-level grading within rice checks, which allows farmers to manage rice ponds more precisely and eliminate water applied to compensate for uneven land surfaces. Techniques for on-farm water recycling have also been developed and are used where water use cannot be accomplished more efficiently at the district level.

The ongoing advancement of on-farm rice water management practices has challenged water suppliers to provide increasingly higher levels of service to their customers, spurring a host of delivery system modernization upgrades. Many suppliers are investing in modernization so that they can provide the levels of delivery reliability, flow steadiness, and flexibility needed for modern rice cultivation and on-farm water conservation while reducing operational spillage from distribution systems.

Environmental benefits of rice production are discussed in Section 3.3.2.1.

3.3.1.2 Other Crop Water Management

Approximately 120,000 acres in the region are planted to other crops, with roughly two thirds of this acreage planted to permanent crops. Water demands associated with other crops are composed predominantly of crop ET plus some application of water for cultural practices, such as frost protection during blossoming and pre-irrigation to condition soil for tillage, for germination of certain crops, and to replenish root zone soil water. Although leaching is theoretically part of the irrigation requirement, water and soil salinity levels in the region and corresponding leaching requirements are generally low. Thus, leaching is generally not factored explicitly into irrigation requirements.

Drip irrigation of tree and vine crops was introduced in the 1970s as the technology was being pioneered, and has steadily expanded. Nearly every new permanent crop planting within the past 10 to 15 years has been accompanied by installation of either drip or, more recently, micro-sprinkler irrigation systems (note: together, drip and micro-sprinkler irrigation are called microirrigation). Although the original impetus for micro irrigation development was water conservation, early adopting growers quickly learned there were other significant production advantages. The ability to maintain and control soil moisture levels for optimum growth, coupled with the ability to apply fertilizers dissolved in the applied irrigation water, resulted in earlier production, significant yield increases, and improved fruit and nut quality. Growers quickly realized that the appreciable cost of microirrigation, ranging from roughly $1,500 to $2,500 per acre in initial capital outlay (in today's dollars), was quickly recovered and paid dividends thereafter. Water conservation has generally not been a strong incentive for adoption of microirrigation in the region because water supplies are generally adequate and reliable, and because applied water that is not consumed returns to the system.

One challenge that has confronted water suppliers and growers is meeting the high-frequency, low volume delivery requirements of micro irrigation systems with existing open canal distribution systems that were designed to deliver water infrequently for short durations at high flow rates for surface irrigation. For example, an 80-acre walnut orchard that might have been delivered water every 2 weeks at a rate of 10 cubic feet per second for 2 days for surface irrigation might require 2 cubic feet per second for 14 hours every day for microirrigation. Suppliers in the region serving orchards have evaluated opportunities to modify infrastructure and operations to better accommodate these new requirements as part of this plan (see attachments to Volume II, Sections 3 through 8). Even with system upgrades, the microirrigation requirements sometimes cannot be completely satisfied, and in some cases growers convert to a groundwater supply source to maximize delivery flexibility in order to fully realize the potential benefits of micro irrigation. Additionally, a groundwater well is completely under the grower's control and produces clean water that needs minimal filtration, significantly simplifying irrigation management. With the conversion from surface water to groundwater supplies, deep percolation of applied surface water is reduced and groundwater pumping is increased, placing additional stress on the aquifer. In other regions of the state, notably the San Joaquin Valley, these effects driven by the same factors have contributed to groundwater overdraft.

Annual crops and pasture remain predominantly surface-irrigated with graded furrow and border strip methods being the most commonly used. Generally, graded borders are used with alfalfa, pasture, and other hay and forage crops; and furrows are used for row crops such as corn, safflower, and sunflower. Both methods, particularly furrows, require that some tailwater be generated in order to achieve adequate irrigation of the lower ends of fields. On-farm tailwater reuse systems are not commonly used, primarily because reuse occurs at the supplier and subregional scales, and is more cost effective compared to on-farm reuse.

3.3.2 Environmental and Recreational

3.3.2.1 Managed Wetlands and Rice Habitat

Managed wildlife habitat and riparian vegetation comprises approximately 70,000 acres or 15 percent of lands within the region. Designated areas with managed habitat in the region are summarized in Table 3.5. These areas include a combination of publicly and privately owned lands. Private lands in the area have conservation easements to maintain wetlands habitat in perpetuity.

In addition to use of water within the region to provide winter habitat for migratory birds, surface outflows from the region enter Butte Creek and the Sutter Bypass, providing important instream flows supporting migration of salmon and steelhead and other downstream uses of water for wildlife habitat. Outflows from the region are discussed in greater detail in Sections 3.4 and 3.5.

3.3.2.1.1 Managed Wetlands

Wildlife areas (including refuges and wildlife management areas) in the region provide valuable habitat and opportunities for educational and recreational activities such as bird watching, and hunting. Habitat types in wildlife areas include seasonal, semi-permanent, and permanent wetlands, as well as riparian areas along streams and sloughs.

Seasonal wetlands water management practices are based on “Moist-soil management,” a concept developed in Missouri and implemented in the Central Valley for several decades (DFG and CWA, 1994). The ideal practice consists of fall flooding in August or September, with maintenance of ponds through the winter and drawdown in March over the course of two to three weeks. Following drawdown, “moist-soil” plants germinate and produce important waterfowl foods. Additionally, invertebrates supported by moist-soil management provide a high protein food source for waterfowl and migrating shorebirds in late winter and early spring. In addition to winter flooding, moist-soil plants may require one or more irrigations in the summer to sustain plant growth and control weeds such as cocklebur. In cases where adequate water is not available to support adequate food production, waterfowl may become crowded in smaller areas, which can lead to disease problems (USBR 1989).

Resident wetland species require semi-permanent and permanent wetlands for survival during the dry summer period. These species may include breeding ducks and shorebirds, as well as reptile species such as the Giant Garter Snake (GGS) and Western Pond Turtle. Semi-permanent wetlands or “brood ponds” are flooded during summer but draw down and dry for two to six months. In addition to providing protection from predators, the ponds support the growth of invertebrates as a food supply. Permanent wetlands, which remain continuously flooded, are important for aquatic species such as GGS and for resident waterfowl to provide protection from predators during molting.

Table 3.5. Regional Wildlife Areas.

Management Area	Estimated Acres in Region	Lead Agency	Water Supplies
Butte Sink Wildlife Management Area and National Wildlife Refuge	19,050	USFWS	WCWD releases to Butte Creek, drain and stream inflows
Upper Butte Basin Wildlife Area	9,597	CDFW	WCWD deliveries, drain and stream inflows
Gray Lodge Wildlife Area	9,090	CDFW	BWGWD deliveries, CVPIA deliveries through BWGWD, groundwater, drain inflows
Sutter National Wildlife Refuge	3,796	USFWS	SEWD deliveries, inflows to East Borrow Canal from Wadsworth Canal and Butte Slough
North Central Valley Wildlife Management Area	9,942	USFWS	Drains and stream flows
Sutter Bypass Wildlife Area	3,204	CDFW	Primarily aquatic and riparian habitat along east and west borrow canals
Oroville Wildlife Area	3,287[12]	CDFW	Primarily riparian habitat along Feather River
Feather River Wildlife Area	2,640	CDFW	Primarily riparian habitat along Feather River
Sacramento River National Wildlife Refuge	2,341	USFWS	Primarily riparian habitat along Sacramento River
Colusa Bypass Wildlife Area	1,248	CDFW	Sacramento River flood flows
Sacramento River Wildlife Area	618[13]	CDFW	Primarily riparian habitat along Sacramento River

3.3.2.1.2 Rice Wetlands Habitat

In addition to dedicated habitat areas, a majority of the rice fields in the region are flooded in the winter to promote rice straw decomposition and to create winter habitat for migratory birds and other wildlife. It is estimated that approximately 120,000 acres, on average, have been flooded for rice straw decomposition and habitat regionally in recent years. Use of water during the winter for rice decomposition and habitat increased substantially between 1992 and 2001, largely driven by the phasing out of burning of rice straw as a result of the Connelly-Areias-Chandler Rice Straw Burning Reduction Act of 1991. The acreage flooded for decomposition and habitat has remained relatively steady since around 2001 and has become integral to rice production practices.

Fields are typically flooded following harvest in October or November and remain flooded to February. Flooded conditions and crop residue prove favorable conditions for waterfowl and other migratory birds during the winter. Rice provides 60 percent of all the food that wintering waterfowl consume in the region each year, with every 3 acres of rice being equivalent to

[12] Estimated area within region. Total area of Oroville Wildlife Area is 11,938 acres.
[13] Estimated area within region. Total area of Sacramento River Wildlife Area is 4,114 acres.

approximately 2 acres of wetlands in terms of habitat value. It is estimated that for the Sacramento Valley as a whole, tailwater from winter flooding of rice supplies 57 percent of water used by wetlands. In total, rice land supports 230 species, including 187 birds, 27 mammals, and 16 amphibians/reptiles. Of these, 31 are considered species of special concern by the conservation community (CRC 2011).

3.3.2.1.3 Water Use

Estimates of winter applied water for rice straw decomposition and managed wetlands within the region between 1999 and 2012 are summarized in Table 3.6. These estimates are based on estimated applied water from the IDC simulation for the October to March period. The applied water demand estimates represent the estimated water required to flood these lands during the winter period to create and maintain wetlands habitat. Applied water comes from a combination of supplier deliveries, direct diversions from streams and drains, and groundwater pumping. These estimates are somewhat uncertain and may differ from actual applied water amounts; measurements of water use for public and private wetlands in the region are generally not available. Additionally, some water is applied for managed wetlands occurs as early as August, and applied water for semi-permanent wetlands occurs to some extent in the summer months. The purpose of isolating applied water during the months of October to March is to distinguish this period from the primary irrigation season (April through September).

As indicated in Table 3.6, applied water estimates for managed wetlands during winter range from approximately 110,000 af to 140,000 af in recent years, with an average of approximately 130,000 af for the October – March period. Applied water demands for rice decomposition ranged from approximately 140,000 af to 250,000 af, with an annual average of approximately 220,000 af.

Estimates of applied water for managed wetlands in the region do not necessarily represent optimal conditions. Wildlife managers face several challenges in meeting water needs for optimal habitat, including increased competition for available water, increased regulation of habitat water management, capacity and timing constraints of existing conveyance facilities, and lack of conveyance facilities in some cases.

3.3.2.2 Aquatic Habitat

Butte Creek is a host to spring-run Chinook salmon (*Oncorhynchus tshawytscha*), a State and Federal threatened species; fall-run Chinook salmon (*Oncorhynchus tshawytscha*); and steelhead trout (*Oncorhynchus mykiss*), a Federal threatened species, that migrate through Butte Creek. The spring run fish migrate into the creek typically between March and June to spawn and over-summer north of the region between Parrot-Phelan Dam and Centerville Dam in the Butte Creek Canyon. Spawning begins in late September to mid-October and occurs in relatively warmer water than other runs in the Sacramento Valley. Fry tend to emerge in September or October and out-migrate through March or remain in the stream for a full year. Outmigration is typically through the Sutter Bypass, though some fish may return to the Sacramento River via the Butte Slough Outfall Gates. Some salmon and steelhead rear in the East Borrow Canal of the Sutter Bypass in spring and early summer, though elevated water temperatures above 70^0 F can be lethal to the fish. (BCWP 1998, DWR 2004)

Table 3.6. Annual Winter Applied Water for Managed Wetlands and Rice Straw Decomposition.

Water Year	Managed Wetlands (af)	Rice Decomposition and Wetlands (af)	Total (af)
1999	114,090	143,757	257,847
2000	131,502	180,508	312,010
2001	124,436	198,074	322,510
2002	132,186	209,771	341,956
2003	129,450	209,798	339,248
2004	133,391	221,941	355,332
2005	122,766	261,603	384,369
2006	127,323	214,213	341,536
2007	137,385	231,863	369,248
2008	132,383	234,867	367,250
2009	133,550	246,751	380,301
2010	122,234	227,743	349,977
2011	122,789	210,262	333,051
2012	134,424	228,821	363,245
Average	**128,422**	**215,712**	**344,134**

In 2009, DFG prepared minimum instream flow recommendations for Butte Creek between Centerville Dam and Parrot-Phelan Dam that specify monthly recommended instantaneous flows in normal and dry years (DFG 2009) (Figure 3.5). These flows are greater than the current 40 cfs minimum instream flow requirements for Butte Creek below Parrott-Phelan Dam between October and June. The flows are intended to support spawning and holding by fish in the reach. For purposes of this plan it has been assumed that these flows would also be desirable in lower reaches of the Creek within the region, although it is recognized that in lower reaches not used for spawning and holding lesser flows may be acceptable at times, provided they would not result in fish passage problems. Historically, fish passage problems existed at times between the WCWD siphon and the Parrot-Phelan diversion; however these issues have been largely addressed. For example, through an agreement between USFWS, DFG, M&T Chico Ranch, and Parrot Investment Company in 1996, diversions have been reduced by 40 cfs, increasing streamflow and reducing passage problems.

Conditions in Butte Creek in the vicinity of WCWD but upstream of the WCWD Main Canal siphon can be approximated using available data based on the Butte Creek near Durham (BCD) stream gage (California Water Data Library station A04265); however, it should be noted that diversions occur between the gage and the siphon, including by Rancho Esquon at Adams Dam and by the Gorrill Ranch at the Gorrill dam. As a result, actual flows in Butte Creek upstream of the siphon are less than indicated by the gage. Gorrill Ranch diversions are reported as part of this plan. In addition to diversions occurring in this reach, there may be losses (seepage) to the groundwater system (or gains, at times). Butte Creek's interaction with the groundwater basin in the reach is uncertain and unquantified.

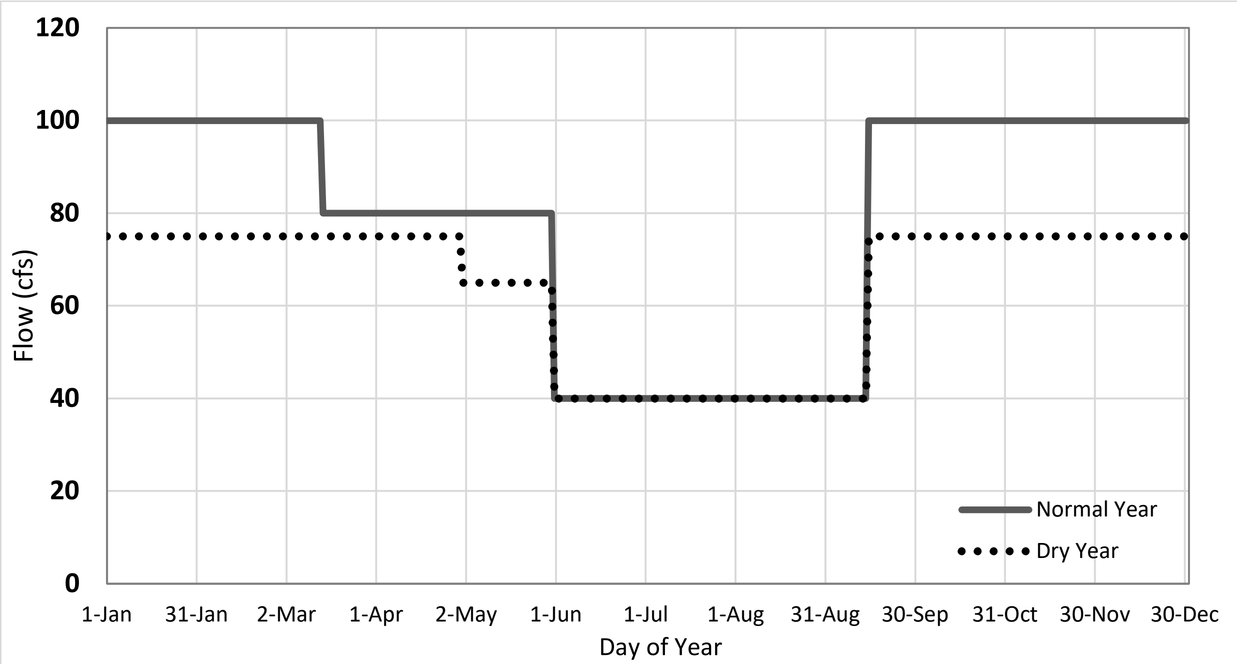

Figure 3.5. Recommended Instream Flows for Spring-Run Chinook Salmon Spawning and Holding in Butte Creek between Centerville Dam and Parrot-Phelan Dam (DFG 2009).

Average daily flows by month at the BCD gage for 2007 to 2009, three dry or critically dry years, are shown in Figure 3.6. Additionally, the average of minimum daily flows by month are shown for this period. Flows are plotted on a logarithmic scale to facilitate examination of low flows during summer months. These flows are shown in comparison to the recommended instream flows above Parrot-Phelan Dam as a point of reference; however, note that the recommended flows in upper reaches are not necessarily ideal for lower reaches, particularly when fish are not migrating. Average flows met or exceeded recommended instream flows for the spawning and holding area for dry years between December and June but were less than recommended between July and October. Average minimum flows met or exceeded recommended flows between January and June but were less than recommended between July and December.

Conditions in Butte Creek downstream of the WCWD Main Canal siphon and Butte Creek Spill are measured at the Butte Creek near Western Canal (BWC) stream gage (California Water Data Library station A04158). Average daily flows by month at the BWC gage for 2007 to 2009 are shown in Figure 3.7 along with the average of minimum daily flows by month for this period. Average flows exceeded recommended instream flows for the spawning and holding area for dry years. Average minimum flows exceeded recommended values in January to March and were close to recommended values for the remainder of the year. Flows at this location are greater than at the BCD gage as a result of return flows from WCWD and potentially groundwater accretions.

Historically, DWR maintained a gage on Butte Creek approximately 1.5 miles north of Colusa Highway west of Gridley (BCG, California Water Data Library station A04150). This station was discontinued at the end of 1999. Average daily flows by month at the BCG gage for 1991, 1992, and

1994, three critically dry years, are shown in Figure 3.8 along with the average of minimum daily flows by month for this period. Average flows exceeded recommended instream flows for the spawning and holding area for dry years in all months other than April and May, and average minimum flows fell below recommended in March, April, and May, the primary period for in-migration. Reduced flows in this portion of the creek during 1991 and 1992 resulted in large part from a reduction in surface water supplies to WCWD and the Joint Districts of 50 percent, which correspondingly resulted in a reduction in agricultural return flows from WCWD, RID, and BWGWD normally present. Minimum flows were approximately 100 cfs across the other six years during which the gage was active.

Conditions in Butte Creek downstream of the Butte Sink and upstream of the Sutter Bypass are measured at the Butte Slough near Meridian (BSM) stream gage (California Water Data Library station A02972). Average daily flows by month at the BSM gage for 2007 to 2009 are shown in Figure 3.9 along with the average of minimum daily flows by month for this period. Average flows and average minimum flows exceeded recommended instream flows for the spawning and holding area for dry years in all months. Flows at this location are greater than at the BWC gage as a result of agricultural return flows and groundwater accretion.

Historical outflows from the Sutter Bypass can be estimated based on the Sacramento Slough near Karnak gage (California Water Data Library site A02925) and the RD1500 gage (site A02926) immediately upstream, which was active until 2003. By subtracting RD1500 inflows from west of the bypass from Sacramento Slough outflows, Sutter Bypass outflows can be approximated. Average daily flows by month for 1991, 1992, and 1994, three critically dry years, are shown in Figure 3.10 along with the average of minimum daily flows by month for this period. Average flows exceeded recommended instream flows for the spawning and holding area for dry years in all months, and average minimum flows exceeded recommended flows in all months except July and October. Reduced flows during 1991 and 1992 resulted in large part from a reduction in surface water supplies to Feather River Settlement Contractors of 50 percent, which correspondingly resulted in a reduction in agricultural return flows normally present.

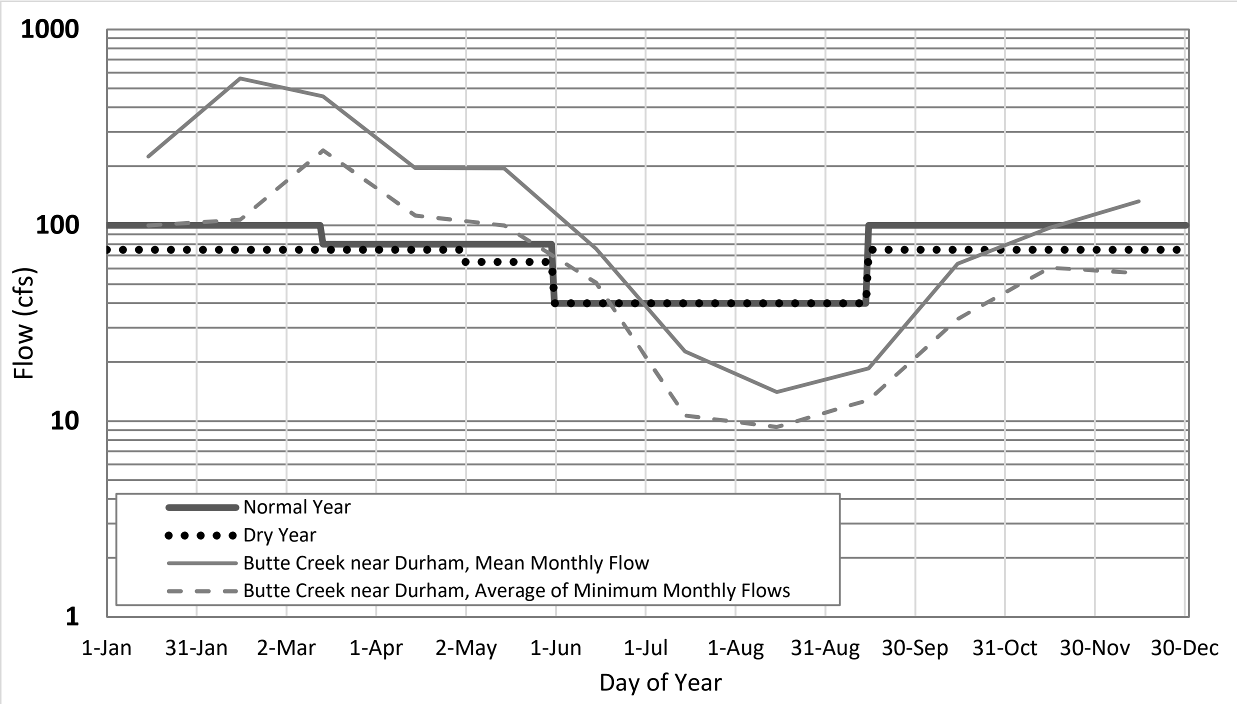

Figure 3.6. Recommended Butte Creek Instream Flows and 2007-2009 Average and Minimum Monthly Flows in Butte Creek near Durham.

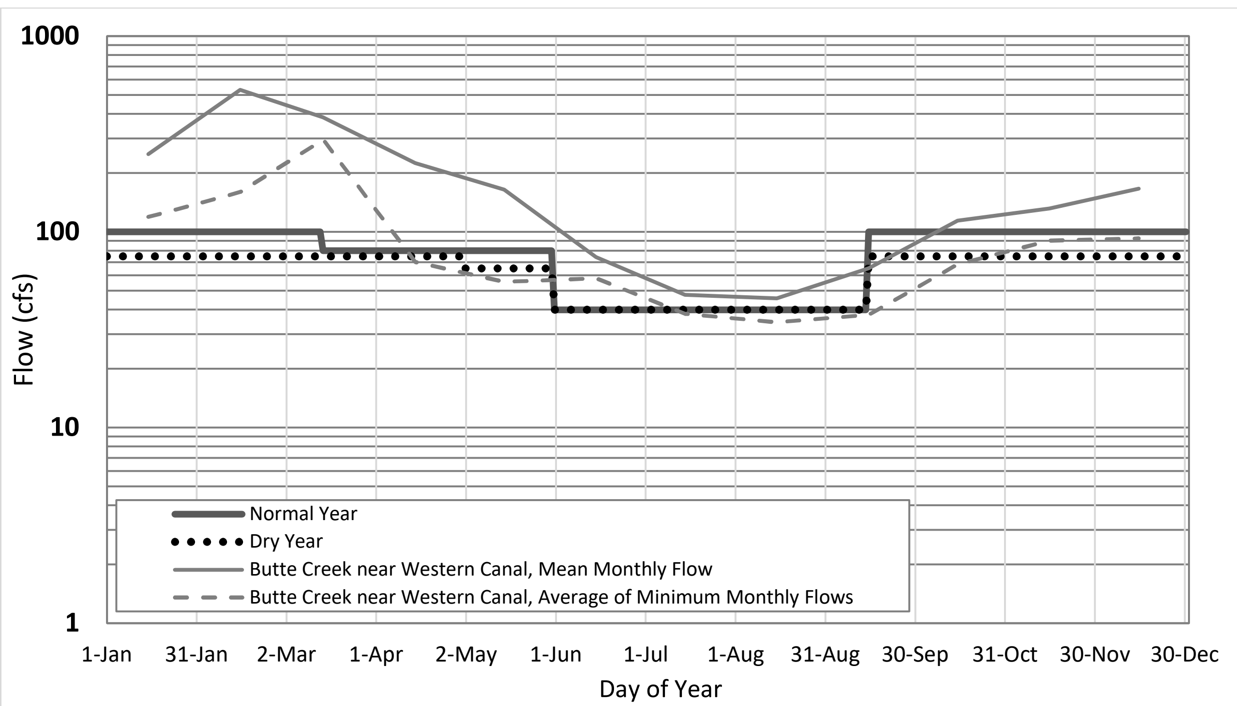

Figure 3.7. Recommended Butte Creek Instream Flows and 2007-2009 Average and Minimum Monthly Flows in Butte Creek near Western Canal.

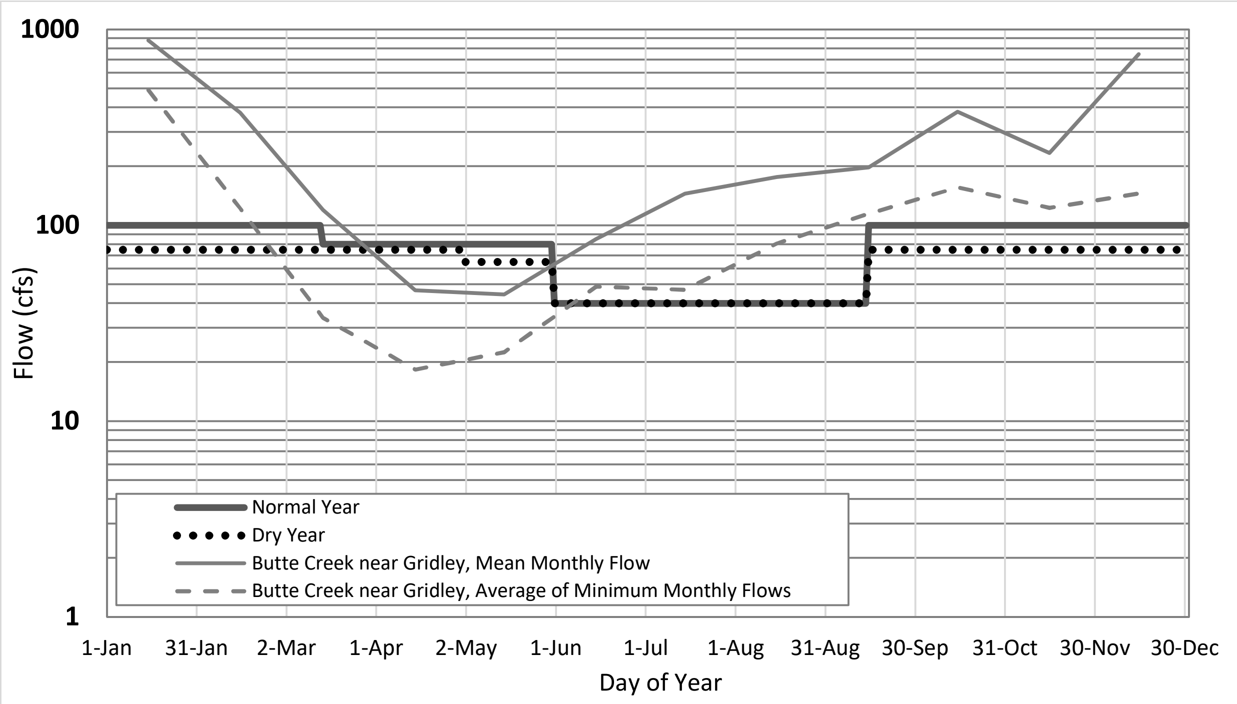

Figure 3.8. Recommended Butte Creek Instream Flows and 1991, 1992, and 1994 Average and Minimum Monthly Flows in Butte Creek near Gridley.

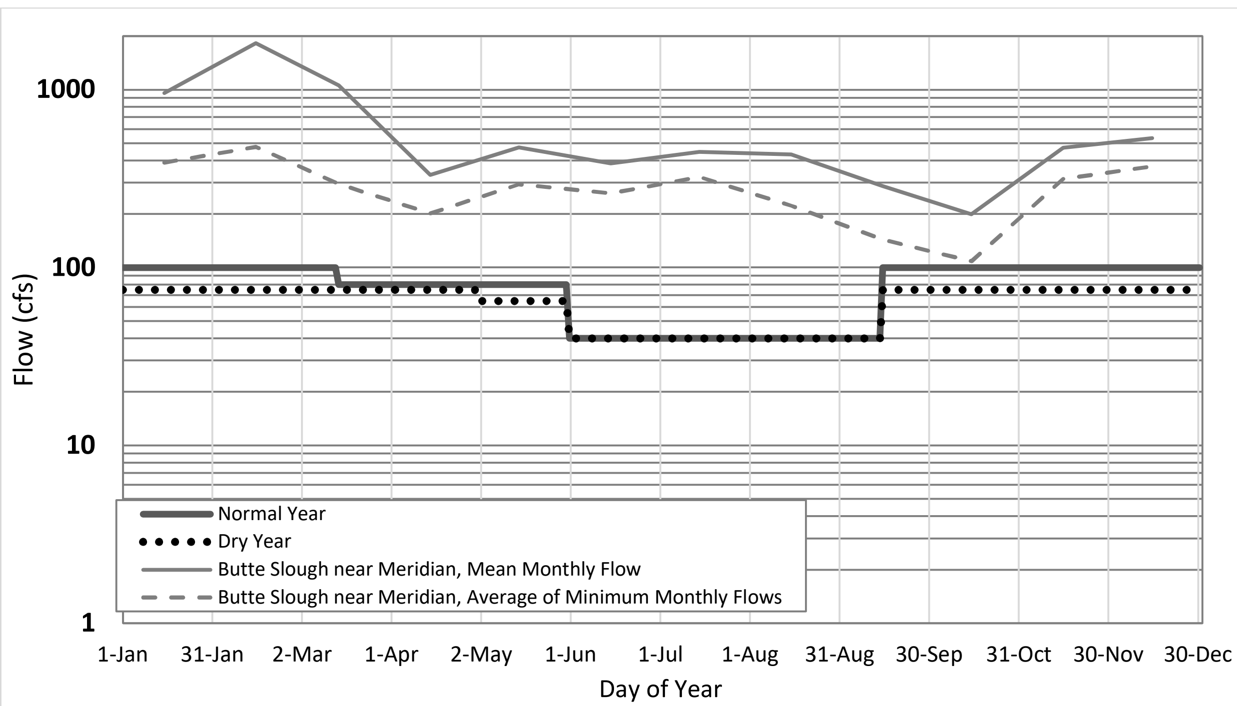

Figure 3.9. Recommended Butte Creek Instream Flows and 2007-2009 Average and Minimum Monthly Flows in Butte Slough near Meridian.

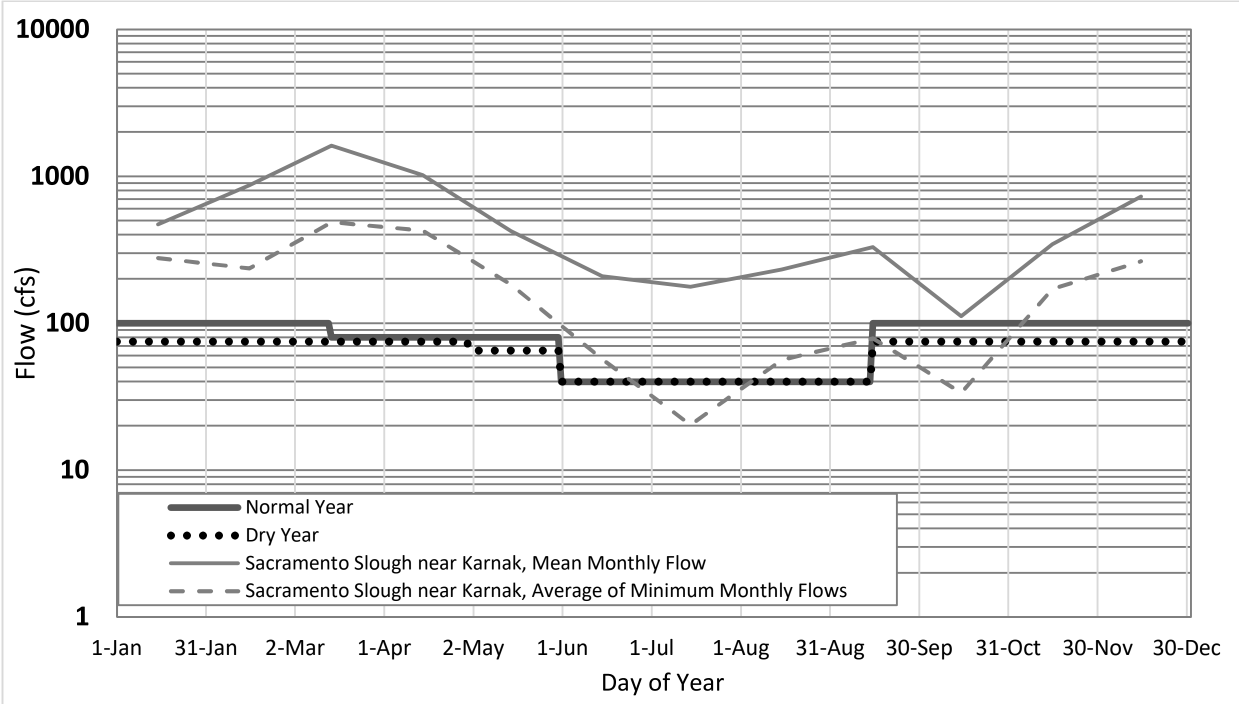

Figure 3.10. Recommended Butte Creek Instream Flows and 2007-2009 Average and Minimum Monthly Flows in Sacramento Slough near Karnak.

3.3.3 Municipal and Industrial

Yuba City diverts water from the Feather River for municipal and industrial (M&I) use. Other communities within the region such as Gridley, Live Oak, Biggs, and other unincorporated areas rely on groundwater for M&I use.

3.3.4 Groundwater Recharge

Surface water and groundwater interactions within the region include flows to the groundwater system from surface water at certain places and times and, similarly, flows to the surface water system from the groundwater system at certain places and times. Flows to the groundwater system include deep percolation of applied water and precipitation and seepage from canals, drains, and streams. Flows from the groundwater system to the surface layer include groundwater pumping, shallow groundwater interception and consumption by vegetation, and shallow groundwater interception by (accretions to) canals, drains, and streams. For purposes of this plan, a detailed water balance analysis has been conducted to estimate these interactions for the region as a whole. This analysis provides insight into the interconnectivity of the surface water and groundwater systems in the region and is described in greater detail in Section 3.5. This section provides a summary of estimated groundwater and surface water interactions within the region on a water year basis, including estimates of net groundwater recharge resulting from a combination of irrigation, precipitation, and natural surface water inflows. Recharge through localized seepage and deep percolation replenishes the groundwater system to the benefit of water users within and adjacent to the region.

Estimates of deep percolation were developed as part of the IDC analysis described previously. Additionally, independent estimates of deep percolation were developed from available delivery data and ET and tailwater estimates for individual fields served by water suppliers in the region, which allowed for field-scale water balance analysis. Deep percolation of applied irrigation water and precipitation were calculated for individual land use and soil combinations for the region as a whole and aggregated based on historical acreage estimates. Estimates of deep percolation for a given land use and soil combination are influenced by applied water, precipitation, and ET. Estimated annual deep percolation volumes for water years 1999 to 2012 are provided in Table 3.7, along with total recharge expressed as a volume and as a depth of water for each year. Seepage and accretions were not estimated independently for the region as a whole and are represented in estimates of shallow groundwater interception described below. Estimates of seepage were developed for the primary water districts and are described in their respective water balance sections of this plan (Volume II, Sections 3 through 7).

Table 3.7. Deep Percolation, 1999-2012.

Water Year	Deep Percolation of Applied Water (af)	Deep Percolation of Precipitation (af)	Net Deep Percolation	
			af	af/ac
1999	543,525	168,297	711,822	1.5
2000	568,351	174,144	742,495	1.6
2001	560,443	127,824	688,267	1.5
2002	589,223	179,674	768,897	1.6
2003	598,891	179,014	777,905	1.6
2004	622,010	189,128	811,138	1.7
2005	584,910	185,996	770,906	1.6
2006	587,565	252,847	840,412	1.8
2007	589,228	75,386	664,614	1.4
2008	614,649	133,279	747,928	1.6
2009	602,791	95,277	698,068	1.5
2010	610,649	160,908	771,557	1.6
2011	592,203	257,717	849,920	1.8
2012	599,649	128,785	728,434	1.5
Average	**590,292**	**164,877**	**755,169**	**1.6**

As indicated in Table 3.7, total deep percolation between 1999 and 2012 ranged from approximately 665,000 af to 850,000 af per year between 1999 and 2012, or from 1.4 af to 1.8 af per acre. On average, deep percolation was estimated to be approximately 755,000 af per year (1.6 af/ac), with approximately 78 percent originating from applied water and 22 percent originating from precipitation.

Groundwater pumping was calculated based on applied water demands as estimated using IDC by land use and soil type and based on estimated acres served by groundwater from DWR land use surveys and information obtained through consultation with agricultural water suppliers. Estimates of regional groundwater pumping ranged from 260,000 af to 348,000 af per year for the period of analysis, with average estimated pumping of 302,000 af per year.

Groundwater level monitoring data and field observations suggest that the shallow groundwater system and regional aquifer are coupled within portions of the region at certain times. As a result, an unsaturated aquifer zone may not be present to receive recharge in all areas at all times. Depth to water in wells is typically less than ten feet in primary rice growing areas, and drains often flow even when irrigation is not occurring. These conditions likely result from limited groundwater pumping in these areas along with sustained use of surface water for irrigation over past decades. As a result, it is likely that a substantial portion of the water percolating into the soil from ponded fields and seeping from canals is unable to flow downward but rather flows horizontally to where it is intercepted by non-ponded vegetation or by drains, providing base flow. Thus, these flows represent potential recharge that is essentially "rejected" by the groundwater system. Shallow groundwater interception is shown conceptually in Figure 3.11.

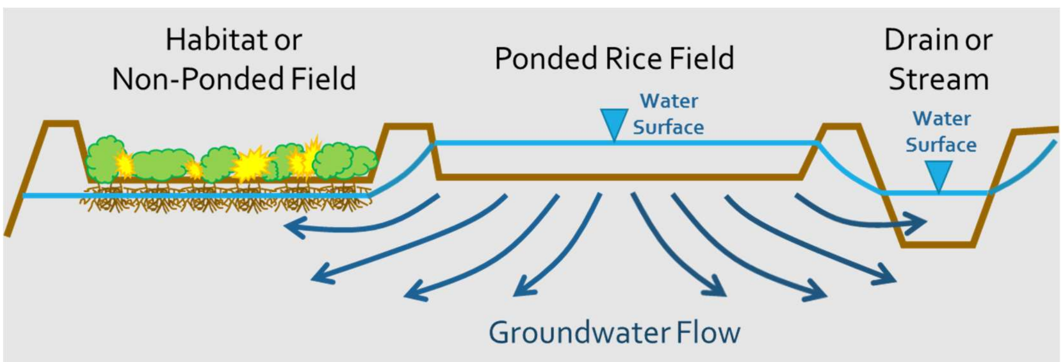

Figure 3.11. Conceptualization of Shallow Groundwater Interception in Rice Growing Areas.

In areas where an unsaturated zone is present, water infiltrating into the soil in ponded fields may encounter impermeable layers caused by plow pan or natural soil features and thus flow laterally to adjacent lands or provide base flow for drains. Additional information is needed to distinguish shallow groundwater interception in areas where the shallow and regional groundwater systems are coupled from areas with perched shallow groundwater.

Shallow groundwater interception was calculated as the closure term of the regional water balance by subtracting all other measured or estimated inflows from the sum of all measured or estimated outflows and change in storage over time. As described above, because seepage from and accretions to canals, drains, and streams were not estimated independently for the regional water balance, shallow groundwater interception is net of these exchanges between the groundwater system and the surface layer.

Estimates of regional shallow groundwater interception ranged from 185,000 af to 325,000 af per year, with average estimated interception of 245,000 af. To a certain extent, the variability in year-to-year estimates of shallow groundwater interception results from the fact that it is calculated as the water balance closure and thus reflects errors in estimates of other inflows, outflows, and change in storage; however, it appears that precipitation additionally influences shallow groundwater interception. In years of high precipitation, less shallow groundwater interception appears to occur. Due to the relatively large uncertainty in shallow groundwater interception from year to year, additional information is needed to better understand this apparent relationship.

Shallow groundwater interception in the region has additionally been estimated as part of the Central Valley Hydrologic Model developed by USGS (Faunt 2009). Model subregions 4 and 5 encompass the Feather River Region and representing approximately 1.1 million acres. Average ET derived from shallow groundwater for this area was estimated to be approximately 810,000 af per year between 1999 and 2003, or 0.76 af per ac. By comparison, estimates developed for this plan over the same period are 245,000 af per year over 429,000 acres (regional acres, net of Sutter Buttes), or 0.57 af per ac.

Groundwater recharge net of well pumping and shallow groundwater interception represents the net amount of water contributing to groundwater storage from irrigation and precipitation processes. Net recharge was calculated by subtracting estimated pumping and shallow groundwater interception from total recharge. As described above, shallow groundwater interception occurs when drains, creeks, or other waterways intercept or “gain” water from the shallow groundwater system, which may be perched or connected to the regional aquifer. Additionally, shallow groundwater can be intercepted and consumed by natural or other non-ponded vegetation. Net annual recharge estimates for 1999 to 2012 are provided in Table 3.8.

As indicated in Table 3.8, net recharge between 1999 and 2012 ranged from approximately 27,000 af to 405,000 af, or from 0.1 af/ac to 0.9 af per acre of net recharge per year. On average, net recharge was approximately 208,000 af per year, or 0.4 af/ac. Year to year variability in net recharge is primarily a result of variability in deep percolation of precipitation and groundwater pumping. In dry years, less precipitation is available for recharge, and irrigation requirements increase, leading to increased pumping. Conversely, in wet years more precipitation is available for recharge, and pumping requirements are lessened, resulting in reduced withdrawals.

3.3.5 Transfers and Exchanges

Water suppliers in the region have participated in several water transfers in recent years. Transfers have occurred both within the region among Feather River water suppliers as well as with the State and other parties elsewhere in California. Internal transfers are allowed under the diversion agreements between WCWD and the State and between the Joint Districts and the State. These transfers are made possible by water conservation at the district-scale, which allows for unused supplies by one district to be transferred to another district. In recent years, internal transfers have occurred primarily between BWGWD, BWD, RID and SEWD, where BWD and SEWD have provided water to BWGWD and RID.

Table 3.8. Net Groundwater Recharge, 1999-2012.

Year	Deep Percolation of Applied Water (af)	Deep Percolation of Precip-itation (af)	Ground-water Pumping (af)	Shallow Groundwater Interception (af)	Net Recharge	
					af	af/ac
1999	543,525	168,297	285,064	271,043	155,714	0.3
2000	568,351	174,144	297,290	223,228	221,978	0.5
2001	560,443	127,824	309,775	267,436	111,056	0.2
2002	589,223	179,674	306,040	236,491	226,365	0.5
2003	598,891	179,014	283,664	209,683	284,559	0.6
2004	622,010	189,128	312,959	243,340	254,840	0.5
2005	584,910	185,996	267,024	212,323	291,559	0.6
2006	587,565	252,847	273,600	187,348	379,464	0.8
2007	589,228	75,386	312,246	325,222	27,146	0.1
2008	614,649	133,279	334,727	284,167	129,034	0.3
2009	602,791	95,277	324,590	287,373	86,105	0.2
2010	610,649	160,908	316,867	227,488	227,201	0.5
2011	592,203	257,717	259,948	185,419	404,553	0.9
2012	599,649	128,785	348,340	265,392	114,702	0.2
Average	**590,292**	**164,877**	**302,295**	**244,711**	**208,163**	**0.4**

Water transfers in the region have occurred based on crop idling, groundwater substitution, and unused surface water supplies. Crop idling transfers have been most common in recent years, with WCWD and the Joint Districts each participating. Groundwater substitution transfers have not occurred in Butte County since 1994. In 1996, voters approved Measure G, which created Chapter 33 of the county code which, in part, requires that parties wishing to substitute groundwater for surface water to be transferred outside of the county or to pump groundwater for direct transfer outside of the county receive a permit. Groundwater substitution transfers have been conducted in recent years by water suppliers in the Sutter County portion of the region, including BWD, SEWD, and GHMWC. Additional detail describing water transfers in the region is provided under the description of water uses by each supplier in Volume II, Sections 3 through 8 of this plan.

3.4 Drainage

Drainage within the region is accomplished through a network of drains and natural waterways that are used to collect runoff of precipitation, provide shallow groundwater relief, and convey tailwater from farmed lands. Drains are generally maintained by individual reclamation and drainage districts, including RD777, RD833, RD784, RD2054, RD2056, DD100 and DD200. Additionally, DWR maintains several flood control facilities in the region that also serve to provide drainage, including the East-West Interceptor Canal, Wadsworth Canal, Sutter Bypass, and several other local maintenance areas.

Measurements of tailwater production and operational spillage within districts are generally not available, in part due to the integration of the distribution and drainage systems within the supplier service areas, although several suppliers are proceeding with outflow measurement to enhance water management capabilities as described in Volume II of this plan. In many cases, water is conveyed from canals and laterals into drains for delivery to downstream water users. Estimates of tailwater production and surface water outflows for each of the suppliers included in this plan are provided in the individual water supplier water balance sections. This section summarizes estimated surface outflows for the region as a whole.

Estimated surface outflows from the region between water years 1999 and 2012 are summarized in Table 3.9. Total surface outflows ranged from approximately 460,000 af to 7,370,000 af, with an average of 2,000,000 af. The high degree of variability in annual outflows results primarily from the use of the Sutter Bypass for flood control during wet years. In such years, large flood flows are routed through the bypass to prevent flooding of adjacent lands. Outflows from the Butte Slough Outfall Gates, Cox Spill, and PMWC are relatively steady by comparison.

In order to evaluate surface outflows in years without substantial flooding, outflows for the five years with the least combined inflow from the Moulton, Colusa, and Tisdale weirs along the Sacramento River were selected. These years, ranked from least to most weir inflow were 2012, 2007, 2008, 2009, and 2001. In each year, total weir inflows were less than 150,000 af annually. Surface outflows ranged from 460,000 af to 660,000 af during these years, with an average of 580,000 af. In contrast, average surface outflows for years with substantial flood flows were 2,790,000 af, nearly five times greater.

Table 3.9. Surface Outflows, 1999-2012.

Water Year	Surface Outflows (af)				Total Surface Outflows (af)
	Sutter Bypass	Butte Slough Outfall Gates	Cox Spill	Plumas MWC Estimated Return Flow	
1999	2,496,187	73,391	8,908	1,518	2,580,004
2000	3,527,820	129,609	7,826	1,824	3,667,079
2001	383,772	204,442	10,282	1,225	599,721
2002	818,487	345,298	8,948	2,023	1,174,757
2003	2,465,881	116,082	8,092	1,252	2,591,307
2004	2,810,418	100,667	9,658	1,196	2,921,939
2005	977,459	214,359	9,244	966	1,202,029
2006	7,218,146	141,836	9,328	1,212	7,370,522
2007	394,423	180,283	8,614	1,539	584,859
2008	447,809	150,625	10,512	1,732	610,678
2009	513,281	138,582	5,906	2,000	659,769
2010	854,095	141,842	6,566	1,384	1,003,887
2011	2,420,739	181,161	7,290	1,204	2,610,395
2012	275,798	176,680	9,506	1,361	463,345
Average	**1,828,880**	**163,918**	**8,620**	**1,460**	**2,002,878**

3.5 *Water Accounting (Water Balance Summary)*

The regional water balance structure was shown previously in Figure 3.1. An accounting center representing the groundwater system is also included in Figure 3.1 to account for exchanges between the root zone and the underlying groundwater system; however, a complete balance for the underlying aquifer has not been developed because not all inflows and outflows into the groundwater system (such as horizontal boundary flows) have been estimated.

The water balance results are presented on a water year basis for 1999 through 2012. Underlying the annual results is a more detailed water balance in which all flow paths are estimated on a monthly basis.

3.5.1 Water Balance Results

A regional water balance combining individual inflows and outflows into general categories is shown in Figure 3.12 for the water year and for the April to September primary irrigation season, based on average values between 1999 and 2012. In each figure, average volumes are presented for each inflow and outflow category, as well as average volumes expressed in acre-feet per acre. Average monthly inflows to and outflows from the region are further summarized in Figures 3.13 and 3.14, respectively. Detailed annual water balance results for the region are summarized in Tables 3.10 (inflows) and 3.11 (outflows and change in storage). In Table 3.11, performance indicators characterizing regional water management and performance are additionally provided.

3.5.2 Characterization of Water Management and Performance

Monthly inflow and outflow patterns provide insight into water management within the region, which is heavily influenced by water management for rice. The observed monthly patterns likely differ from individual fields, and reflect the full population of fields in the region.

Diversions begin in April or May and continue at relatively steady levels through August, decreasing in September as fields are drained for harvest. In October and November diversions again increase and continue through December to flood fields and managed wetlands for rice straw decomposition and habitat. Diversions cease in January in preparation for the next year’s crop.

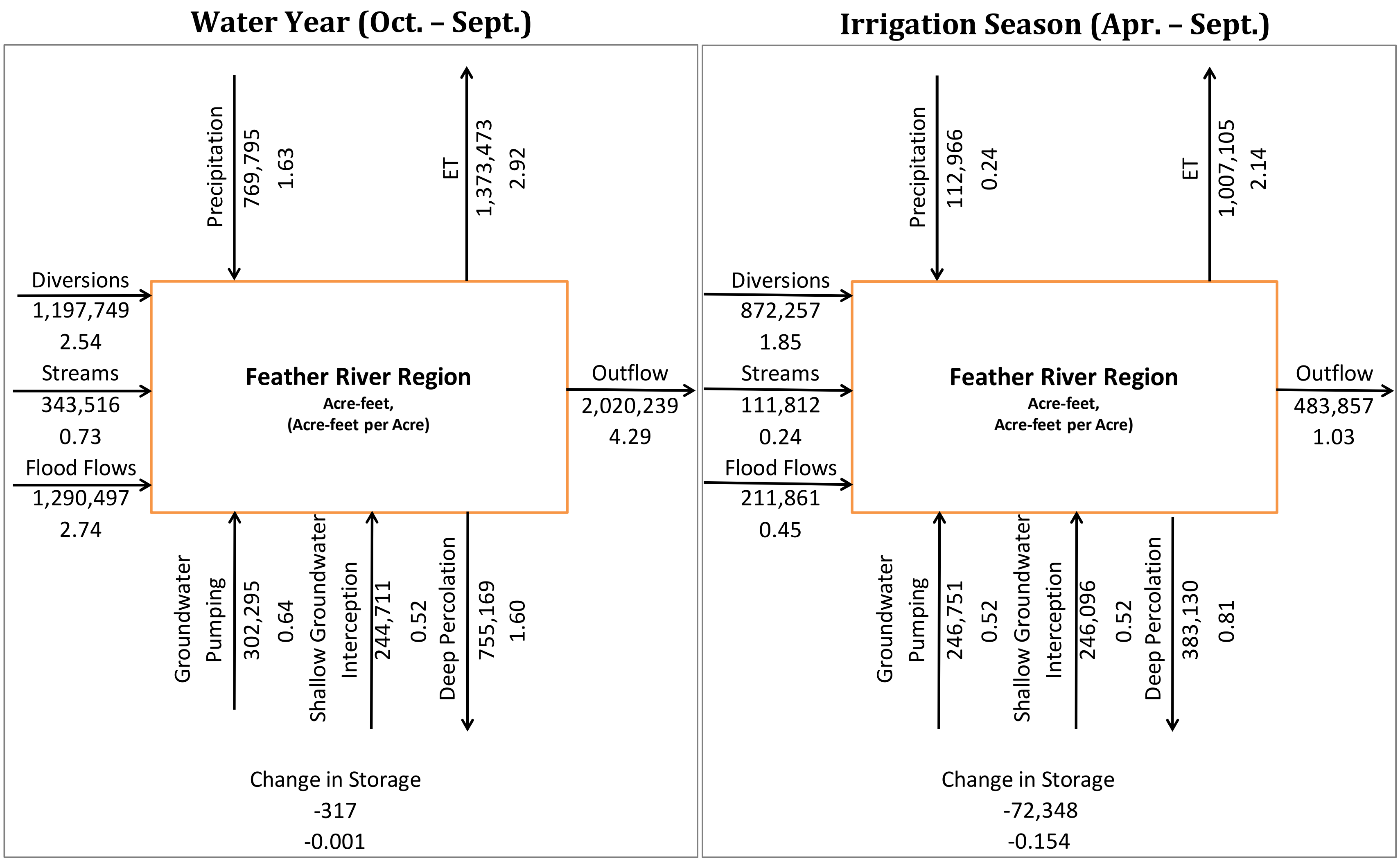

Figure 3.12. Average Annual Regional Water Balance, 1999-2012 (acre-feet and acre-feet/acre).

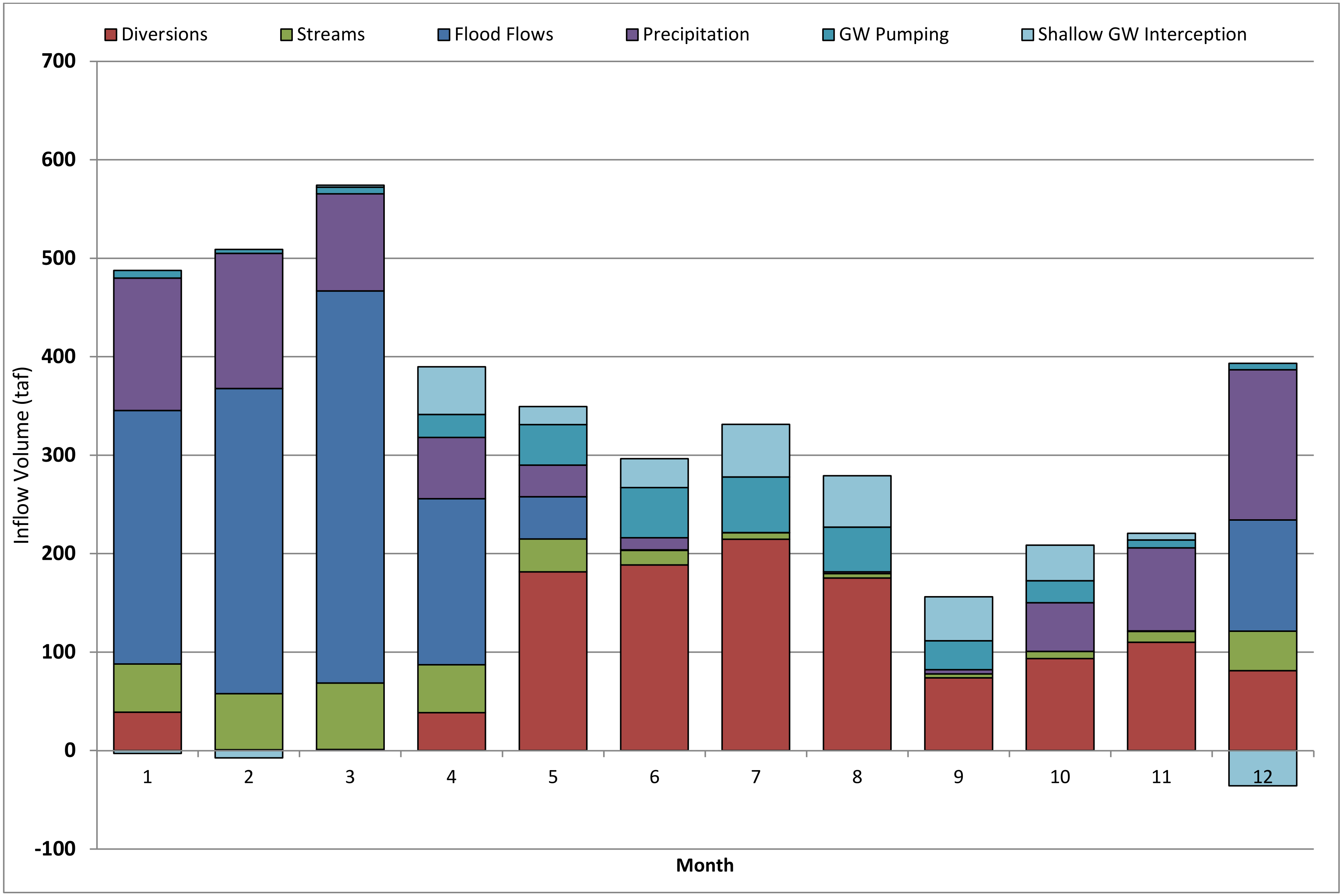

Figure 3.13. Average Monthly Inflows, 1999-2012.

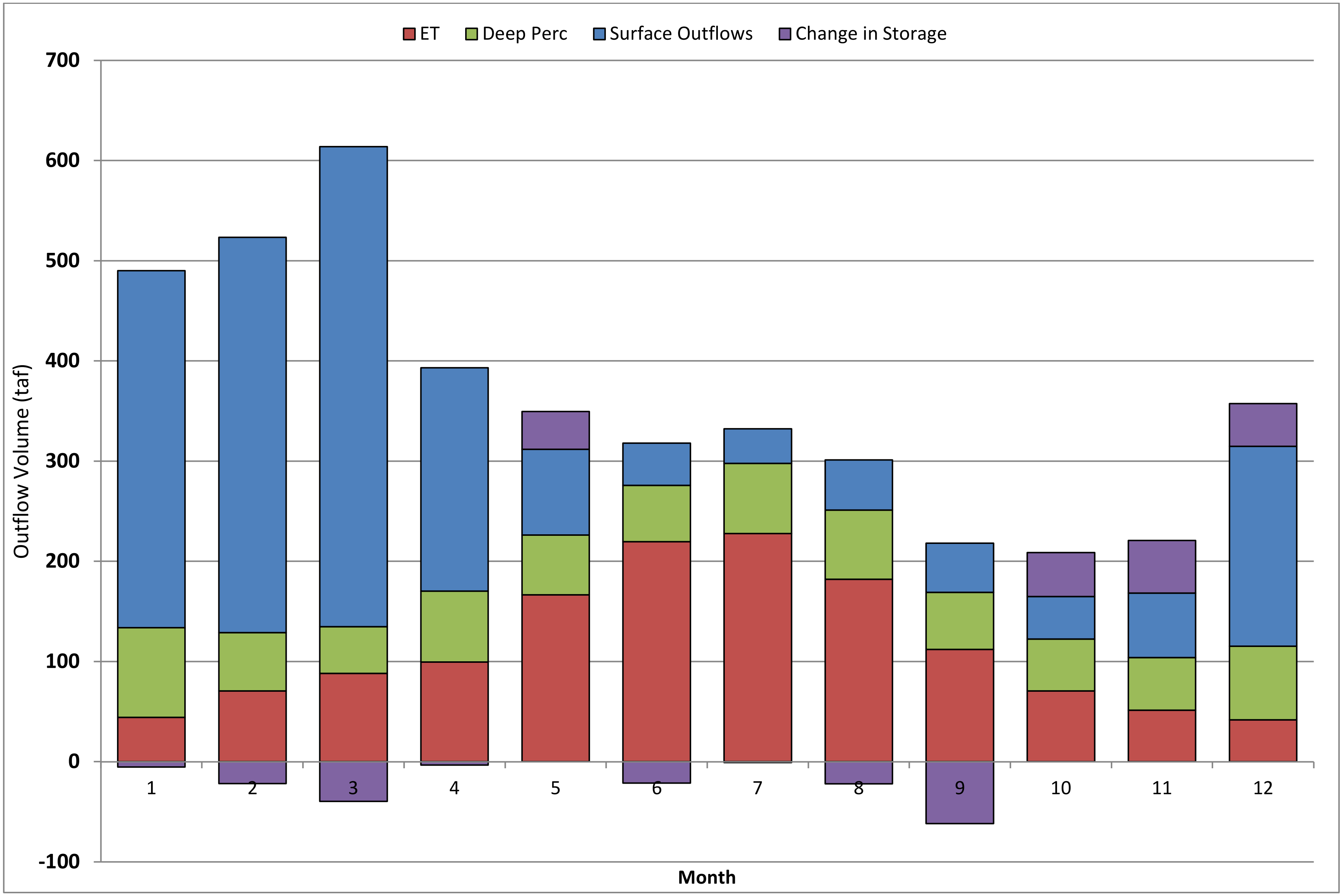

Figure 3.14. Average Monthly Outflows, 1999-2012.

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Table 3.10. Regional Inflows, 1999-2012.

	Inflows (af)																						
	Diversions[1]												Streams				Flood Control						
Water Year	Western Main Canal	Richvale Main Canal	374 Lateral	Sutter-Butte Canal	Sunset Pumps	Yuba City	Oswald WD	Feather WD	Tudor MWC	Garden Highway MWC	Plumas MWC	Llano Seco	RD1004	Butte Creek	Little Dry Creek	Cherokee Canal	Angel Slough	Moulton Weir	Colusa Weir	Tisdale Bypass	Precip-itation	Ground-water Pumping	Shallow Ground-water Interception
1999	289,095	142,312	4,332	541,011	13,688	10,559	1,753	16,365	4,520	16,809	10,117	8,995	87,167	301,954	6,466	53,578	42,368	103	742,818	1,111,758	638,109	285,064	271,043
2000	321,352	145,719	4,050	550,703	11,688	11,065	546	14,552	4,294	14,006	12,160	12,836	103,214	242,420	5,616	46,461	36,760	48,259	2,000,705	916,478	838,500	297,290	223,228
2001	298,505	155,032	4,304	562,263	9,156	14,116	289	10,995	3,707	12,511	8,165	7,814	113,990	118,183	3,719	30,763	24,340	0	63,709	71,447	651,076	309,775	267,436
2002	300,986	146,636	4,515	594,785	10,864	12,411	275	12,671	3,548	15,704	13,489	6,884	107,102	182,880	5,053	41,799	33,072	5,042	296,198	256,930	775,240	306,040	236,491
2003	257,119	132,378	4,076	554,865	6,272	16,040	457	8,368	3,068	16,769	8,347	4,721	105,092	379,470	11,115	91,950	72,752	4,731	751,822	865,738	913,549	283,664	209,683
2004	325,402	163,195	4,325	621,459	9,316	18,028	782	7,155	3,841	16,871	7,976	6,234	104,477	238,725	6,067	50,194	39,714	119,448	1,342,867	716,861	745,377	312,959	243,340
2005	280,303	157,107	3,901	593,963	2,452	16,938	560	7,408	3,495	14,463	6,443	3,658	82,187	240,809	6,187	51,182	40,496	0	227,872	224,664	897,832	267,024	212,323
2006	291,042	154,499	3,939	592,131	5,312	17,256	456	3,169	3,085	12,513	8,078	4,584	84,517	582,720	13,219	109,355	86,523	232,108	3,125,227	2,707,283	1,088,400	273,600	187,348
2007	332,607	170,766	4,113	647,277	6,222	18,305	632	14,685	2,487	12,780	10,258	6,556	94,158	115,152	3,316	27,434	21,706	0	13,944	26,755	467,187	312,246	325,222
2008	330,411	148,913	3,289	596,221	356	18,954	1,372	10,572	3,269	17,864	11,547	6,339	99,955	117,026	3,871	32,024	25,338	0	29,372	73,544	592,923	334,727	284,167
2009	325,619	144,444	3,101	569,531	5,316	18,760	1,619	8,970	970	16,544	13,332	7,325	97,891	179,398	5,050	41,774	33,052	0	30,874	91,037	582,314	324,590	287,373
2010	309,798	125,550	4,091	550,958	2,622	17,952	1,073	6,734	2,791	8,293	9,228	3,791	98,392	220,579	5,767	47,707	37,746	432	124,362	216,596	817,282	316,867	227,488
2011	289,878	136,932	3,795	566,432	4,114	18,055	922.21	6,619	3,422	16,644	8,028	1,489	83,510	359,587	8,393	69,430	54,933	53,609	756,460	812,931	1,110,797	259,948	185,419
2012	306,572	137,798	2,924	563,999	5,460	18,345	891.42	5,791	3,326	16,969	9,071	4,744	84,436	145,788	3,682	30,463	24,103	0	0	4,979	658,541	348,340	265,392
Minimum	257,119	125,550	2,924	541,011	356	10,559	275	3,169	970	8,293	6,443	1,489	82,187	115,152	3,316	27,434	21,706	0	0	4,979	467,187	259,948	185,419
Maximum	332,607	170,766	4,515	647,277	13,688	18,954	1,753	16,365	4,520	17,864	13,489	12,836	113,990	582,720	13,219	109,355	86,523	232,108	3,125,227	2,707,283	1,110,797	348,340	325,222
Average	304,192	147,234	3,911	578,971	6,631	16,199	831	9,575	3,273	14,910	9,731	6,141	96,149	244,621	6,251	51,723	40,922	33,124	679,016	578,357	769,795	302,295	244,711
Median	303,779	146,178	4,063	567,982	5,841	17,604	707	8,669	3,374	16,124	9,150	6,287	98,142	229,652	5,691	47,084	37,253	268	262,035	240,797	760,308	307,908	239,916

1. Diversions represent the full October - September water year and thus include water use during the irrigation season and during the winter period.

Table 3.11. Regional Outflows, 1999-2012.

Water Year	Outflows (af)									Change in Storage (af)	Performance Indicators		
	Surface Outflows					Evapotranspiration		Deep Percolation					
	Sutter Bypass Outflow	Butte Slough Outfall	Cox Spill Outflow	Plumas MWC Return Flows	Butte Slough Irr. Co. Diver-sions	ET_{aw}	ET_{pr}	Deep Percolation of Applied Water	Deep Percolation of Precipitation		Water Manage-ment Fraction[1]	Surface Water Supply Fraction	Consump-tive Use Fraction[2]
1999	2,496,187	73,391	8,908	1,518	15,387	976,722	323,591	543,525	168,297	-7,541	0.995	0.80	0.78
2000	3,527,820	129,609	7,826	1,824	18,211	1,085,278	355,445	568,351	174,144	-6,606	0.995	0.80	0.82
2001	383,772	204,442	10,282	1,225	17,141	1,122,395	310,270	560,443	127,824	3,500	0.995	0.79	0.84
2002	818,487	345,298	8,948	2,023	15,886	1,099,273	306,621	589,223	179,674	3,180	0.995	0.80	0.81
2003	2,465,881	116,082	8,092	1,252	17,286	1,003,280	317,129	598,891	179,014	-4,862	0.995	0.80	0.81
2004	2,810,418	100,667	9,658	1,196	17,623	1,080,847	269,022	622,010	189,128	4,044	0.995	0.80	0.77
2005	977,459	214,359	9,244	966	16,450	982,600	370,825	584,910	185,996	-1,544	0.995	0.81	0.78
2006	7,218,146	141,836	9,328	1,212	17,644	979,047	380,815	587,565	252,847	-2,077	0.995	0.81	0.77
2007	394,423	180,283	8,614	1,539	17,497	1,115,033	243,826	589,228	75,386	7,980	0.995	0.81	0.78
2008	447,809	150,625	10,512	1,732	17,211	1,132,709	237,345	614,649	133,279	-3,818	0.995	0.79	0.81
2009	513,281	138,582	5,906	2,000	17,805	1,148,632	266,247	602,791	95,277	-1,638	0.995	0.79	0.85
2010	854,095	141,842	6,566	1,384	18,139	1,032,413	323,273	610,649	160,908	6,831	0.995	0.78	0.80
2011	2,420,739	181,161	7,290	1,204	18,824	903,850	427,856	592,203	257,717	500.94	0.995	0.81	0.74
2012	275,798	176,680	9,506	1,361	17,951	1,099,233	335,042	599,649	128,785	-2,389	0.995	0.77	0.82
Minimum	275,798	73,391	5,906	966	15,387	903,850	237,345	543,525	75,386	-7,541	0.995	0.77	0.74
Maximum	7,218,146	345,298	10,512	2,023	18,824	1,148,632	427,856	622,010	257,717	7,980	0.995	0.81	0.85
Average	1,828,880	163,918	8,620	1,460	17,361	1,054,379	319,094	590,292	164,877	-317	0.995	0.80	0.82
Median	915,777	146,234	8,928	1,372	17,560	1,083,063	320,201	590,716	171,221	-1,591	0.995	0.79	0.82

1. Assumes 0.5% of diversions consumed as evaporation or riparian ET based on water balance results for individual suppliers.
2. Assumes approximately 15% of diversions leave the distribution system as seepage, spillage, or evaporation based on individual supplier water balances.

Monthly ET generally follows the pattern of ET_o, increasing in the spring and summer as temperatures and day length and available solar radiation increase and then decreasing in the winter. Actual ET rates are relatively similar to reference values due to the availability of adequate surface water supplies to support crop growth and relatively moist conditions throughout the growing season. Deep percolation is relatively constant over time due to the use of available surface water during the majority of the year, increasing somewhat in the winter as a result of precipitation and decreasing prior to planting and following harvest as a result of dry conditions. Surface outflows increase during the winter as a result of the passage of flood flows through the system and are also influenced by return flows from winter flooding of rice fields and managed wetlands.

The monthly change in storage in the surface layer reflects rice growing and winter flooding as well, with water entering storage in May, remaining relatively constant in June and July, and leaving storage as fields are drained in August and September. Storage then increases again October through December due to winter flooding and decreases in January through March as fields are drained in preparation for planting.

On a water year basis, substantial recharge of the groundwater system occurs as a result of the use of surface water within the region. It is estimated that approximately 208,000 af of groundwater recharge net of groundwater pumping and shallow groundwater interception occur annually within the region. Net recharge is somewhat limited due to shallow groundwater conditions resulting largely from historical use of surface water and limited pumping. Approximately 245,000 af of shallow groundwater interception is estimated to occur annually. Groundwater interception supports the growth of native and non-ponded vegetation and provides base flow for streams and drains. Negative groundwater interception between December and February may result from limited consumption (ET) of shallow groundwater by vegetation during this period as well as net losses (seepage) from streams, drains, and canals resulting from drawdown of groundwater levels from pumping in the prior irrigation season and associated recharge of the groundwater system.

Comparing total inflows to the region to total outflows to meet consumptive demands plus recoverable return flows available for use by others or the environment, a Water Management Fraction (WMF) may be calculated[14]. This indicator describes the amount of the total water supply not lost irrecoverably to evaporation from canal and drain systems (Equation 3.2).

$$Water\ Management\ Fraction = \frac{Evapotranspiration + Return\ Flows}{Inflows} \qquad [3.2]$$

For the region as a whole, estimates of canal seepage have not been developed at this time. Based on individual supplier water balances described in Volume II, Sections 3 through 7 of this plan, it is estimated that the regional WMF is approximately 0.995, indicating that essentially all available surface water supply is used to meet irrigation demands or is recoverable for downstream surface

[14] The WMF is based on methodologies to quantify the efficiency of agricultural water use developed by DWR (2012) and has been broadened to include all beneficial ET as well as all water supplies.

water and groundwater uses. The only non-recoverable losses are evaporation from canals; no return flows flow to saline water bodies or groundwater.

The basic objective of irrigation in the region is to meet crop and environmental water demands in the most effective and efficient manner practical. Comparing total surface water supply (other than precipitation falling on farmed lands) to total irrigation supply including groundwater pumping, a surface water supply fraction (SWSF) may be calculated as an indicator of the relative amount of the total irrigation supply derived from surface water (Equation 3.3).

$$Surface\ Water\ Supply\ Fraction = Deliveries\ /\ (Deliveries + Groundwater\ Pumping) \qquad [3.3]$$

The regional SWSF was approximately 0.80 between 1999 and 2012, demonstrating the reliability of and reliance on surface water supplies by Feather River (and Sacramento River) water suppliers. In the event of reduced surface water allocations due to surface water shortages, private groundwater pumping can be increased to some extent to minimize lost production, resulting in decreased SWSF for those years. It is estimated that the SWSF in the shortage years of 1991 and 1992 was approximately 0.65, indicating that even in years of reduced supply, surface water is the primary water source to meet demands.

Comparing ET_{aw} to total applied irrigation water, a crop consumptive use fraction (CCUF) may be calculated as an indicator of the relative amount of applied irrigation water consumed to grow the crop[15] (Equation 3.4) (DWR 2012b).

$$Crop\ Consumptive\ Use\ Fraction = Crop\ ET\ of\ Applied\ Water\ /\ (Deliveries + Groundwater\ Pumping) \qquad [3.4]$$

Between 1999 and 2012, the regional CCUF ranged from 0.74 to 0.85 with an overall average of 0.82. These CCUF values are calculated at the regional scale and reflect reuse in the region within and among districts.

15 As discussed throughout this plan, in addition to crops, water is applied to create and enhance managed wetlands. For purposes of analysis, the consumptive use of water for habitat is considered in calculation of the CCUF.

4. Water Management Activities, Objectives, and Opportunities

4.1 Overview

This section describes water management activities, objectives (WMOs), and opportunities to enhance water management in the region. The regional water balance described in the previous section and supplier water balances and historical water use described in Volume II, Sections 3 through 8 provide a technical basis for identifying regional water management objectives and specific actions that water users could take to enhance water management and monitoring both within their service areas and collectively within the region. The descriptions of individual suppliers and evaluations of Efficient Water Management Practices (EWMPs) and water use efficiency improvements in Volume II describe ongoing, planned, and potential future activities that could be taken to enhance water management to meet local, regional, or statewide objectives. Additionally, potential consequential effects of changes in water management are identified that should be considered given the flow-through or "cascading" nature of water use in the region, whereby water used in one area for agricultural or environmental uses but not consumed returns to the system for reuse by others. Existing and potential future water management activities represent tools that could be drawn on to meet one or more objectives, depending on conditions and opportunities over time.

4.2 Water Use Efficiency in the Feather River Region

As described by NCWA (2011), analysis of efficiency in interconnected systems such as the Feather River region should not focus on individual uses or water users without also considering consequential effects of water management actions related to upstream and downstream water uses. Thus, the hydrology of the system as a whole should be incorporated into evaluations of individual components of the system (Keller and Keller 1995). Additionally, increased levels of water use efficiency can be achieved in many cases by improving sequential uses within the region, effectively managing how water moves through the system.

By developing a detailed understanding of the hydrology of and water management within the region as part of the Feather River Regional AWMP, the groundwork has been laid for further development of specific actions to meet water management objectives, and by accounting for the relationships between water users within the region, potentially undesirable consequential effects have been identified that can be collaboratively avoided or minimized while still achieving desired benefits.

The water balances developed as part of this plan clearly demonstrate the importance of considering both consumptive and non-consumptive uses of water when evaluating water use efficiency. Although there is negligible opportunity to increase water supplies by reducing irrecoverable losses of water, there are opportunities to increase local, regional, and statewide water supply and water supply reliability by better managing *when* and *where* (1) available water supplies are used and (2) water returns to the system.

A conceptual example of this is the Butte Creek system. To the extent that there are times when return flows to Butte Creek are not necessary or when the quality of return flows is not optimal for species of interest, there is the potential to implement water conservation measures to reduce these return flows. The conserved water could then be retained in storage for other uses at other times. The ultimate destination of the conserved water could be to deliver it to Butte Creek directly through WCWD's distribution system to meet flow timing or water quality objectives or to provide it for use by others who rely on water from the Feather River, including SWP contractors. It is also important to consider the impact of commingling of Feather River and Butte Creek flows on threatened spring-run Chinook salmon to avoid confusing migrating spring-run salmon as discussed in Section 4.3.2.

In order to evaluate statewide benefits, an evaluation of SWP operations would need to be conducted to determine whether the ability exists to store any conserved water for other uses. In periods during which operators must make releases to meet flow or water quality requirements, reductions in Butte Creek flows that would otherwise return to the Sacramento River could result in increased release requirements at Lake Oroville. Implementation of such a project would require substantial coordination among regional water users, the State, and likely others, but could be accomplished.

4.3 Water Management Activities

Water managers in the region have partnered with wildlife managers and others historically to greatly improve habitat for migratory birds, fishes, and other species while maintaining water supply reliability for irrigation and other uses. Historical, current, planned, and potential water management activities are described throughout this plan. In particular, the detailed evaluation of EWMPs provided for each participating supplier in Volume II, Sections 3 through 8, includes a description of EWMP implementation and corresponding WUE improvements. Suppliers are implementing technically feasible EWMPs at locally cost effective levels and have achieved substantial WUE improvements over past decades. Additionally, the suppliers have identified and evaluated additional opportunities to enhance water management capabilities to achieve local, regional, or statewide WMOs. These additional efforts are being implemented as funding allows and based on prioritization among many potential projects and myriad requirements that face suppliers on a day-to-day basis in serving their customers.

Past and ongoing regional water management activities include projects that span supplier boundaries or occur outside of supplier service areas to improve and protect important wetlands and aquatic habitat, as described below.

4.3.1 Wetlands Water Management

Efforts to protect, restore, and enhance wetlands habitats in the region and Central Valley as a whole have been led to a large part in recent years by the Central Valley Joint Venture (CVJV), a collaborative group of private organizations, state and federal agencies, and others. CVJV was formed in 1988 under the North American Waterfowl Management Plan (NAWMP) (CVJV 2006). In

1990, CVJV developed a strategic plan to implement habitat conservation. In 2006, the plan was updated to incorporate new information and to broaden activities beyond waterfowl to include specific habitat objectives for shorebirds, waterbirds, and riparian songbirds.

The 1990 CVJV implementation plan identified six conservation objectives for Central Valley waterfowl:

- Protect 80,000 additional wetland acres through land acquisitions,
- Secure firm, timely, high quality water supplies for refuges and wildlife areas,
- Secure CVP power to support wetlands management,
- Increase wetlands by 120,000 acres,
- Enhance habitat on 292,000 acres of public and private lands, and
- Enhance waterfowl habitat on 443,000 acres of agricultural lands.

These objectives were distributed across nine basins, including two basins encompassing the Feather River region (Butte and Sutter basins). By 2006, substantial progress was made toward meeting the 1990 objectives in the region and the Central Valley as a whole. In particular, 72 percent of water supply objectives were met through the CVPIA, and 119 percent of agricultural enhancement objectives were met through winter flooding of rice fields for habitat. Winter flooding of rice land in the region is discussed in greater detail in Section 3.3.2.1.

The 2006 plan expands the conservation area to include habitat for the additional bird groups listed above and quantifies conservation objectives where possible. The conservation objectives include identification and evaluation of water needs and challenges. Wetlands water supplies have improved in several areas following enactment of the CVPIA in 1992, which guaranteed "Level 2" supplies to public wetlands, which represent average deliveries prior to 1990. The CVPIA also identified Level 3 and Level 4 supplies, representing optimal supplies for existing habitat and full habitat development, respectively.

To meet Level 4 water supply requirements in the region, the CVPIA Refuge Water Supply Program has resulted in the construction of new facilities in the region and led to the development of agreements for districts to provide firm water supplies to certain refuges. BWGWD has been providing water made available under the CVPIA to Gray Lodge Wildlife Area for several years and is currently in the process of increasing the capacity of its distribution system to reliably deliver Level 4 supplies in the future. Similarly, SEWD provides water to Sutter National Wildlife Refuge, and RID and WCWD provide water for wetlands in the Upper Butte Basin Wildlife Area. The refuge water supply program is an example of successful collaboration between agricultural water suppliers and wildlife managers in the region.

Other local efforts to provide water for wetlands habitat also occur. For example, WCWD has historically released water to Butte Creek during winter months for use by duck clubs downstream of the district. Releases are based on a 1922 agreement discussed in greater detail in Volume II, Section 7. These releases have been on the order of 15,000 to 30,000 af in recent years.

For the Butte and Sutter basins, as described by CVJV (2006), 10,835 acres of wetlands had been protected through acquisition of land and easements as of 2003, or 103 percent of basin-specific goals. Improved water supplies for Gray Lodge Wildlife Area and Sutter National Wildlife Refuge are progressing, with construction of facilities in BWGWD beginning in 2013 and a feasibility study underway to identify long term conveyance for Sutter. A total of 18,553 acres of wetlands were restored in the Butte and Sutter basins by 2003, or 48 percent of basin-specific goals. 132,662 acres of enhanced waterfowl habitat on agricultural lands was achieved in the Butte and Sutter basins, or 94 percent of basin-specific goals.

Despite significant advances in creating and protecting wetlands habitat and securing water supplies, wildlife managers continue to face challenges in meeting water needs for optimal habitat, including increased competition for available water, increased regulation of habitat water management, capacity and timing constraints of existing conveyance facilities, and lack of conveyance facilities in some cases.

4.3.2 Aquatic Habitat

The Butte Creek system is complex due to the presence of both spring- and fall-run salmon and steelhead, commingling of Feather River water with Butte Creek water, and other factors. Spring-run salmon in Butte Creek are a genetically distinct species and rely on the natural chemistry of creek flows in the creek when migrating to navigate the system and reach spawning areas. As a result, the presence of Feather River water can confuse migrating adults. Correspondingly, it is desirable to maximize the portion of natural flow in Butte Creek, while also maintaining desired instream flows.

Historically, fish passage problems existed in Butte Creek within the region. These issues have been largely addressed and continue to be addressed through the WCWD Fish Passage Improvement Project, the CVPIA Anadromous Fish Restoration Program (AFRP), and the DWR Fish Passage Improvement Program (FPIP) which have been successful at restoring salmon populations in Butte Creek. The spring-run experienced a ten-fold increase through the program as compared to baseline conditions with an average production of approximately 1,000 fish per year, for the 1967-1991 baseline period as compared to 10,000 fish per year, on average, between 1992 and 2010 (USFWS 2014b). The fall-run salmon population in the creek has experienced a more than three-fold increase from approximately 800 fish to 2,500 fish per year over the same period. These successes resulted from more than 50 projects completed at a cost of nearly $35 million[16]. Notable projects within the Feather River region include the following (USFWS 2014a):

- Removal of Point-Four Dam (WCWD, 1993)
- Real-time flow monitoring and feedback (AFRP, 1996 – 2001)
- Removal of four dams, construction of WCWD Gary N. Brown Butte Creek Siphon, elimination of 12 unscreened diversions, and augmentation of creek flows (WCWD, 1997 – 1998)

[16] Only projects through 2004 are included. Reported by CDFG (2005).

- Installation of Gorrill Diversion fish screen and fish ladders (WCWD, 1998)
- Replacement of Sanborn Slough weir (AFRP, 1999 – 2001)
- Replacement and upgrade of weir and riser at Drumheller Slough (AFRP, 1999 – 2002)
- Upgrade of three weirs on the west side of the Sutter Bypass and five weirs in the Butte Sink (AFRP, 2001 – 2005)
- Replacement and upgrade of White Mallard Dam (AFRP, 2004 – 2007)
- Replacement and upgrade of Willow Slough Weir (FPIP, 2002 – 2011)
- Replacement and upgrade of Weir #2 (FPIP, 2002 – 2013)
- Installation of fish screens at Sutter Bypass pumping plants (ongoing)

There could be opportunities to modify current agricultural water management practices to better meet environmental objectives in Butte Creek related to flows, flow timing, and water quality; however, they require case-by-case evaluation and the involvement of both agricultural and environmental water managers in the region, including wetlands managers. Modifications to agricultural water management to achieve desired benefits must also consider possible consequential, unwanted effects. The water balance analyses presented in this section for the region and for individual suppliers in Volume II, Sections 3 through 7 of this plan provide a basis for more detailed discussion and evaluation of opportunities. Potential benefits of modified agricultural water management could include the following:

- Increased Butte Creek natural flow, as a portion of total flow in the Butte Creek system;
- Increased instream flows, optimized for timing and amount;
- Cooler water temperatures;
- Increased dissolved oxygen; and
- Decreased turbidity.

One example of a potential opportunity would be to replace existing diversions from Butte Creek in the region with Feather River water. This would increase both the total amount of water in the creek and the portion of water from Butte Creek natural flows. Diversions from Butte Creek occurring within the region include the Gorrill Ranch diversion in WCWD, RD1004, and diversions for agricultural and environmental uses in the Butte Sink and Sutter Bypass.

Due to their life cycle, migratory fishes are influenced by habitat conditions not only in the region, but also in the Delta and Pacific Ocean. As described above, substantial advances have been made in recent years to improve aquatic habitat in the region and Sacramento Valley as a whole. Within the Feather River Region, Butte Creek and the Feather River are important waterways that support migratory fish populations. Advances that have been made in the region and valley as a whole are described by Vogel (2011), including an evaluation of additional needs to restore fish populations. Much of the remaining opportunity lies in the Delta, where predation is a serious issue. It is suggested by Vogel that some benefits of water management activities in the region are negated by these juvenile predation issues.

4.4 Water Management Objectives

Water management objectives (WMOs) vary depending on perspective. For purposes of this plan, local, regional, and statewide water management objectives are discussed.

4.4.1 Local

From a local, agricultural perspective, the objective of a water supplier is to provide water to customers for irrigation in a manner that supports optimal crop production. In essence, this fundamental objective translates to the following characteristics of delivery service:

- Reliable and sufficient amounts and suitable quality to meet crop water requirements,
- Frequencies, rates, and durations that align with crop water requirements, soils, and irrigation methods, and
- Affordable costs to allow for financial stability of farm enterprises.

WMOs from an agronomic perspective are discussed in greater detail for rice and other crops grown in the region in Section 3.3.1.

Another way to characterize WMOs is in the context of WUE improvement categories discussed in the WUE evaluations for individual suppliers included in Volume II, Sections 3 through 7 of this plan. These categories include increased supply and supply reliability, improved water quality, and reduced energy costs through reduced pumping and increased energy efficiency.

4.4.2 Regional

Regional and statewide WMOs were developed by DWR and the CALFED Bay-Delta Program, a cooperative effort undertaken between 2000 and 2007 among state, federal, and public stakeholders to improve California's water supply and the ecological health of the Sacramento-San Joaquin River Delta. The CALFED WUE element included an agricultural component with two primary objectives: (1) encourage implementation of EWMPs at locally cost effective levels, and (2) provide funding to incentivize EWMP implementation where not locally cost effective (CALFED 2000).

The WMOs developed through the CALFED process are referred to as Targeted Benefits (TBs) and Quantifiable Objectives (QOs). TBs include water quality, quantity, and instream flow and timing and may be considered QOs depending on the level of detail at which the TB is defined (i.e., whether specific quantities of flow are identified). QOs represent numerical targets that could be achieved to attain the targeted benefits. The TBs and QOs were developed for 21 subregions within the Central Valley, two of which include portions of the Feather River region. Subregion 4 (Mid-Sacramento Valley, Chico Landing to Knight's Landing) includes the area west of Butte Creek from Llano Seco south to the Butte Slough Outfall Gates and the area to the south within the Sutter

Bypass. Subregion 5 (Lower Feather River and Yuba River) includes the remainder of the Feather River region east of Butte Creek and west of the Feather River[17].

CALFED TBs related to the Feather River Region are summarized in Table 4.1. Several of the TBs have been addressed in recent years through regional efforts and are described elsewhere in this plan. Additional benefits could be attained through potential water supplier projects evaluated as part of this plan and described in Volume II. Additional detail describing TBs and QOs is available from CALFED (2000).

WMOs and resulting activities in the region for environmental uses of water were discussed in greater detail for wetlands and aquatic habitat in Section 4.3. Regional objectives are generally to sustain and enhance agricultural productivity by meeting irrigation demands and environmental quality throughout the region with particular focus on wetlands and aquatic habitat, including the over 70,000 acres of managed wetlands and the Butte Creek system, which is one of three remaining streams in the Sacramento Valley supporting spring-run Chinook salmon, a State and Federal threatened species. These objectives align with TBs 34-36 and 47-49 for wetlands areas and with TBs 37-38 and 43-44 for aquatic ecosystems.

Table 4.1. CALFED Targeted Benefits Corresponding to the Feather River Region.

Region	TB No.	Location	Category	Description
4	83	Sacramento Slough	Quality	Reduce pesticides to enhance and maintain beneficial uses.
4 & 5	33 & 46	All Affected Lands	Quantity	Decrease nonproductive ET to increase water supply.
4 & 5	34, 35, 47, & 48	Wetlands and Other Suitable Lands	Quantity	Provide long-term diversion flexibility to increase water supply.
4	36	Sutter National Wildlife Refuge	Quantity	Provide long-term diversion flexibility to increase water supply.
5	37 & 38	Butte Creek and Feather River	Flow	Provide flow to improve aquatic ecosystem conditions.
5	40 & 41	Feather River	Quality	Reduce pesticides to enhance and maintain beneficial uses of water.
5	42	Sacramento Slough near Verona	Quality	Reduce salinity to enhance and maintain beneficial uses of water.
5	43 & 44	Butte Creek and Feather River	Quality	Reduce temperatures to enhance and maintain aquatic species.
5	49	Gray Lodge Wildlife Area	Quantity	Provide long-term diversion flexibility to increase water supply.

4.4.3 Statewide

Statewide WMOs generally align with regional objectives described above; benefits to water quantity, quality, or instream flows occurring within the region also benefit the State as a whole.

[17] An exception is PMWC, which lies east of the Feather River.

Additionally, statewide WMOs include increasing overall statewide water supply and supply reliability through water transfers across region boundaries. Almost all water suppliers in the region participate in water transfers to some degree, either through crop idling, groundwater substitution, or a combination of both. Additional water may be available through additional efforts, including water conservation actions that result in net increases in overall water supply, or that conserve water that would otherwise be lost from the system but could be retained in storage for use during periods of shortage in other regions[18]. Potential projects evaluated by water suppliers to enhance water management capabilities as part of this plan could support such efforts. Opportunities to further meet statewide WMOs require evaluation on a case-by-case basis to consider project operations and potential consequential effects to downstream agricultural, environmental, and other water uses.

4.5 Water Management Opportunities (Potential Projects to Enhance Water Management Capabilities)

As part of evaluating existing water management activities by suppliers in the region as they relate to EWMPs identified in the CWC, several projects were identified and developed with the potential to modify the timing and amount of water in the system or to hold water in storage through local conservation. These projects do not have the potential to increase water supply, but could be used to increase supply reliability or to improve habitat conditions by modifying when and where water flows through the system. Implementation of individual projects would essentially provide tools that could be applied to contribute to one or more WMOs to achieve targeted benefits. For example, a project that would improve supply reliability at a specific time and a specific location could also be used to improve wetlands or aquatic habitat by strategically rerouting flows to another place at another time. A key requirement of many such activities is the ability to store water and release it at the optimum time to contribute to meeting WMOs.

Projects identified and evaluated for each participating water supplier are summarized in Table 4.2. In the time since the original FRRAWMP was developed, a number of projects have been implemented to enhance water management capabilities for suppliers. For each project, the following information is provided:

- Supplier – Supplier evaluating project.
- Project – Project evaluated. Individual projects may include several sites to be improved, multiple phases of implementation, and multiple levels of improvement. Projects are described in detail in Volume II, Sections 3 through 8 (supplier projects) and Section 10 (Joint District projects).

[18] As discussed previously, water not consumed within the region is available for use downstream in the Delta or by other users, negligible potential exists to increase local or regional water supplies. However, to the extent that some of this water ultimately flows to the San Francisco Bay and Pacific Ocean when it is not needed to meet Delta water quality objectives or other needs, it could potentially be retained in storage, effectively increasing statewide water supplies.

- Initial Cost – Upfront costs for final design, permitting, construction, etc. Cost estimates are from 2014.
- Annualized Capital Recovery and O&M – Amortized annual costs for implementation including initial cost, operations, and maintenance. Amortized capital costs estimated by component based on estimated useful life.
- Targeted Flow Paths – Flow paths expected to be modified through implementation.
- Potential Benefits – Water use efficiency (WUE) improvement categories potentially addressed through implementation. Additional discussion of water use efficiency categories is provided in the descriptions of supplier EWMP implementation and corresponding WUE improvements in Volume II, Sections 3 through 7.
- Modified Flow Quantity – Estimated potential change in targeted flow path, representing potential change in annual volume. These quantities represent the amount of water that could be rerouted to meet water management objectives and do not represent an overall change in regional or statewide water supplies. The indicated range reflects uncertainties in volume changes.
- Unit Implementation Cost – Annual implementation cost per acre-foot of modified flow. The indicated range reflects uncertainties in volume changes.
- Potential Targeted Benefits by Location and Category – Relationship of project to targeted benefits summarized in Table 4.1. A "✓" indicates that the project has the potential to achieve benefits for a given location (e.g., Butte Creek) and benefit category (instream flows, water quality, or water quantity) by changing the timing and amount of water flowing through the system. Specifics of implementation depend on the project and targeted benefit. For example, system modernization by a water supplier could result in reduced operational spillage, allowing for reduced diversions. This water could thus remain in storage and be released at a time and location aligned with a targeted benefit, such as to increase instream flows in the Feather River, for example.

The combination of a large number of potential projects with a large number of potential benefits and corresponding potential tradeoffs necessitates close collaboration among water suppliers and others in the region and state, including wildlife managers, agricultural water users outside of supplier service areas, and project operators. A comprehensive understanding of relative costs, benefits, and tradeoffs is required to optimize water management to provide multiple benefits while maintaining environmental, economic, and social sustainability.

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Table 4.2. Summary of Potential Projects to Enhance Water Management Capabilities and Linkage to Targeted Benefits by Location and Category.

Supplier	Project	Initial Cost	Annualized Capital Recovery and O&M	Targeted Flow Paths	Potential Benefits	Modified Flow Quantity (af)	Unit Implemen-tation Cost ($/af)	Potential Targeted Benefits by Location and Category: Butte Creek		Feather River		Sacramento Slough	Gray Lodge	Sutter NWR	Wet-lands[1]	All Affected Lands
								Flow[2]	Quality[3]	Flow[2]	Quality[4]	Quality[5]	Quantity[6]	Quantity[7]	Quantity[8]	Quantity[9]
BWGWD	System Modernization	$3,843,975	$273,566	Operational Spillage, Tailwater, Drainage Outflows, Deliveries, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality	2,000 to 5,000	$55 to $137	✓	✓	✓	✓	✓	✓	✓	✓	
	Boundary Flow and Primary Spill Measurement and Drainwater Recovery	$916,975	$117,696	Operational Spillage, Tailwater, Drainage Outflows, Diversions		5,000 to 15,000	$8 to $24	✓	✓	✓	✓	✓	✓	✓	✓	
BWD	System Modernization	$14,368,423	$891,896	Operational Spillage, Tailwater, Drainage Outflows, Deliveries, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality	2,000 to 5,000	$178 to $446	✓	✓	✓	✓	✓	✓	✓	✓	
	Boundary Flow and Primary Spill Measurement and Drainwater Recovery	$1,019,755	$101,132	Operational Spillage, Tailwater, Drainage Outflows, Diversions		3,500 to 10,500	$10 to $29	✓	✓	✓	✓	✓	✓	✓	✓	
	Removal of Bottlenecks	$869,221	$47,613	Diversions, Deliveries	Increased refuge water supply and supply reliability, delivery flexibility	See Sutter Butte Conveyance Study (GEI 2006)								✓	✓	
	Improved Service to Pressurized Systems: Sunset and Webster Pipeline Conversion	$2,416,000	$333,200	Diversions, Deliveries, Deep Percolation	Improved air quality, energy conservation, increased water supply and supply reliability	Not estimated at this time			✓			✓				✓
	Improved Service to Pressurized Systems: Improved Turnout Configuration and Debris Management	Unit costs only estimated at this time. Projects to be developed.		Diversions, Deliveries, Deep Percolation	Improved air quality, energy conservation, increased water supply and supply reliability	Not estimated at this time			✓			✓				✓
RID	System Modernization	$12,822,115	$941,583	Operational Spillage, Tailwater, Drainage Outflows, Deliveries, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality	5,000 to 12,750	$74 to $188	✓	✓	✓	✓	✓	✓	✓	✓	
	Boundary Flow and Primary Spill Measurement and Drainwater Recovery	$1,333,296	$116,547	Operational Spillage, Tailwater, Drainage Outflows, Diversions		4,500 to 13,500	$9 to $26	✓	✓	✓	✓	✓	✓	✓	✓	
	Alternative Delivery to Secondary Service Area Using Kelleher Dam	$1,114,000	$61,000	Spillage, Seepage, Deliveries		Not estimated at this time									✓	

Supplier	Project	Initial Cost	Annualized Capital Recovery and O&M	Targeted Flow Paths	Potential Benefits	Modified Flow Quantity (af)	Unit Implemen-tation Cost ($/af)	Potential Targeted Benefits by Location and Category								
								Butte Creek		Feather River		Sacramento Slough	Gray Lodge	Sutter NWR	Wet-lands[1]	All Affected Lands
								Flow[2]	Quality[3]	Flow[2]	Quality[4]	Quality[5]	Quantity[6]	Quantity[7]	Quantity[8]	Quantity[9]
SEWD	System Modernization	$12,983,535	$980,638	Operational Spillage, Tailwater, Drainage Outflows, Deliveries, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality; energy conservation	5,200 to 12,750	$77 to $189	✓	✓	✓	✓	✓	✓	✓	✓	
	Boundary Flow and Primary Spill Measurement and Tailwater Recovery	$645,055	$90,968	Operational Spillage, Tailwater, Drainage Outflows, Diversions		4,000 to 11,000	$8 to $23	✓	✓	✓	✓	✓	✓	✓	✓	
	Improved Service to Pressurized Systems: Improved Turnout Configuration and Debris Management	Unit costs only estimated at this time. Projects to be developed.		Diversions, Deliveries, Deep Percolation	Improved air quality, energy conservation, increased water supply and supply reliability	Not estimated at this time			✓			✓				✓
WCWD	System Modernization	$11,341,652	$762,817	Operational Spillage, Tailwater, Drainage Outflows, Deliveries, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality	4,800 to 12,000	$64 to $159	✓	✓	✓	✓	✓	✓	✓	✓	
	Boundary Flow and Primary Spill Measurement	$260,411	$26,619	Operational Spillage, Tailwater, Drainage Outflows, Diversions		720 to 2,400	$11 to $37	✓	✓	✓	✓	✓	✓	✓	✓	
	Little Butte Creek Reservoir Main Canal Bypass Project	$12,815,000	$758,000	Surface Inflows, Surface Outflows		Not estimated at this time		✓	✓					✓	✓	
FWD	Distribution System Improvements	$1,268,872	$110,627	Deliveries, Operational Spillage, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality; energy conservation	100 to 250	$443 to $1,106			✓		✓			✓	
GHMWC	System Modernization	$1,115,000	$79,644	Operational Spillage, Tailwater, Drainage Outflows, Deliveries, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality; energy conservation	300 to 750	$106 to $265	✓	✓	✓	✓	✓	✓	✓	✓	
	Boundary Flow and Primary Spill Measurement	$412,600	$36,939	Operational Spillage, Tailwater, Drainage Outflows, Diversions		75 to 225	$164 to $493	✓	✓	✓	✓	✓	✓	✓	✓	
	Debris Management	$121,080	$7,880	Deliveries, Diversions	Delivery flexibility, improved water quality, energy conservation	Not estimated at this time									✓	

Supplier	Project	Initial Cost	Annualized Capital Recovery and O&M	Targeted Flow Paths	Potential Benefits	Modified Flow Quantity (af)	Unit Implemen-tation Cost ($/af)	Potential Targeted Benefits by Location and Category: Butte Creek Flow[2]	Butte Creek Quality[3]	Feather River Flow[2]	Feather River Quality[4]	Sacramento Slough Quality[5]	Gray Lodge Quantity[6]	Sutter NWR Quantity[7]	Wet-lands[1] Quantity[8]	All Affected Lands Quantity[9]
PMWC	System Modernization	$721,488	$48,628	Operational Spillage, Tailwater, Drainage Outflows, Deliveries, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality; energy conservation	240 to 600	$81 to $203	✓	✓	✓	✓	✓	✓	✓	✓	
TMWC	Distribution System Improvements	$1,168,389	$100,131	Deliveries, Operational Spillage, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality; energy conservation	40 to 100	$1,001 to $2,503			✓		✓			✓	
Joint Districts	System Modernization	$3,182,900	$220,000	Deliveries, Operational Spillage, Diversions	Increased water supply and supply reliability, delivery flexibility, and/or instream flow; improved water quality	2,600 to 6,500	$34 to $85	✓	✓							

1. Also includes other suitable lands, including agriculture.
2. Provide flow to improve aquatic ecosystem conditions. Could occur through conservation of water in a specific location or at a specific time to allow for redirection of flow to a different location at a different time to strategically benefit habitat by utilizing available storag
3. Reduce temperatures to enhance and maintain aquatic species. Could occur through conservation of warm water ultimately flowing to the Creek or through conservation of water in a specific location or at a specific time to allow for delivery to the creek at a different location at a different time to strategically reduce temperature by utilizing available storage.
4. Reduce temperatures and pesticides to enhance and maintain aquatic species. Could occur through conservation of warm water ultimately flowing to the Creek or through conservation of water in a specific location or at a specific time to allow for delivery to the creek at a different location at a different time to strategically reduce temperature by utilizing available storage. Additional strategies include reduced farm runoff through improvements in irrigation technology.
5. Reduce salinity and pesticides to enhance and maintain beneficial uses. Could occur through conservation of water in a specific location or at a specific time to allow for redirection of flow to Sacramento Slough at a different time to strategically benefit habitat by utilizing available storage, or through reductions in tailwater return flows to the Butte Creek/Sutter Bypass system.
6. Provide long-term diversion flexibility to increase water supply. Could occur through conservation of water in a specific location or at a specific time to allow for redirection of flow to Gray Lodge at a different time to strategically benefit habitat by utilizing available stora
7. Provide long-term diversion flexibility to increase water supply. Could occur through conservation of water in a specific location or at a specific time to allow for redirection of flow to Sutter NWR at a different time to strategically benefit habitat by utilizing available stora
8. Provide long-term diversion flexibility to increase water supply. Could occur through conservation of water in a specific location or at a specific time to allow for redirection of flow to or other affected lands at a different time to strategically benefit habitat by utilizing available storage.
9. Decrease nonproductive ET to increase water supply. Nonproductive ET is limited primarily to canal and drain evaporation, a relatively minor consumptive use. Some potential may exist to reduce nonproductive ET by supporting microirrigation to reduce or eliminate wetted soil and drainflows (and corresponding evaporation). May be countered by increased crop ET from improved crop production.

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5. Climate Change

Climate change has the potential to directly impact surface water resources in the Feather River Region and to indirectly impact groundwater resources. This chapter includes a discussion of the potential effects of climate change on the region, followed by a description of the resulting potential impacts on water resources in the region, including impacts to water supply, water demand, water quality, and flood control. Finally, actions by water users in the region that are currently underway or that could be implemented to help mitigate future impacts are identified. Additional resources regarding water management planning for climate change are also provided.

5.1 Potential Climate Change Effects

Several potential effects of climate change have been identified by the scientific community, including shorter winters, reduced winter snowpack, more variable and extreme weather conditions, and increased atmospheric water demand (i.e., ET_o). Additionally, climate change could affect water quality through increased flooding and subsequent erosion; greater concentration of contaminants, if any, in the water supply; and warmer water, which could lead to increased growth of algae and other aquatic plants. Rising sea level is also a potential effect of climate change. However, since the Region is not located in the Sacramento-San Joaquin River Delta, this discussion of climate change focuses on climate change effects and impacts related to the regional water supply, water quality, water demand, and flood protection but does not discuss potential effects of rising sea level.

5.1.1 Feather River Runoff

Review of the historical flow record for the Feather River at Oroville between 1906 and 2012 reveals potential climate change effects on winter snowpack and spring runoff (Figure 5.1). Over the last century, April to July full natural flow as a percentage of water year full natural flow appears to show a decreasing trend, resulting in a change of approximately ten percent. In contrast, water year full natural flow has not decreased (Figure 5.2). The combination of these two figures suggests that the amount of runoff occurring during the April to July period has decreased, while the amount occurring during the remainder of the year has increased. Figure 5.3 shows average monthly full natural flow for the period from 1906 to 1960 and from 1961 to 2012 along with the percent change between the first half and second half of the preceding century. Comparing these periods, increases in runoff have occurred in October through March, with decreases in April through August. Average September runoff remained similar. The greatest increases in runoff occurred in January and December with the greatest decreases occurring in April and May.

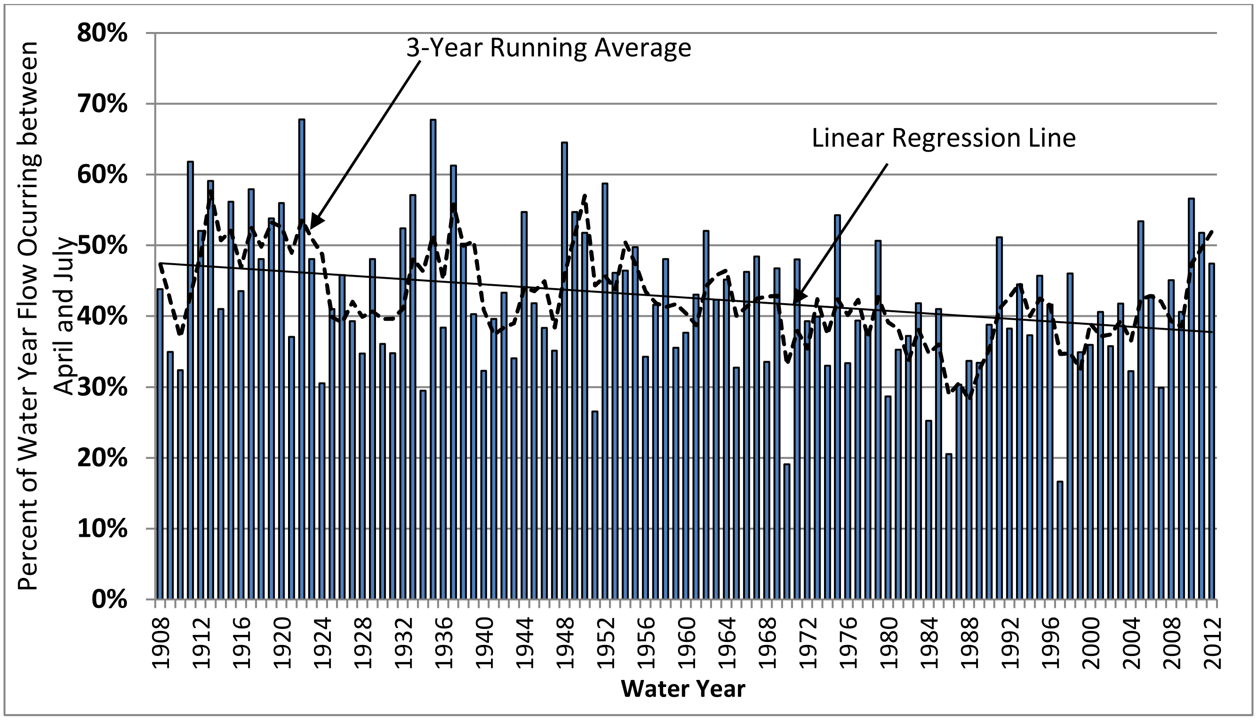

Figure 5.1. Annual April through July Full Natural Flow for Feather River at Oroville as Percentage of Water Year Full Natural Flow.

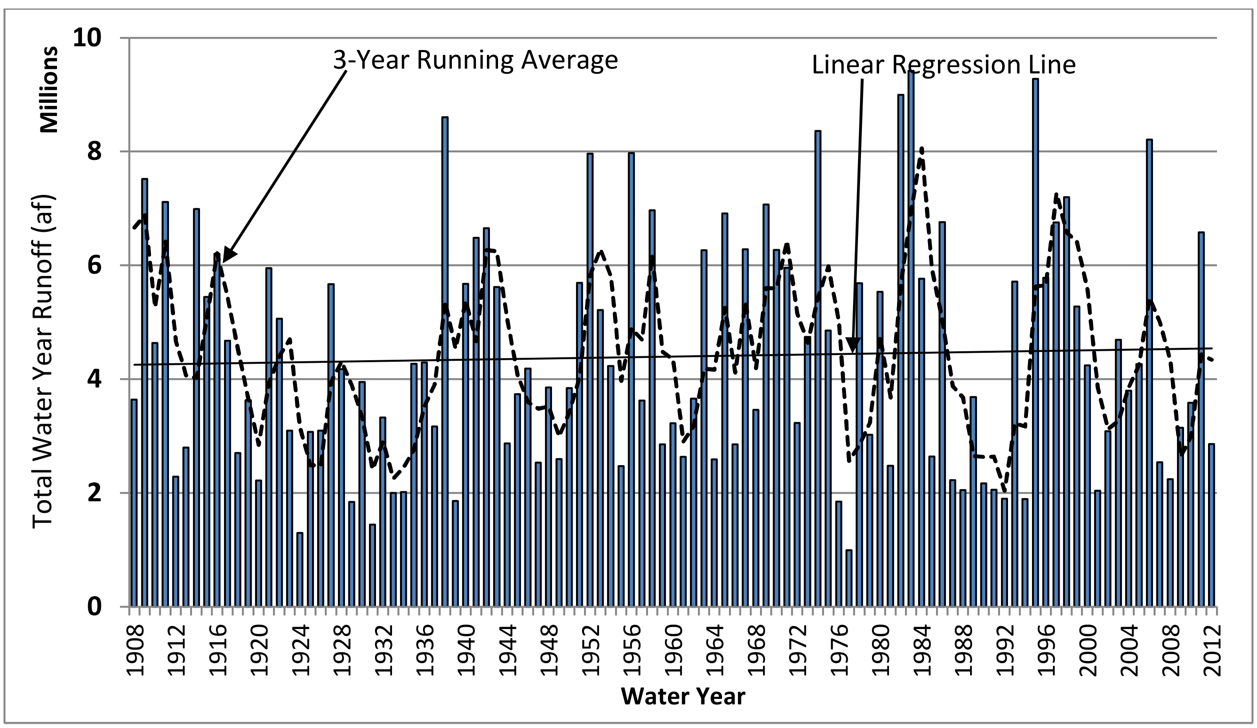

Figure 5.2. Water Year Full Natural Flow for Feather River at Oroville.

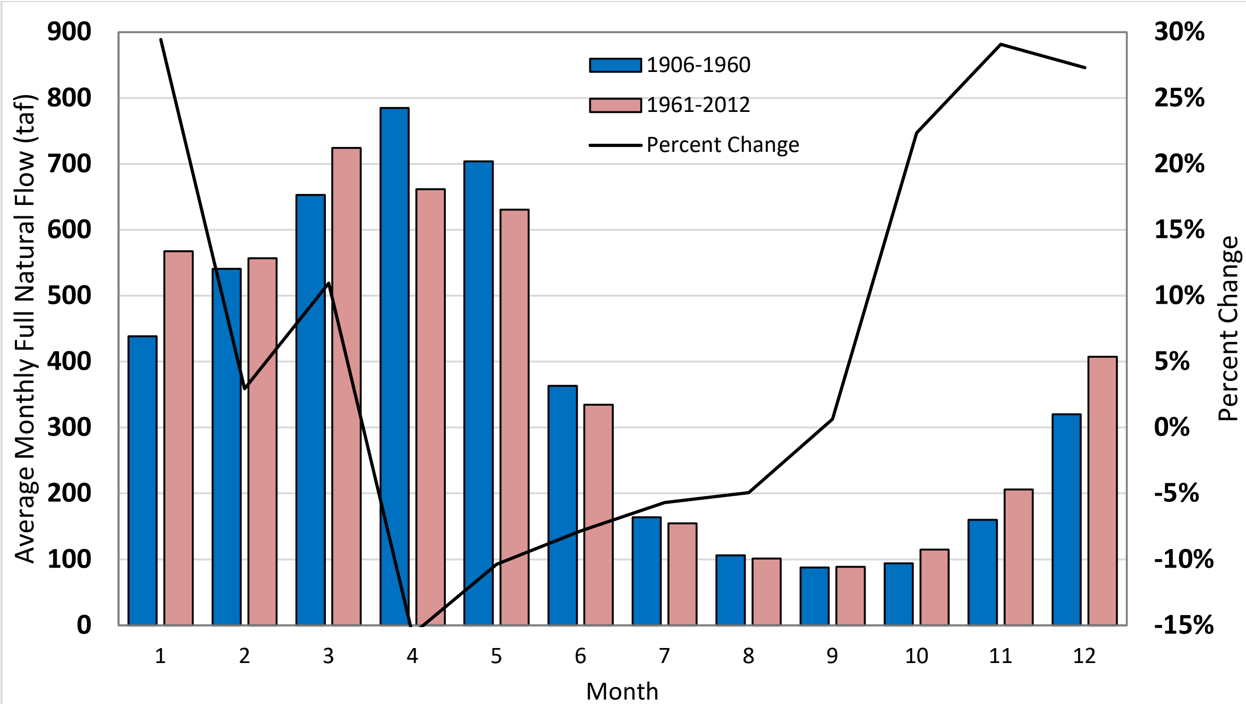

Figure 5.3. Mean Monthly Full Natural Flow and Percent Change, 1906-1960 and 1961-2012.

Recent projections of full natural flow reported by USBR for the Feather River at Oroville (USBR 2011) suggest that runoff between April and July as a percentage of total runoff could continue to decrease over the next 100 years as shown in Figure 5.4. The figure shows the 5th percentile, median, and 95th percentile April to July Feather River runoff at Oroville as a percentage of total water year runoff for 1950 to 2100 based on 112 separate hydrologic projections driven by global climate models with a range of assumptions regarding future carbon dioxide emissions. Projections from 1950 to present do not represent actual historical runoff. Actual spring runoff as a percentage of total runoff is also shown. As indicated, the actual runoff pattern differs greatly from the median of projection results, but generally falls within the range across all projections. Similar to actual conditions over the past 100 years, the projections do not collectively predict a substantial change in total water year runoff, but rather a shift in timing resulting from reduced snowpack.

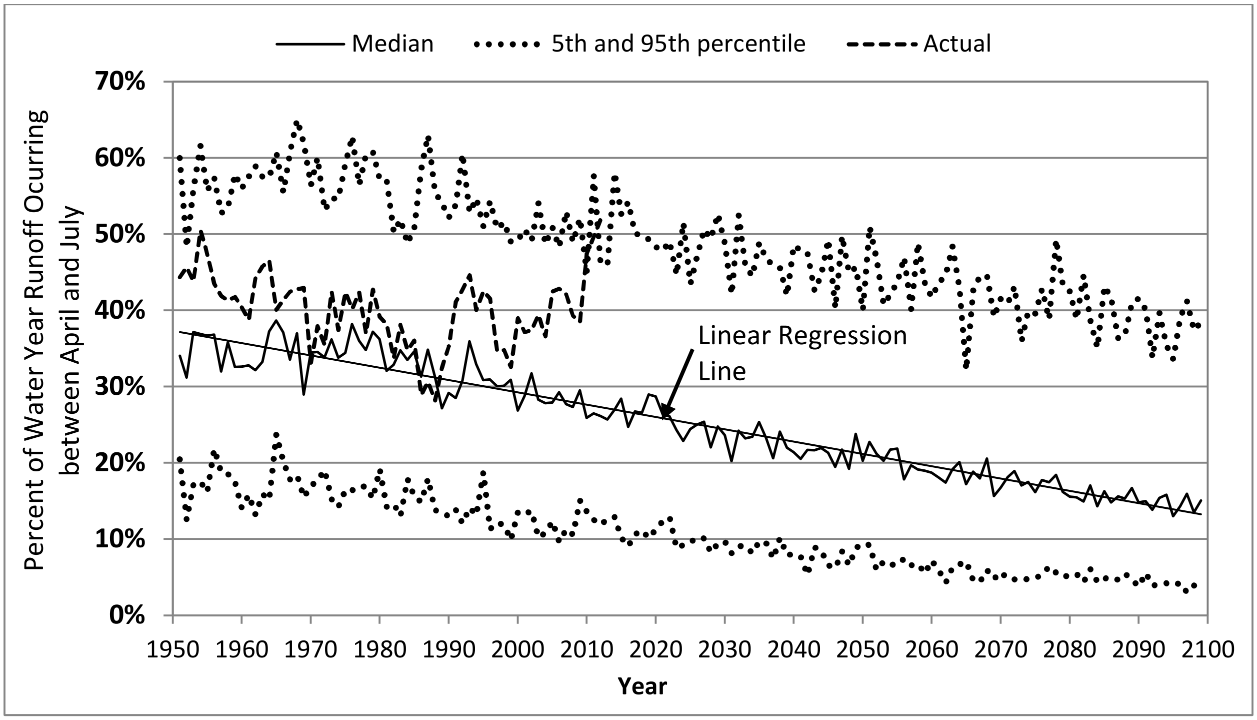

Figure 5.4. Projected (1950 – 2100) and Actual (1950 – 2012) Annual April through July Full Natural Flow for Feather River at Oroville as Percentage of Water Year Full Natural Flow (USBR 2011).

5.2 Potential Climate Change Impacts

The effects of climate change will likely influence and impact water resources in the Feather River region. This section describes potential impacts on water supply, water demand, water quality, and flood control.

5.2.1 Potential Impacts on Water Supply

The shift in runoff to the winter period has the potential to impact surface water supply in the future if sufficient storage is not available to retain winter runoff until it is needed to meet irrigation demands. Storage in the region occurs through SWP facilities at Lake Oroville, and storing and delivering water is constrained by several factors including but not limited to runoff in the watershed, available storage in reservoirs, minimum in-stream flow requirements, contractual obligations to water users, and required releases for flood control. These shifts in total inflows to Lake Oroville in the future could increase the probability that total river supplies would be less than that required to meet agricultural, environmental, and other demands on the Feather River and to meet the needs of those receiving water from Lake Oroville elsewhere in the State.

According to their settlement agreement with the State, all of the participating water suppliers (with the exception FWD, who do not possess a settlement agreement) are subject to surface water supply reductions under the following conditions:

- DWR forecasted April to July unimpaired runoff into Lake Oroville is less than 600,000 af[19], or
- Total current year predicted and prior year actual deficiencies in unimpaired runoff (as compared to 2,500,000 af) exceed 400,000 af for one or more successive prior water years with less than 2,500,000 af of runoff

Reductions of up to 50 percent can occur in any one year, but cannot exceed 100 percent in any seven consecutive years. Historically, reductions have occurred only in 1977, 1991, 1992, and 2015. In each year, surface water supplies were reduced by 50 percent. As indicated in Figure 5.4, the likelihood of reductions in the future may increase as a result of reductions in April to July Feather River runoff, which is tied directly to the first condition above.

In the Butte Creek watershed, the potential effect of reduced spring runoff would be to reduce Butte Creek water supplies for agricultural and environmental demands on Butte Creek.

Potential impacts of climate change on Feather River water supplies have additionally been evaluated in detail by DWR as part of the SWP reliability report (DWR 2013b).

5.2.2 Potential Impacts on Crop Consumption

Climate change has the potential to affect crop evapotranspiration and resulting irrigation water demands within the region. Changes in precipitation, temperature, and atmospheric CO2 affect crop evapotranspiration (ET) and net irrigation water requirements (NIWR). Global climate models (GCMs) have been used to project future climate change and impacts on crop water demands. In particular, the Bureau of Reclamation released a report entitled West-Wide Climate Risk Assessment: Irrigation Demand and Reservoir Evaporation Projections (WWCRA) (USBR 2015) in February 2015. The study uses climate change projections to calculate future ET and NIWR throughout the Western U.S., including California's Central Valley. Projections for the Central Valley were developed for DWR planning units used to evaluate statewide water supplies and demands as part of the California Water Plan. The region falls primarily within Planning Unit 507E (PU507E). This section describes potential changes in crop ET, a climate change effect, while impacts on NIWR are described in Section 5.2.4, below.

The Bureau of Reclamation's study utilizes future climate projections from GCMs to simulate crop evapotranspiration under climate change and to estimate resulting net irrigation requirements. The specific dataset selected for predicting future irrigation demands was the World Climate Research Program (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3). Original GCM projections are developed at a spatial resolution of 100 to 250 km. In order to develop data on a usable scale to support local and regional planning, CMIP3 projections were downscaled to 12 km square sections using the statistical algorithm known as bias comparison and spatial disaggregation

[19] The final, official forecast must be made by April 10 of each year.

(BCSD). One hundred and twelve BCSD-CMIP3 projections were created based on combinations of GCM and potential future greenhouse gas emission scenarios.

Crop ET and NIWR were estimated using a model simulating crop growth and irrigation demands over time under baseline and modified climate scenarios. Specifically, the ET Demands model, a daily root zone water balance simulation applying the FAO-56 dual crop coefficient approach, was used to estimate crop ET and NIWR. Reference ET was calculated based on climate projections for each of the five modeled climate scenarios using the Food and Agricultural Organization (FAO) Report56 reference ET approach. The GCMs climatic conditions were limited to only daily maximum and minimum temperature and daily precipitation. Therefore, other climate parameters needed to estimate reference ET, such as solar radiation, humidity, and wind speed, were approximated for baseline and future time periods using empirical equations (USBR 2015). In order to evaluate potential impacts of changes in temperature on the timing of crop growth and overall season length, simulations were conducted assuming both static and dynamic crop phenology. To simulate dynamic phenology, growing degree day (GDD) based crop curves were used. By incorporating GDD into the analysis, projected changes in temperature influence the timing and speed of crop growth. Increased temperatures result in earlier, shorter growing seasons for annual crops. Crop evapotranspiration is projected to increase in areas where perennial crops are grown and smaller increases are projected for areas where annual crops are grown.

Potentially, each of the 112 climate projections could be simulated in the ET Demands model to develop projections of future ET and NIWR; however, due to the wide variety of crop types and agricultural practices in the West this would create enormous computation and data handling requirements. Instead, five different climate change scenarios were created using the ensemble hybrid formed delta method. The future conditions of warm-dry, warm-wet, hot-dry, hot-wet and central tendency were used. Three future periods for these five conditions were selected to project climate change, including the 2020’s (2010-2039), 2050’s (2040-2069) and 2080’s (2070-2099).

Average air temperature in PU507E is projected to increase for each of the five scenarios for each future period as shown in Figure 5.5. Projected temperature increases range from 1.3 to 2.6 deg. F during the 2020’s period, 2.7 to 4.6 deg. F during the 2050’s period, and 3.9 to 7.0 deg. F during the 2080’s period.

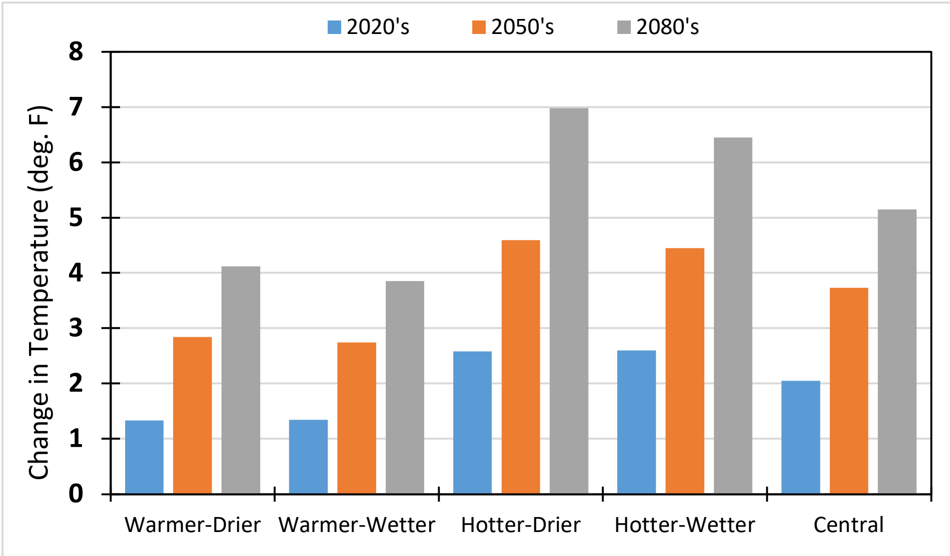

Figure 5.5. WWCRA Projected Temperature Change

Potential changes in precipitation resulting from climate change are relatively uncertain for California's Central Valley due to uncertainty in the future position of the jet stream. As a result, some GCMs and emission scenario combinations predict increased precipitation under climate change, while other combinations predict decreased precipitation. Percent changes in projected average annual precipitation for PU507E are shown in Figure 5.6. Under wetter conditions increases in precipitation of 5.6 to 11.8 percent between the 2020's and the 2080's are predicted, while under drier conditions, decreases in precipitation of 7.1 to 14.9 percent between the 2020's and the 2080's are predicted. The central tendency results in a predicted slight decrease in precipitation of 0.5 to 1.7 percent during the 2080's period.

From the projected temperature and precipitation results, WWCRA used impact models to develop projected reference ET and actual ET estimates. The results are shown below in Figures 5.7 and 5.8, respectively. Increases in both reference ET and actual ET are projected in most model scenarios. Projected reference ET increases range from 1.8 to 3.6 percent during the 2020's period, 3.7 to 6.3 percent during the 2050's period, and 5.1 to 9.5 percent during the 2080's period. Projected actual ET changes range from -0.03 to 0.6 percent during the 2020's period, -0.5 to 0.7 percent during the 2050's period, and -1.6 to 0.4 percent during the 2080's period. Reference ET is expected to increase significantly more than actual ET due to changes in phenology of annual crops, discussed in the following paragraph.

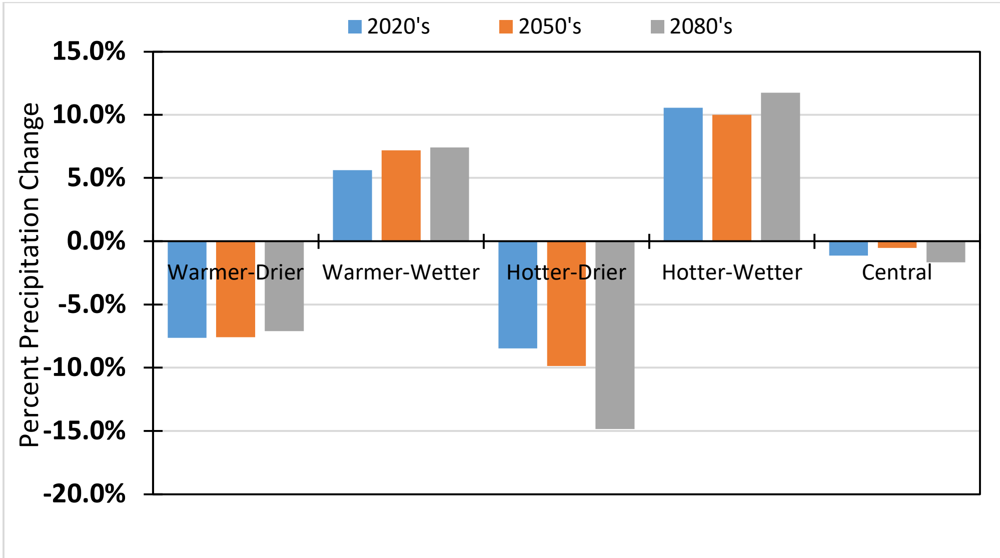

Figure 5.6. WWCRA Projected Precipitation Change.

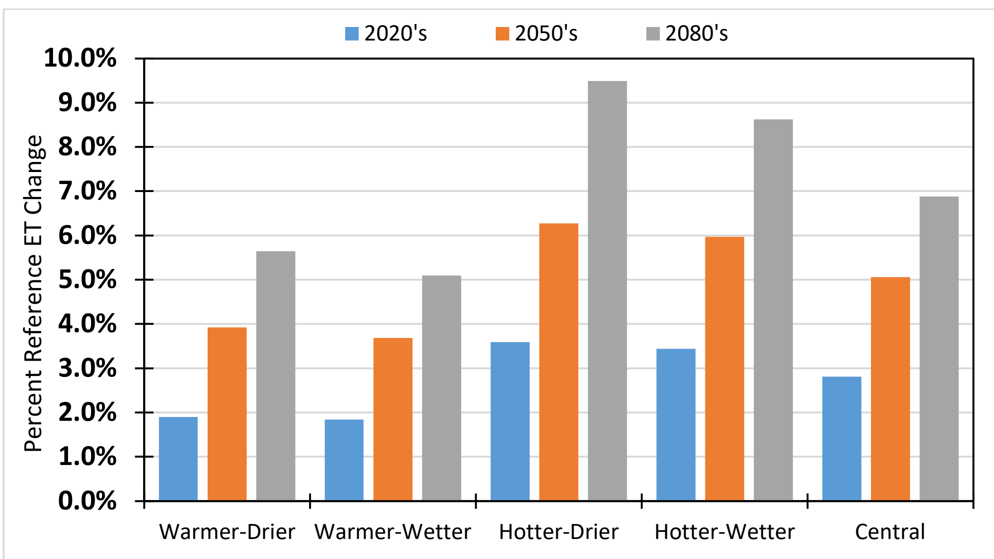

Figure 5.7. WWCRA Projected Reference ET Change.

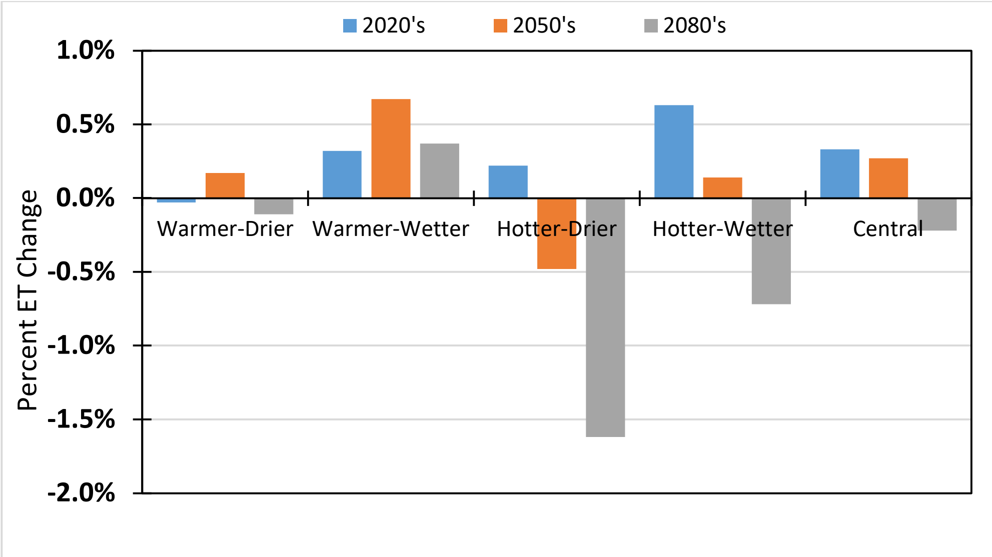

Figure 5.8. WWCRA Projected ET Change Assuming Non-Static Phenology.

Projected actual ET estimates assume non-static phenology for annual crops rather than static phenology. Non-static phenology is believed to be more accurate as plant growth depends heavily on temperature. With temperature expected to increase, crop growing seasons are expected to be shorter, which is accounted for in non-static phenology by using growing degree days. There is less projected impact on actual ET with non-static phenology than when static phenology is assumed. If static crop phenology is assumed, percent changes in actual ET would be similar to the projected changes in reference ET. Reference ET is expected to increase significantly more due to the projected temperature increases.

5.2.3 Potential Impacts on Water Quality

Increased erosion and turbidity under climate change, if it occurred, would likely not significantly affect the water quality of the Feather River as it affects agricultural irrigation. Additionally, there are no known contaminants that could be concentrated to levels that would affect agricultural irrigation if spring runoff from the upper watershed were to decrease, particularly due to the dilution of such contaminants in reservoirs upstream of the agricultural lands in the region. Increased water temperature could result in additional challenges for the suppliers in controlling aquatic plants in their distribution systems to maintain capacity, to the extent that the increase is great enough to result in substantially increased plant growth, although reservoir operations control water temperatures to a large degree. Increased turbidity and algae growth, if substantial, could pose additional challenges to filtering surface water for micro-irrigation of orchard crops and operation of reuse pumps.

5.2.4 Potential Impacts on Water Demand

The USBR publication, West-Wide Climate Risk Assessment: Irrigation Demand and Reservoir Evaporation Projections, showed crop ET is expected to change, as discussed previously, due to effects of climate change, such as temperature increase and other climate factors (USBR 2015). NIWR is typically expected to increase for the 2020 and 2050 climate scenarios presented in the USBR report, shown in Figure 5.9. Additionally, changes in precipitation timing and amounts could result in greater irrigation requirements to meet ET demands. Changes in the timing of crop planting, development, and harvest could also result in changes to the timing of irrigation demands during the year; all impacting the NIWR. Projected NIWR changes range from 0.3 to 1.1 percent during the 2020's period, -0.4 to 1.1 percent during the 2050's period, and -1.9 to 0.6 percent during the 2080's period. Projected NIWR are based on non-static crop phenology for annual crops.

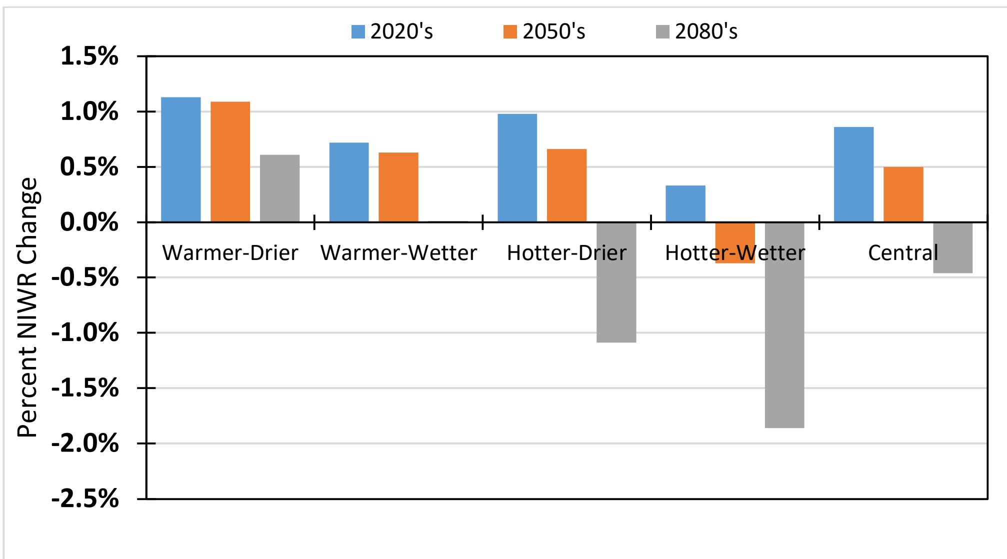

Figure 5.9. WWCRA Projected Net Irrigation Water Requirement Change Assuming Non-Static Phenology.

When interpreting results, several uncertainties must be accounted for. Estimating the effects of carbon dioxide (CO2) on irrigation demand requires the use of physiological crop growth models and was not included in the WWCRA. In general, increased atmospheric CO2 is expected to reduce stomatal conductance and transpiration, which would lead to reduced ET, all else equal. Changes in the types of crops grown, irrigated area, and irrigation efficiencies also affect the amount of irrigation water requirements. For further information, please refer to the West-Wide Climate Risk Assessment: Irrigation Demand and Reservoir Evaporation Projections (USBR 2015).

5.2.5 Potential Flood Control Impacts

Flood control in the region is currently accomplished through the cooperative activities of DWR, the Sutter Butte Flood Control Agency (SBFCA), and others. Due to the potential for future precipitation to occur as rain rather than snow and corresponding increased runoff during winter months, increasing pressure on regional flood management systems may occur in the future. Flood control activities are beyond the purview of agricultural water suppliers participating in this plan.

Potential increased winter inflows to Lake Oroville resulting from climate change could result in increased flooding if reservoir capacities are not increased or flood control operations are not modified. Changes to flood control operations resulting in increased reserve capacity for runoff would result in less available water supply to meet irrigation and environmental demands.

5.3 Strategies to Mitigate Climate Change Impacts

Although there is general consensus that climate change is occurring and the effects of climate change are being observed, the timing and magnitude of climate change impacts remains uncertain. Agricultural water suppliers in the Feather River region will most likely mitigate climate change impacts with this uncertainty in mind through an adaptive management approach while pursuing long-term operational and other changes to increase supply reliability. Under adaptive management, key uncertainties will be identified (e.g., April – July runoff as a percentage of annual runoff, total runoff, average temperature, and reference evapotranspiration), and strategies will be developed and implemented to address the related climate change impacts. As actual impacts occur, strategies will be prioritized and modified as appropriate.

Several strategies for agricultural water providers and other water resources entities to mitigate climate change impacts have been identified (DWR 2008, CDM 2011). These strategies include those included as part of the California Water Plan 2009 Update (DWR 2010a) and the draft California Water Plan 2013 Update (DWR 2013a) as well as strategies identified as part of the California Climate Adaptation Strategy (CNRA 2009). Many of these strategies are already being implemented by the agricultural water suppliers in the region to meet local and regional water management objectives and will be enhanced as needed as climate change impacts occur.

Resource strategies that are being implemented or could be implemented by the suppliers in the Feather River region to adapt to climate change are summarized in Table 5.1.

Table 5.1. Strategies to Mitigate Climate Change Impacts.

Source	Strategy	Status
California Water Plan (DWR 2009)	Reduce water demand	The suppliers are implementing all technically feasible, locally cost-effective EWMPs identified by SBx7-7 to achieve water use efficiency improvements in operations and to encourage efficient water management by individual water users.
	Improve operational efficiency and transfers	As described above and elsewhere in this AWMP, the suppliers are implementing improvements to increase operational efficiency of irrigation facilities. Additionally, the suppliers actively transfer water through available agreements to satisfy environmental, urban, and other water needs.
	Increase water supply	The suppliers have increased available water supply through reuse of drain water, increased operational efficiencies, and voluntary water transfers. In the future, the suppliers will seek additional opportunities to increase available water supply. Constructing additional surface water storage would increase water supply and allow for more winter period runoff to be held for release during the primary irrigation season.
	Improve water quality	The suppliers and other regional entities will continue to monitor groundwater quality and surface water quality and develop and implement strategies as needed to address water quality concerns related to climate change.
	Practice resource stewardship	The suppliers are active stewards of water through their efficient use of water resources within their service areas including beneficial groundwater recharge. Additionally, many of the suppliers provide water for environmental uses, such as public and private wetlands.
	Improve flood management	DWR and others provide flood management within the Feather River region. DWR will continue to operate SWP facilities as appropriate based on climate change impacts. The suppliers will coordinate and collaborate with flood managers as needed to improve flood management.
	Other strategies	Other strategies include crop idling, irrigated land retirement, and rainfed agriculture. Under severely reduced water supplies, the suppliers could consider these strategies.
California Climate Adaptation Strategy (CNRA 2009)	Aggressively increase water use efficiency	Described above under "Reduced water demand" and "Improve operational efficiency and transfers."
	Practice and promote integrated flood management	Described above under "Improve flood management."
	Enhance and sustain ecosystems	Described above under "Practice resource stewardship."
	Expand water storage and conjunctive management	Described above under "Increase water supply."
	Fix Delta water supply	Water transfers by the suppliers could be used to help meet Delta water supply objectives.
	Preserve, upgrade, and increase monitoring, data analysis, and management	The suppliers have upgraded and increased monitoring, data analysis, and management as part of ongoing operations. The suppliers will continue to preserve, upgrade, and increase these efforts in the future and have evaluated potential projects to increase monitoring as part of this plan.
	Plan for and adapt to sea level rise	Projections indicate that sea levels could rise by 2 to 5 feet by 2100. Direct impacts on the suppliers are not anticipated, although the suppliers could consider a role to help mitigate impacts to affected areas through water transfers or other means.

5.4 Additional Resources for Water Management Planning for Climate Change

Much work has been done at State and regional levels to evaluate the effects and impacts of climate change and to develop strategies to manage available water resources effectively under climate change. The following resources provide additional information describing potential impacts of climate change and water resources planning for climate change:

- Progress on Incorporating Climate Change into Planning and Management of California's Water Resources. California Department of Water Resources Technical Memorandum. July 2006. (DWR 2006)
- Climate Change and Water. Intergovernmental Panel on Climate Change. June 2008. (IPCC 2008)
- Managing An Uncertain Future: Climate Change Adaptation Strategies for California's Water. California Department of Water Resources Report. October 2008. (DWR 2008)
- 2009 California Climate Change Adaptation Strategy. California Natural Resources Agency Report to the Governor. December 2009. (CNRA 2009)
- Climate Change and Water Resources Management: A Federal Perspective. U.S. Geological Survey. (USGS 2009)
- Managing an Uncertain Future. California Water Plan Update 2009. Volume 1, Chapter 5. March 2010. (DWR 2010a)
- Climate Change Characterization and Analysis in California Water Resources Planning Studies. California Department of Water Resources Final Report. December 2010. (DWR 2010b)
- Climate Change Handbook for Regional Water Planning. Prepared for U.S. Environmental Protection Agency and California Department of Water Resources by CDM. November 2011. (CDM 2011)
- Climate Action Plan—Phase 1: Greenhouse Gas Emissions Reduction Plan. California Department of Water Resources. May 2012. (DWR 2012c)
- Climate Change and Integrated Regional Water Management in California: A Preliminary Assessment of Regional Perspectives. Department of Environmental Science, Policy and Management. University of California at Berkeley. June 2012. (UCB 2012)
- State Water Project Final Delivery Reliability Report 2011. California Department of Water Resources. June 2012. (DWR 2012d)
- California Adaptation Planning Guide: Planning for Adaptive Communities. California Emergency Management Agency and California Natural Resources Agency. July 2012 (Cal EMA & CNRA 2012)
- Managing an Uncertain Future. Draft California Water Plan Update 2013. Volume 1, Chapter 5. November 2013. (DWR 2013a)
- State Water Project Draft Delivery Reliability Report 2013. California Department of Water Resources. December 2013. (DWR 2013b)

- U.S. Bureau of Reclamation (USBR). 2015. West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections. Technical Memorandum No. 86-68210-2014-01. Available at www.usbr.gov/watersmart/baseline/index.html. (USBR 2015)
- Perspectives and Guidance for Climate Change Analysis. August 2015. California Department of Water Resources Climate Change Technical Advisory Group. (DWR-CCTAG 2015)
- SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water 2016. March 2016. (USBR, 2016a).
- Sacramento and San Joaquin Rivers Basin Study. March 2016. (USBR, 2016b)
- Actions for Sustainability. California Water Plan Update 2018. Chapter 3. 2018. (DWR, 2018a)
- Safeguarding California Plan: 2018 Update, California's Climate Adaptation Strategy. California Natural Resources Agency. January 2018. (CNRA, 2018)
- Indicators of Climate Change in California. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. May 2018. (Cal EPA, 2018)
- Resource Guide: DWR-Provided Climate Change Data and Guidance for Use During Groundwater Sustainability Plan Development. July 2018. (DWR 2018b)
- Climate, Drought, and Sea Level Rise Scenarios for California's Fourth Climate Change Assessment. Report #CCCA4-CEC-2018-006. August 2018. Pierce, D.W., J.F. Kalansky, and D.R. Cayan. (Pierce et al. 2018)
- Climate Action Plan—Phase 2: Climate Change Analysis Guidance. California Department of Water Resources. September 2018. (DWR, 2018c)
- Climate Action Plan—Phase 3: Climate Change Vulnerability Assessment. California Department of Water Resources. February 2019. (DWR, 2019)
- Climate Action Plan—Phase 1: Greenhouse Gas Emissions Reduction Plan. California Department of Water Resources. July 2020. (DWR, 2020)
- Cal-Adapt website tools, data, and resources for exploring California's climate change research and developing adaption plans. Available at https://cal-adapt.org/

6. Recommendations

Recommendations have been developed through the preparation of this regional AWMP based on the process of characterizing the region with respect to its physical setting; surface water and groundwater hydrology; agricultural water supplier entities, facilities, and policies; water management objectives, activities, and opportunities; and potential effects, impacts, and adaptation strategies for climate change. In general, these recommendations are related to closing information gaps to support improved understanding of regional hydrology, better defining water management objectives, and pursuing opportunities to achieve those objectives.

6.1 Re-Establish Historical Monitoring Locations and Identify New Sites

While information describing inflows to and outflows from the region is relatively abundant, limited information is available describing surface flows between water use areas within the region. In particular, information describing inflows to and flows along the Butte Creek system are limited. Several historical stream gage sites have been discontinued or are no longer maintained. As a result, current hydrologic conditions and system responses to water management activities are not adequately monitored. Supplier water balances developed as part of this plan and presented in Volume II, Sections 3 through 7 provide insight into the timing and location of return flows to the system from irrigation, and include measured volumes from recent monitoring efforts, but are still subject to uncertainty. Improved understanding of flows in the Butte Creek/Sutter Bypass system is important for multiple operational and analytical purposes.

From an operational perspective, improved knowledge of return flows can help support improved water management by water suppliers to increase local water supply reliability or to support other local, regional, or statewide water management objectives. Additionally, better knowledge of flows can help wildlife managers better respond to changes in instream flows and water quality and to ensure that adequate conditions exist.

From an analytical perspective, improved knowledge of flows in the Butte Creek system and agricultural return flows to the system would lead to increased understanding of system responses to changing water management and natural hydrologic conditions. Additionally, this improved knowledge would support the development of plans aimed at meeting water management objectives through more precise information describing system behavior.

It is recommended that consideration be given to re-establishing historical monitoring locations while identifying additional sites to be added. In particular, it would be beneficial re-establish a site to monitor flows from RD1500 into the Sutter Bypass (California Water Data Library site A02926), so that regional outflows could be estimated directly by subtracting these flows from the Sacramento Slough near Karnak site (California Water Data Library site A02925). Additionally, it would be beneficial to establish a monitoring site on the East Borrow Canal below the bifurcation of Butte Slough to improve understanding of the division of flows entering the bypass. Additional sites to characterize reaches of the system located near major inflow locations should be identified and established as a next step. Information describing flows within Butte Creek and the Sutter Bypass, coupled with advances in boundary outflow monitoring by upstream water suppliers would provide a basis for further evaluating opportunities to enhance habitat or meet other WMOs through changes in agricultural water management.

6.2 Improve Monitoring of Surface Water Outflows and Refine Water Balances to Improve Understanding of Surface-Groundwater Interactions and Net Recharge

Primary information gaps are related to surface-groundwater interactions. Individual fluxes cannot be practically directly measured in most cases. These include deep percolation, groundwater pumping, seepage, and shallow groundwater interception, which includes both consumptive use of shallow groundwater and accretions of base flow by streams and drains. Results of the water balances developed as part of this AWMP indicate that net recharge of the groundwater system occurs in the region. Improved understanding of these interactions would enhance the evaluation of conjunctive management opportunities to increase local water supplies to meet local and regional water management objectives. The primary value of additional information would be to better understand net exchange between the surface and groundwater systems and the individual fluxes contributing to net exchange, as well as to better understand cause and effect relationships between the use of surface water or groundwater and flows in streams and storage and water levels in underlying aquifers.

The approach to improve confidence in estimates of surface water-groundwater interactions is complementary with objectives for closing information gaps related to surface hydrology. It is recommended that efforts be made to increase information describing surface water outflows from water use areas, followed by refinement of water balances to allow for improved estimation of net recharge. Following improvements to estimates of net recharge, the contributions of individual surface water-groundwater fluxes should be refined through investigations of canal seepage and gains and losses in streams and drains and through field-scale water balances to better estimate deep percolation resulting from irrigation and precipitation. Benefits of these efforts could include enhanced calibration of existing and possible future regional groundwater models used to evaluate potential water management activities under current or potential future conditions to evaluate potential benefits and tradeoffs.

6.3 Better Define Water Management Objectives

WMOs are described in this plan from local, regional, and statewide perspectives. Local WMOs are related to supporting optimal crop production or WUE improvements such as increased supply and supply reliability, improved water quality, and reduced energy costs through reduced pumping and increased energy efficiency. Regional WMOs have been developed through the CALFED process in the form of TBs, but there remain opportunities to quantify the timing and amount of changes in flows in the system to meet or contribute to desired benefits.

It is recommended that agricultural and environmental water managers in the region collaborate to identify specific opportunities to achieve targeted benefits. This process would start by developing conceptual strategies identifying sources and destinations of flows to be modified, including potential changes in flow timing. The types of strategies could include any of the following:

- Reduce flow at a selected source location and simultaneously increase flow at a selected destination location;
- Reduce flow at a selected location, retain the water in storage, and increase the flow at the same location at a different time;
- Reduce flow at a selected source location, retain the water in storage, and increase the flow at a selected destination location at a different time; or
- Replace the source of water at a selected location with water form a different source. Examples could include replacing Feather River water with drain water, replacing Butte Creek water with Feather River water, etc.

Once a conceptual strategy is developed, timing and amounts of flows to be re-routed would be identified, as well as potential routes to convey the water, as applicable. This information would provide the basis for the development of partnerships among agricultural suppliers and environmental water managers or others, as appropriate. These partnerships could then collaborate to seek funding and develop formal agreements to implement identified projects, as discussed in Section 6.5, below.

6.4 Pursue Implementation of Projects Directly Linked to Water Management Objectives

Several projects identified and evaluated as part of this plan can be directly linked to water management objectives. For example, projects generally would increase local water supply reliability to enable water suppliers to better meet customer demands during periods of shortage. It is recommended that these projects be pursued by individual suppliers to the extent that funding is available. Funding may be available internally or through external sources such as grant programs.

Improvements to individual sites should be prioritized to maximize cost-effectiveness. The system modernization projects identify specific sites to be improved over a series of phases beginning with key inflow and outflow locations and then progressing from primary control structures to secondary and tertiary structures within each distribution system. Additionally, different levels of improvement have been identified beginning with key physical improvements and progressing to additional improvements to provide remote monitoring capabilities to further enhance water management. It is anticipated that as part of implementation, specific sites to be improved and levels of improvement will be refined based on further evaluation by supplier staff; however, the information contained in this plan provides a basis for pursuing funding to implement improvements.

6.5 Develop Partnerships to Implement Projects Addressing Regional Water Management Objectives

In many cases, local benefits of enhanced water management through physical and operational improvements are less than implementation costs; however, opportunities may exist to enhance water management capabilities to meet multiple WMOs. For example, partnerships could be established among agricultural suppliers and environmental water managers to modify agricultural water management to re-route flows to desired locations at desired times to provide targeted benefits for managed wetlands or aquatic habitat. At other times, these projects could provide local benefits, such as increased supply reliability to meet customer demands. Partnerships could be directly between individual agricultural suppliers, environmental water managers, or others and could involve several parties working in coordination to achieve multiple benefits. These potential opportunities require refinement of WMOs, as discussed in Section 6.3. Following the refinement of WMOs, it is recommended that partnerships be pursued to enhance water management through future updates of this regional AWMP and other interim opportunities.

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