




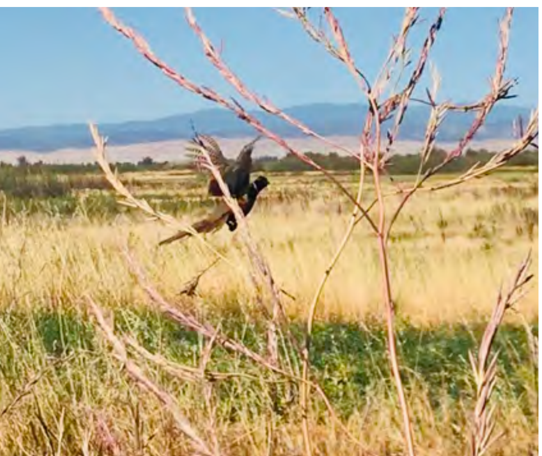


Colusa Groundwater Authority &
Glenn Groundwater Authority

Colusa Subbasin Groundwater Sustainability Plan

FINAL REPORT – DECEMBER 2021

COLUSA SUBBASIN

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FINAL REPORT | DECEMBER 2021

Colusa Subbasin
Groundwater Sustainability Plan

PREPARED FOR

Colusa Groundwater Authority &
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Project No. 277-60-20-11

Grant Davids, PE Principal Engineer	12-03-21 Date	Ken Loy, PG Principal Hydrogeologist	12-03-21 Date
Anna Reimer, PG Project Hydrogeologist	12-03-21 Date	Katherine Klug, PhD Project Engineer	12-03-21 Date

FINAL REPORT | DECEMBER 2021

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ACKNOWLEDGEMENTS

Groundwater Sustainability Agencies

Colusa Groundwater Authority GSA

Member Agencies

County of Colusa, City of Colusa, City of Williams, Glenn-Colusa Irrigation District, Maxwell Irrigation District, Westside Water District, Princeton-Codora-Glenn Irrigation District, Provident Irrigation District, Colusa County Water District, Reclamation District 108, Reclamation District 479, Colusa Drain Mutual Water Company, Two representatives of private groundwater pumpers

Glenn Groundwater Authority GSA

Member Agencies

City of Orland, City of Willows, County of Glenn, Glenn-Colusa Irrigation District, Glide Water District, Kanawha Water District, Monroeville Water District, Orland-Artois Water District, Princeton-Codora-Glenn Irrigation District, Provident Irrigation District

Technical Advisory Committees

Colusa Groundwater Authority TAC
Glenn Groundwater Authority TAC

Consultant Team

Davids Engineering, Inc.
ERA Economics
West Yost
Woodard & Curran, Inc.
California State University, Sacramento

Cover Photographers

Carli Marengo
Denise Carter
Hilary Reinhard
Jean Miller
Mary Fahey
Mirna Albarran-Jack

In Remembrance of Byron Alan Clark, PE

(February 4, 1976 - April 3, 2021)
Thanks for his excellent leadership and foundational work in the development of the Colusa Subbasin GSP

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µg/L	Micrograms Per Liter
µS/cm	MicroSiemens Per Centimeter
3D	Three-Dimensional
AB	Assembly Bill
AEM	Airborne Electromagnetic
af	Acre-Feet
af/yr	Acre-Feet per Year
amsl	Above Mean Sea Level
AN	Above Normal Water Year
Authorities	Colusa Groundwater Authority and Glenn Groundwater Authority
AWMP	Agricultural Water Management Plan
bgs	Below Ground Surface
BMO	Basin Management Objective
BMP	Best Management Practice
BN	Below Normal Water Year
Brown Act	Ralph M. Brown Act (Government Code § 54950-54963)
C	Critically Dry Water Year
C&E Plan	Communication and Engagement Plan
C2VSimFG	California Central Valley Groundwater-Surface Water Simulation Model – Fine Grid
Cal Water	California Water Service Company
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CASGEM	California's Statewide Groundwater Elevation Monitoring Program
CCP	Comprehensive Conservation Plan
CCR	California Code of Regulations
CCWD	Colusa County Water District
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CDMWC	Colusa Drain Mutual Water Company
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
cfs	Cubic Feet per Second
CGA	Colusa Groundwater Authority
CGPS	Continuously Operating Global Positioning System
CIMIS	California Irrigation Management Information System
CNRA	California Natural Resources Agency

Colusa Drain	Colusa Basin Drainage Canal System
COOP	Cooperative Observer Network
Cr^{6+}	Hexavalent Chromium
CRC	California Rice Commission
CREP	Conservation Reserve Enhancement Program
CSAMT	Controlled Source Audio-Frequency Magnetotellurics
CT	Central Tendency
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability
CWC	California Water Code
D	Dry Water Year
DAC	Disadvantaged Community
DDW	Division of Drinking Water
Delta	San Joaquin-Sacramento River Delta
DMS	Data Management System
DTSC	Department of Toxic Substance Control
DTW	Depth to Water
DWD	Dunnigan Water District
DWR	Department of Water Resources
EC	Electrical Conductivity
EDA	Economically Distressed Area
Eh	Redox potential
ESA	Endangered Species Act
ET	Evapotranspiration
ET_{aw}	Evapotranspiration of Applied Water
EWMP	Efficient Water Management Practices
eWRIMS	Electronic Water Rights Information Management System
Flood Board	Central Valley Flood Protection Board
Flood-MAR	Flood-Managed Aquifer Recharge
FSS	Facilitation Support Services
ft	Feet
ft bgs	Feet Below Ground Surface
ft/day	Feet Per Day
GAMA	Groundwater Ambient Monitoring and Assessment
GCC	Glenn County Code
GCID	Glenn-Colusa Irrigation District
GDE	Groundwater Dependent Ecosystems
GGA	Glenn Groundwater Authority

GIS	Geographic Information System Mapping
GMP	Groundwater Management Plan
GP	General Plan
gpm	Gallons Per Minute
GPS	Global Positioning System
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
GWE	Groundwater Elevations
GWS	Groundwater System
HCM	Hydrogeologic Conceptual Model
HUC	Hydrologic Unit Code
ICONS	Interconnected Surface Water in California's Central Valley
ID	Identification
IHM	Integrated Hydrologic Model
ILRP	Irrigated Lands Regulatory Program
InSAR	Interferometric Synthetic Aperture Radar
IRWMP	Integrated Regional Water Management Plan
IWFM	Integrated Water Flow Model
JPA	Joint Powers Authority
JPL	Jet Propulsion Laboratory
LAFCO	Local Agency Formation Commission
Ma	Million Years Ago
maf	Million Acre Feet
maf/yr	Million Acre Feet Per Year
MAR	Managed Aquifer Recharge
MCL	Maximum Contaminant Level
MG	Million Gallons
mg/L	Milligrams per Liter
MGD	Millions of Gallons Per Day
MHI	Median Household Income
MO	Measurable Objective
MSR	Municipal Service Reviews
MT	Minimum Threshold
NAD	North American Datum
NASA	National Aeronautics and Space Administration
NAVD 88	North American Vertical Datum of 1988
NCCAG	Natural Communities Commonly Associated with Groundwater
NCEI	National Centers for Environmental Information
NCWA	Northern California Water Association

NEPA	National Environmental Policy Act
NHD	National Hydrology Dataset
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSV	Northern Sacramento Valley
NWIS	National Water Information System
O&M	Operation and Maintenance
OAL	Office of Administrative Law
OAWD	Orland-Artois Water District
OES	Office of Emergency Service
OSWCR	Online System of Well Completion Reports
OUWUA	Orland Unit Water Users Association
P&G	Proctor and Gamble
PBO	Plate Boundary Observatory
PCE	Tetrachloroethylene
PHG	Public Health Goal
Planned PMA	Planned Projects and Management Actions
PMA	Projects and Management Actions
ppb	Part Per Billion
ppm	Parts Per Million
RD108	Reclamation District 108
Reclamation	U.S. Bureau of Reclamation
RMN	Representative Monitoring Network
RPE	Reference Point Elevation
RWMP	Regional Water Management Plan
SAGBI	Soil Agricultural Groundwater Banking Index
SB	Senate Bill
SCADA	Supervisory Data and Control Acquisition
SDAC	Severely Disadvantaged Community
SDWIS	Safe Drinking Water Information System
SGMA	Sustainable Groundwater Management Act
SHPO	State Historic Preservation Office
SIP	Shelter-in-Place
SMC	Sustainable Management Criteria
SMCL	Secondary Maximum Contaminant Level
SRSC	Sacramento River Settlement Contractors
SSURGO	Soil Survey Geographic Database

Subbasin	Colusa Subbasin
SVHMP	Sacramento Valley Height Modernization Project
SVSim	Sacramento Valley Simulation Model
SVWQC	Sacramento Valley Water Quality Coalition
SWN	State Well Number
SWPPP	Storm Water Pollution Prevention Plan
SWRCB	State Water Resources Control Board
SWS	Surface Water System
TAC	Technical Advisory Committee
taf	Thousand Acre-Feet
taf/yr	Thousand Acre-Feet Per Year
TCC	Tehama-Colusa Canal
TCCA	Tehama-Colusa Canal Authority
TDS	Total Dissolved Solids
TNC	The Nature Conservancy
Tribes	California Native American Tribes
UC	University of California
UC-ANR	University of California Agriculture and Natural Resources
UNAVCO	University NAVSTAR Consortium
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UWMP	Urban Water Management Plan
W	Wet Water Year
WCR	Well Completion Report
WDL	Water Data Library
WDR	Waste Discharge Requirements
WMP	Water Management Plan
WRCC	Western Regional Climate Center

Preface

Development of the Colusa Subbasin Groundwater Sustainability Plan (GSP), like many others throughout California, has coincided with one of the most severe and extensive droughts that has ever gripped the western United States. As of this writing in December 2021, as the final Colusa Subbasin GSP is being assembled, drought conditions throughout most of California, including the Colusa Subbasin (Subbasin), are classified as "exceptional", the most extreme classification defined by the U.S. Drought Monitor (USDM)[1]. Historically, observed impacts during exceptional drought generally include: widespread water shortages, depleted surface water supplies, extremely low federal surface water deliveries, curtailment of water rights, extremely high surface water prices, increased groundwater pumping to satisfy water demands, dry groundwater wells, increased well drilling and deepening, increased pumping costs, wildfire, decreased recreational opportunities, and poor water quality, among other potential impacts reported by the USDM. All of these conditions are currently being experienced to some degree across California and, at least in part, within the Subbasin. In particular, surface water supplies available for irrigation were significantly reduced in both 2020 and 2021, resulting in reduced plantings of some annual crops (primarily rice), and increased groundwater pumping, primarily to sustain permanent tree crops and, to a lesser extent, some annual crops.

As of November 30, 2021, the County of Glenn had received 282 reports of problems associated with groundwater wells, with about 65 percent of those being reports of dry wells. While a few of the reported dry wells are in the foothills outside of the Subbasin, the large majority lie within the Colusa and Corning Subbasins, concentrated in areas around Orland and the northern portion of the County. As of November 30, 2021, the County of Colusa had received 30 landowner reports of problems associated with groundwater wells, with 20 of the reported wells being located within the Subbasin. Of those wells in the Subbasin, 18 are reported as dry. Most reported dry wells are used for domestic water supply. Counts of dry wells in both counties are likely to be low because some landowners choose not to report well problems to the counties. In addition to reported dry wells, there are anecdotal reports of land subsidence around the Arbuckle area in the Colusa County portion of the Subbasin.

At the State level and as a result of the unprecedented dry conditions, Governor Gavin Newsom declared a drought emergency on April 21, 2021, which was subsequently expanded on May 10 to include new drought-impacted areas, including the Sacramento-San Joaquin Delta Watershed. Most recently, on October 19, Governor Newsom issued a proclamation extending the drought emergency statewide. On August 20, the State Water Resources Control Board (SWRCB) issued surface water curtailment orders to approximately 4,500 water right holders in the Sacramento-San Joaquin Delta Watershed to protect drinking water supplies, prevent salinity intrusion into fresh water supplies, and minimize impacts to fisheries and the environment. Given that these curtailment orders are in place for a period of one year, these curtailments have immediate impacts on existing surface water supplies and could impact surface water suppliers' ability to store water this coming winter, thereby potentially impacting available surface water supplies for 2022 and beyond. Given the recent curtailments and an already bleak surface water

[1] The U.S. Drought Monitor (https://droughtmonitor.unl.edu/) is produced through a partnership between the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Center. Information for the State of California is available online at: https://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?CA.

supply condition, there is an increased reliance on groundwater. Currently, all of California's 58 counties have declared drought emergencies, including both Colusa and Glenn Counties.

The reported numbers of dry wells discussed above, many of which were reported relatively early in the dry season, are unprecedented in both counties, raising concerns among landowners and residents, and prompting mitigation and response actions by both counties. The counties are maintaining well reporting and tracking systems to identify localized areas where wells are going dry and/or where other groundwater issues may exist. The counties are also supporting the public through local and regional programs offered through the counties, the U.S. Department of Agriculture (USDA), the Rural Community Assistance Corporation (RCAC), DWR, and the SWRCB that assist with well assessments, well repair and replacement, installation or updates to household water systems, potable water hauling, and low-interest loans to businesses and organizations affected by drought. Both counties have applied for drought relief funding through DWR. At this time, prior to completion and adoption of the GSP, drought response efforts in the Subbasin are the responsibility of the counties, cities, and other local agencies. At some point following adoption of the GSP, those responsibilities may shift to or be coordinated with the GSAs. A strategy for guiding potential coordination between the GSAs, counties, cities, and other local agencies is described in Chapter 7 of the GSP. Coordination would ensure preservation of public health and safety (the purview of the counties and cities) and groundwater sustainability for all beneficial users and uses (the purview of the GSAs).

Technical work and related public involvement processes supporting development of the Colusa Subbasin GSP began in earnest in May 2020 and are nearing completion as of December 2021. Development of the GSP has utilized the best available science and tools, with the most sufficient and credible information and data available for the decisions being made and the time frame available for making those decisions. Current and historical groundwater conditions and water budgets have been evaluated for the Subbasin in alignment with the GSP regulations. The technical work is based primarily on historical records of surface water and groundwater conditions from 1966 through 2015, which includes the prior drought in 2014 to 2015, but not the current drought in 2020 to 2021.

Unfortunately, drought conditions in 2020 and 2021 have coincided with development of the GSP, a timing that has not permitted complete evaluation and inclusion of data from these years in the GSP at this time. Due to the schedule mandated by the Sustainable Groundwater Management Act (SGMA) for completion of GSPs by January 31, 2022, it has not been possible to include conditions that have manifested due to the current drought in development of the Subbasin GSP. Records of drought-related conditions in 2020 to 2021 will not be systematically compiled, quality-controlled, and made publicly available until after the Colusa Subbasin GSP has been adopted. However, those conditions will be factored into the required GSP annual reports and particularly the periodic (five-year) evaluations as they become available.

It is noted that ongoing management of the Subbasin under the GSP will follow an "adaptive management" strategy that involves active monitoring of Subbasin conditions and addressing any challenges related to maintaining groundwater sustainability by scaling and implementing projects and management actions (PMAs) in a targeted and proportional manner in accordance with the needs of the Subbasin. Notwithstanding the information noted above regarding the challenges with GSP preparation and the current drought, some of the planned projects contained within this GSP are being fast tracked to address impacts associated with the current drought. GSP annual reports provide an opportunity each year to evaluate current Subbasin conditions and assess the need for further PMAs. During the periodic evaluations, the GSP will also be reviewed and revised, as needed and as more is known about the effects of current and future conditions.

Colusa County, Glenn County, and the stakeholders within the Subbasin recognize that this GSP isn't the finish line; it is the starting line for sustainable management of the Subbasin. As conditions within the Subbasin change, the GSAs within the Subbasin are committed to an open, transparent, and all-inclusive adaptive management strategy aimed at tackling the important local issues that they face. At the heart of SGMA is the power for locals to solve local problems with local resources. All parties in the Subbasin are committed to doing just that.

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Executive Summary

In September 2014, the California legislature passed, and Governor Jerry Brown signed, the Sustainable Groundwater Management Act (SGMA), which was composed of Assembly Bill (AB) 1739, Senate Bill (SB) 1168, and SB 1319. SGMA is codified in Section 10720 et seq. of the California Water Code. The California Department of Water Resources (DWR) subsequently initiated development of regulations to implement SGMA. In February 2016, DWR released draft emergency regulations for the development of Groundwater Sustainability Plans (GSPs). In July 2016, DWR provided notice of proposed emergency rulemaking and submitted the emergency regulations to the Office of Administrative Law (OAL). These are in California Code of Regulations (CCR), Title 23 Waters, Division 2 Department of Water Resources, Chapter 1.5 Groundwater Management, Subchapter 2 Groundwater Sustainability Plans.

The practical implication of SGMA, and associated regulations to implement SGMA, is to provide for local control of groundwater resources while requiring sustainable management of the state's groundwater subbasins. Under the provisions of SGMA, local agencies must establish governance of their subbasins by forming Groundwater Sustainability Agencies (GSAs) with the authority to develop, adopt, and implement a Groundwater Sustainability Plan (GSP) for the subbasin. The GSP provides a full accounting and description of subbasin groundwater conditions and provides a roadmap for subbasin groundwater management. Under the GSP, GSAs must adequately define and monitor groundwater conditions in the subbasin and establish criteria to maintain or achieve sustainable groundwater management within 20 years of GSP adoption.

The timeline for GSP development and adoption depends on subbasin conditions that are defined by DWR in its Bulletin 118. The Colusa Subbasin (Subbasin) is defined in Bulletin 118 by DWR as a high priority subbasin. This means that the Colusa Subbasin GSAs must develop, adopt, and submit a GSP (or GSPs) covering the entire Subbasin to DWR by January 31, 2022 (CWC Section 10720.7(a)(2)). The Subbasin is managed by two GSAs: the Glenn Groundwater Authority (GGA) and the Colusa Groundwater Authority (CGA). The GSAs have worked collaboratively to develop this single GSP to meet the requirements under SGMA for the entire Subbasin.

The following subsections in this Executive Summary provide an overview of each section of the Colusa Subbasin GSP.

INTRODUCTION (GSP CHAPTER 1)

Groundwater serves as an important source of supply for agricultural, municipal, domestic, industrial, and environmental beneficial uses throughout the Subbasin[1], which underlies approximately 723,823 acres within Colusa and Glenn Counties. Agriculture in the Subbasin relies on approximately 500,000 acre-feet (af) of groundwater (and nearly 1.2 million af of surface water, plus precipitation) annually, on average, to produce an array of commodities that contribute to the agricultural economies of both Colusa County and Glenn County, which have a total combined value of over $1.7 billion dollars.[2] Groundwater also supports essentially all domestic, municipal, and industrial water use in both Counties. The sustainable

[1] Groundwater basin number 5-021.52, part of the Sacramento Valley Groundwater Basin, as defined by DWR Bulletin 118 (DWR, 2006) and updated in February 2019. Additional basin boundary modifications were submitted to DWR in June 2021; however, the modifications have not been approved as of the writing of this GSP.

[2] According to the Colusa County Department of Agriculture, the gross production value of agriculture in the County was $932,963,000 (Crop Report, 2019). According to the Glenn County Department of Agriculture/Weights and Measurements, the gross production value of all agricultural commodities in the County was $806,668,000 (Crop & Livestock Report, 2019).

management of groundwater in the Subbasin is important for long-term prosperity of the communities in the region.

Sustainable management of groundwater is defined under SGMA as the "management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results" (California Water Code [CWC] Section 10721(v)). Undesirable results are associated with each of six sustainability indicators, including chronic lowering of groundwater levels, reduction of groundwater storage, seawater intrusion, degraded water quality, land subsidence, and depletions of interconnected surface water. Undesirable results occur when significant and unreasonable effects for any of the sustainability indicators are caused by groundwater conditions occurring throughout the subbasin. Sea water intrusion, while a SGMA-defined sustainability indicator, was determined to be inapplicable to the Subbasin due to the distances between the Subbasin and the Pacific Ocean, bays, deltas, or inlets ranging from about 30 to 60 miles.

The purpose of this GSP is to characterize groundwater conditions in the Subbasin, evaluate and report on existing conditions relating to the six sustainability indicators, describe existing monitoring, management programs and policies relating to groundwater resource use, document public outreach and communication, establish sustainability goals, and describe projects and management actions (PMAs) the GSAs will implement to achieve sustainable groundwater management within 20 years of implementing the GSP (CCRs Title 23, Section 350.4 (f)).

PLAN AREA (GSP CHAPTER 2)

Figure ES-1 illustrates the Plan Area. The Plan Area, described in detail in Chapter 2 of the GSP, is defined as the Colusa Subbasin (5-021.52), part of the Sacramento Valley Groundwater Basin, as described in Bulletin 118 (DWR, 2006b) with Subbasin boundary updates approved by DWR in February 2019. The Subbasin is generally bounded by Stony Creek to the north, the Coast Ranges to the west, the Sacramento River to the east, and the Colusa-Yolo County boundary and the Colusa County Water District boundary to the south. The Subbasin currently includes about 2.4 square miles (1,500 acres) within Yolo County, but is otherwise located fully within Glenn and Colusa Counties. Additional basin boundary modifications were submitted to DWR in June 2021; however, the modifications have not been approved as of the writing of this GSP. The modifications would adjust the eastern Subbasin boundary to better conform to the boundary of Reclamation District 1004 in Colusa County and would reduce the area of the Subbasin to 1,129 square miles (722,768 acres). The vertical boundaries of the Subbasin are the land surface (upper boundary) and the definable bottom of the basin (lower boundary). The vertical extent of the Subbasin is subdivided into a surface water system (SWS) and groundwater system (GWS). The SWS represents the land surface down to the bottom of plant root zone[3], within the lateral boundaries of the Subbasin. The GWS extends from the bottom of the root zone to the bottom of the Subbasin as defined by the Hydrogeologic Conceptual Model (HCM), within the lateral boundaries of the Subbasin.

[3] The depth to the bottom of the root zone varies by crop, but typically ranges from 2 to 7 feet (ASCE, 2016).

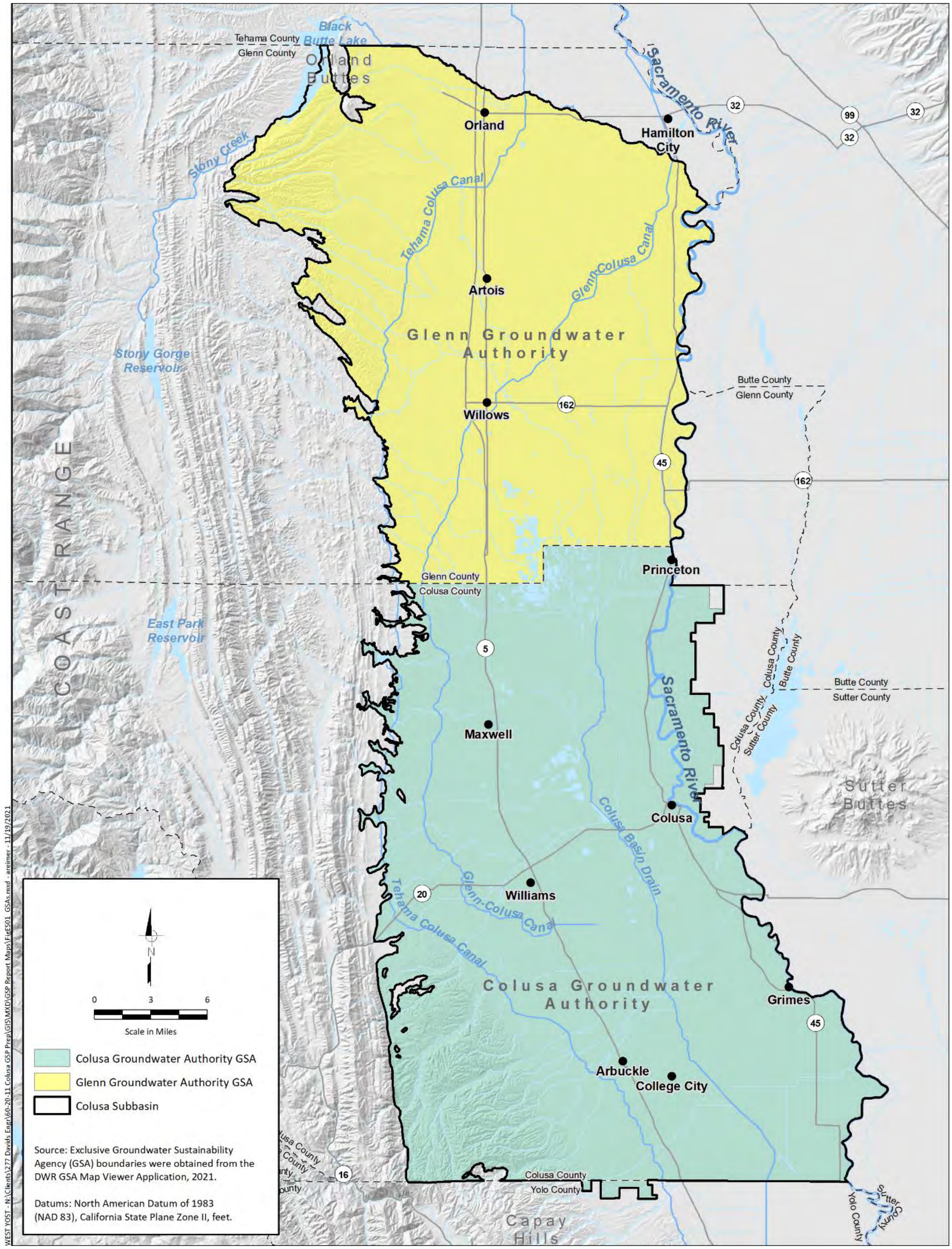

Figure ES-1. Colusa Subbasin GSAs

BASIN SETTING (GSP CHAPTER 3)

Chapter 3 describes the basin setting, including the HCM, current and historical groundwater conditions, and water budget information describing the movement of surface water and groundwater into, through and out of the Subbasin. Each of the three components of the basin setting are summarized below.

Hydrogeological Conceptual Model

The HCM provides the conceptual understanding of the hydrogeologic physical setting, characteristics, and processes that occur within the Subbasin and provides the foundation upon which the components of the water budget are based. The components of the HCM include surficial and subsurface features. Surficial features include topography, hydrology, water supply features, land use, soil types, and geologic outcrops. Subsurface features of the HCM include geologic formations and structures and the presence and characteristics of aquifers and aquitards.

Figure ES-2 shows the geologic component of the HCM. The Subbasin is underlain by one principal aquifer with interconnected unconfined and semiconfined to confined zones. Shallow groundwater in the Subbasin occurs under unconfined conditions in the Holocene stream channel deposits, except where these units are overlain by Holocene basin deposits, creating semiconfined to confined conditions. At greater depths, groundwater occurs under semiconfined to confined conditions in a single heterogeneous aquifer system, composed of predominantly fine-grained sediments enclosing discontinuous lenses of sand and gravel. The aquifer properties, including hydraulic conductivity and degree of confinement are dependent on the properties of the fine-grained units.

Most of the fresh groundwater within the Subbasin is contained within the Tehama Formation (shown as orange in Figure ES-2). The fraction of fresh groundwater contained within the Tehama Formation decreases in the northeastern portion of the Subbasin, where sediments of the Tuscan Formation are more prevalent (shown as pink in Figure ES-2). The interface between sediments of the Tehama and Tuscan Formations, referred to in this GSP as the Tehama-Tuscan Transition Zone, has been documented as mixed Tehama and Tuscan Formation sediments.

There are no defined principal aquitards within the Subbasin, however, the formations deposited under alluvial conditions or volcanic flows with lahars, such as exist in the Tehama and Tuscan Formations, respectively, tend to consist of thick low-permeability sediments interbedded with interconnected channels or lenses of higher-permeability sediment. The low-permeability sediments may impede vertical groundwater flow, but generally do not separate the aquifer system into separate, definable principal aquifers in the Subbasin.

Groundwater Conditions

Chapter 3 describes current and historical groundwater conditions in the Subbasin to support development and implementation of the GSP pursuant to the requirements of SGMA. Current and historical conditions are described for groundwater elevations, estimates of groundwater storage, groundwater quality, land subsidence, and interconnected surface waters. The description of current and historical groundwater conditions directly supports the development of sustainable management criteria presented in Chapter 5.

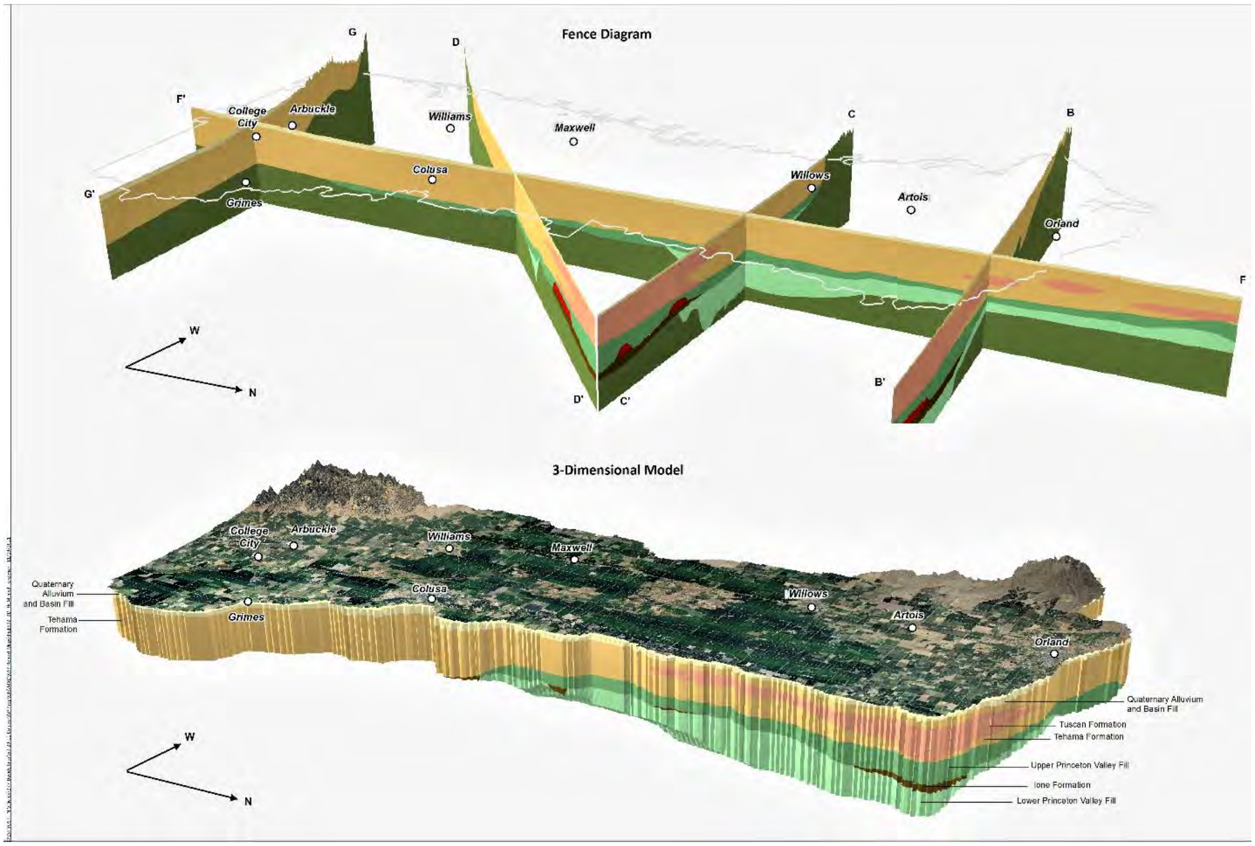

Figure ES-2. 3D Hydrogeologic Conceptual Model

Groundwater elevations measured in spring 2020 are shown on Figure ES-3. Regional groundwater flow within the Subbasin is generally eastward from the margins of the Sacramento Valley toward the Sacramento River and southward towards the Sacramento-San Joaquin Delta. For most of the Subbasin, the groundwater flows in a southeasterly direction, consistent with typical regional trends. South of Arbuckle, however, groundwater flows northeast down from the western uplands before flowing southeast down the valley.

Groundwater pumping has resulted in localized cones of depression that disrupt the regional groundwater flow gradients. Dry conditions and changes in land use have led to increased groundwater pumping in recent years.

Groundwater elevations throughout the Subbasin declined over the prolonged dry period beginning after 2006. The alternating years of average to dry conditions after 2006 have affected shallow wells, some of which have gone dry. The CGA and GGA support the State of California's policy on the Human Right to Water and recognize that drought emergencies have a disproportionate effect on California Native America Tribes (Tribes), Disadvantaged Communities (DAC) and Severely Disadvantaged Communities (SDAC) that rely on groundwater for their drinking water supplies. Many of the communities within the Subbasin are considered disadvantaged or severely disadvantaged. Nearly all of the Subbasin is considered an Economically Distressed Area. This GSP includes information on drought relief efforts coordinated by the Colusa and Glenn Interagency Drought Task Forces to address the effects of drought across the Subbasin and throughout these communities.

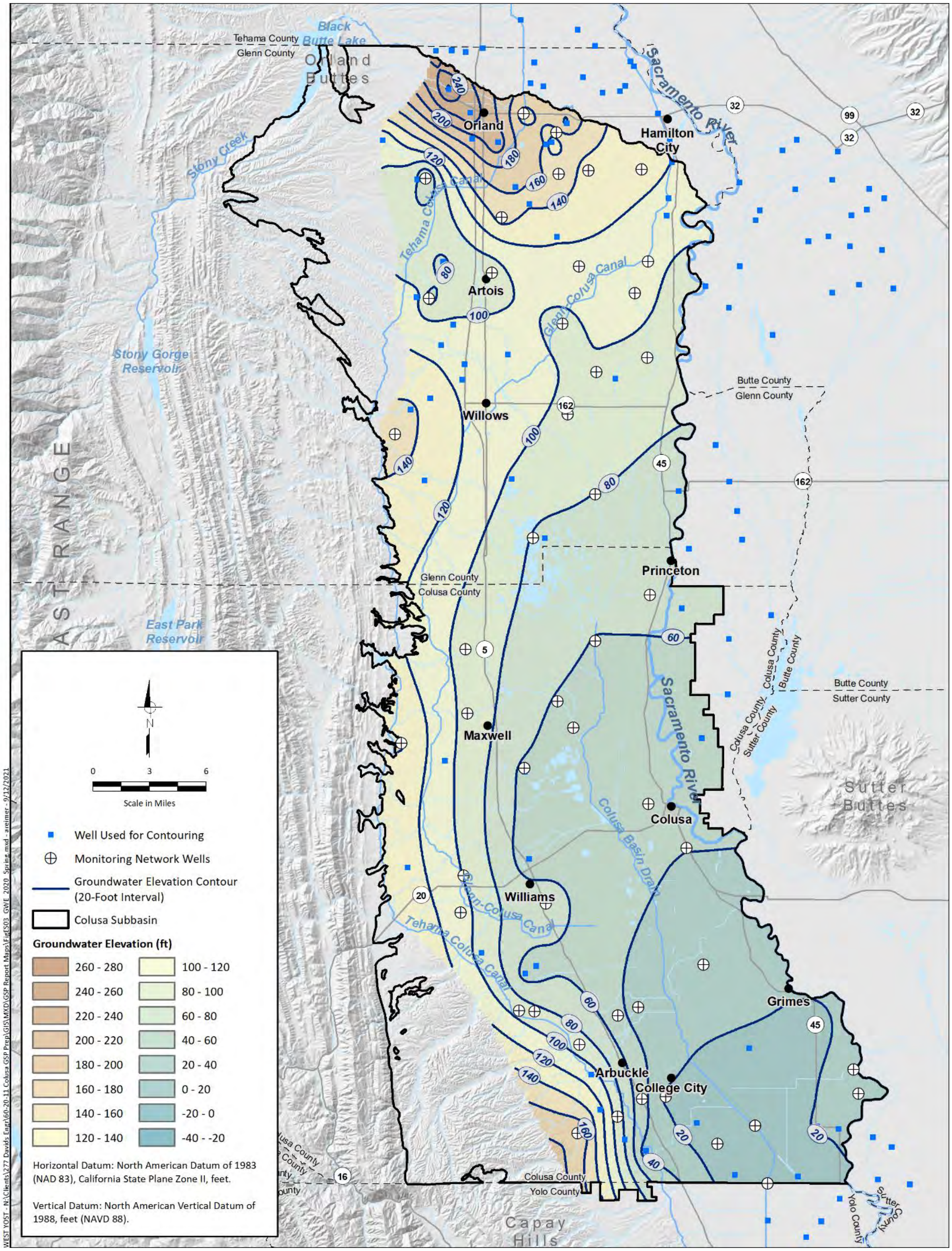

Figure ES-3. Groundwater Elevation Contours Spring 2020

Water Budget Information

A water budget is defined as a complete accounting of all water flowing into and out of a defined volume, which is the entire Subbasin within its defined horizontal and vertical boundaries, over a specified period of time. The water budget facilitates assessment of the total volume of groundwater and surface water entering and leaving the Subbasin over time, along with the change in the volume of water stored within the Subbasin. As required by the GSP emergency regulations, water budgets were developed for historical, current, and projected conditions. A numerical integrated groundwater-surface water flow model was developed based on the fine grid California Central Valley Groundwater-Surface Water Simulation Model (C2VSimFG) and used to support development of water budgets. Three water budgets were developed (including three climate scenarios for projected future conditions):

- A historical water budget evaluates availability or reliability of past surface water supplies and aquifer response to water supply and demand trends relative to water year type. The historical water budget was calculated for the 1990 through 2015 period, which was found to be reasonably representative of the long-term average conditions in the Subbasin. The historical water budget supports understanding of past groundwater conditions, considering surface water and groundwater supplies utilized to meet water demands.
- A current water budget establishes potential future baseline conditions under the assumptions of current land use and water supplies and historical hydrology. Current land use and water supplies are based on observed conditions in 2013 and 2015, representing Shasta Non-Critical and Shasta Critical years, respectively[4]. Historical hydrology from 1966 through 2015 was used to represent an analysis period from 2016 through 2065.
- Future water budgets establish potential future baseline conditions under different scenarios defined by different climate conditions. Three scenarios were developed: baseline without climate change, with 2030 climate change, and with 2070 climate change. The climate change scenarios correspond to the Central Tendency (CT) climate projections. These future water budgets are based on current land use over the same 50-year (1966 through 2015) historical hydrology as was used in the current water budget.

Table ES-1 summarizes the assumptions used in developing the water budgets.

[4] Because surface water supplies are curtailed in Shasta Critical years, the irrigated area and therefore water demands and use are less than in Shasta Non-Critical years.

Table ES-1. Summary of Water Budget Assumptions

Water Budget	Analysis Period	Hydrology	Land Use	Water Supplies
Historical Simulation	1990-2015	Historical	Historical	Historical
Current Conditions Baseline	2016-2065	Historical (1966-2015)	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively, for water diversions; 2006-2015 average for urban demands
Future Conditions, No Climate Change Baseline	2016-2065	Historical (1966-2015)	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively, for water diversions; 2006-2015 average for urban demands
Future Conditions, 2030 Climate Change Baseline	2016-2065	Historical (1966-2015), adjusted based on 2030 climate change with central tendency	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively	Same as Current (see above), adjusted for 2030 climate change
Future Conditions, 2070 Climate Change Baseline	2016-2065	Historical (1966-2015), adjusted based on 2070 climate change with central tendency	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively	Same as Current (see above), adjusted for 2070 climate change

Average annual water budget estimates for the historical water budgets and for the current and projected future water budget scenarios are summarized in Table ES-2 for the groundwater system. Volumes are reported in units of thousand af per year (taf/yr). It is anticipated that the water budgets will be refined and updated over time as part of GSP implementation.

Table ES-2. Average Annual Groundwater System Inflows, Outflows, and Changes in Storage in taf/yr

Component	Historical Simulation	Current Conditions Baseline	Future Conditions, No Climate Change Baseline	Future Conditions, 2030 Climate Change Baseline[a]	Future Conditions, 2070 Climate Change Baseline[a]
Inflows[b]					
Subsurface Water Inflows	200	203	203	205	209
Deep Percolation	441	416	415	415	411
Precipitation	174	162	162	160	156
Applied Surface Water	196	162	162	161	158
Applied Groundwater	72	92	91	94	97
Seepage	345	379	379	387	401
Streams	206	231	231	239	253
Canals and Drains	139	148	148	148	148
Total Inflow	**986**	**997**	**997**	**1,008**	**1,021**
Outflows					
Subsurface Water Outflows	146	149	149	148	147
Groundwater Pumping	502	499	499	525	559
Agricultural	463	458	458	484	516
Urban and Industrial	11	11	10	10	10
Managed Wetlands	28	30	30	31	32
Stream Gains from Groundwater (Stream Accretions)	366	349	349	337	323
Total Outflow	**1,014**	**997**	**996**	**1,011**	**1,028**
Change in Storage (Inflow - Outflow)	**-28**	**1**	**1**	**-3**	**-7**

(a) Central Tendency Climate Change Projections.
(b) Sacramento River Diversions and Stony Creek Diversions are diversions from boundary streams outside the Subbasin. About 20 percent of the total diversions come from streams within the Subbasin and are included in the Sacramento River Inflow.

GSP regulations require the water budget to quantify the sustainable yield for the Subbasin. Sustainable yield is dependent upon conditions in existence at the time, and therefore changes during the implementation period as projects are completed and climate conditions change. Provisional estimates of sustainable yield have been calculated from water budget parameters for each scenario as the long-term annual average groundwater pumping, minus the average annual decrease in groundwater storage. Using this approach, the Subbasin is estimated to have a sustainable yield between 500,000 af and 550,000 af per year.

MONITORING NETWORKS (GSP CHAPTER 4)

Chapter 4 of the GSP documents the Subbasin monitoring networks. Monitoring networks are required to better understand and evaluate changing conditions within the groundwater, surface water, and land surface systems.

To optimize data collection and analysis, the networks need to be easily accessible, spatially and temporally relatable to other monitoring networks, sufficient for demonstrating spatial and temporal trends, and representative of actual conditions. Four monitoring networks meeting these standards are defined for the Subbasin:

1. Groundwater Level Monitoring Network
2. Groundwater Quality Monitoring Network
3. Land Subsidence Monitoring Network
4. Surface Water Monitoring Network

The data collection objectives for the monitoring networks are to characterize:

- Groundwater levels, availability, and flow characteristics, including changes in groundwater storage;
- Groundwater quality;
- Extent and rate of land subsidence; and
- Surface water availability and interactions with groundwater, including impacts to native riparian land and groundwater dependent ecosystems (GDEs).

Data gaps were identified within all of the monitoring networks, and recommended actions are provided in Chapters 4 and 7. Annual reports and future revisions to the GSP will provide updates on actions taken to address data gaps in the monitoring networks over the reporting period.

Representative Monitoring Networks

Representative monitoring networks (RMN) were designated as subsets of the Subbasin monitoring networks. Per 23 CCR §354.36, "Each Agency may designate a subset of monitoring sites as representative of conditions in the basin or an area of the basin…" to evaluate or monitor for sustainability indicators. Representative monitoring locations were designated to evaluate undesirable results due to chronic lowering of groundwater levels, reduction of groundwater storage, degraded water quality, inelastic land subsidence, and depletions of interconnected surface water.

Per DWR's Sustainability Management Criteria Best Management Practice document (BMP), the sustainable management criteria for groundwater levels may be used as a proxy for sustainability indicators that have a significant, demonstrated correlation to groundwater levels. As documented in Chapters 3 and 5 and their supporting technical appendices, reduction of groundwater storage and depletions of interconnected surface water are significantly correlated to groundwater levels in the Subbasin, and therefore those sustainability indicators utilize groundwater levels as a proxy.

In addition to data collected using the RMNs, the GSAs will use data collected using the monitoring networks described in the following sections to evaluate groundwater conditions in the Subbasin. The monitoring networks will be periodically reviewed and modified as needed.

The following subsections provide a summary of each of the Subbasin monitoring networks and the RMNs used to assess groundwater conditions relative to the five sustainability indicators applicable to the Subbasin.

Groundwater Level Monitoring Network

The Subbasin groundwater level monitoring network is based on the existing groundwater monitoring networks of Colusa and Glenn Counties. There are 104 completions in 48 wells in the Subbasin groundwater level monitoring network. All of these wells are currently included in the California's Statewide Groundwater Elevation Monitoring Program (CASGEM) database.

Groundwater level monitoring network requirements documented in the DWR's Monitoring Network BMP and 23 CCR §354.34 were used to evaluate the groundwater monitoring wells in the Subbasin groundwater monitoring network. These requirements are addressed under the following categories:

- Known Construction Characteristics
- Nested Multiple Completion Wells
- Non-Dedicated Monitoring Wells
- Proximity to Streams and Interconnected Surface Waters
- Lateral and Vertical Density
- Accessibility and Usability

Data gaps within the groundwater monitoring network were evaluated for all criteria and categorized as follows:

- Usability of the monitoring site due to:
  - Wells screened across multiple water-bearing units and principal aquifer
- Spatial distribution of monitoring sites with regard to:
  - Presence near a surface water body
  - Lateral and vertical extent of coverage
  - Areas and depths with known groundwater level decline.

Recommended actions to address the data gaps include the addition of existing wells or the construction of new wells to add to the monitoring network. Field studies or surveys are recommended to verify well conditions and construction, and to identify wells to include in the network.

The RMN for chronic lowering of groundwater levels and reduction of groundwater storage sustainability indicators consists of one completion from each of the 48 wells in the groundwater monitoring network.

Groundwater Quality Monitoring Network

Existing regulatory programs address most water quality concerns in the Subbasin, and the CGA and GGA will coordinate with these programs, the lead regulatory agencies, and the regulated community during implementation of this GSP, including during development and implementation of PMAs.

The State Water Resources Control Board (SWRCB) and the Central Valley Regional Water Quality Control Board (CVRWQCB) regulate point and nonpoint source discharges to land that have potential to impact groundwater quality under a range of policy and regulatory programs, including the Basin Plan Amendment for the Salt and Nitrate Control Program, and the Irrigated Lands Regulatory Program (ILRP). The California Department of Toxic Substance Control regulates releases of toxic substances, including those that impact groundwater quality.

The California Safe Drinking Water Act addresses the regulation and control of public water systems in the State of California, including enforcing provisions of the federal Safe Drinking Water Act. The SWRCB Division of Drinking Water (DDW) is the lead agency responsible for enforcement in Colusa and Glenn Counties, including the entire Subbasin.

The CGA and GGA will rely on existing monitoring and reporting carried out by the regulated community within the Subbasin when and where possible to address water quality concerns. The CGA and GGA will conduct supplemental water quality monitoring using existing wells or new monitoring wells constructed for that purpose when and where necessary to fill data gaps and to develop and implement PMAs.

Groundwater quality in the Subbasin is generally good, with local exceedances of water quality objectives for some constituents. The sole groundwater quality concern not addressed by the existing groundwater quality regulatory programs is mobilization of saline water from deeper parts of the aquifer along faults, other geologic structures, or other naturally-occurring zones with high salinity as a result of GSP PMAs and other groundwater development.

Groundwater quality monitoring network locations for the Subbasin consist of wells identified and currently being monitored for salinity (i.e., total dissolved solids or electrical conductivity) under the ILRP and public drinking water supply systems regulated by DDW. The Subbasin groundwater quality monitoring network includes 54 monitoring sites.

The GSAs will coordinate and collaborate with other agencies regarding their monitoring programs, including changes to monitoring sites, monitoring protocols or frequencies, and management actions. Data gaps within the groundwater quality monitoring network were identified with regard to sampling frequency and spatial or vertical coverage in areas of concern.

The RMN for the degraded water quality sustainability indicator consists of 25 monitoring sites to monitor for groundwater quality degradation due to mobilization of brackish or saline groundwater.

Land Subsidence Monitoring Network

The Subbasin land subsidence monitoring network is comprised of benchmarks, continuous global positioning system (GPS) stations, extensometers, and remote sensing data. The land subsidence monitoring network sites and remote sensing programs are managed and monitored through the following agencies and programs.

- California DWR Ground Surface Displacement - Land Subsidence Monitoring Program
  - Includes five extensometers located in or within five miles of the Subbasin.
- University NAVSTAR Consortium (UNAVCO) Plate Boundary Observatory GPS/GNSS Network
  - Includes five continuous GPS stations.
- Sacramento Valley Height Modernization Project
  - Includes 76 benchmarks locations in or within five miles of the Subbasin.
- InSAR Remote Sensing
  - Includes studies and evaluations conducted by assorted federal and international agencies.

Inelastic land subsidence within the Subbasin is monitored at 63 sites in DWR's Sacramento Valley Subsidence Monitoring Benchmark Network.

Data gaps include insufficient benchmark density and insufficient frequency of measurements in the Sacramento Valley Subsidence Monitoring Benchmark Network. Additional benchmarks, continuous GPS stations and extensometers should be installed in areas with known or suspected subsidence, and the Sacramento Valley Subsidence Monitoring Benchmark Network should be resurveyed at least once every five years.

The RMN for land subsidence consists of the 63 Sacramento Valley Height Modernization Project benchmarks within the Subbasin. The benchmarks are evenly distributed throughout the Subbasin, including in areas with known land subsidence.

Surface Water Monitoring Network

Surface water monitoring is necessary for evaluating stream-aquifer relations. Comparing stream flows and stages with groundwater levels from specific monitoring wells can provide insight into how surface waters are interconnected with the groundwater system. The surface water monitoring network includes stream gages on rivers, streams, and canals. All of the stream gages included in the surface water monitoring network are managed and monitored via existing federal and state programs.

Data collected from the surface water monitoring network will be used to:

- Characterize flow conditions including surface water discharge, stage, and baseflows.
- Identify locations and flow periods of ephemeral and intermittent stream channels, if any. The DWR Monitoring Network BMP states that monitoring of ephemeral or intermittent streams should be conducted annually or as appropriate to characterize flow changes.
- Identify temporal trends due to localized, regional, and seasonal surface water discharge and groundwater extraction effects.

- Identify and collect information necessary to evaluate adverse effects to the beneficial use of surface water.
- Support evaluation of stream-aquifer interactions, including effects on surface water supplies due to changes in groundwater levels and effects on native riparian or groundwater dependent ecosystems.

There are 15 active stream gages in the Subbasin surface water monitoring network. The Subbasin surface water monitoring network was established using the best available data and science to identify, assess, and select existing monitor wells and stream gages meeting these requirements. However, significant data gaps exist, which need to be addressed during implementation of this GSP. Until these data gaps are filled, groundwater levels measured in selected wells are being used as a proxy for measurement of the volume and rates of depletions in interconnected surface waters.

The RMN for the depletions of interconnected surface waters sustainability indicator consists of 12 shallow wells from the groundwater level monitoring network meeting the following criteria:

- Constructed to a maximum depth of 200 feet.
- Located more than 2,000 feet and less than five miles from the interconnected surface water feature.

SUSTAINABLE MANAGEMENT CRITERIA (GSP CHAPTER 5)

Sustainable management criteria encompass several important components of GSP development, including a Subbasin sustainability goal that qualitatively describes the overall objectives of the GSP and desired conditions for the Subbasin, and undesirable results statements for each of the five sustainability indicators applicable to the Subbasin. For each of the applicable sustainability indicators, undesirable results occur when groundwater conditions cause significant and unreasonable effects on the beneficial uses and users of groundwater in the Subbasin. The Subbasin will be managed to achieve the sustainability goal and to avoid undesirable results, as consistent with the sustainable management criteria established for each sustainability indicator. Sustainable management criteria include measurable objectives (targets for management), interim milestones (evaluation points over time), and minimum thresholds (the point beyond which undesirable results could occur for a sustainability indicator).

Sustainability Goal

The sustainability goal for the Subbasin is:

> *…to maintain, through a cooperative and partnered approach, locally managed sustainable groundwater resources to preserve and enhance the economic viability, social well-being and culture of all Beneficial Uses and Users, without experiencing undesirable results.*

This goal was created through collaborative, public discussions and evaluation of historical, current, and projected future Subbasin conditions identified in the basin setting (Chapter 3), in alignment with the requirements of §354.24. Through implementation of planned monitoring, projects, management actions, and studies identified in this GSP, the Subbasin will be managed to its sustainability goal to avoid undesirable results for each applicable sustainability indicator.

Sustainability Indicators

The GSP regulations define undesirable results as occurring when significant and unreasonable effects are caused by groundwater conditions occurring for a given sustainability indicator. Significant and unreasonable effects occur when minimum thresholds are exceeded for one or more sustainability indicators. A summary of the sustainable management minimum thresholds, measurable objectives and undesirable results is provided in Table ES-3.

Undesirable results occur when significant and unreasonable effects to any of the six sustainability indicators defined by SGMA, five of which are applicable to the Subbasin, are caused by groundwater conditions occurring throughout the Subbasin. The overarching sustainability goal and the absence of undesirable results are expected to be achieved by 2042 through implementation of PMAs. The sustainability goal will be maintained through proactive monitoring and management by the GSAs. Table ES-4 summarizes whether, for each of the six sustainability indicators, undesirable results have occurred, are occurring, or are expected to occur in the future in the Subbasin without and with GSP implementation.

Table ES-3. Summary of Minimum Thresholds, Measurable Objectives, and Undesirable Results

Sustainability Indicator	Monitoring Network	Undesirable Result	Minimum Threshold (MT)	Measurable Objective (MO)
Chronic Lowering of Groundwater Levels	48 Representative Monitoring Network (RMN) wells monitored at least 2 to 3 times annually by DWR	25% (12 of 48) RMN wells fall continuously below their MT for 24 consecutive months	The lower of 50% of measured historical groundwater elevation range below the historical measured low elevation and the elevation corresponding to the 20th percentile of domestic well depths in the RMN well's Thiessen polygon, subject to interbasin coordination and consistency to ensure operational compatibility	Mean of the most recent 5 years of available groundwater elevation measurements up to 2020 subject to interbasin coordination and consistency to ensure operational compatibility; A fixed value, not a rolling average
Reduction in Groundwater Storage	48 RMN wells monitored at least 2 to 3 times annually by DWR (same as Groundwater Level monitoring network)	Use groundwater levels as proxy	Use groundwater levels as proxy	Use groundwater levels as proxy
Seawater Intrusion	Not applicable	Not applicable	Not applicable	Not applicable
Degraded Groundwater Quality	25 RMN wells monitored by others at variable intervals under existing State of California regulatory programs	Electrical conductivity (EC) in 25% (6 of 23) of the RMN wells exceeds the MT for two (2) consecutive years	The higher of EC of 900 microSiemens per centimeter (µS/cm) (the recommended California Secondary Maximum Contaminant Level) OR the pre-2015 historical maximum measured EC	EC of 700 µS/cm (corresponding to an agricultural water quality objective providing for no yield reduction for crops commonly grown in the Subbasin)
Land Subsidence	Existing Sacramento Valley Height Modernization Project (SVHMP) benchmarks (63 sites)	20% or more (13 of 63) monitoring sites (benchmarks) experience subsidence rates above the MT	0.5 feet per five years	0.25 feet per five years
Depletions of Interconnected Surface Waters	12 RMN wells less than 200 feet deep and between 2,000 feet and five miles of interconnected stream (Sacramento River, Colusa Drain, Stony Creek)	25% (3 of 12) RMN wells fall below their MT for 24 consecutive months	Ten (10) feet below the observed fall 2015 groundwater level (Fall 2015 level is the measured elevation recorded on the date closest to Oct 15)	Mean of last 5 years available groundwater elevation measurements subject to interbasin coordination and consistency to ensure operational compatibility; A fixed value, not a rolling average

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Table ES-4. Summary of Undesirable Results Applicable to the Plan Area

Sustainability Indicator	Historical Period	Existing Conditions	Future Conditions without GSP Implementation	Future Conditions with GSP Implementation (after 2040)
Chronic Lowering of Groundwater Levels[(a)]	No	No	No	No
Reduction of Groundwater Storage	No	No	No	No
Land Subsidence[(b)]	No	No	Possible	No
Seawater Intrusion	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Degraded Water Quality	No	No	No	No
Depletion of Interconnected Surface Water	No	No	No	No

(a) Groundwater levels have declined in response to generally dry conditions after 2006, leading to localized cones of depression in the Orland-Artois area of Glenn County and the Arbuckle area of Colusa County. Dry wells have been reported in both counties during the 2014 and 2021 droughts. As described in Chapter 7, interagency drought task forces are responding to the drought emergency in both counties. These local efforts, which are coordinated with state and federal agencies, are expected to address short-term needs, and undesirable results requiring state intervention are not expected to be triggered.

(b) Historical rates of inelastic land subsidence have exceeded measurable objectives and minimum thresholds at some locations in the Subbasin but have not triggered undesirable results. Undesirable results are expected to be avoided through implementation of the GSP and associated PMAs.

Chronic Lowering of Groundwater Levels

An undesirable result for chronic lowering of groundwater levels in the Subbasin is experienced if sustained groundwater levels are too low to reasonably satisfy beneficial uses within the Subbasin over the planning and implementation horizon of this GSP. Undesirable results for the chronic lowering of groundwater levels have not occurred historically and are not currently occurring. The projected Subbasin water budget finds that these effects are not likely to occur under future scenarios, including under projected climate change.

Minimum thresholds for the chronic lowering of groundwater levels were developed primarily by considering historical and current groundwater conditions, with lesser emphasis on projected future groundwater conditions. The minimum threshold for each groundwater level representative monitoring well (48 in total) is calculated by the deeper of the 20th percentile of the shallowest domestic well depths in each monitoring well's Thiessen polygon or the 50 percent of range below the historical low groundwater elevation. The minimum threshold is calculated as the 20th percentile of the shallowest domestic well depths at a majority of sites (35 sites). The minimum thresholds align with the State's Human Right to Water policy by supporting the ability of drinking water beneficial users, including DACs, SDACs and Tribes, to access safe, clean, and affordable water for human consumption, cooking, and sanitary purposes.

Reduction of Groundwater Storage

An undesirable result for the reduction of groundwater storage is experienced if storage volumes are insufficient to reasonably satisfy beneficial uses within the Subbasin over the planning and implementation horizon of this GSP. This GSP uses groundwater level minimum thresholds as a proxy for the reduction of groundwater storage sustainability indicator. Undesirable results related to groundwater storage have not occurred historically and are not currently occurring. The projected Subbasin water budget finds that these effects are not likely to occur under future scenarios, including under projected climate change.

Monitoring for a reduction of groundwater storage in the Subbasin uses groundwater levels as a proxy for determining sustainability, as permitted by 23 CCR §354.28(d). Minimum thresholds are defined using the groundwater levels criteria. Benefits to groundwater storage are expected to coincide with groundwater level management.

Seawater Intrusion

Seawater intrusion is not an applicable sustainability indicator because seawater intrusion is not present and is not likely to occur in the Subbasin due to the distances between the Subbasin and the Pacific Ocean, bays, deltas, or inlets ranging from about 30 to 60 miles.

Inelastic Land Subsidence

An undesirable result is experienced if groundwater withdrawal causes inelastic land subsidence that substantially interferes with the condition or functionality of critical infrastructure (e.g., roads, canals, pipelines) within the Subbasin over the planning and implementation horizon of this GSP. The thresholds set for inelastic land subsidence have been established so that when 20 percent of representative monitoring locations (i.e., 13 of 63 locations) exceed their minimum thresholds, an undesirable result is detected.

The minimum threshold for this sustainability indicator has been set at 0.5 feet per five years (6 inches), which was determined through review of historical subsidence conditions between 2008 and 2017 using data from DWR's Sacramento Valley Height Modernization Project.

Degraded Water Quality

An undesirable result for degraded water quality in the Subbasin is experienced if, as the result of PMAs implemented under the GSP or other groundwater development (such as groundwater extraction or groundwater recharge), groundwater quality for regulated constituents is degraded to levels exceeding historical levels existing prior to January 1, 2015, or applicable water quality objectives, including drinking water standards, whichever are greater over the planning and implementation horizon of this GSP. Existing regulatory programs address most water quality concerns, and the CGA and GGA will coordinate with these programs, the lead regulatory agencies, and the regulated community within the Subbasin during implementation of this GSP, including during development and implementation of PMAs.

The minimum threshold for degraded water quality has been established as the higher of either 900 microSiemens per centimeter (µS/cm) EC, which is consistent with the recommended California Secondary Maximum Contaminant Level (SMCL), or the pre-2015 historical maximum recorded EC value. In developing the minimum thresholds for groundwater quality, beneficial uses of groundwater as a drinking water supply and as an agricultural supply were considered. Setting minimum thresholds using this methodology is protective of beneficial users and uses of groundwater, including agricultural, municipal, and domestic uses in the Subbasin. The minimum threshold for degraded water quality is calculated to be at an EC level that allows for adequate flexibility within the pre-2015 historical maximum EC level, to compensate for changing groundwater conditions during drought periods, while protecting SMCLs established for aesthetic reasons, such as taste, odor, and color.

The minimum threshold aligns with the State's Human Right to Water policy by supporting the ability of drinking water beneficial users, including DACs, SDACs and Tribes, to access safe, clean, and affordable water for human consumption, cooking, and sanitary purposes.

Depletion of Interconnected Surface Water

An undesirable result for depletions of interconnected surface water is experienced if significant and unreasonable effects to stream flows, significant and unreasonable effects to riparian and riverine habitat, and significant and unreasonable effects to groundwater dependent ecosystems (GDEs) occur. This GSP uses minimum thresholds based on groundwater levels as a proxy for the depletion of interconnected surface water indicator. It is necessary to use groundwater levels as a proxy due to the surface water monitoring network being inadequate to monitor effects of groundwater on surface water flows. This is discussed in more detail in Chapter 5. The undesirable result for depletions of interconnected surface water is considered to occur during GSP implementation when 25 percent of representative monitoring wells (i.e., 3 of 12 wells) fall below their minimum groundwater elevation thresholds for 24 consecutive months. The three wells must be the same subset of wells, not any combination of three wells. These criteria were determined based on the evaluation of best available data pertaining to the Subbasin's specific conditions and characteristics, as described in the Plan Area and Groundwater Conditions sections of this GSP, in conjunction with input and feedback from the public, local stakeholders and GSA members.

The minimum thresholds set for managing depletions of interconnected surface water differ from the minimum thresholds set for managing chronic lowering of groundwater levels. Minimum thresholds for depletions of interconnected surface waters were determined based on evaluation of historical data from the monitoring network for interconnected surface water, which is composed of 12 monitoring wells no deeper than 200 feet located between 2,000 feet and five miles of interconnected streams in the Subbasin. The minimum thresholds set at these sites for assessing impacts to interconnected surface waters were calculated by finding the groundwater elevations in Fall of 2015 and adding 10 feet to that depth. Measurements selected for Fall 2015 were found by selecting measurements closest to October 15, 2015, considered to the be period of lowest groundwater elevations during the last drought based on review of historical groundwater levels and hydrologic data. The minimum threshold was selected such that groundwater levels near interconnected surface water courses would be protective of the beneficial use of shallower groundwater near streams and rivers, including those of shallower domestic users and potential groundwater dependent ecosystems. Levels from Fall 2015 represent conditions during a drought period but are generally believed to have still protected beneficial users at that time and therefore avoid undesirable results. The addition of 10 feet to the Fall 2015 groundwater depth to water is intended to provide an appropriate margin of operational flexibility in the future during GSP implementation based on recommendations made through discussion with the GSAs and stakeholders.

PROJECT AND MANAGEMENT ACTIONS (GSP CHAPTER 6)

The overarching sustainability goal and the absence of undesirable results are expected to be achieved by 2042 through implementation of PMAs. PMAs were formulated primarily to address possible future changes in Subbasin conditions that could cause undesirable results over the long term, and in the near term, to address effects of recent historical (2014-2015) and current (2020-2021) drought conditions that pose challenges to groundwater management in the northwest and southwest portions of the Subbasin respectively.

PMA development and implementation in the Subbasin applies an adaptive management approach informed by continued monitoring of groundwater conditions using the monitoring networks. Recognizing the GSP data gaps and uncertainties in the basin setting (per 23 CCR §354.44(d)), and recognizing known areas with declining groundwater levels, the adaptive management approach in the Subbasin includes:

- Planned PMAs that are expected to be implemented primarily to address current, localized declining groundwater levels in the Orland and Arbuckle areas. At full implementation, planned PMAs are expected to provide more than 80 taf/yr in combined gross average annual benefits that will offset groundwater pumping and support groundwater sustainability in the Subbasin.
- A portfolio of other ongoing and potential PMAs to achieve and maintain long-term sustainable groundwater management across the Subbasin, which will be implemented if established measurable objectives cannot be maintained and minimum thresholds are being approached.

Development of PMAs was informed by an evaluation of possible future changes in Subbasin conditions through comparison of the projected future water budget conditions without climate change and projected future water budget conditions adjusted by 2070 CT climate change factors. The aggregate changes in groundwater storage, 0.8 percent, and net stream accretion, 0.5 percent, across the Subbasin without PMAs are considered to be within standard modeling error for this type of analysis. However, there are localized declining groundwater levels that have occurred over the past 15 to 20 years in the northwest and southwest portions of the Subbasin near the cities of Orland and Arbuckle, respectively. Water budget analyses suggest that groundwater level decline in these areas is due primarily to drought. A series of mostly dry years beginning in about 2007 has resulted in increased irrigation demands, curtailments of Central Valley Project surface water supplies, and consequent increases in groundwater pumping in these areas. Similar dynamics exist in the Orland area, compounded by recent expansion of irrigated agriculture into previously undeveloped lands that rely on groundwater supplies only. Localized effects of declining groundwater levels include stranding of shallow domestic and irrigation wells and increased rates of land subsidence, raising concerns both locally and more broadly within the Subbasin that mitigation actions should be taken as soon as possible.

PMAs described in this GSP are expected to manage the balance of groundwater extractions and recharge to ensure that lowering of groundwater levels or depletion of supply during periods of drought is offset by increases in groundwater levels or storage in other years. In particular, PMAs that provide in-lieu and direct recharge benefits in the Orland and Arbuckle areas are planned to increase the use and recharge of available surface water supplies during wetter years, offsetting any potential increases in groundwater pumping during drought when curtailments of surface water supplies may occur.

PMAs are classified according to implementation status. Planned PMAs are those that will support sustainable groundwater management in the Subbasin over the GSP implementation period, and in the nearer-term will help to mitigate historical and current drought effects. Ongoing PMAs are those that have already been implemented and support groundwater management. Potential PMAs are a suite of options available to the GSAs if future monitoring indicates the need for such actions. Table ES-5 summarizes the planned PMAs for the Subbasin. The average annual gross benefit of these PMAs at full implementation is 84,000 af per year.

Table ES-5. Summary of Planned PMAs					
Project	Project Type	Proponent	Year Implemented	Estimated Capital / Establishment Cost, $ (thousands)[a]	Gross Average Annual Benefit, taf/yr
Colusa County Water District (CCWD) In-Lieu Groundwater Recharge	In-Lieu GW[b] Recharge	CCWD	2021	$100	27
Colusa Drain MWC (CDMWC) In-Lieu Groundwater Recharge	In-Lieu GW Recharge	CDMWC	2021	$100	28
Colusa Subbasin Multi-Benefit Recharge	Direct GW Recharge	CGA, GGA, and TNC[c]	2021	$4 per site	5.2
Orland-Artois Water District (OAWD) Land Annexation and In-Lieu Groundwater Recharge	Direct and In-Lieu GW Recharge	OAWD	2020	$20,000	23
Sycamore Slough Groundwater Recharge Pilot Project	Direct GW Recharge	Landowner	2021	$28	0.5[d]

(a) Annual costs are summarized in the "Project Costs" sections of the project descriptions, below.
(b) GW = Groundwater
(c) TNC = The Nature Conservancy
(d) Project goal is to recharge 5 taf over 10 years.

PLAN IMPLEMENTATION (GSP CHAPTER 7)

The estimated average annual cost of implementing the GSP increases from approximately $1.5 million to about $9.5 million per year by 2027 (including annualized capital costs). Implementation costs are summarized across four categories:

- **One-Time Capital Costs and Studies**. These include capital costs that are not debt financed and studies to support GSP and PMA implementation. Studies include updates to the HCM to support required annual and five-year reports for DWR as well as other planning studies to support GSP implementation. To expand monitoring network data and evaluate Subbasin conditions more comprehensively, 15 GSP studies will be conducted. These include various planning, technical, and economic/fiscal studies that will aid in implementing PMAs and the monitoring of sustainability indicators outlined in Chapter 5. The studies are described in Chapter 7.
- **Debt-Financed Capital**. This includes capital costs that would likely be debt-financed. There is only one planned PMA that may be debt-financed, the OAWD land annexation project. GSP implementation costs shown below correspond to the annual debt service payment, not the total capital cost. Project proponents are concurrently working to refine estimated project costs

- **PMA Operations and Maintenance**. This includes annual expenses for the operation of planned PMAs, for example, annual water supply purchases for within-subbasin transfers to support in-lieu recharge.
- **GSA Administration**. These costs include operating expenses such as administration of the GSP, plan development, legal services, and communications for GSA staff and its technical advisers. This also includes costs for annual reporting and preparation of five-year assessments that must be submitted to DWR.

Table ES-6 summarizes the estimated annual expenses for each of these cost categories. The GSAs will continually evaluate GSP implementation progress and reassess the implementation plan and associated costs.

Table ES-6. Summary of Estimated Total GSP Implementation Costs

Cost Category	2022	2023	2024	2025	2026	2027+
Other Capital/Studies	$556,000	$1,120,000	$685,000	$460,000	$460,000	$630,000
Debt-Financed PMA Capital Repayment	-	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000
PMA O&M	-	$4,033,000	$6,675,000	$6,675,000	$6,675,000	$6,675,000
GSA Admin/Studies	$914,700	$987,900	$968,200	$968,200	$968,200	$1,148,200
Total	**$1,470,700**	**$7,160,900**	**$9,348,200**	**$9,123,200**	**$9,123,200**	**$9,473,200**

Development of this GSP was funded through a Proposition 1 Grant, and contributions from individual GSAs (e.g., through in-kind staff time, or separately contracted consulting services). Each GSA is also funding additional, ancillary studies and implementation efforts. To fund GSA operations and GSP implementation, the GSAs are developing a financing plan that will include one or more of the following financing approaches:

- **Grants and low-interest loans**. GSAs will continue to pursue grants and low interest loans to help fund planning studies and other GSA activities. However, grants and low-interest loans are not expected to cover most GSA operating costs for GSP implementation.
- **Other fees and charges**. Other fees may include permitting fees for new wells or development, transaction fees associated with contemplated groundwater markets, or commodity-based fees, all directed at aiding with sustainability objectives. Depending on the justification and basis for a fee, it may be considered a property-related fee subject to voting requirements of Article XIII D of the California Constitution (passed by voters in 1996 as Proposition 218).
- **Assessments**. Special benefit assessments under Proposition 218 could include a per-acre (or per parcel) charge to cover GSA costs. This could also include per acre-foot assessments, or a hybrid approach.
- **Taxes**. This could include general property related taxes that are not directly related to the benefits or costs of a service (ad valorem and parcel taxes), or special taxes imposed for specific purposes related to GSA activities.

The GSAs are pursuing a combined approach, targeting available grants and low interest loans, and considering a combination of fees and assessments to cover operating and program-specific costs. As required by statute and the Constitution, GSAs would complete a rate study and other analysis to document and justify any rate, fee, or assessment. GGA and CGA activities are currently supported under assessments associated with a rate study that runs through 2024.

The GSP implementation schedule allows time for GSAs to develop and implement PMAs and meets all sustainability objectives by 2042. While some sustainability projects began immediately after SGMA became law and are already contributing to Subbasin goals, the GSAs will begin implementing other GSP activities in 2022, with full implementation of PMAs to achieve sustainability by 2042. Figure ES-4 illustrates the GSP implementation schedule for PMAs implemented by each GSA. The GSP implementation schedule also shows mandatory reporting and updating for all GSAs, including annual reports and five-year periodic updates (evaluations) prepared and submitted to DWR.

Task Name	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Plan Implementation																					
GSP Submittal to DWR	X																				
Memorandum of Understanding	X																				
Annual Reports	X	X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X	
Five-Year Periodic Evaluation						X					X					X					X
Outreach and Communication																					
Monitoring and DMS																					
GSP Studies																					
Planned Projects and Management Actions																					
Colusa Subbasin Multi-Benefit Groundwater Recharge																					
OAWD District Land Annexation and In-Lieu Groundwater Recharge																					
Sycamore Slough Groundwater Recharge Pilot Project																					
CCWD In-Lieu Groundwater Recharge																					
Colusa Drain MWC In-Lieu Groundwater Recharge																					

Legend
- Submittal: X
- Planning and Development
- Implementation
- Ongoing Activity

Figure ES-4. Colusa Subbasin Implementation Schedule

CHAPTER 1
Introduction

1.1 PURPOSE OF THE GROUNDWATER SUSTAINABILITY PLAN

On September 16, 2014, Governor Jerry Brown signed into law a three-bill legislative package composed of Assembly Bill (AB) 1739, Senate Bill (SB) 1168, and SB 1319, collectively known as the Sustainable Groundwater Management Act (SGMA), which is codified in Section 10720 et seq. (§10720) of the California Water Code.

This legislation created a statutory framework for sustainable groundwater management in California and required local agencies of high- and medium-priority groundwater basins to halt overdraft and bring basins into balanced levels of pumping and recharge within 20 years. SGMA empowered local agencies to form Groundwater Sustainability Agencies (GSAs) to manage basins sustainably and required GSAs to adopt Groundwater Sustainability Plans (GSPs) for non-critically overdrafted medium- and high-priority groundwater basins in California by calendar year 2022.

SGMA defines sustainable groundwater management as *"management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results"* (SGMA Regulations §10721(v)). Undesirable results are defined by SGMA as the following effects:

1. Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply
2. Significant and unreasonable reduction of groundwater storage
3. Significant and unreasonable seawater intrusion
4. Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies
5. Significant and unreasonable land subsidence that substantially interferes with surface land uses
6. Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water

The Colusa Groundwater Authority (CGA) and Glenn Groundwater Authority (GGA), or Authorities, are exclusive GSAs covering the entire geographic extent of the Colusa Subbasin (Subbasin). The CGA GSA and GGA GSA are referred to as the Subbasin GSAs. The Authorities and their member agencies are discussed more in Chapter 2. The Authorities have worked collaboratively with all interested stakeholders to prepare this GSP. The purpose of this GSP is to characterize groundwater conditions in the Subbasin; evaluate and report on existing conditions relating to the six sustainability indicators; describe existing monitoring programs, management programs, and policies relating to groundwater resource use; identify data gaps within the aforementioned GSP topics and provide recommended actions to address those data gaps[1]; document public outreach and communication;; establish sustainability goals; and describe programs and management actions the GSAs will implement to achieve sustainable groundwater management within

[1] Chapter 3 defines data gaps within the hydrogeologic conceptual model and provides recommendations to close them. Chapter 4 of the GSP describes analyses of existing data gaps in the Subbasin, and proposed actions to address data gaps in each monitoring network. Chapter 7 further describes proposed studies and actions to address and fill data gaps identified throughout the Colusa Subbasin GSP.

20 years of implementing the GSP (California Code of Regulations [CCR] Title 23 Section 350.4(f) [23 CCR §350.4(f)]).

While the GSP focuses on groundwater projects and management actions by the Subbasin GSAs, these actions are considered in the context of the entire basin setting. The Authorities have and will continue to coordinate the actions of other GSAs in the region in an effort to achieve sustainability at a regional level.

1.2 SUSTAINABILITY GOAL

As mandated under 23 CCR §354.24, the Subbasin GSAs have established a *"sustainability goal for the basin that culminates in the absence of undesirable results within 20 years of the applicable statutory deadline."*

The sustainability goal for the Subbasin GSP is:

> *… to maintain, through a cooperative and partnered approach, locally managed sustainable groundwater resources to preserve and enhance the economic viability, social well-being and culture of all Beneficial Uses and Users, without experiencing undesirable results.*

Chapter 5, Sustainable Management Criteria, of the GSP describes the sustainability goal for the GSAs and is based on information from the basin setting, discussions of the measures that will be implemented to ensure that the Subbasin will be operated within its sustainable goal, and an explanation of how the sustainability goal is likely to be achieved and maintained within the 20-year planning and implementation horizon. The Subbasin GSAs can and should continue to assess the reasonableness of the sustainability goal in the years to come.

1.3 AGENCY INFORMATION

The CGA and the GGA have led the effort to develop a single GSP for the Subbasin, in collaboration with interested Subbasin stakeholders and interbasin agencies (described extensively in Section 2.7). Collectively, these two GSAs have been deemed exclusive GSAs and cover the entire Subbasin.

The Subbasin is located within the larger Sacramento Valley Groundwater Basin and spans the eastern portions of Colusa and Glenn Counties. It is generally bounded by Stony Creek to the north, the Coast Ranges to the west, the Sacramento River and the Reclamation District 1004 western boundary to the east, and the Colusa-Yolo County boundary and the Colusa County Water District Boundary to the south.

The Subbasin has been designated as a high-priority basin by the California Department of Water Resources (DWR) with implications under the SGMA. In compliance with SGMA deadlines, the Subbasin GSP will be completed, adopted, and submitted to DWR by January 31, 2022. Both the CGA and GGA will adopt the GSP and continue to work collaboratively on GSP implementation.

1.3.1 Agency Organization and Management Structure

The CGA and the GGA have been deemed the exclusive GSAs that cover the entire Subbasin. The CGA was formed on June 29, 2017 as a 12-member Joint Powers Authority (JPA) with 12 Director seats. It is the exclusive GSA for the Colusa County portion of the Subbasin, and a small portion of the Butte Subbasin in Colusa County. Members of the CGA Board include:

- County of Colusa
- City of Colusa
- City of Williams
- Glenn-Colusa Irrigation District
- Maxwell Irrigation District and Westside Water District
- Princeton-Codora-Glenn Irrigation District and Provident Irrigation District
- Colusa County Water District
- Reclamation District 108
- Reclamation District 479
- Colusa Drain Mutual Water Company
- Two (2) Private Pumper Representatives recommended by the Colusa County Groundwater Commission and appointed by the Colusa County Groundwater Board of Supervisors

The GGA was formed on June 20, 2017, as a nine-member JPA with eight Director seats. The JPA was later amended on October 14, 2019, to add a tenth member and one additional Director seat, for a total of nine Director seats. The GGA is the exclusive GSA for the Glenn County portion of the Subbasin. Members of the GGA include:

- City of Orland
- City of Willows
- County of Glenn
- Glenn-Colusa Irrigation District
- Glide Water District
- Kanawha Water District
- Monroeville Water District
- Orland-Artois Water District
- Princeton-Codora-Glenn Irrigation District
- Provident Irrigation District

Each GSA Board has final authority for GSP implementation. Except for the Private Pumper Representatives, Board members are chosen in public meetings by the respective governing boards of the Member Agencies. Alternates for each Board member are chosen in the same manner by the same Member Agencies. Private Pumper Representatives on the CGA Board are recommended by the Colusa County Groundwater Commission and appointed by the Colusa County Board of Supervisors in a public meeting.

Contact information for each GSA Manager is provided below:

Colusa Groundwater Authority:

Denise Carter, County Supervisor
(530) 458-0502
1213 Market Street
Colusa, CA 95932
dcarter@countyofcolusa.com

Glenn Groundwater Authority:

Lisa Hunter, Water Resources Coordinator
(530) 934-6540
225 North Tehama Street
Willows, CA 95988
lhunter@countyofglenn.net

1.3.1.1 Coordination Agreements

23 CCR §357.4(a) states that "*Agencies intending to develop and implement multiple Plans pursuant to Water Code Section 10727(b)(3) shall enter into a coordination agreement to ensure that the Plans are developed and implemented utilizing the same data and methodologies, and that elements of the Plans necessary to achieve the sustainability goal for the basin are based upon consistent interpretations of the basin setting.*"

The two Subbasin GSAs have jointly prepared one GSP for the entire Colusa Subbasin. As such, coordination agreements are neither required nor applicable to the Subbasin.

1.3.2 Legal Authority

On May 14, 2018, the CGA and GGA notified DWR of their intent to prepare a GSP for the Subbasin (5-021.52). The preparation of the GSP is being coordinated and overseen by the GSAs. The Authorities hold regular meetings that are open to the public and have formed a Joint Technical Advisory Committee (TAC) to coordinate Subbasin-wide activities. Periodic TAC meetings, which are also open to the public, allow coordination with the technical consulting team tasked with preparing the GSP and coordination activities in adjacent subbasins. All meeting materials and information relevant to SGMA planning and implementation are readily available to the public via websites, newsletters, emails, presentations, and public meetings. Public engagement, notices, and communication records are discussed in Chapter 2.

1.3.3 Estimated Implementation Cost and Agencies' Approach to Meet Costs

Total GSP implementation costs are estimated to increase from approximately $1.5 million per year in 2022 to approximately $9.5 million per year by 2027. These estimated costs are inclusive of all currently envisioned GSP-related activities required for successful implementation. This includes GSA administrative costs and technical studies that are required for annual updates and five-year reporting requirements totaling around $1 million per year. Projects and management action (PMAs) capital repayment costs are estimated at approximately $1 million (the total capital outlay is approximately $20 million). Project and management action development technical studies and non-debt financed capital is estimated to equal $0.5 to $1.1 million per year. Annual operations and maintenance (O&M) for projects is approximately $4 to $6.7 million per year. A substantial share of project O&M costs are attributed to water purchases for in-lieu recharge projects providing approximately 84,000 acre-feet of benefits at full implementation. Table 1-1 summarizes estimated annual GSP implementation costs for the Subbasin as a whole.

Table 1-1. Total Estimated Annual GSP Implementation Cost Summary						
Cost Category	2022	2023	2024	2025	2026	2027+
Other Capital/Studies	$556,000	$1,120,000	$685,000	$460,000	$460,000	$630,000
Debt-Financed PMA Capital Repayment	-	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000
PMA O&M	-	$4,033,000	$6,675,000	$6,675,000	$6,675,000	$6,675,000
GSA Admin/Studies	$914,700	$987,900	$968,200	$968,200	$968,200	$1,148,200
Total	**$1,470,700**	**$7,160,900**	**$9,348,200**	**$9,123,200**	**$9,123,200**	**$9,473,200**

Development of this GSP was primarily funded through a Proposition 1 Sustainable Groundwater Planning Grant. In addition, the GSAs' activities were funded by fees collected under separate rate studies covering the five-year period spanning fiscal years 2019/20 through 2023/24. These were prepared as property-related fees for water service under Proposition 218. The implementation of the GSP and future SGMA compliance will be a substantial undertaking. It will likely require GSAs and other local entities to collect some combination of fees, assessments, and taxes, as well as seek additional outside funding, grants, and low-interest borrowing. The Subbasin GSAs will develop a financing plan for the overall implementation of the GSP that will specify funding sources and cost-allocation approaches across entities for the different GSP implementation activities (see Chapter 7 and Appendix 7A for a description of existing options).

1.4 GSP ORGANIZATION

The GSP is organized in accordance with 23 CCR §354 as follows:

- **Preface** sets the context for development and adoption of the GSP during a drought emergency
- **Executive Summary** provides a summary of the major topics discussed in the GSP
- **Chapter 1** introduces the Subbasin GSAs and the development of this GSP
- **Chapter 2** provides a summary of the Plan Area, monitoring and management programs, land uses, additional GSP elements and notice and communication
- **Chapter 3** discusses the Basin Setting, including the hydrogeologic conceptual model for the Subbasin, water features and conveyance infrastructure, groundwater conditions, and water budget analyses
- **Chapter 4** reviews the Monitoring Networks within the Subbasin pertaining to groundwater levels, water quality, inelastic land subsidence, and depletions of interconnected surface water
- **Chapter 5** identifies Sustainable Management Criteria, including goals, measurable objectives, minimum thresholds, and undesirable results
- **Chapter 6** identifies Projects and Management Actions that work to achieve the GSAs' sustainability goal
- **Chapter 7** discusses Plan Implementation, including anticipated costs, schedule of implementation, and annual reporting and evaluations
- **Chapter 8** provides References cited in the GSP

To facilitate DWR review and provide references to the applicable GSP regulations, Table 1-2, Checklist for GSP Submittal, cross-references the chapters of this GSP to applicable GSP regulations. Terminology used in this GSP is consistent with the SGMA definitions provided in California Water Code (CWC) §10721 and in 23 CCR §351. Appendix 1A provides a glossary of terms.

Table 1-2. Preparation Checklist for GSP Submittal					
GSP Regulations Section	Water Code Section	Requirement	Description	Chapter/Section in GSP	Initial Page Number in GSP
Article 3. Technical and Reporting Standards					
352.2		Monitoring Protocols	• Monitoring protocols adopted by the GSA for data collection and management • Monitoring protocols that are designed to detect changes in groundwater levels, groundwater quality, inelastic surface subsidence for basins for which subsidence has been identified as a potential problem, and flow and quality of surface water that directly affect groundwater levels or quality or are caused by groundwater extraction in the basin	• Chapter 4.2 • Chapter 4.2	• 4-1 • 4-1
Article 5. Plan Contents, Subarticle 1. Administrative Information					
354.4		General Information	• Executive Summary • List of references and technical studies	• Executive Summary • Chapter 8	• ES-1 • 8-1
354.6		Agency Information	• GSA mailing address • Organization and management structure • Contact information of Plan Manager • Legal authority of GSA • Estimate of implementation costs	• Chapter 1.3.1 • Chapter 1.3.1 • Chapter 1.3.1 • Chapter 1.3.2 • Chapters 1.3.3, 7	• 1-3 • 1-3 • 1-3 • 1-4 • 1-4, 7-1
354.8(a)	10727.2(a)(4)	Map(s)	• Area covered by GSP • Adjudicated areas, other agencies within the basin, and areas covered by an Alternative • Jurisdictional boundaries of federal or State land • Existing land use designations • Density of wells per square mile	• Figure 2-1 • Figures 2-3, 2-4 • Figures 2-4, 2-5 • Figure 2-8 • Figure 2-7	• 2-3 • 2-6, 2-7 • 2-7, 2-12 • 2-16 • 2-15
354.8(b)		Description of the Plan Area	• Summary of jurisdictional areas and other features	• Chapter 2.1.2	• 2-4
354.8(c) 354.8(d) 354.8(e)	10727.2(g)	Water Resource Monitoring and Management Programs	• Description of water resources monitoring and management programs • Description of how the monitoring networks of those plans will be incorporated into the GSP • Description of how those plans may limit operational flexibility in the basin • Description of conjunctive use programs	• Chapter 2.2 • Chapter 2.2.1 • Chapter 2.2.2 • Chapter 2.2.4	• 2-17 • 2-17 • 2-25 • 2-26

Table 1-2. Preparation Checklist for GSP Submittal					
GSP Regulations Section	Water Code Section	Requirement	Description	Chapter/Section in GSP	Initial Page Number in GSP
354.8(f)	10727.2(g)	Land Use Elements or Topic Categories of Applicable General Plan	• Summary of general plans and other land use plans • Description of how implementation of the GSP may change water demands or affect achievement of sustainability and how the GSP addresses those effects • Description of how implementation of the GSP may affect the water supply assumptions of relevant land use plans • Summary of the process for permitting new or replacement wells in the basin • Information regarding the implementation of land use plans outside the basin that could affect the ability of the Agency to achieve sustainable groundwater management	• Chapter 2.3.1 • Chapter 2.3.2 • Chapter 2.4 • Chapter 2.5 • Chapter 2.3.3	• 2-27 • 2-29 • 2-31 • 2-32 2-31
354.8(g)	10727.4	Additional GSP Contents	**Description of Actions related to:** • Control of saline water intrusion • Wellhead protection • Migration of contaminated groundwater • Well abandonment and well destruction program • Replenishment of groundwater extractions • Conjunctive use and underground storage • Well construction policies • Addressing groundwater contamination cleanup, recharge, diversions to storage, conservation, water recycling, conveyance, and extraction projects • Efficient water management practices • Relationships with State and federal regulatory agencies • Review of land use plans and efforts to coordinate with land use planning agencies to assess activities that potentially create risks to groundwater quality or quantity • Impacts on groundwater dependent ecosystems	• Chapter 3.2.4 • Chapter 2.5.3 • Chapter 4.2.2, 4.2.5 • Chapter 6.5.2 • Chapter 6 • Chapter 2.2.4, 6.5.1 • Chapter 2.2.3, 2.5 • Chapter 6 • Chapters 2.2.1, 6 • Chapter 2.7, 7 • Chapter 2.3 • Chapters 4.2.5, 5.3.6, 6.5.1	• 3-66 • 2-33 • 4-15, 4-30 • 6-83 • 6-1 • 2-26, 6-59 • 2-26, 2-32 • 6-1 • 2-17, 6-1 • 2-34, 7-1 • 2-27 • 4-30, 5-15, 6-59

Table 1-2. Preparation Checklist for GSP Submittal

GSP Regulations Section	Water Code Section	Requirement	Description	Chapter/Section in GSP	Initial Page Number in GSP
354.10		Notice and Communication	• Description of beneficial uses and users • List of public meetings • GSP comments and responses • Decision-making process • Public engagement • Encouraging active involvement • Informing the public on GSP implementation progress	• Chapter 2.7.1 • Chapter 2.7.2 • Appendix 2B • Chapter 2.7.1 • Chapter 2.7.2 • Chapter 2.7.1 • Chapter 2.7.3	• 2-34 • 2-39 • Appendix 2B • 2-34 • 2-39 • 2-34 • 2-43
Article 5. Plan Contents, Subarticle 2. Basin Setting					
354.14		Hydrogeologic Conceptual Model	• Description of the Hydrogeologic Conceptual Model • Two scaled cross-sections • Map(s) of physical characteristics: topographic information, surficial geology, soil characteristics, surface water bodies, source and point of delivery for imported water supplies	• Chapter 3.1 • Figures 3-11, 3-12, 3-13 • Figures 3-4, 3-5, 3-6, 3-7, 3-8, 3-9, 3-10	• 3-1 • 3-22, 3-23, 3-24 • 3-8, 3-9, 3-11, 3-12, 3-14, 3-18, 3-21
354.14(c)(4)	10727.2(a)(5)	Map of Recharge Areas	• Map delineating existing recharge areas that substantially contribute to the replenishment of the basin, potential recharge areas, and discharge areas	• Figures 3-18, 3-19, 3-20	• 3-45, 3-47, 3-48
	10727.2(d)(4)	Recharge Areas	• Description of how recharge areas identified in the plan substantially contribute to the replenishment of the basin	• Chapter 3.1.11	• 3-43
354.16	10727.2(a)(1) 10727.2(a)(2)	Current and Historical Groundwater Conditions	• Groundwater elevation data • Estimate of groundwater storage • Seawater intrusion conditions • Groundwater quality issues • Land subsidence conditions • Identification of interconnected surface water systems • Identification of groundwater-dependent ecosystems	• Chapter 3.2.2 • Chapter 3.2.3 • Chapter 3.2.4 • Chapter 3.2.5 • Chapter 3.2.6 • Chapter 3.2.7 • Chapter 3.2.8	• 3-55 • 3-65 • 3-66 • 3-66 • 3-73 • 3-76 • 3-81

Table 1-2. Preparation Checklist for GSP Submittal					
GSP Regulations Section	Water Code Section	Requirement	Description	Chapter/Section in GSP	Initial Page Number in GSP
354.18	10727.2(a)(3)	Water Budget Information	• Description of inflows, outflows, and change in storage • Quantification of overdraft • Estimate of sustainable yield • Quantification of current, historical, and projected water budgets	• Chapter 3.3 • Chapter 3.3.6 • Chapter 3.3.7 • Chapter 3.3.4	• 3-84 • 3-111 • 3-111 • 3-93
	10727.2(d)(5)	Surface Water Supply	• Description of surface water supply used or available for use for groundwater recharge or in-lieu use	• Chapter 6	• 6-1
354.20		Management Areas	• Reason for creation of each management area • Minimum thresholds and measurable objectives for each management area • Level of monitoring and analysis • Explanation of how management of management areas will not cause undesirable results outside the management area • Description of management areas	• Chapter 3.4 • Not applicable • Not applicable • Not applicable • Not applicable	• 3-112 • Not applicable • Not applicable • Not applicable • Not applicable
Article 5. Plan Contents, Subarticle 3. Sustainable Management Criteria					
354.24		Sustainability Goal	• Description of the sustainability goal	• Chapter 5.2	• 5-3
354.26		Undesirable Results	• Description of undesirable results • Cause of groundwater conditions that would lead to undesirable results • Criteria used to define undesirable results for each sustainability indicator • Potential effects of undesirable results on beneficial uses and users of groundwater	• Chapter 5.3 • Chapter 5.3 • Chapter 5.3 • Chapter 5.3	• 5-4 • 5-4 • 5-4 • 5-4
354.28	10727.2(d)(1) 10727.2(d)(2)	Minimum Thresholds	• Description of each minimum threshold and how they were established for each sustainability indicator • Relationship for each sustainability indicator • Description of how selection of the minimum threshold may affect beneficial uses and users of groundwater • Standards related to sustainability indicators • How each minimum threshold will be quantitatively measured	• Chapter 5.4 • Chapter 5.4 • Chapter 5.4 • Chapter 5.4 • Chapter 5.4	• 5-17 • 5-17 • 5-17 • 5-17 • 5-17

Table 1-2. Preparation Checklist for GSP Submittal					
GSP Regulations Section	Water Code Section	Requirement	Description	Chapter/Section in GSP	Initial Page Number in GSP
354.30	10727.2(b)(1) 10727.2(b)(2) 10727.2(d)(1) 10727.2(d)(2)	Measurable Objectives	• Description of establishment of the measurable objectives for each sustainability indicator • Description of how a reasonable margin of safety was established for each measurable objective • Description of a reasonable path to achieve and maintain the sustainability goal, including a description of interim milestones	• Chapter 5.4 • Chapter 5.4 • Chapter 5.4	• 5-17 • 5-17 • 5-17
Article 5. Plan Contents, Subarticle 4. Monitoring Networks					
354.34	10727.2(d)(1) 10727.2(d)(2) 10727.2(e) 10727.2(f)	Monitoring Networks	• Description of monitoring network • Description of monitoring network objectives • Description of how the monitoring network is designed to: demonstrate groundwater occurrence, flow directions, and hydraulic gradients between principal aquifers and surface water features; estimate the change in annual groundwater in storage; monitor seawater intrusion; determine groundwater quality trends; identify the rate and extent of land subsidence; and calculate depletions of surface water caused by groundwater extractions • Description of how the monitoring network provides adequate coverage of Sustainability Indicators • Density of monitoring sites and frequency of measurements required to demonstrate short-term, seasonal, and long-term trends • Scientific rational (or reason) for site selection • Consistency with data and reporting standards • Corresponding sustainability indicator, minimum threshold, measurable objective, and interim milestone • Location and type of each monitoring site within the basin displayed on a map, and reported in tabular format, including information regarding the monitoring site type, frequency of measurement, and the purposes for which the monitoring site is being used	• Chapter 4.2 • Chapter 4.1 • Chapter 4.2 • Chapter 4.2 • Chapter 4.2 • Chapter 4.2 • Chapter 4.2 • Chapter 5.4 • Chapter 4.2; Figures 4-1, 4-2, 4-3, 4-4, 4-5; Tables 4-1, 4-4, 4-5, 4-6; Appendix 4B	• 4-1 • 4-1 • 4-1 • 4-1 • 4-1 • 4-1 • 4-1 • 5-17 • 4-1, 4-4, 4-11, 4-17, 4-23, 4-28, 4-5, 4-16, 4-22, 4-27, Appendix 4B

Table 1-2. Preparation Checklist for GSP Submittal					
GSP Regulations Section	Water Code Section	Requirement	Description	Chapter/Section in GSP	Initial Page Number in GSP
			• Description of technical standards, data collection methods, and other procedures or protocols to ensure comparable data and methodologies	• Chapter 4.2	• 4-1
354.36		Representative Monitoring	• Description of representative sites • Demonstration of adequacy of using groundwater elevations as proxy for other sustainability indicators • Adequate evidence demonstrating site reflects general conditions in the area	• Chapter 4.2.5 • Chapters 5.3, 5.4; Appendix 5B • Chapter 4.2.5	• 4-30 • 5-4, 5-17; Appendix 5B • 4-30
354.38		Assessment and Improvement of Monitoring Network	• Review and evaluation of the monitoring network • Identification and description of data gaps • Description of steps to fill data gaps • Description of monitoring frequency and density of sites	• Chapter 4.2 • Chapter 4.2 • Chapter 4.2 • Chapter 4.2	• 4-1 • 4-1 • 4-1 • 4-1
Article 5. Plan Contents, Subarticle 5. Projects and Management Actions					
354.44		Projects and Management Actions	• Description of projects and management actions that will help achieve the basin's sustainability goal • Measurable objective that is expected to benefit from each project and management action • Circumstances for implementation • Public noticing • Permitting and regulatory process • Time-table for initiation and completion, and the accrual of expected benefits • Expected benefits and how they will be evaluated • How the project or management action will be accomplished. If the projects or management actions rely on water from outside the jurisdiction of the Agency, an explanation of the source and reliability of that water shall be included. • Legal authority required • Estimated costs and plans to meet those costs • Management of groundwater extractions and recharge	• Chapter 6.2 • Table 6-3 • Chapter 6.3 • Chapter 6.3 • Chapter 6.3 • Chapter 6.3 • Chapter 6.3 • Chapter 6.3 • Chapter 6.3 • Chapter 6.3 • Chapter 6	• 6-6 • 6-13 • 6-15 • 6-15 • 6-15 • 6-15 • 6-15 • 6-15 • 6-15 • 6-15 • 6-1
354.44(b)(2)	10727.2(d)(3)		• Overdraft mitigation projects and management actions	• Chapter 6	• 6-1

Table 1-2. Preparation Checklist for GSP Submittal					
GSP Regulations Section	Water Code Section	Requirement	Description	Chapter/Section in GSP	Initial Page Number in GSP
Article 8. Interagency Agreements					
357.4	10727.6	Coordination Agreements – Shall be submitted to the Department together with the GSPs for the basin and, if approved, shall become part of the GSP for each participating Agency.	**Coordination Agreements shall describe the following:** • A point of contact • Responsibilities of each Agency • Procedures for the timely exchange of information between Agencies • Procedures for resolving conflicts between Agencies • How the Agencies have used the same data and methodologies to coordinate GSPs • How the GSPs implemented together satisfy the requirements of SGMA • Process for submitting all Plans, Plan amendments, supporting information, all monitoring data and other pertinent information, along with annual reports and periodic evaluations • A coordinated data management system for the basin • Coordination agreements shall identify adjudicated areas within the basin, and any local agencies that have adopted an Alternative that has been accepted by the Department	Chapter 1.3.1	1-3

(a) The California Water Code and regulation sections, GSP requirements, and requirement descriptions listed in this table were taken verbatim from the California Department of Water Resources *Guidance Document for the Sustainable Management of Groundwater: Preparation Checklist for GSP Submittal* (December 2016).

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CHAPTER 2
Plan Area

2.1 SUMMARY OF JURISDICTIONAL AREAS AND OTHER FEATURES

2.1.1 Groundwater Basin Boundaries

The Plan Area is defined as the Colusa Subbasin (Groundwater Basin No. 5-021.52), which is part of the Sacramento Valley Groundwater Basin, as described in California Department of Water Resources (DWR) Bulletin 118 (DWR, 2006a) with boundary updates approved in February 2019. The current configuration of the Subbasin covers approximately 1,131 square miles (723,823 acres).

The Subbasin is generally bounded by Stony Creek to the north, the Coast Ranges to the west, the Sacramento River to the east, and the Colusa-Yolo County boundary and the Colusa County Water District to the south. The Subbasin currently includes about 2.4 square miles (1,500 acres) within Yolo County. Additional basin boundary modifications were submitted to DWR in June 2021; however, the proposed basin boundary modifications have not been approved as of the submittal of this GSP. The modifications would adjust the eastern Colusa Subbasin (Subbasin) boundary to better conform to the boundary of Reclamation District 1004 in Colusa County and would reduce the area of the Subbasin to 1,129 square miles (722,768 acres).

The vertical boundaries of the subbasin are the land surface (upper boundary) and the definable bottom of the subbasin (lower boundary). The definable bottom was established as part of development of the hydrogeologic conceptual model (HCM) discussed in Chapter 3. The vertical extent of the subbasin is subdivided into a surface water system (SWS) and groundwater system (GWS). The SWS extends from the land surface down to the bottom of root zone, within the lateral boundaries of the subbasin. The GWS extends from the bottom of the root zone to the base of the aquifer system, as defined in the HCM based on the base of freshwater and bedrock structural contours, within the lateral boundaries of the subbasin.

The Subbasin is hydraulically connected with surrounding subbasins along shared boundaries, the western boundary of Reclamation District 1004, and the Glenn and Colusa County boundaries. The Subbasin adjoins the following subbasins (Table 2-1 and Figure 2-1):

- Corning Subbasin (5-021.51) to the north
- Butte Subbasin (5-021.70) to the east/northeast
- Sutter Subbasin (5-021.62) to the east/southeast
- Yolo Subbasin (5-021.67) to the south

No groundwater subbasins border the western portion of the Subbasin.

Table 2-1. Adjacent Subbasins and Associated GSAs

Subbasin	SGMA Basin Priority	GSA(s)
Corning Groundwater Subbasin 5-021.51	High	• Tehama County Flood Control & Water Conservation District GSA • Corning Subbasin GSA
Butte Groundwater Subbasin 5-021.70	Medium	• Biggs-West Gridley Water District GSA • Butte County GSA • Butte Water District GSA • City of Biggs GSA • City of Gridley GSA • Colusa Groundwater Authority GSA • Glenn County GSA • Reclamation District 1004 GSA • Reclamation District 2106 GSA • Richvale Irrigation District GSA • Western Canal Water District GSA
Sutter Groundwater Subbasin 5-021.62	Medium	• Butte Water District GSA • City of Live Oak GSA • City of Yuba City GSA • Reclamation District No. 70 GSA • Reclamation District No. 1500 GSA • Reclamation District No. 1660 GSA • Sutter County GSA • Sutter Extension Water District GSA • Sutter Community Service District GSA
Yolo Groundwater Subbasin 5-021.67	High	• Yolo Subbasin GSA

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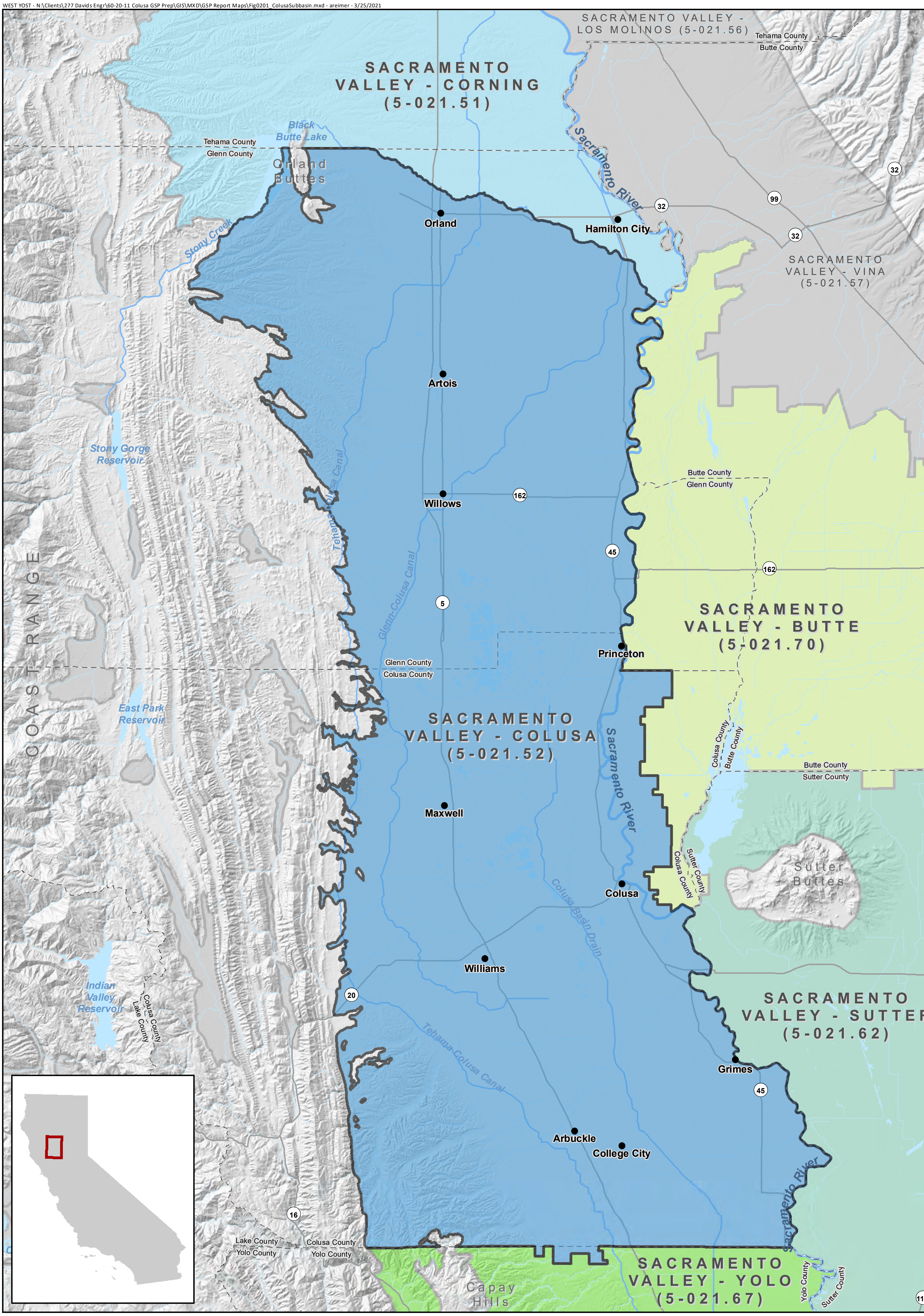


Source: California DWR Bulletin 118 Groundwater Basins v.6.1, revised in 2019.

Datums: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

- Colusa Subbasin (5-021.52)
- Non-Adjacent Groundwater Basins

Adjacent Groundwater Basins

- Corning Subbasin (5-021.51)
- Butte Subbasin (5-021.71)
- Sutter Subbasin (5-021.62)
- Yolo Subbasin (5-021.67)

Figure 2-1

Area Covered by this GSP: Colusa Subbasin

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin
Groundwater Sustainability Plan

2.1.2 Groundwater Sustainability Plan Area

The Subbasin is divided among two GSAs for GSP development (Figure 2-2). Figure 2-3 shows the agencies comprising each GSA. The Colusa Groundwater Authority (CGA) for the Colusa County portion of the Subbasin is a Joint Powers Authority (JPA) with 12 member agency representatives/Director seats. The CGA is comprised of Colusa County, two cities, six[1] water districts, two reclamation districts, a water company, and two appointed private groundwater pumper representatives. The Glenn Groundwater Authority (GGA) is similarly a JPA for the Glenn County portion of the Subbasin. The GGA is comprised of ten member agency representatives including Glenn County, two cities, and seven water/irrigation districts.

Primary urban areas within the Subbasin include the incorporated cities of Orland and Willows in Glenn County and the cities of Colusa and Williams in Colusa County as well as the unincorporated communities of Artois, Princeton, Maxwell, Arbuckle, Grimes and College City. Interstate 5 and State Route 45 traverse the Subbasin north to south while State Routes 20, 32, and 162 are the primary east-west thoroughfares.

There are no adjudicated areas or areas addressed in an alternative to a GSP within the Subbasin.

2.1.2.1 Water Purveyors

The Subbasin is served by several water purveyors, providing water for urban, agricultural, and environmental resource uses (Figure 2-4). These water purveyors include cities, special districts, mutual water companies, reclamation districts, and investor-owned water utilities

Municipal Water Purveyors

Municipal water purveyors and municipal water users in the Subbasin rely on groundwater to meet domestic water needs. Refer to Table 2-2, Municipal Water Purveyors, for the municipal water purveyors in the Subbasin. A description of each of the incorporated cities' water services facilities is provided further below.

Several small water systems are located in the Subbasin. State small water systems provide piped water to the public for human consumption; serve at least five, but not more than 14, service connections; and do not regularly serve drinking water to more than an average of 25 individuals daily for more than 60 days out of the year (California Health and Safety Code §116275). State small water systems may rely on either groundwater or surface water supply.

In addition to the municipal water purveyors and State small water systems, rural domestic water needs are typically met with groundwater from individual private wells. These private groundwater pumpers are represented on the CGA Board by two appointed private groundwater pumper representatives that serve on the Colusa County Groundwater Commission. Glenn County private groundwater pumpers are represented in GGA by Glenn County and Monroeville Water District.

Municipal and rural domestic water supplies in the Subbasin largely serve Disadvantaged Communities (DACs), Severely Disadvantaged Communities (SDACs), and Economically Distressed Areas (EDAs). As described in Section 2.1.2.3, nearly all of the Subbasin is considered an EDA and many communities within the Subbasin are considered DACs, including the City of Orland, the City of Willows, the City of Colusa, and the communities of Artois, Princeton, and Grimes. Additionally, many of the rural residential and agricultural properties located within the unincorporated areas of Glenn County and Colusa County are identified as DACs or SDACs. These users typically rely on groundwater to meet their water needs.

[1] Four water agencies are represented by two member agency representatives/Director seats. Maxwell Irrigation District and Westside Water District share one Director seat. Princeton-Codora-Glenn Irrigation District and Provident Irrigation District also share one Director seat.

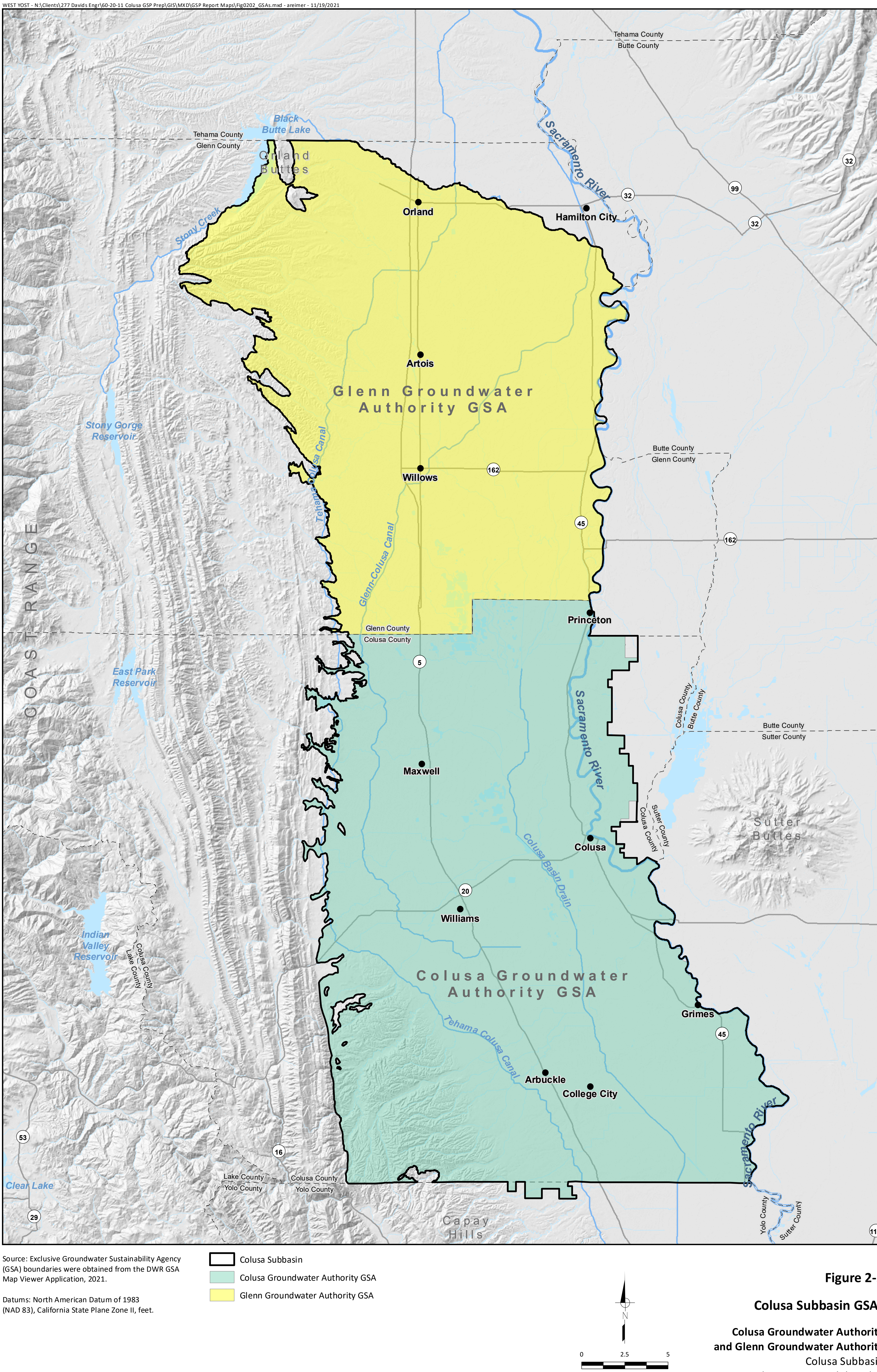
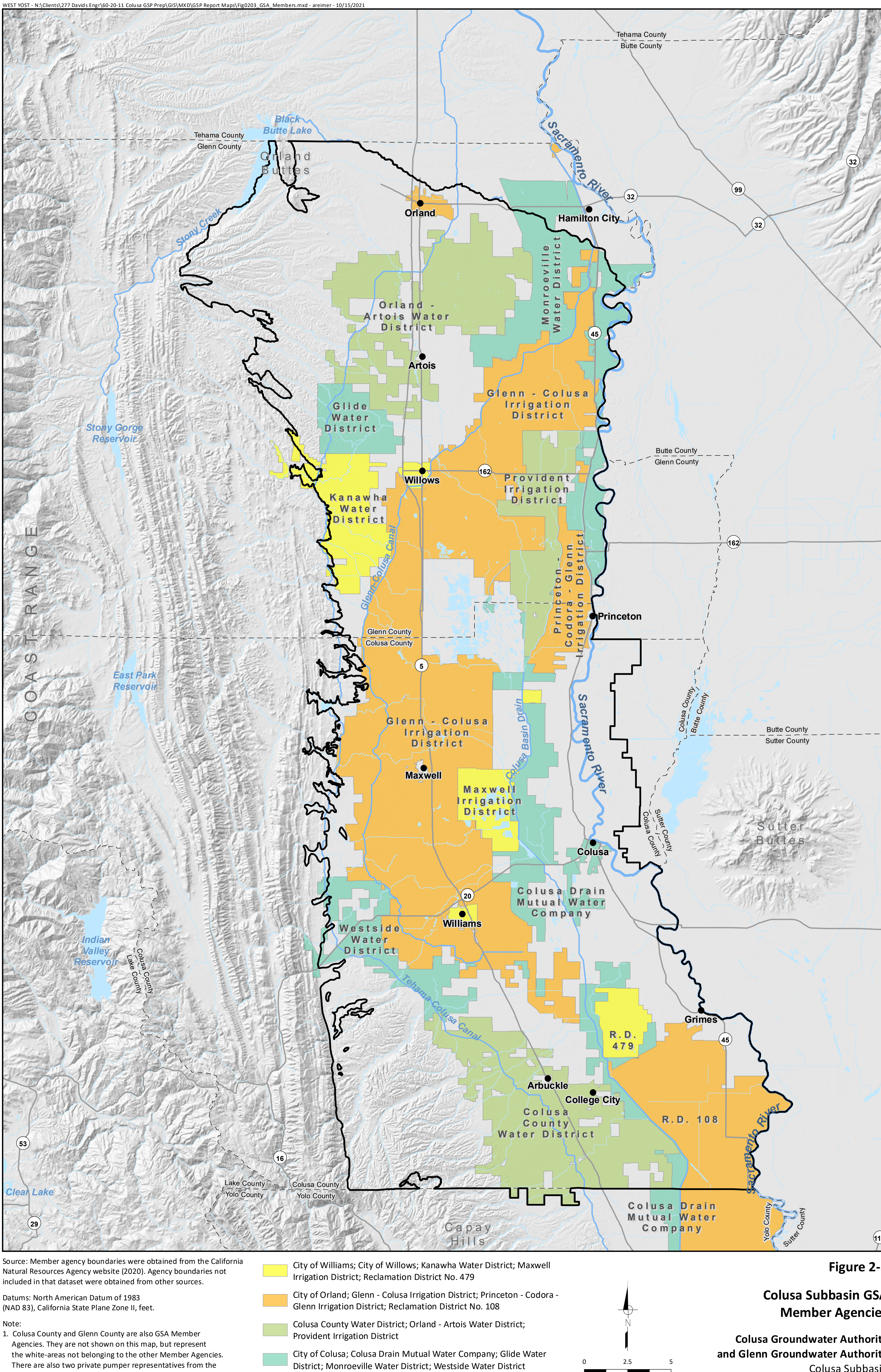


Figure 2-2

Colusa Subbasin GSAs

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan



Source: Member agency boundaries were obtained from the California Natural Resources Agency website (2020). Agency boundaries not included in that dataset were obtained from other sources.

Datums: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Note:
1. Colusa County and Glenn County are also GSA Member Agencies. They are not shown on this map, but represent the white-areas not belonging to the other Member Agencies. There are also two private pumper representatives from the Colusa County Groundwater Commission on the CGA Board.
2. Where service areas overlap, only one agency is shown.

Figure 2-3

Colusa Subbasin GSA Member Agencies

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

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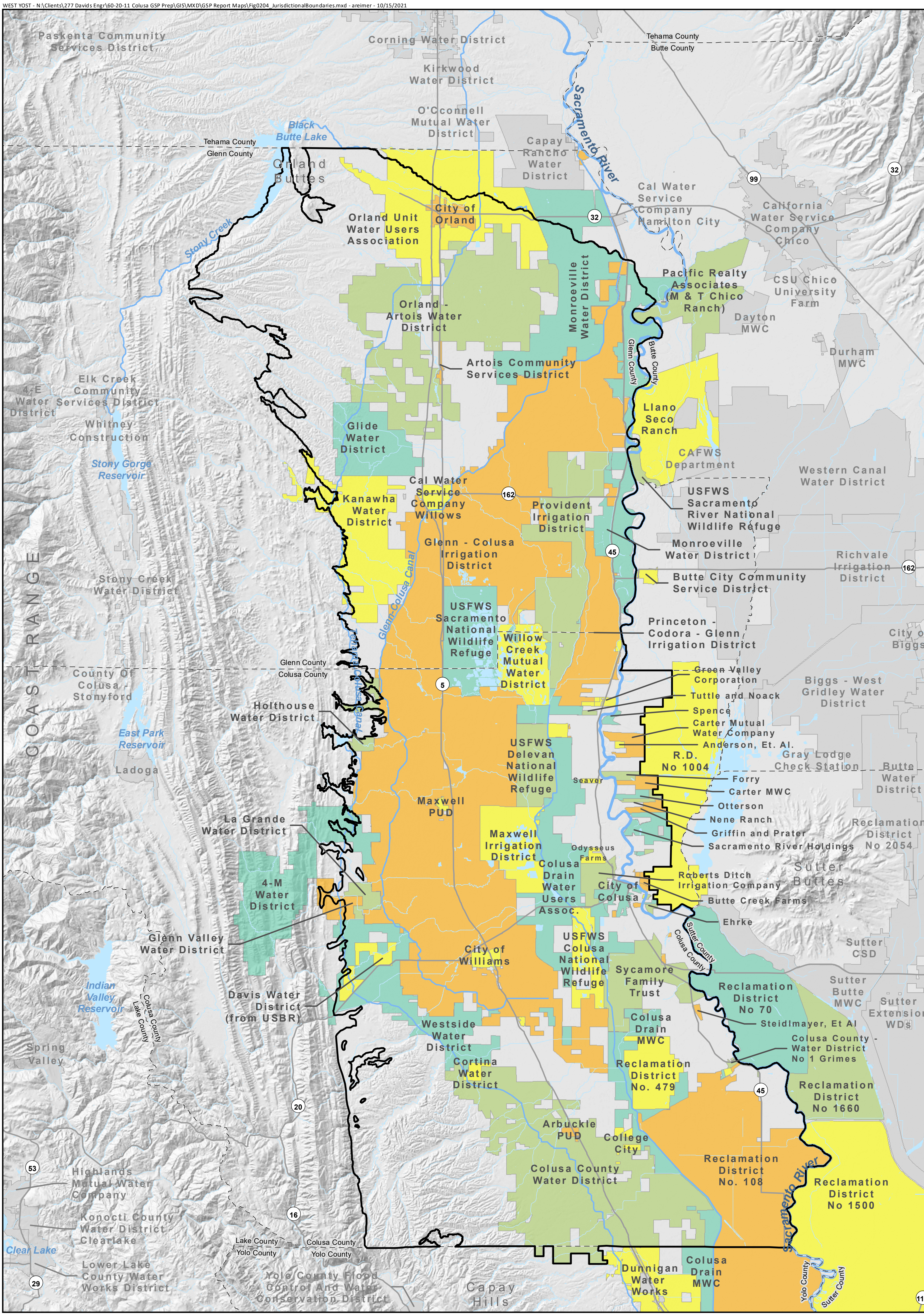


Source: Member agency boundaries were obtained from the California Natural Resources Agency website (2020). Agency boundaries not included in that dataset were obtained from other sources.

Datums: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Note:
1. Where service areas overlap, only one agency is shown.
2. Butte County is listed as water district in the CNRA file. Butte County, like Colusa or Glenn County, is not shown as a distinct water district on this map.
3. Small water services agencies are not labeled on this map.

Colusa Subbasin

Water Agencies not Within or Adjacent to the Colusa Subbasin

Water Agencies Within or Adjacent to the Colusa Subbasin are Displayed in the Colors Shown Below and Labelled in the Map

N

0 2.5 5

Scale in Miles

Figure 2-4

Water Districts and Jurisdictional Boundaries

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin Groundwater Sustainability Plan

Table 2-2. Municipal Water Purveyors within the Colusa Subbasin

County	Colusa Subbasin Water Purveyor	GSA Member Agency		Service Area Population	No. Connections	No. Wells	Annual Volume Served
		CGA	GGA				
Colusa	City of Colusa	X		5,698	2,126	5	1675 af
Colusa	City of Williams	X		5,287	2,100	3	1039 af
Colusa	Arbuckle Public Utility District			2,300	794	4	
Colusa	Del Oro Water Company Arbuckle District			188	55	2	48 af[(a)]
Colusa	Colusa County Waterworks District #1 - Grimes			381	123	1	3.5 af
Colusa	Colusa County Waterworks District #2 - Princeton			303	125	2	
Colusa	Maxwell Public Utility District			1,294	392	3	242 af
Glenn	City of Orland		X	7,501	2,315	6	2504 af
Glenn	City of Willows/Cal Water Willows District		X	7,118	2,371	7	1044 af
Glenn	Del Oro Water Company Black Butte District			284	85	1	46 af[(a)]
Glenn	Artois Community Services District			198	53	2	75 af[(b)]

(a) Average annual acre-feet (af) from 2016-2020
(b) Public Water System Annually Reported Water Production and Deliver Information - 2016 average annual

City of Colusa, Colusa County

The City of Colusa provides domestic water for residential, commercial, and industrial uses within the City limits. The City obtains water from five groundwater wells that are 200 feet or more in depth. Based on the 2007 General Plan Update Master Environmental Impact Report, there were 2,126 service connections and a population of approximately 5,698. Of the service connections, 1,914 are residential land uses, 195 commercial uses, and the remainder are industrial and other uses. In 2006, the annual production for all five wells was approximately 545.8 million gallons (mg) or 1,675 acre-feet (af).

City of Williams, Colusa County

The City of Williams provides domestic water for residential, commercial, and industrial uses within the City limits. According to the 2012 General Plan, there were approximately 2,100 service connections serving an estimated population of 5,287. Water is supplied by three active and two standby groundwater wells, pumping a total of approximately 2,800 gpm. The wells are approximately 120 to 500 feet deep. The average annual water flow is about 400,000 gallons per day up to 1.2 to 1.5 mg on a peak day; the month of July is historically the peak month with approximately 36.5 mg or 1,039 af pumped in 2016.

City of Orland Water System, Glenn County

The City of Orland's primary water system consists of six wells distributed throughout the City. The wells have an average depth of approximately 200 feet, and the average depth to groundwater is generally between 20 and 50 feet. The wells produce between approximately 500 and 1,200 gpm each. The water transmission and distribution systems consist of approximately 30 miles of pipeline for a population of 7,501 residents and 2,315 service connections.

City of Willows/Cal Water Willows District, Glenn County

Domestic water service in the City of Willows, and the adjacent unincorporated area, is provided by the California Water Service Company (Cal Water), Willows District (District). The District operates seven groundwater wells, two storage tanks, and 36 miles of pipeline. From 2010 to 2015, the District delivered an average of 1.2 mg of water per day to more than 2,342 service connections. The 2015 Urban Water Management Plan prepared by Cal Water, contains many of the elements required by SGMA and thus already serves as a road map toward the implementation of SGMA for the District. Some of these components include actions to develop additional water supplies to maintain supply reliability, water quality, and recycled water.

The City of Willows Water Department owns and operates a small water system just south of the District boundaries, south of Road 53, which consists of one well and three service connections.

Agriculture Water Purveyors

Table 2-3 summarizes the main agricultural water purveyors in the Subbasin, excluding smaller Central Valley Project (CVP) contractors and diverters with service areas less than 1,000 acres.

National Wildlife Refuges

There are three National Wildlife Refuges within the Subbasin, the Sacramento National Wildlife Refuge, Delevan National Wildlife Refuge, and Colusa National Wildlife Refuge. These three refuges along with the Sutter Refuge, Sacramento River Refuge, and three wildlife management areas comprise the Sacramento National Wildlife Refuge Complex. Figure 2-4 shows the locations of the refuges.

The Sacramento National Wildlife Refuge is 10,819 acres and is comprised of 7,086 acres of managed wetlands and 3,360 acres of unmanaged wetlands, grasslands, alkali meadow, vernal pools and riparian habitats.

The Delevan Refuge consists of 5,877 acres and is comprised of approximately 4,600 acres of managed wetlands and approximately 984 acres of unmanaged wetlands, grasslands, alkali meadows, vernal pools, and riparian habitats.

The Colusa Refuge consists of over 4,686 acres. It is comprised of approximately 3,347 acres of managed wetlands and 1,191 acres of unmanaged wetlands, grasslands, alkali meadows, vernal pools, and riparian habitats. The Refuge is bisected by the Colusa Basin Drain, which drains the Subbasin southeast to the Sacramento River.

A Comprehensive Conservation Plan (CCP) guides the management of the Refuges and includes a variety management tools, including Water Management Plans. The recurring five-year Water Management Plan updates document water use, identify water supply system needs, and outline steps required to improve both efficiency and quantity of water used. The preparation of these plans is a requirement of the Central Valley Project Improvement Act, which requires the U.S. Bureau of Reclamation (USBR) to purchase and deliver water to these Refuges.

Table 2-3. Agricultural and Other Water Purveyors within the Colusa Subbasin

County	Water Purveyor	GSA Member Agency		Service Area Size, acres[(a)]	Primary Water Source	Annual Surface Water Supply Volume, af[(b)]	Supply Volume Description
		CGA	GGA				
Agricultural Water Purveyor[(c)]							
Colusa/Glenn	Glenn-Colusa Irrigation District	X	X	160,000	SW	704,100	Average annual supplies under all rights and contracts, 2003 to 2012 (2012 WMP)
Colusa	Reclamation District No. 108	X		59,000	SW	155,000	Average annual supplies under all rights and contracts, 2003 to 2012 (2012 WMP)
Colusa	Colusa County Water District	X		46,000	SW	51,000	Average annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
Colusa	Colusa Drain Mutual Water Company	X		37,000	SW	variable	Surface water supply available to the CDMWC consists solely of the Colusa Drain and its tributaries; depends on return flow or drainage water from other districts.
Colusa	4-M Water District			18,000	SW	1,900	Average annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
Colusa/Glenn	Provident Irrigation District	X	X	17,000	SW	67,800	Average annual supplies under all rights and contracts, 2003 to 2012 (2012 WMP)
Colusa/Glenn	Princeton-Codora-Glenn Irrigation District	X	X	11,000	SW	68,200	Average annual supplies under all rights and contracts, 2003 to 2012 (2012 WMP)
Colusa	Westside Water District	X		15,000	SW	29,000	Average annual supplies under all rights and contracts, 2001 to 2010 (2010 WMP)
Colusa	Maxwell Irrigation District	X		9,000	SW	7,800	Average annual USBR CVP supplies, 1990 to 2015
Colusa	Sycamore Family Trust			8,000	SW	31,800	Max. CVP Contract Amount (Contract 14-06-200-2146A-R-1)
Colusa	Reclamation District No. 479	X		6,000	SW	drain water	Conveys drain water and relies on the RD 2047 to convey drainage water to the Sacramento River.
Colusa	Carter MWC			2,000	SW	7,100	Max. CVP Contract Amount (Contract 14-06-200-2401A-R-1)
Colusa	Davis Water District			2,000	SW	2,300	Average Annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
Colusa	Glenn Valley Water District			2,000	SW	900	Average annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
Colusa	Holthouse Water District			2,000	SW	1,100	Average annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
Colusa	Roberts Ditch Irrigation Company			2,000	SW	4,400	Max. CVP Contract Amount (Contract 14-06-200-935A-R-1)
Colusa	La Grande Water District			1,000	SW	4,300	Average annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
Colusa	Cortina Water District			< 1,000	SW	800	Average annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
Colusa/Glenn	Willow Creek Mutual Water Company			8,000	SW	2,500	Typical average diversions in years when water is available, 2010-2020 (eWRIMS A028238)
Glenn	Monroeville Water District		X	37,000	GW	N/A	Formed and approved in 2016 as a water district representing groundwater users
Glenn	Orland-Artois Water District		X	30,000	SW	53,000	Max. CVP Contract Amount (Contract 14-06-200-8382A)
Glenn	Orland Unit Water Users Association			27,000	SW	88,000	Average annual diversions, 2002-2016 (2017 AWMP)
Glenn	Kanawha Water District		X	17,000	SW	26,000	Average annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
Glenn	Glide Water District		X	10,000	SW	11,400	Average annual USBR CVP deliveries from Tehama-Colusa Canal, 1990 to 2015
National Wildlife Refuges							
Colusa/Glenn	USFWS Sacramento National Wildlife Refuge			11,000	SW	33,000 (50,000)[(d)]	Average annual supplies under all rights and contracts, 1995 to 2004 (2006 WMP) CVPIA Full Level 4 volumes shown in parentheses
Colusa	USFWS Delevan National Wildlife Refuge			6,000	SW	21,000 (30,000)[(d)]	Average annual supplies under all rights and contracts, 1995 to 2004 (2006 WMP) CVPIA Full Level 4 volumes shown in parentheses
Colusa	USFWS Colusa National Wildlife Refuge			4,000	SW	19,000 (25,000)[(d)]	Average annual supplies under all rights and contracts, 1995 to 2004 (2006 WMP) CVPIA Full Level 4 volumes shown in parentheses

(a) Area from water district shapefiles, rounded to 1,000 acres.
(b) Volume rounded to 100 acre-feet (af). Average annual, typical annual, or maximum contract annual volume (see description).
(c) Main agricultural water purveyors in the Colusa Subbasin, excluding most smaller purveyors and diverters with service areas of less than 1,000 acres and smaller purveyors and diverters without publicly available information.
(d) Annual Full Level 4 water supplies during unconstrained conditions are shown in parentheses. During constrained conditions, these same refuges generally are provided 75% of this quantity, as stipulated in their water delivery agreements with the U.S. Bureau of Reclamation. CVPIA Full Level 4 supply quantities were not used in the projected water budgets due to the uncertainty in those quantities actually being provided.

GW = Groundwater
SW = Surface water
N/A = Not Available

2.1.2.2 Jurisdictional Boundaries of Other Agencies

There are federal, tribal, and state public lands within the Subbasin, as shown on Figure 2-5.

Federal lands located within the Subbasin include portions of land managed by the Bureau of Land Management and USBR. There are three Wildlife Refuges within the Subbasin managed by the United States Fish and Wildlife Service including the Sacramento National Wildlife Refuge, Delevan National Wildlife Refuge, and Colusa National Wildlife Refuge. These Wildlife Refuges are discussed in preceding sections of this GSP.

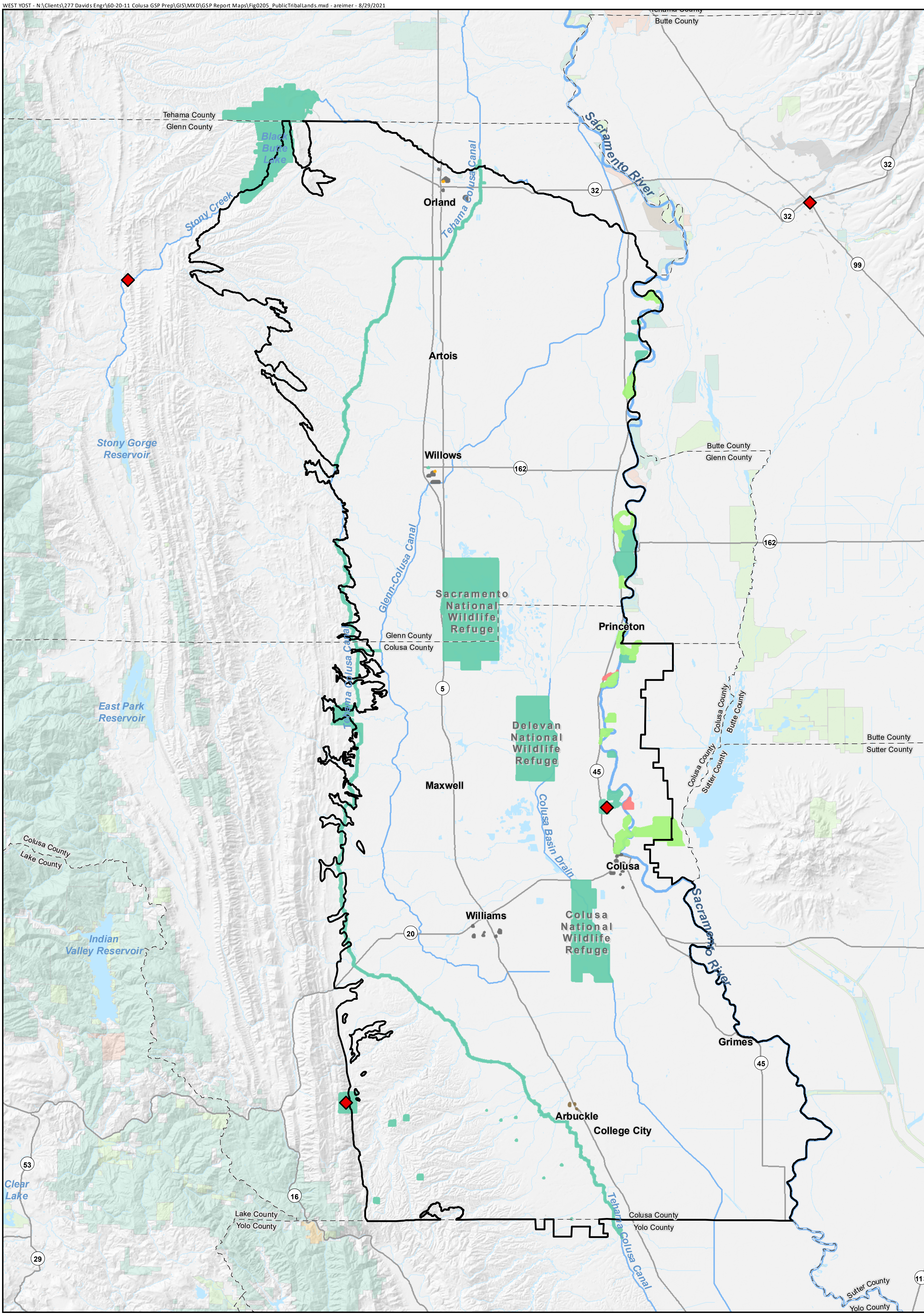
Tribal lands within the Subbasin are owned by the Cachil Dehe Band of Wintun Indians/Colusa Rancheria and the Cortina Indian Rancheria of Wintun Indians Public and Tribal Lands (Figure 2-5).

State lands managed by the California Department of Fish and Wildlife are primarily located along the Sacramento River.

2.1.2.3 Disadvantaged Communities

Many of the communities within the Subbasin are considered either a DAC, a community whose median household income (MHI) is less than 80 percent of the statewide MHI, or an SDAC, a community whose MHI is less than 60 percent of the statewide MHI. Disadvantaged communities are shown on Figure 2-6. The Cities of Orland, Willows, and Colusa, as well as the communities of Artois, Princeton, and Grimes are classified as census place DACs. Most of Subbasin includes rural residential and agricultural properties located within the unincorporated portions of Glenn County and Colusa County. The majority of these areas are identified as DACs or SDACs based on census blocks and census tracts.

Additionally, nearly all of the Subbasin is considered an EDA because it is rural, has a low population density, and has an MHI of less than 85 percent of the statewide MHI. The only area within the Subbasin that is not considered an EDA is the portion of the Subbasin that exists within Yolo County. The entirety of the Subbasin that is within Glenn and Colusa Counties is considered an EDA.



Source: Public and tribal lands were obtained from the State of California Governor's Office of Emergency Services (CalOES) GIS Data Hub, 2020.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Note: Land designations outside of the Colusa Subbasin are faded back.

Tribal Land
Federal Land
State Land
County Land
City Land
Special District
Non Profit Area
Colusa Subbasin

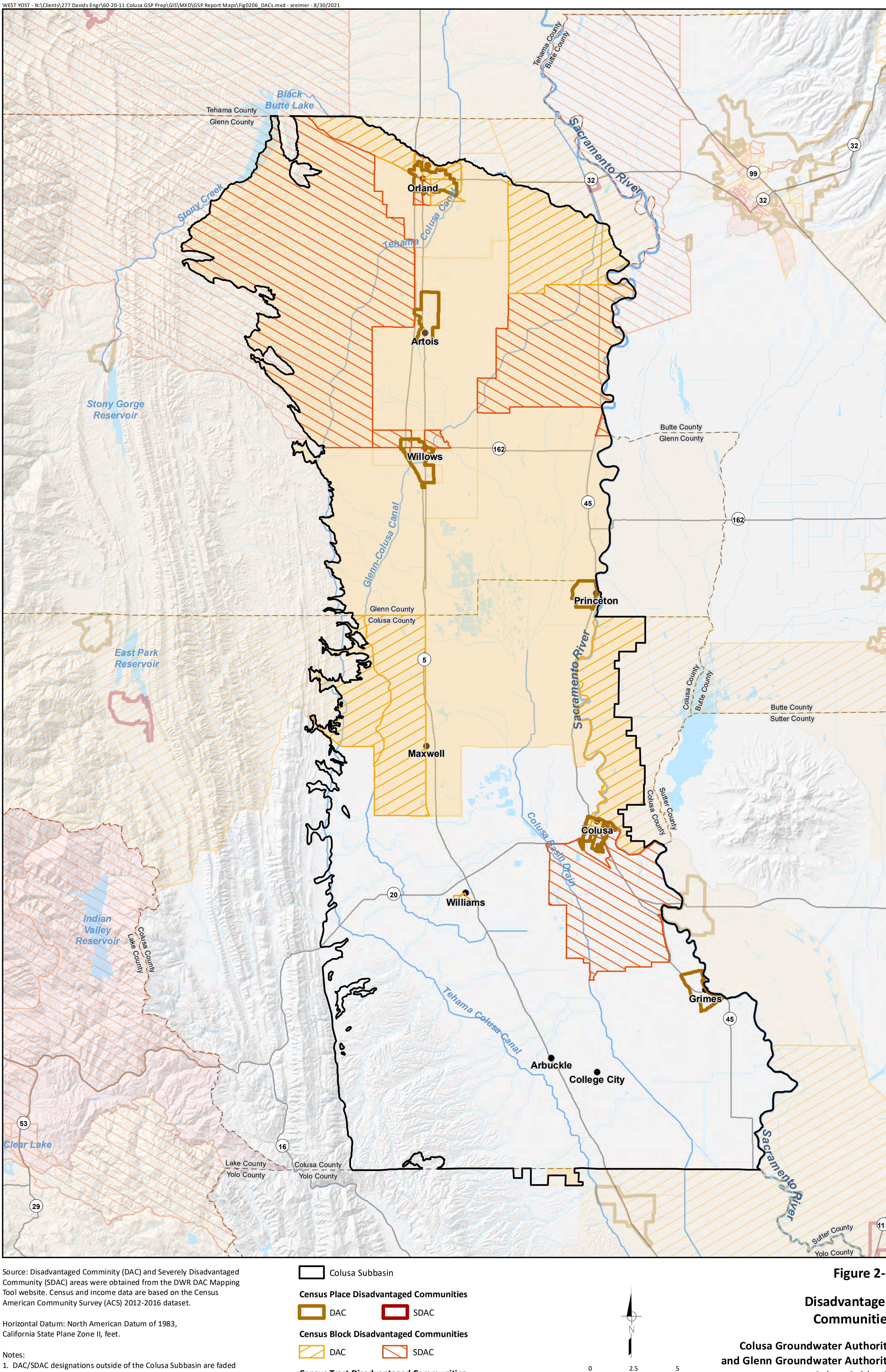
N

0 2.5 5
Scale in Miles

Figure 2-5

Public and Tribal Lands

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan



Source: Disadvantaged Comminity (DAC) and Severely Disadvantaged Community (SDAC) areas were obtained from the DWR DAC Mapping Tool website. Census and income data are based on the Census American Community Survey (ACS) 2012-2016 dataset.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Notes:
1. DAC/SDAC designations outside of the Colusa Subbasin are faded back.
2. All of the Colusa Subbasin except for the small area that falls within Yolo County is categorized as an economically distressed area (EDA).

Figure 2-6

Disadvantaged Communities

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin
Groundwater Sustainability Plan

2.1.2.4 Well Density per Square Mile

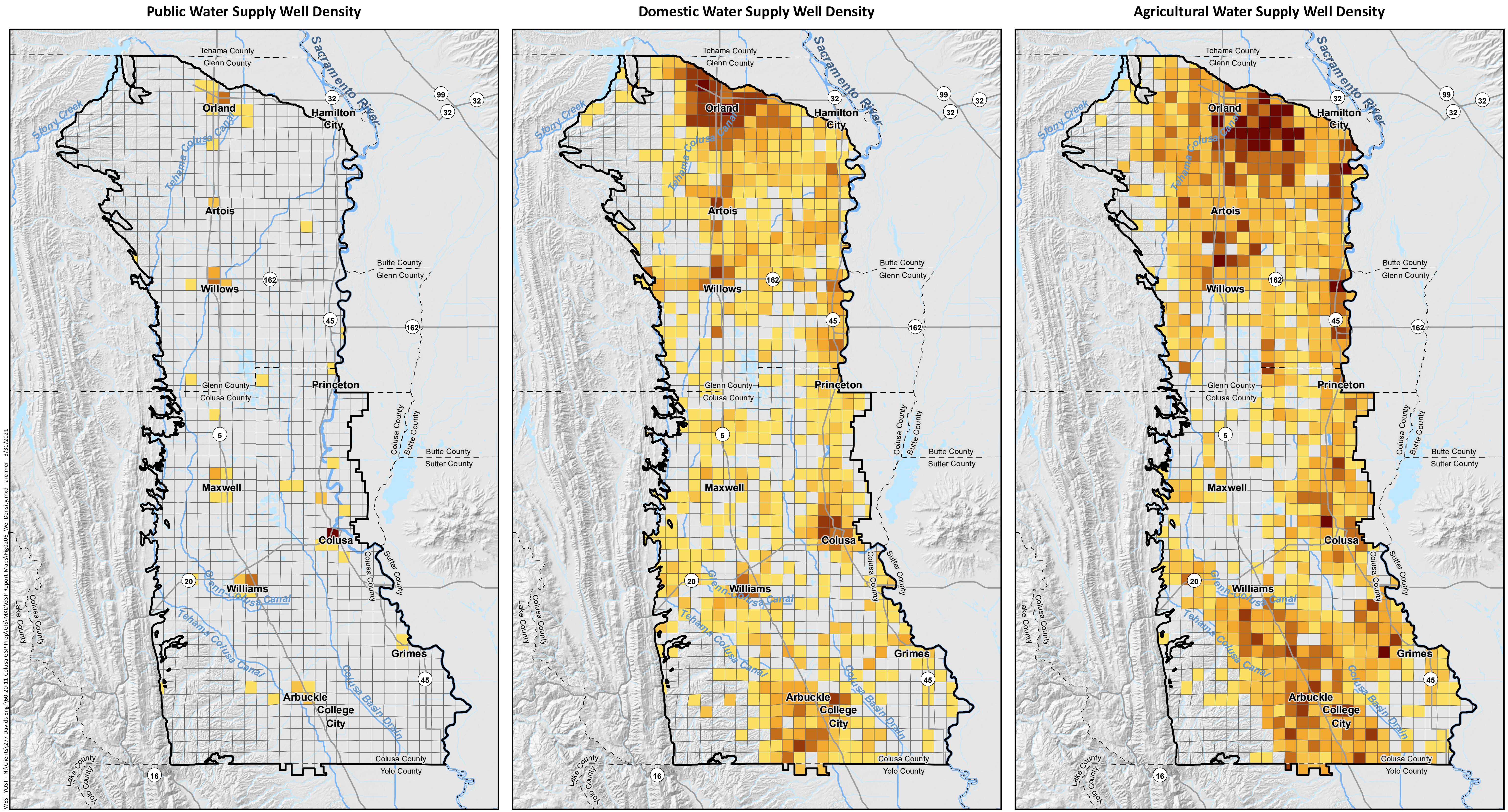
The densities of public water supply, domestic, and agricultural wells per public land survey section within the Subbasin are shown in panels from left to right on Figure 2-7. Each section is approximately one square mile. The number of wells reported by section was determined using data from the California DWR Online System of Well Completion Reports (OSWCR) well completion report (WCR) database provided via the California Open Data Portal (DWR, 2021a). The downloaded dataset only includes wells with WCRs that have been submitted to DWR and is only as accurate as the information provided on the WCRs. Well locations are based on either information provided in the WCRs or are located at the center of their designated public land survey township, range, and section. As such, the well densities shown on Figure 2-6 and reported here are representative of well distribution but may not reflect the actual number of existing or active wells per well use type within the subbasin (i.e., public water supply, domestic, or agricultural well).

Public water supply wells are mostly concentrated in urban areas near cities and towns. Domestic water supply wells are more spread out throughout the Subbasin but occur in higher numbers surrounding urban areas and along the Sacramento River. The densest square mile concentration of domestic wells exceeds 100 wells and occurs near Orland. Agricultural wells are more widespread than public wells and tend to be concentrated outside the urban areas. The densest square mile concentration of agricultural wells exceeds 10 wells, an order of magnitude less than that of domestic wells.

According to the WCR database, there are approximately 73 public supply wells, 3,500 domestic wells, and 2,600 agricultural wells within the Subbasin. Averaged over the entire Subbasin, this is equivalent to approximately 0.06 public supply wells, 3.1 domestic wells, and 2.3 agricultural wells per square mile. Wells not planned for groundwater extraction, based on information provided on the WCRs, or with an unknown or unspecified use designation were not included in this analysis.

2.1.3 Existing Land Use Designations

Land use areas in the Subbasin are broadly classified across three sectors: agricultural, urban, and native vegetation (Figure 2-8). Agricultural land use (and water use) encompasses all agricultural crops reported in the Subbasin. Urban land uses are associated with the cities and communities within the Subbasin and typically include residential, commercial, industrial, public and quasi-public, and semi-agricultural land. Native lands are designated as native lands that are either privately managed or managed by the U.S. Fish and Wildlife Service as wildlife refuges.



Source: Well locations are those included in the Online System for Well Completion Reports (OSWCR) and were obtained from the California Open Data Portal.

Horizontal Datum: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Note:
1. The well database was filtered based on the planned use for each well. The planned use designated in the database may not match what the well is/was actually used for.
2. Wells with unknown use or uses other than water supply were not included in this analysis.

Colusa Subbasin

Public Water Supply Wells per Square Mile

- 0
- 1
- 2
- 3
- 4
- 5
- > 5

Domestic Water Supply Wells per Square Mile

- 0
- 1 - 2
- 3 - 5
- 6 - 10
- 11 - 25
- 26 - 100
- > 100

Agricultural Water Supply Wells per Square Mile

- 0
- 1
- 2 - 3
- 4 - 5
- 6 - 7
- 8 - 10
- > 10

N

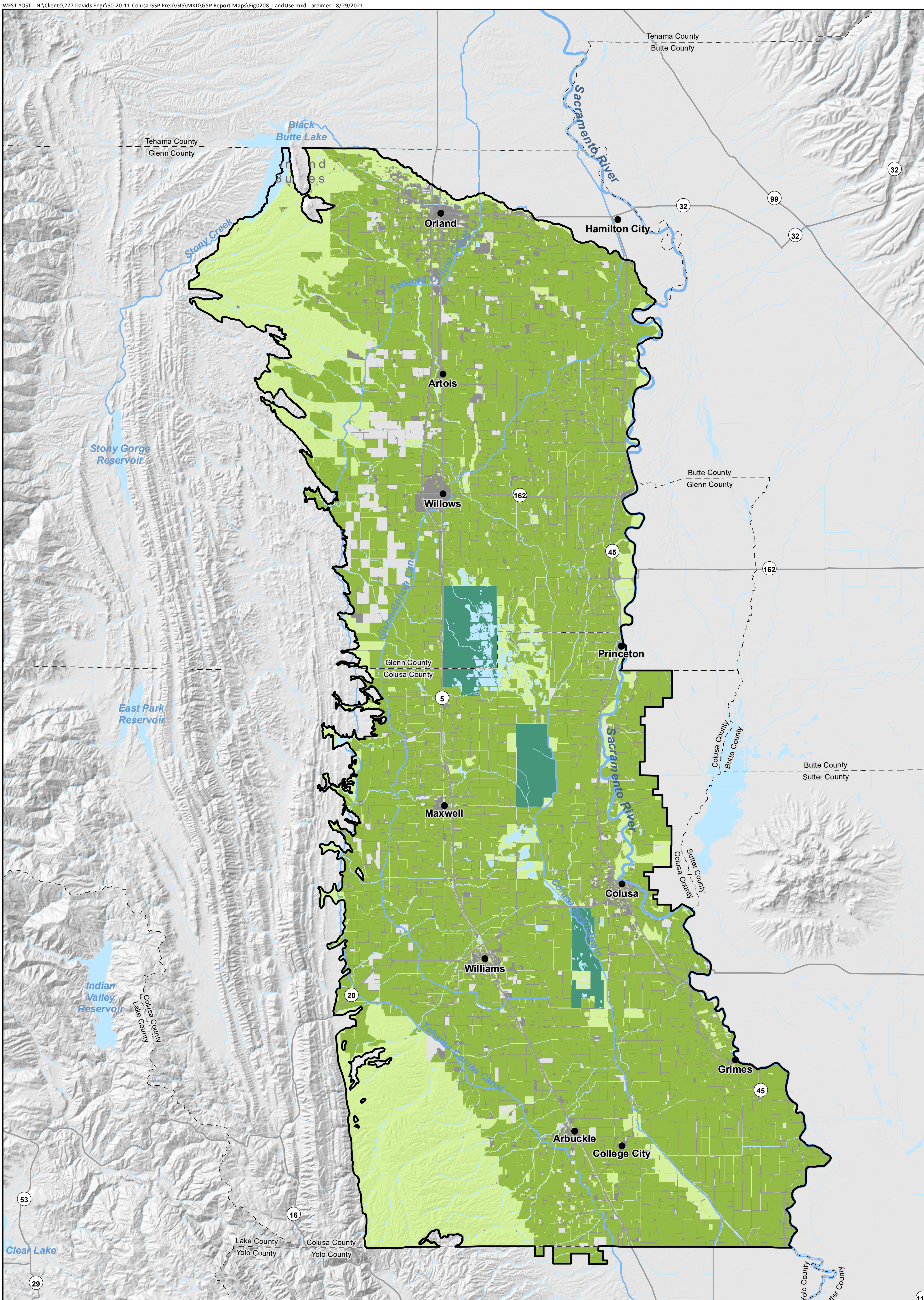
0 4 8
Scale in Miles

Figure 2-7

Density of Wells within the Colusa Subbasin

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin
Groundwater Sustainability Plan



Source: Source: Land uses depicted in this map were surveyed in 2014 for Colusa, Glenn, and Yolo Counties via the Department of Water Resources Land Use Survey.

Datum: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Note:
1. Land use outside of the Colusa Subbasin is not shown on this map.

Colusa Subbasin

Land Use (2014)

- Agriculture
- Native
- Native - Wildlife Refuge
- Urban
- Idle

N

0 2.5 5
Scale in Miles

Figure 2-8

Land Use

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

2.2 WATER RESOURCES MONITORING AND MANAGEMENT PROGRAMS

2.2.1 Monitoring and Management Programs

Existing surface and groundwater monitoring and management programs within the Subbasin are identified below with a summary of water planning documents applicable to the Subbasin GSAs. Existing groundwater, surface water, and land subsidence monitoring locations included in the monitoring and management programs below were considered for incorporation into the Subbasin monitoring networks, as discussed in Chapter 4.

Continued monitoring is required to track the progress of the GSP implementation by providing data on groundwater and surface water availability in the Subbasin. See Chapter 6 for more details of applicable projects that require additional monitoring to fill data gaps. See Chapter 7 for details about proposed GSP studies that will fill those data gaps.

2.2.1.1 Water Planning Documents

The local agencies that formed the Subbasin GSAs have prepared and adopted water planning documents that discuss surface and groundwater supplies, distribution infrastructure, and implementation and monitoring programs.

Development and implementation of this GSP has and will continue to consider the interests of all beneficial uses and users of groundwater, including agricultural water users, municipal water users, DACs, SDACs, groundwater dependent ecosystems (GDEs) and environmental users, tribes, and other stakeholders. Implementation of this GSP will support GSP goals for the protection of DACs, SDACs, natural resources, and GDEs, in coordination with implementation of the plans listed below, consistent with SGMA regulations.

Regional Water Plans

- **Northern Sacramento Valley (NSV) Integrated Regional Water Management Plan (IRWMP) (approved 2014, updated 2020, adopted 2021):** The six counties of Butte, Colusa, Glenn, Shasta, Sutter, and Tehama have been working together to take an integrated approach to water-related issues such as economic health and vitality; water supply reliability; stormwater and flood management; water quality improvements; and ecosystem protection and enhancement. The NSV IRWMP is a collaborative effort to enhance coordination of the water resources in a region. The NSV IRWMP involves multiple agencies, stakeholders, tribes, individuals and groups to address water-related issues and offer solutions which can provide multiple benefits to the region. The NSV IRMWP was adopted by the NSV Board on April 14, 2014 and received final approval from the California DWR on July 24, 2014. The NSV IRWMP was updated in 2019/2020 to comply with new DWR requirements. In March 2020, the NSV Board adopted the Revised Draft NSV IRWMP.

- **Sacramento Valley Regional Water Management Plan (RWMP) (adopted 2006, updated 2012):** The RWMP focuses on four subbasins, including the Colusa Subbasin, and addresses water supply and water use of participating water districts. The RWMP discusses regional water measurement programs; provides analysis of water management quantifiable objectives; and actions to implement and achieve quantifiable objectives. The geographic boundary of the area covered by the Sacramento Valley RWMP and served by the participating Sacramento River Settlement Contractors (SRSC) is the portion of the Sacramento River Basin from Shasta Dam to the Sacramento metropolitan area.
- **Agricultural Water Management Plan (2012) – Participating Sacramento River Settlement Contractors:** The 2012 Sacramento Valley Regional Water Management Plan Annual Update (2012 RWMP Annual Update) was prepared by the SRSC in cooperation with the USBR, in accordance with the Regional Criteria for Evaluating Water Management Plans for the Sacramento River Contractors (Regional Criteria). The Regional Criteria specifies that the participating SRSCs will jointly file an annual update every subsequent year to report on implementation actions taken, along with any additions and revisions to the RWMP.
- **Colusa Basin Watershed Management Plan (2012):** This Watershed Management Plan focuses on the following eight goals as identified by stakeholders and the Technical Advisory Committee (TAC):
    1. Protect, maintain, and improve water quality.
    2. Promote activities to ensure a dependable water supply for current and future needs.
    3. Preserve agricultural land and open space.
    4. Manage and reduce invasive plant populations.
    5. Reduce destructive flooding.
    6. Enhance soil quality and reduce erosion.
    7. Preserve and enhance native habitat.
    8. Address unknown future effects of climate change.

Water Management Plans

- U.S. Fish and Wildlife Service (USFWS) Comprehensive Conservation Plan for the Sacramento, Delevan, Colusa, and Sutter National Wildlife Refuges – Water Management Plans
- Colusa County Water District Water Management Plan (2015)
- Orland-Artois Water District Water Management Plan (2020)

Urban Water Management Plans

- Willows District Urban Water Management Plan (2015)

Groundwater Management Plans

- **Colusa County Groundwater Management Plan (adopted 2008):** The Colusa County Groundwater Management Plan was adopted in 2008. In preparing the Groundwater Management Plan, Colusa County intended that it be applicable countywide and serve the following purposes:
    1. To be responsible stewards of the water resources in Colusa County.
    2. To be eligible for grant funding to increase the understanding of the groundwater basins underlying Colusa County.
    3. To retain local control of water management decisions.

  Colusa County's goals for groundwater management (as developed with input from the public through meetings, workshops, and surveys) are to:
    1. Ensure a Reliable Water Supply
    2. Ensure Long-Term Groundwater Sustainability
    3. Optimize Conjunctive Use of Surface Water and Groundwater
    4. Protect Water Rights
    5. Maintain Local Control
    6. Prevent Unnecessary Restrictions on Groundwater Use
- **Glenn County Groundwater Management Plan (adopted 2000, revised 2012):** The Glenn County Groundwater Management Plan was adopted in 2000 (Ordinance No. 1115), and later revised in 2012 (Ordinance No. 1237) with an aim to protect the County's groundwater resource. Incorporation of the Preliminary Plan and the Export Water Transfer Guidelines in Ordinance No. 1237 was especially important for this goal. The Glenn County Groundwater Management Plan uses the Basin Management Objective (BMO) of Groundwater Basin Management, which encompasses six key elements:
    1. Management Areas and Sub-Areas, which groups groundwater users together who have the same vested interest in maintaining the groundwater resource at mutually agreeable levels.
    2. BMO Parameters requires management objectives for minimum groundwater levels.
    3. Public input is provided through the Glenn County Water Advisory Committee.
    4. Establishing a groundwater quality monitoring network.
    5. Adaptive management to resolve non-compliance with management objectives.
    6. Enforcement and conflict resolution when a BMO threshold is exceeded.

Drought Management Plans

- **Sacramento River Settlement Contractors Drought Management Plan (2016):** Water contracts with various entities specify contractual water deliveries be made except during dry periods. During periods of reduced water supplies, deliveries are decreased in accordance with the curtailment terms in the contracts. CVP contractors along the Sacramento River can generally be grouped into two major categories: SRSCs and CVP Water Service Contractors. SRSCs within the Subbasin include Glenn-Colusa Irrigation District, Provident Irrigation District, Princeton-Codora-Glenn Irrigation District, and Reclamation

District 108. CVP Water Service Contractors within the Subbasin include 4-M Water District, Colusa County Water District, Cortina Water District, Davis Water District, Glenn Valley Water District, Glide Water District, Holthouse Water District, Kanawha Water District, La Grande Water District, Myers-Marsh Mutual Water District, Orland-Artois Water District, and Westside Water District.

General Plans (refer to Section 2.3.1)

- Colusa County General Plan
- Glenn County General Plan
- City of Colusa General Plan
- City of Williams General Plan
- City of Orland General Plan
- City of Willows General Plan

Municipal Service Reviews

- The Local Agency Formation Commission (LAFCO) in each County conducts reviews of municipal services provided in a county by region, subregion or other designated geographic area, as appropriate, for the service or services provided by a governing entity. Municipal Service Reviews (MSRs) provide written summaries of the six topics pertaining to service infrastructure:
    1. Growth and population projections for the affected area.
    2. The location and characteristics of any disadvantaged unincorporated communities within or contiguous to the sphere of influence.
    3. Present and planned capacity of public facilities and adequacy of public services, including infrastructure needs or deficiencies.
    4. Financial ability of agencies to provide services.
    5. Status of, and opportunities for shared facilities.
    6. Accountability for community service needs, including governmental structure and operational efficiencies.
- The following GSA member agencies have readily available MSRs:
    1. City of Colusa MSR (Draft 2021)
    2. City of Orland MSR (2014)
    3. City of Willows MSR (2014)
    4. Kanawha / Glide Water District MSR (2020)
    5. Orland-Artois Water District MSR (2019)

2.2.1.2 Surface Water Monitoring and Management Programs

Surface water flows into and within the Subbasin are monitored through existing federal, state, regional, and local programs. Data and spatial information from these monitoring programs were used to support GSP development, including water budget development, per 23 CCR Section 354.18.

Federal, State, and Regional Programs

Table 2-4 lists the existing surface water monitoring networks with publicly available data and their respective websites.

Table 2-4. Existing Surface Water Monitoring Programs

Surface Water Monitoring Network	Responsible Agency	Surface Water Monitoring Type	Website
National Water Information System (NWIS)	U.S. Geological Survey (USGS)	Discharge	https://waterdata.usgs.gov/nwis
Water Data Library (WDL)	California Department of Water Resources (DWR)	Discharge	http://wdl.water.ca.gov/waterdatalibrary/
California Data Exchange Center (CDEC)	California DWR and U.S. Bureau of Reclamation	Discharge; Reservoir Conditions	http://cdec.water.ca.gov/cdecstation2/ https://www.usbr.gov/

Local Programs

Local monitoring programs in the Subbasin include:

- Colusa County Water District's Supervisory Control and Data Acquisition (SCADA) system, which is used to automate and measure incoming flows to the distribution system from canal side pumping facilities (2010 Water Management Plan [WMP]).
- Colusa County Water District's use of SonTek, McCrometer, and Venturi flow meter devices to measure and record inflows.
- GCID's diversion metering and publicly-available online reporting system, in compliance with SB 88 (https://www.gcid.net/sb88compliance).
- GCID's main canal SCADA and automation project (https://www.gcid.net/operations-main-canal).
- GCID's drain outflow monitoring project, with water measurement and telemetry equipment at key outflow sites (https://www.gcid.net/operations-drain-outflow).
- Orland-Artois Water District's (OAWD) distribution system metering and SCADA system (2020 WMP), including:
  - Metered inflows using Venturi meters and Doppler meters across five locations.
  - SCADA system used for monitoring and operating pumps.

- Orland Unit Water Users Association's (OUWUA) SCADA system, which has been expanded and enhanced in recent years to include more than 10 additional sites and additional outflow monitoring capabilities (2017 Agricultural Water Management Plan [AWMP]).
- OUWUA's use of Rubicon FlumeGates, SonTek acoustic Doppler meters, propeller meters, and McCrometer magnetic flow meters (among other) to measure and record deliveries (2017 WMP).
- OUWUA's records of grower deliveries in its water orders database (2017 WMP).
- Westside Water District's Tehama-Colusa Canal delivery monitoring system, including McCrometer propellers and SonTek meters installed at canal mileposts 71.46 through 90.00 (2010 WMP).
- RD108's SCADA system used to measure incoming flows.
- RD108's delivery measurement system and water accounting database.

Efficient Water Management Practices

Water conservation and water use efficiency are important considerations in achieving groundwater sustainability. Efficient water management practices (EWMPs), as defined in CWC §10902, include all reasonable and economically justifiable programs to improve the delivery and use of water used for agricultural purposes. Broad efforts to improve water use efficiency in areas across the Subbasin are identified in the General Plans of counties and cities that overlie the Subbasin.

For agricultural water suppliers that must develop, adopt, and implement AWMPs, CWC §10608.48 identifies key EWMPs that suppliers must implement, some without exception and some if locally cost-effective and technically feasible. Non-exempted agricultural water suppliers throughout the Subbasin have adopted and are currently implementing AWMPs. Information on specific activities, programs, and efforts to implement key EWMPs can be found in those AWMPs.

For CVP contractors that must develop, adopt, and implement WMPs, implementation of key Best Management Practices (BMPs) is also described throughout their WMPs. These BMPs generally align with EWMPs described in the AWMPs and are aimed at improving water use efficiency. CVP contractors throughout the Subbasin are actively implementing WMPs. Information on specific activities, programs, and efforts to implement key BMPs can be found in those WMPs.

Irrigated Lands Regulatory Program

The Central Valley Regional Water Quality Control Board (CVRWQB) has adopted waste discharge requirements (WDRs) for discharges from irrigated commercial croplands to protect both surface water and groundwater supplies. When land is in agricultural production it is generally irrigated and fertilized. It is assumed that portions of the soil amendments, particularly fertilizer, are converted to nitrate, which has the potential to percolate into the groundwater. The Irrigated Lands Regulatory Program (ILRP) regulates such discharges. Growers can manage the loading of nitrate to groundwater through the implementation of effective management practices. Commercial irrigated lands, including managed wetlands, are required to obtain regulatory coverage.

2.2.1.3 Groundwater Monitoring and Management Programs

Both Counties currently have wells included in California's Statewide Groundwater Elevation Monitoring Program (CASGEM) program. Glenn County also has a Basin Management Objective groundwater level monitoring well network. Colusa County's current groundwater monitoring network consists of wells originally identified in its Groundwater Management Plan (GMP) but has since been revised. These and other existing groundwater monitoring programs are described in more detail in the following sections. Proposed new groundwater monitoring sites were evaluated based on existing sites from DWR and USGS groundwater monitoring networks, and recommendations from County staff.

Groundwater Level Monitoring

Table 2-5 lists existing groundwater level monitoring programs with publicly available data and their respective websites.

Table 2-5. Existing Groundwater Level Monitoring Programs

Groundwater Monitoring Network	Responsible Agency	Website
National Water Information System (NWIS)	U.S. Geological Survey (USGS)	https://waterdata.usgs.gov/nwis
Water Data Library (WDL)	California Department of Water Resources (DWR)	http://wdl.water.ca.gov/waterdatalibrary/
California's Statewide Groundwater Elevation Monitoring Program (CASGEM)	California DWR	https://www.casgem.water.ca.gov/ Note: site requires a username and password
County-Specific Groundwater Level Monitoring Programs	County of Colusa and County of Glenn	Colusa County: http://countyofcolusa.org/index.aspx?NID=660 Glenn County: http://www.countyofglenn.net/committee/water-advisory-committee/management-plan

Groundwater Extraction Monitoring

The replenishment of groundwater extractions occurs through various forms of recharge. The types and amounts of historical and current recharge are described in detail in Section 3.3 (Water Budget Information), and future estimates of recharge are discussed in Chapter 3 and detailed in Appendix 3D (Groundwater Model Documentation). Future replenishment of groundwater extractions that will occur with implementation of projects and management actions (PMAs) for this GSP are described in detail in Chapter 6.

Groundwater Quality Monitoring

Table 2-6 lists the groundwater quality monitoring networks with publicly available data and their respective websites.

Violations of drinking water quality regulations, which could impact access to clean drinking water and violate California Water Code Section 106.3, are included in the U.S. Environmental Protection Agency (USEPA) Safe Drinking Water Information System (SDWIS) website, which is listed in Table 2-6.

Table 2-6. Existing Groundwater Quality Monitoring Programs

Groundwater Monitoring Network	Responsible Agency	Website
National Water Information System (NWIS)	U.S. Geological Survey (USGS)	https://waterdata.usgs.gov/nwis
Water Data Library (WDL)	California Department of Water Resources (DWR)	http://wdl.water.ca.gov/waterdatalibrary/
Public Water Agencies and Municipalities	State Water Resources Control Board (SWRCB) Division of Drinking Water (DDW) and U.S. Environmental Protection Agency (USEPA)	https://data.ca.gov/dataset/drinking-water-public-water-system-information , https://sdwis.waterboards.ca.gov/PDWW/ , https://www.epa.gov/enviro/sdwis-search
GeoTracker and GeoTracker Groundwater Ambient Monitoring and Assessment (GAMA) Programs	SWRCB	http://geotracker.waterboards.ca.gov/ , http://geotracker.waterboards.ca.gov/gama/
Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS)	Central Valley Salinity Coalition	https://www.waterboards.ca.gov/centralvalley/water_issues/salinity/ [(a)]
Irrigated Lands Regulatory Program (ILRP)	Central Valley Regional Water Quality Control Board	https://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/ , Surface Water: http://ceden.waterboards.ca.gov/AdvancedQueryTool Groundwater: Not available online[(a, b)]
Glenn County Annual Water Quality Sampling Program	County of Glenn	http://www.countyofglenn.net/committee/water-advisory-committee/water-quality[(a)]

(a) Groundwater quality data are not available online. Groundwater quality monitoring data as part of these monitoring programs should be obtained directly from the responsible agencies.

(b) Some groundwater quality data collected under ILRP by the California Rice Commission and the Sacramento Valley Water Quality Coalition is available through the GeoTracker GAMA and USGS NWIS websites. The full groundwater quality dataset should be obtained directly from the responsible coalition.

Land Subsidence Monitoring

Table 2-7 lists the existing land subsidence monitoring networks and data sets with publicly available data, and their respective websites.

Table 2-7. Existing Land Subsidence Monitoring Programs

Subsidence Monitoring Network	Responsible Agency	Website
Interferometric Synthetic Aperture Radar (InSAR) Surveys[a]	European Space Agency; Japanese Space Exploration Agency; Italian Space Agency; Canadian Space Agency; German Aerospace Center; National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL)	http://www.esa.int/ESA , http://global.jaxa.jp/ , http://www.asi.it/en , http://www.asc-csa.gc.ca/eng/ , http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10002/ , https://data.cnra.ca.gov/dataset/nasa-jpl-insar-subsidence
Continuous Global Positioning System (GPS) Benchmarks	National Geodetic Survey; University NAVSTAR Consortium (UNAVCO); Berkeley Seismological Laboratory	https://www.ngs.noaa.gov/NGSDataExplorer/# , http://www.unavco.org/data/data.html , http://seismo.berkeley.edu/networks/index.html
Extensometers	California Department of Water Resources (DWR)	http://wdl.water.ca.gov/groundwater/landsubsidence/LSmonitoring.cfm
Sacramento Valley Height-Modernization Project	California DWR Northern District and U.S. Bureau of Reclamation	Not Available[b]

(a) The InSAR sources currently house unprocessed raw survey data but not interpretative reports for specific regions. Some of the reports using InSAR to study subsidence specific to California can be found on DWR's website

(b) Sacramento Valley Height-Modernization project data are not available online.

2.2.2 Impacts to Operational Flexibility

There are existing groundwater management and/or monitoring programs that may limit the operational flexibility during implementation of the GSP, including design criteria, flood control programs, measures that limit groundwater pumping, or limitations on surface water deliveries reducing surface water supplies available for conjunctive use programs. Ongoing coordination with the entities responsible for these programs will support operational flexibility. Ongoing coordination with the entities responsible for the surface water and groundwater monitoring programs described above will support GSP implementation.

2.2.3 Groundwater Ordinances

Colusa County Code, Chapter 43, Groundwater Management, provides guidance for groundwater transfers and groundwater substitution practices to assure the overall economy and environment of the County is protected by fostering prudent water management practices.

Glenn County Code Section 20.030, Groundwater Coordinated Resource Management Plan, provides guidance for the continued availability of groundwater by limiting the extraction of groundwater through groundwater monitoring, protecting groundwater quality, and minimizing land subsidence. In addition, Section 20.080 provides well drilling requirements prior to the drilling or abandonment of a well, and Exhibit C contains export water transfer guidelines.

2.2.4 Conjunctive Use Programs

Surface water and groundwater are used conjunctively throughout the Subbasin to meet water management objectives. Generally, within each agricultural water purveyor's service area, available surface water is used on a preferential basis to satisfy crop water requirements, with groundwater pumped by private landowners as needed to supplement available surface water supplies. The amount of groundwater pumped in any given year depends primarily on the crop water requirements (which vary by the crop types planted each year and weather conditions), and on the quantity of surface water available during that year.

For the agricultural water purveyors with highly reliable and adequate surface water supplies, including the SRSCs, private groundwater pumping is generally small compared to surface water use, except in years when their surface water supplies are reduced according to settlement contract terms, and in years when surface water is transferred (both within and outside the Subbasin), and groundwater is pumped to substitute for transferred surface water.

The CVP Water Service Contractors along the Tehama Colusa Canal have federal contracts that provide less reliable surface water supplies, which can vary from zero to 100 percent of their maximum contract quantities and is dependent on annual CVP water allocation decisions made by USBR. Consequently, groundwater pumping is highly variable depending on each year's water allocation and, to a lesser extent, variability in crop water demands.

Conjunctive use also occurs across purveyor boundaries involving transfers of temporarily available excess surface water from some agricultural water purveyors to others who desire to use more surface water to conserve groundwater supplies. In some years, surface water transfers occur from entities outside the Subbasin to Subbasin purveyors, also reducing the amount of groundwater pumping.

Colusa County Code, Chapter 43, Groundwater Management, encourages the conjunctive use of surface water and groundwater supplies.

2.3 LAND USE ELEMENTS OR TOPIC CATEGORIES OF APPLICABLE GENERAL PLANS

This section provides information on the general plans within the Subbasin.

2.3.1 Summary of General Plans/Other Land Use Plans

California Government Code (§65350-65362) requires that each county and city in the state develop and adopt a General Plan. The General Plan is a comprehensive long-term plan for the physical development of the county or city and must contain eight state-mandated elements including: land use, housing, circulation, conservation, noise, safety, open space, and environmental justice. The General Plan may also contain other voluntary elements.

General Plans and information from other land use planning activities were compiled for review and consideration during GSP preparation and for coordination during GSP implementation. This section includes a summary of those plans being implemented in the Subbasin.

Two counties and four cities share land use planning responsibilities and authorities for the Subbasin. These include:

- Colusa County
- Glenn County
- City of Colusa
- City of Williams
- City of Orland
- City of Willows

Most of the General Plans prepared by these entities contain goals, objectives, and policies relating to water supplies, water use, water quality, and water resources. Land use designations, assumptions on growth, preservation of agricultural lands, or protection of environmental resources are examples of land use planning that could result in changes in water use over the planning horizon.

As part of the GSP preparation, General Plans for Colusa and Glenn Counties and the cities of Colusa, Williams, Orland, and Willows were reviewed. City and County boundaries are shown in Figure 2-1.

There are no other land use plans applicable within the Subbasin.

2.3.1.1 Colusa County General Plan

In July 2012, Colusa County adopted its 2012 Comprehensive General Plan Update (Colusa County, 2012). The General Plan area covers the entire County, which overlies the Colusa County portion of the Subbasin, as shown in Figure 2-1. Although the protection of natural resources in the County is addressed throughout the General Plan, key goals with respect to water resources are contained in the Agriculture Element and Conservation Element. Table 1 of Appendix 2A identifies the selected Colusa County General Plan Goals and Policies applicable to water resources management.

2.3.1.2 Glenn County General Plan

Glenn County's current General Plan was last updated in 1993, and thus is undergoing a comprehensive update. It is anticipated that the General Plan Update will take place from 2019 through the fall of 2021. The General Plan area covers the entire County, which overlies the Glenn County portion of the Subbasin, as shown in Figure 2-2. The General Plan goals, policies, and implementation presented in Table 2 of Appendix 2A are from the 1993 General Plan and are divided into three subject areas: Natural Resources, Public Safety, and Community Development. Table 2 of Appendix 2A identifies the selected Glenn County General Plan Goals, Policies, and Implementation measures applicable to water resources management.

2.3.1.3 City of Colusa General Plan

In October 2007, the City of Colusa adopted its 2005-2025 General Plan Update (City of Colusa, 2007). The General Plan area covers the City of Colusa, which is located adjacent to the Sacramento River in the eastern portion of Colusa County within the Subbasin, as shown in Figure 2-1. Although the protection of natural resources in the City is addressed throughout the General Plan, key goals with respect to water resources are contained in Land Use Element; Community Character and Design Element; Safety Element; the Parks, Recreation and Resource Conservation Element, of which includes water resources; and Municipal Facilities Element. Table 3 of Appendix 2A identifies the selected City of Colusa General Plan Goals, Policies, and Implementation Actions applicable to water resources management.

2.3.1.4 City of Williams General Plan

In May 2012, the City of Williams adopted its 2010 General Plan Update (City of Williams, 2010). The General Plan area covers the City of Williams, which is located in the central portion of Colusa County within the Subbasin, as shown in Figure 2-1. Key goals with respect to water resources are contained throughout the General Plan Elements. Table 4 of Appendix 2A identifies the selected City of Williams General Plan Goals and Policies applicable to water resources management.

2.3.1.5 City of Orland General Plan

The City of Orland is located in the northeast portion of Glenn County within the Subbasin, as shown in Figure 2-1. In 2003, the City of Orland updated its General Plan through a comprehensive review of all elements. Previous to that, minor revisions to the General Plan had been made in 2000, with the original adoption of the Plan in 1974. The 2008-2028 General Plan Update revises the 2003 General Plan, in order to reflect upon changing conditions and issues, and to provide a direction for the future growth of the City. The Orland General Plan is a comprehensive document that provides policies and guidelines for the future expansion and development of the community. The City addresses key goals and policies with respect to water resources within in Safety Element and Open Space, Conservation and Public Facilities Element. Table 5 of Appendix 2A identifies the selected City of Orland General Plan Goals, Policies, and Programs applicable to water resources management.

2.3.1.6 City of Willows

The City of Willows is located in the southern portion of Glenn County within the Subbasin, as shown in Figure 2-1. The City of Willows General Plan was adopted in 1999, with land use amendments made in 2000 and 2010. The Willows General Plan provides policies and guidelines for the future expansion and development of the community. The City addresses key goals and policies with respect to water resources. Table 6 of Appendix 2A identifies the selected City of Willows General Plan Goals, Policies, and Programs applicable to water resources management.

2.3.2 Implementation Effects on Water Demands and Sustainability

All six of the county and city General Plans in the Subbasin were adopted prior to the development of the GSAs and this GSP. Consequently, these General Plans have not directly considered the potential implications or impacts of this GSP's implementation on urban water demands or supplies within these jurisdictions. It should be noted that Glenn County is currently preparing a comprehensive General Plan Update and may take into consideration sustainable water actions identified in this GSP.

Each of the General Plan's land use elements and land use plans forecast future land development and make assumptions for future urban and agricultural water demands.

Typically, unincorporated communities depend on community water systems that may rely on either surface or groundwater, or both. Rural residential land uses not part of a community system typically rely on individual groundwater wells. Developed urban land uses, such as that within cities, typically rely on groundwater supplies accessed by municipal wells. Therefore, when cities grow or rural densities increase, generally surface water use decreases and groundwater demand increases. The GSP incorporates actions that encourage land use agencies to participate in efforts to increase groundwater recharge to offset increased water demands. Depending on changing future conditions in the Subbasin, the GSP also incorporates potential demand management actions that could be implemented, if needed, to offset water demands and support groundwater sustainability (see Section 6.5.2).

2.3.2.1 Effects on Colusa County Water Demands

Several goals and policies of the Colusa County General Plan work to balance agricultural land uses with preserving and protecting waters, soils, and natural resources necessary to ensure agricultural operations. Policies support water development projects that provide additional sources of water for agricultural use, yet also encourage the preservation of water resources. In addition, the General Plan requires that new residential development connect to municipal water systems and requires development to demonstrate sufficient water supplies are available. The General Plan encourages conservation of water resources including the conservation of biological communities that protect wetlands, riparian habitat, and aquatic resources and thus contribute to the protection of groundwater resources and water quality. The General Plan includes goals and policies that work to ensure a sustainable and long-term supply of reliable water to meet the needs of residents, businesses, and agricultural land uses. Land use policies provide for the harmonious use of land and the preservation of the County's resources, including water. Lastly, the General Plan encourages local, regional, and state multi-agency planning efforts as well as coordination with water providers to manage water supplies and avoids groundwater overdraft, water quality degradation and other adverse environmental impacts. Refer to Appendix 2A for selected Colusa County General Plan Goals and Policies.

GSP implementation is anticipated to be consistent with the Colusa County General Plan's goals to balance agricultural land uses with the preservation and protection of water resources necessary to ensure agricultural operations. The GSP supports these policies by identifying and considering PMAs that work to reduce groundwater extraction, promote groundwater recharge, and utilize additional surface water for irrigation. Although implementation of the GSP would alter the source of water for irrigation to promote groundwater sustainability, it does not alter water demands.

2.3.2.2 Effects on Glenn County Water Demands

The Glenn County General Plan is undergoing a comprehensive update. However, the existing General Plan does address the protection of water resources in connection with the preservation of agricultural lands and the recognition of the value of agricultural land uses, particularly ricelands for habitat, watershed management, and groundwater recharge. General Plan policies oppose the exportation of groundwater, protect groundwater recharge areas and groundwater quality, encourages water conservation and education, promotes interagency coordination. The General Plan also addresses wetlands, aquatic resources, and riparian habitat protection in conjunction with supporting efforts to improve water availability for agricultural users. Water quality policies include the protection of groundwater to ensure that the holding capacity of the area is not exceeded. The General Plan address coordination between the County and water purveyors including creating uniform policies and standards for providing cost-effective water services, particularly in unincorporated areas located within city urban limits.

Refer to Appendix 2A for selected Glenn County General Plan Goals and Policies applicable to water demand.

GSP implementation is anticipated to be consistent with the Glenn County General Plan's goals to protect water resources and aquatic resource habitat in connection with the preservation of agricultural land uses. The GSP supports these policies by identifying and considering PMAs that reduce groundwater extraction and focuses on using surface water for agricultural irrigation and groundwater recharge. Although implementation of the GSP would alter the source of water for irrigation to promote groundwater sustainability, it does not alter water demands.

2.3.2.3 Effects on City of Colusa Water Demands

The City of Colusa's General Plan Goals and Policies provide for a logical land use planning process that includes adequate management of public services, including water supply. As part of the implementation of the General Plan the City has prepared water and storm drainage master plans to address water quality, supply, recycling, distribution, and water conservation. The General Plan also works to ensure that new development respects the natural environment, protects the City's water resources, and minimizes the development of new water sources and facilities while providing water services. Refer to Appendix 2A for selected City of Colusa General Plan Goals and Policies applicable to water demand and management.

GSP implementation focuses on the protection of groundwater resources and identifies and considers PMAs that focus on surface water use for agricultural irrigation and groundwater recharge. Implementation of the GSP would not conflict with the City's water supply, service, and conservation goals nor would it alter water demands.

2.3.2.4 Effects on City of Williams Water Demands

The City of Williams General Plan identifies policies that pertain to water supply and associated demand in the land use and character, public safety and facilities as well as open space and conservation elements. New development in the City requires that adequate public services, including water supply, is available. In addition, although not specifically related to water demand, the preservation of water related resources, including wetlands, riparian areas, and other aquatic habitats provides for improved water quality of water supply sources, including groundwater. Implementing actions identify the need for groundwater protection measures in subdivisions as well as developing water efficient landscaping standards for new development. Refer to Appendix 2A for selected City of Williams General Plan Goals, Policies, and Implementing Actions that address water demand and management.

GSP implementation focuses on the protection of groundwater resources and identifies and considers PMAs that focus on surface water use for agricultural irrigation and groundwater recharge. Implementation of the GSP would not conflict with the City's water quality, aquatic resources, and water conservation goals nor would it alter water demands.

2.3.2.5 Effects on City of Orland Water Demands

The City of Orland General Plan Safety Element policies address the potential for subsidence associated with groundwater extraction. Goals include the conservation, enhancement, and management of water resources to protect water quality and ensure adequate long-term supply for domestic, agricultural, and industrial land uses. Policies support maintaining groundwater infiltration, improving groundwater quality, and encourages water conservation. Refer to Appendix 2A for selected City of Orland General Plan Goals and Policies applicable to water demand and supply.

GSP implementation focuses on the protection of groundwater resources and identifies and considers PMAs that focus on surface water use for agricultural irrigation and groundwater recharge. Implementation of the GSP would not conflict with the City's water quality, subsidence, and water conservation goals nor would it alter water demands.

2.3.2.6 Effects on City of Willows Water Demands

The City of Willows General Plan Land Use Element addresses new growth and the desire to maintain flexibility to changing conditions. Goals include the provision of adequate services, including water. Refer to Appendix 2A for selected City of Willows General Plan goals, objectives, and policies. It is anticipated that implementation of the GSP and the PMA addressing urban water conservation for the City of Willows would reduce water demands and thereby reduce groundwater extraction thereby promoting groundwater sustainability.

2.3.3 Effects of Land Use Plans Outside Subbasin

Outside the Subbasin, other land use plans have been developed as part of the general plans for Tehama County to the north, Butte and Sutter Counties to the east, and Yolo County to the south. These general plans are similar in scope to the Colusa and Glenn County General Plans described above in that they each contain goals, policies, and implementing actions that address water supply, water quality, conservation, enhancement, and management of water resources for a variety of land uses. In addition, the subbasins surrounding the Subbasin, which include Corning Subbasin to the north; Vina, Butte, and Sutter Subbasins to the east; and Yolo Subbasin to the south, have been identified as either high or medium priority and are also required to prepare and be managed under a GSP by January 31, 2022. As such, future land use changes in the jurisdictions within these subbasins will also need to be managed to achieve sustainability. As long as these subbasins are managed to achieve sustainability, each jurisdictions' General Plan and corresponding land use plan are not expected to affect the ability of the Subbasin GSAs to achieve sustainable groundwater management.

2.4 GSP IMPLEMENTATION EFFECTS ON WATER SUPPLY ASSUMPTIONS

Implementation of the GSP will require the Subbasin to operate sustainably by 2042. The GSP includes PMAs that focus on balancing groundwater pumping with expanded surface water use and groundwater recharge. Implementation of GSP PMAs generally alter the source of water supplies (i.e., using surface water to supplement groundwater supplies); however, planned PMAs do not reduce the supplies necessary to meet the water demands of the various land uses within the Subbasin.

2.5 SUMMARY OF PERMITTING PROCESS FOR WELLS IN COLUSA SUBBASIN

The GSAs in the Subbasin will seek to work with Colusa and Glenn Counties to align future well permitting with the Subbasin's sustainability goal established under this GSP. Also, in alignment with the findings of California's Third Appellate District, the GSAs will work with their respective counties to address the need to prevent impact on public trust values in surface water from new wells, depending on how this issue evolves in the State.

2.5.1 Human Right to Water

The State recognizes the Human Right to Water pursuant to California Water Code Section 106.3, which states, "*every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitary purposes*." The human right to water extends to all Californians, including disadvantaged individuals and groups and communities in rural and urban areas (SWRCB, 2021). The GSAs will seek to work with their respective counties, SWRCB staff and stakeholders in support of SWRCB's efforts, "*to develop new systems or enhance existing systems to collect data and identify and track communities that do not have, or are at risk of not having, safe, clean, affordable, and accessible water for drinking, cooking, and sanitary purposes*" (SWRCB, 2021). These efforts may have a nexus with well permitting by Colusa and Glenn Counties.

The CGA and GGA are committed to working cooperatively to achieve the core values in California Water Code Section 106.3. Private groundwater pumper representation within the GSAs and community engagement via public workshops and outreach are venues through which those potentially most vulnerable to loss of clean drinking water are able to share information and concerns throughout the GSP development and implementation process. During preparation of this GSP, public meetings were held at times, places and in a manner that supported and allowed for effective engagement of all stakeholders.

2.5.2 Colusa County

Within Colusa County, including the Subbasin, the Colusa County Environmental Health Division is entrusted with all permitting and enforcement for the construction, reconstruction, and destruction of wells. Wells under their oversight include agricultural/irrigation wells, observation/monitoring wells, exploratory/boring wells, and domestic water supply wells.

In order to provide minimum standards for the proper regulation of well drilling and abandonment, Colusa County has adopted the State of California, DWR Bulletin 74-81 and 74-90 water and well standards. In addition, the County provides guidance for the construction or destruction of wells, including well location to protect from pollution or contamination, well casing requirements, and minimum depths of annular seal for various well types.

The application process for Water Well Permits is handled online through the Colusa County Permits Online website: https://www.countyofcolusa.org/725/Water-Wells. This site provides the information necessary to apply and provides a link to submit an application online.

2.5.3 Glenn County

Within Glenn County, including the Subbasin, the Glenn County Environmental Health Department is responsible for all permitting and enforcement for the construction, reconstruction, destruction, and renewals of wells.

Glenn County Code (GCC), Title 20, Chapter 80 - Water Well Drilling Permits and Standards, details the well drilling requirements necessary for the protection of groundwater within the County. A permit is required for any type of well for the extraction of groundwater. An application is required to be submitted for review and approval. Permits to construct expire one year after issuance. In order to provide minimum standards for the proper regulation of well drilling and abandonment, Glenn County has adopted the State of California, DWR Bulletin 74-81 and 74-90 water and well standards. In addition to DWR standards, the County has established standards for annular well seals and well casings (GCC Section 20.080.060). In addition, an inspection is required before grouting occurs and a drilling log is to be submitted to the building inspector. Permits can be revoked if a violation to the County Code has been determined.

Information and fees associated with the well permit process can be found online at:

> https://www.countyofglenn.net/dept/planning-community-development-services/environmental-health/eh-resources .

2.5.4 Wellhead Protection

Wellhead protection refers to both the immediate location of the well in terms of well and pump station design features (e.g., well pad, annual seal) and the broader area surrounding the well. Both Colusa and Glenn Counties establish annular seals and other design requirements as part of well design standards.

2.6 ADDITIONAL GSP ELEMENTS

SGMA requires that the following topics are addressed in the GSP. See below for references to where each topic is addressed.

- **Control of seawater water intrusion:** See Chapter 3, Section 3.2.4 for an explanation of why the seawater intrusion sustainability indicator does not apply to the Subbasin.
- **Migration of contaminated groundwater:** Migration of contaminated groundwater is discussed in Chapter 4, Section 4.2.
- **Replenishment of groundwater extractions:** Recharge projects are discussed in Chapter 6.
- **Activities implementing, opportunities for, and removing impediments to, conjunctive use or underground storage:** Projects and management actions are discussed in Chapter 6.
- **Well construction policies:** Well construction policies are contained in Section 2.5.
- **Measures addressing groundwater contamination cleanup, groundwater recharge, in-lieu use, diversions to storage, conservation, water recycling, conveyance, and extraction projects:** Projects and management actions are discussed in Chapter 6.
- **Efficient water management practices, as defined in CWC §10902, for the delivery of water and water conservation methods to improve the efficiency of water use:** Details on efficient water management practices are discussed in Section 2.2.1.

- **Efforts to develop relationships with state and federal regulatory agencies:** Details on this topic can be found in Section 2.7.
- **Processes to review land use plans and efforts to coordinate with land use planning agencies to assess activities that potentially create risks to groundwater quality or quantity:** Details on this topic can be found in Section 2.3.
- **Impacts on GDEs:** GDEs are discussed in Chapter 3, Chapter 4, and Chapter 5.

2.7 NOTICE AND COMMUNICATION

This section documents public notice and communication of GSP activities.

2.7.1 Overview

SGMA requires broad and diverse stakeholder involvement in GSA activities and the development and implementation of the Colusa Subbasin GSP. The intent of SGMA is to ensure successful, sustainable management of groundwater resources at the local level. Success requires engagement by beneficial users (defined below). Engagement is far more likely when beneficial users receive consistent messaging of information and are provided opportunities to shape the path forward as it relates to SGMA.

Section 354.10. (Notice and Communication) of the GSP Regulations states the following requirements:

> *Each Plan shall include a summary of information relating to notification and communication by the Agency with other agencies and interested parties including the following:*
>
> *(a) A description of the beneficial uses and users of groundwater in the basin, including the land uses and property interests potentially affected by the use of groundwater in the basin, the types of parties representing those interests, and the nature of consultation with those parties.*
>
> *(b) A list of public meetings at which the Plan was discussed or considered by the Agency.*
>
> *(c) Comments regarding the Plan received by the Agency and a summary of any responses by the Agency.*
>
> *(d) A communication section of the Plan that includes the following:*
>
> *(1) An explanation of the Agency's decision-making process.*
>
> *(2) Identification of opportunities for public engagement and a discussion of how public input and response will be used.*
>
> *(3) A description of how the Agency encourages the active involvement of diverse social, cultural, and economic elements of the population within the basin.*
>
> *(4) The method the Agency shall follow to inform the public about progress implementing the Plan, including the status of projects and actions. The following addresses these requirements.*

To guide and facilitate beneficial user engagement in the GSP process, a Communication and Engagement Plan (C&E Plan) was created by the GSAs in the Subbasin to:

- Provide the GSAs and beneficial users guidance to ensure consistent messaging of SGMA requirements and related Subbasin data and information,
- Provide a roadmap to the GSAs and beneficial users to ensure everyone has an opportunity for meaningful input into GSA decision-making, including GSP development,
- Describe processes that are experienced by beneficial users as fair and respectful to the diverse range of interests in the Subbasin,
- Make transparent to beneficial users, their opportunities to contribute to the development of a GSP, and
- Ensure that information reaches all beneficial users who have an interest in the Subbasin.

Like many components of this GSP, the C&E Plan has and will periodically be updated throughout GSP development and SGMA implementation. Said updates will reflect changing conditions in the subbasin and responses by the GSAs to address these changes and to ensure effective outreach and communication take place with beneficial users. These updates reflect the role of the C&E Plan as a "living document" that provides a compilation and repository of various engagement activities implemented or planned to be implemented by the GSAs.

The above C&E Plan topics are discussed in the subsections below. Supporting information and record-keeping files are included in the appendices and/or on the respective websites of the Subbasin GSAs (described below):

- Appendix 2B: Comment tracking, copies of received comments, and responses to comments regarding project management actions, draft GSP chapters, and general inquiries
- Appendix 2C: Coordination meeting and outreach contact distribution lists
- Appendix 2D: Engagement and media materials for interbasin coordination meetings, information workshops, public meetings and hearings, SGMA workshops, public events, and Subbasin branding
- Appendix 2E: Communication and Engagement Plan

2.7.1.1 COVID-19 Global Pandemic

In March 2020, the COVID-19 global pandemic necessitated changes in all aspects of California society including public gatherings and the rules defining how public agencies conduct events. Several Executive Orders were issued by Governor Newsom to address necessary changes in the Ralph M. Brown Act (Government Code § 54950-54963) (Brown Act) which dictates the rules and manner in which local public agencies notice and conduct their sponsored meetings and ensures public transparency of, and accessibility to, almost all aspects of said gatherings. Under statewide "shelter-in-place" (SIP) mandates, all public gatherings were prohibited by the State government. These changes required that between March 13, 2020, and continuing to May 25, 2021, all meetings individually and jointly convened by the GSAs were conducted through web-based, virtual meeting and telephone-based methods, consistent with protocols allowable through the COVID-related Executive Orders. The CGA and GGA resumed in-person Board meetings on May 25 and July 12 (respectively) with an accommodation for conference call participants.

The following sections describe actions and events employed to ensure that GSA meetings and GSP development were conducted with the required level of transparency and accessibility. Activities and events that took place prior to March 2020 SIP mandates were conducted in person and virtually thereafter. Despite the June 15, 2021 "Reopening" of California, the GSAs chose to retain virtual meeting methods for TAC meetings and some public engagement events. Other events were and are expected to be conducted in person (described below). Lastly, the following sections also note additional steps taken by the GSAs during the COVID-19 pandemic to modify public engagement and information and ensure that beneficial users remained fully informed of GSA efforts and GSP content. Input received by the GSAs during outreach events or via email correspondence, as well as comments received on the draft GSP are tabulated in Appendix 2B.

2.7.1.2 Description of Beneficial Uses and Users in the Basin

Under the requirements of SGMA, all beneficial uses and users of groundwater must be considered in the development of GSPs, and GSAs must encourage "*the active involvement of diverse social, cultural, and economic elements of the population.*" As defined in SGMA (CWC §10723.2), "*the GSA shall consider the interests of all beneficial uses and users of groundwater, as well as those responsible for implementing groundwater sustainability plans. These interests include, but are not limited to, all of the following:*

- *(a) Holders of overlying ground water rights, including:*
  - *(1) Agricultural users.*
  - *(2) Domestic well owners.*
- *(b) Municipal well operators.*
- *(c) Public water systems.*
- *(d) Local land use planning agencies.*
- *(e) Environmental users of groundwater.*
- *(f) Surface water users, if there is a hydrologic connection between surface and groundwater bodies.*
- *(g) The federal government, including, but not limited to, the military and managers of federal lands.*
- *(h) California Native American Tribes.*
- *(i) Disadvantaged communities (DAC), including, but not limited to, those served by private domestic wells or small community water systems.*
- *(j) Entities listed in Section 10927 that are monitoring and reporting ground water elevations in all or a part of a groundwater basin managed by the groundwater sustainability agency."*

In this context, the GSAs have approached SGMA engagement as needing to include any stakeholders who have an interest in groundwater use and management in the Subbasin. Their interest may be related to GSA activities, GSP development and implementation, and/or water access and management in general. To assist identifying categories of beneficial uses and users in the Subbasin, the C&E Plan included a Stakeholder Engagement Chart for GSP Development (Table 2-8 and Appendix 2E) (consistent with guidance promulgated by DWR). To facilitate regular communication with said stakeholders, the GSAs have maintained and continually updated, distribution lists of GSA-specific Beneficial Users (also known as Interested Parties Lists). These lists are presented in Appendix 2C and described below in Section 2.7.3.1.

Table 2-8. Stakeholder Engagement Chart for GSP Development

Category of Interest	Examples of Stakeholder Groups	Engagement Purpose
General Public	• Citizens groups • Community leaders • Interested individuals • Universities/Academia	Inform to improve public awareness of sustainable groundwater management
Land Use	• Municipalities • Local land use agencies • Regional land use agencies • Community Service Districts	Consult and involve to ensure land use policies are supporting GSPs and there are no conflicting policies between the GSAs / GSP and said local government agencies
Private Users	• Private pumpers (domestic and agricultural) • Schools and colleges • Hospitals	Inform and involve in assessing impacts to groundwater users
Urban/ Agricultural Users	• Water agencies • Irrigation districts • Municipal water companies • Mutual water companies • Resource conservation districts • Farmers/Farm Bureaus • Water Districts • Water user associations • Irrigated Lands Regulatory Program Coalition	Collaborate to ensure sustainable management of groundwater
Industrial Users	• Commercial and industrial self-suppliers • Local trade associations or groups	Inform and involve in assessing impacts to users
Environmental and Ecosystem Uses	• Federal and State agencies • Wetland managers • Environmental groups	Inform and involve to consider / incorporate potential ecosystem impacts to GSP process
Surface Water Users	• Irrigation Districts • Water Districts • Water user associations • Agricultural users	Inform and involve to collaborate to ensure sustainable water supplies
Economic Development	• Chambers of commerce • Business groups/associations • Elected officials • State Assembly members • State Senators • Economic Development Team	Inform and involve to support a stable economy
Human Right to Water	• Disadvantaged communities • Small water systems • Environmental justice groups/community-based organizations • De minimis well owners	Inform and involve to provide safe and secure groundwater supplies to all communities reliant on groundwater
Tribes	• Federally Recognized Tribes: — Cachil Dehe Band of Wintun Indians — Kletsel Dehe Wintun Nation (Cortina Rancheria) • Non-Federally Recognized Tribes	Inform, involve and consult with tribal government
Federal Lands	• U.S. Fish and Wildlife Service • U.S. Bureau of Reclamation • U.S. Army Corps of Engineers	Inform, involve and collaborate to ensure basin sustainability
Integrated Water Management	• Regional water management groups (IRWM regions) • Flood agencies	Inform, involve and collaborate to improve regional sustainability

2.7.1.3 Decision-Making Processes

As noted above, SGMA is implemented in the Subbasin by the CGA and GGA. The GSAs have jointly developed this GSP and as such, the respective Boards are the final decision-makers for GSP content. To ensure effective governance of the GSP process including robust technical analysis and discussions, and associated public engagement, the GSAs convened a TAC and an Executive Committee for each GSA. The GSAs are legal public agencies, formed as Joint Powers Authorities through the execution of Joint Powers Agreements consistent with the Joint Exercise of Powers Act, as codified in California Government Code Section 6500. The Boards, in concert with the TACs and Executive Committees, create the primary structure for governance, information exchange, and decision making for each GSA. From the inception of each GSA, all meetings of all entities within their jurisdictional purview have been conducted with an effort to be inclusive to all stakeholders. All meetings requiring Brown Act compliance were conducted in such a manner, with appropriate public noticing of meeting agendas, associated meeting materials and subsequent availability of meeting summaries. All such materials are and have been available at the respective CGA and GGA websites:

- Colusa Groundwater Authority website: https://colusagroundwater.org/
- Glenn Groundwater Authority website: https://www.countyofglenn.net/dept/planning-community-development-services/water-resources/glenn-groundwater-authority

Prior to and after necessary adjustment in public engagement due to COVID, the TACs have played a particularly key role to ensure public disclosure of all technical information, public discussion of technical factors, and transparent development of technical recommendations that have then been delivered to the respective Boards for their consideration and decision making. The TACs have met in approximately monthly joint sessions. They include members of each GSA Board and other advisory representatives appointed by each Board and who deliberate on technical topics.

Regarding decision-making procedures by the Boards, to ensure compliance with GSP regulations regarding "*…opportunities for public engagement and…how public input and response will be used*" (and additive to Brown Act requirements) the GSAs have adopted a comprehensive tabular GSP comment tracking system as part of the GSP Administrative Record to continually record beneficial user input and to regularly update the respective Boards on said input. Appendix 2B presents the comment tracking system (including GSP development comments and responses). The comment tracking system is updated on a regular basis by facilitation staff and is then included in the agenda packet for each GSA Board meeting. General input comments have been tracked since 2019, and comments on the draft GSP have been tracked since draft chapters were released beginning in spring 2021. The agenda for each Board meeting includes a specific item calling attention to the updated comment tables and allowing time for each Board to make inquiry about and discuss any comments received. Prior to key GSP decision milestones, each Board agenda defines said decision as a formal action which could include discussion by each Board about associated public input recorded in the comments tables that might inform their decision-making. Further, consistent with and expanding on Brown Act requirements, each Board and TAC meeting includes the following periods of public comment on their respective agendas:

- Introductory public comment period at the beginning of the meeting for topics not included in the current agenda
- Public comment periods for each agenda item
- Public comment periods to be held prior to any formal action taken by the Board and/or TAC

2.7.2 Engagement Opportunities

2.7.2.1 Public Engagement Opportunities

Prior to formation of the legal GSAs (2015 through June 2017), and thereafter through October 2021, the parties that make up the CGA and GGA have collectively sponsored, publicized and conducted 242 separate meetings including:

- 40 Pre-Agency Formation SGMA governance meetings,
- 181 GSA meetings (Boards, Committees, Subcommittees and Joint Meetings), and
- 21 public meetings and workshops.[2]

Prior to the respective GSA's being formed as legal public agencies, interested parties and organizations already noticed to the State as intending to form individual GSAs began meeting in the respective counties of Colusa and Glenn. These meetings were funded by DWR's Facilitation Support Services (FSS) program in an effort to support GSA formation. Respectively titled the Colusa GSA Work Group and the Glenn Governance Work Group, all meetings of these groups were publicly noticed and associated information was posted on the websites of the respective counties' websites. In total, the Colusa GSA Work Group met 25 times (including full Work Groups and topic specific subcommittees) between January 2016 and June 2017 (at which point the legal GSA was formed as per statute). Similarly, the Glenn Governance Work Group met 15 times between April 2016 and June 2017 when their work similarly culminated in the formation of the legal GSA as per statute.

Following the formation of the CGA and GGA as legal public agencies, there have been collectively 196 more meetings at which the public has had the opportunity to engage prior to and during the GSP development process.

As referenced above, for all GSA meetings (full and joint Board meetings, Committee and Subcommittee meetings) requiring compliance with the Brown Act, agendas are posted no less than 72 hours before a meeting and all materials presented in said meetings are made accessible for the public to access through either of the respective GSA's websites or through hard copies available at the respective GSA's administrative offices.

For meetings not required to be compliant with the Brown Act, presentation materials and event agendas were posted on the respective GSA websites either before or at the latest, immediately after each event. Once the GSAs had jointly established a social media presence (fall 2020), all public outreach meetings were similarly publicized through Facebook and Twitter. This included TAC, Board, and Executive Committee meetings as well as SGMA Series and other public events.

All meetings described below as "Public Meetings and Workshops" were noticed to the standing lists of media organizations and outreach partners (Appendix 2C), with press releases and associated requests for said organizations to publicize said events through public notices, feature articles, newsletters, email listservs, and similar. The following provides a general description of the engagement venues provided by

[2] "Public meetings" are open to the public and allow comments and feedback from the public, but are not exclusively held for that purpose (e.g., Board meetings, TAC meetings). "Public workshops" and "public outreach meetings" are open to the public and are primarily designed to engage with the public and stakeholders to solicit their opinions and feedback.

the GSAs. Appendix 2D presents background outreach materials for most of the events described below (if said materials are not already accessible through the respective GSA websites):

- **Individual GSA Meetings**: Each GSA in the Subbasin held regular, publicly-noticed, publicly accessible meetings, generally on a monthly schedule. From legal inception to date and as consistently compliant with the Brown Act:
  - The CGA has held 43 GSA Board Meetings.
    - The CGA has also held 9 Long-Term Funding Committee Meetings.
  - The GGA has held 54 GSA Board Meetings.
- **GSA Executive Committee Meetings**: Consistent with their respective by-laws, each GSA formed and then regularly convened an Executive Committee to address high-level administrative decisions. To date and as consistently compliant with the Brown Act:
  - The CGA has held 10 Executive Committee Meetings.
  - The GGA has held 36 Executive Committee Meetings.
  - The CGA and GGA have held 4 joint Executive Committee Meetings.
- **Joint GSA meetings:** The GSAs convened 4 times for publicly-noticed, publicly accessible joint meetings. The intent of the joint GSA meetings was to provide a forum for representatives from each GSA to share perspectives and information about GSP development and SGMA implementation, and near the end of the GSP development process, to ensure shared expectations and approvals of the GSP.
- **Inter-basin SGMA Coordination Meetings:** On a regular basis, inter-basin meetings of representatives from the Colusa Subbasin met with representatives from the adjacent Corning, Butte, Sutter and Yolo Subbasins (and other non-adjacent subbasin representatives) to discuss interconnected groundwater conditions, potential impacts and other factors related to groundwater management across the larger Sacramento Valley Basin.
- **GSA-specific and Joint Technical Advisory Committee Meetings:** As previously described, GSA-specific TACs were formed to review technical content, work with the technical consultant team and advise their respective GSA Boards on GSP development. The TACs generally met on a monthly basis and always in publicly-noticed, publicly accessible meetings.
  - The CGA and GGA have held 19 Joint TAC Meetings.
  - The CGA has held 1 GSA-Specific TAC Meeting.
  - The GGA has held 1 GSA-Specific TAC Meeting.
- **GSA Formation Working Group Meetings:** As described above, in the initial stages of GSA formation, close to 40 separate, eligible GSA organizations noticed the DWR of their intent to form separate GSAs. Using funding provided through DWR's FSS program, all said parties convened into two Subbasin Working Groups which convened every 4 to 8 weeks for close to two years to negotiate mutual governance agreements that became the basis for the two JPAs to be formed as the respective CGA and GGA. The meetings took place in person; always as publicly-noticed and publicly accessible events held in Colusa and Willows, California.

- **Public Meetings and Workshops**: In 2015, three initial meetings were held to discuss general SGMA information and were co-sponsored by the Glenn County Water Advisory Committee, the Glenn County Farm Bureau, and the University of California Cooperative Extension. In January 2016 (including in advance of the CGA and GGA being legally formed), Subbasin representatives started public events to inform beneficial users about SGMA.
  - **General Education / Information: January and March 2016** - A series of 2 kickoff public meetings were held respectively at the Colusa County Fairgrounds and Orland Memorial Hall to describe SGMA requirements and background, early governance and implementation steps, anticipated methods for public engagement and to provide an opportunity for public question and answer sessions with a panel of eligible GSA leaders actively involved in the governance development process.
  - **GSA Financing – Proposition 218 Public Information Meetings: January and April 2019 -** In support of the respective GSA's efforts to establish long range funding, 4 public information meetings were held respectively at the Colusa Indian Community Events, the Glenn Success Square Conference Center, the City of Willows City Council Chambers and the Ord Bend Community Hall. The meetings included background about SGMA implementation and compliance, presentations about Proposition 218, discussion of associated financing options and requirements, and opportunities for questions and answers.
  - **GSA Financing – Proposition 218 Public Ballot Hearings: June and July 2019** - In support of the respective GSA's efforts to establish long range funding, 2 final Proposition 218 ballot hearings were held respectively at the Colusa Industrial Properties and the City of Willows Council Chambers. Meetings were held as formal GSA Board meetings with an allowance for public feedback on the ballot process, followed by a formal counting of submitted ballots and a final determination of election outcomes.
  - **SGMA General Information, Basin Setting and Sustainable Management Criteria Workshops: 2019** - The GSAs sponsored a series of public workshops in 2019. Two GSA-specific events were held respectively at the Colusa Veterans of Foreign Wars Hall and the Glenn Success Square Conference Center. The purpose of each workshop was to provide an update on Basin Setting conditions, Subbasin Water Budget, modelling efforts, conduct small group exercises about potential significant and unreasonable conditions associated with sustainability indicators, and to conduct question and answer sessions. Individual and small group worksheets were prepared by workshop participants providing collective beneficial user input to the GSAs about potential groundwater sustainability problem areas in the Subbasin.
    - **Town Hall Meetings 2019:** The CGA in partnership with the Colusa County Groundwater Commission sponsored 3 locally focused Town Hall meetings in March 2019 to informally update them on GSA and GSP status and how they could participate. Appendix 2D-4 included example materials from these meetings. These meetings were focused respectively on the following communities:
      - Arbuckle / Williams / College City
      - Colusa / Princeton / Grimes
      - Maxwell / Williams

- **SGMA Series** – Beginning in February 2020 and extending in virtual and then virtual and in-person formats through October 2021, the GSAs sponsored a series of 8 paired public meetings (one in daytime / one in evening). These meetings focused on the following:
  - **February 2020** – On-Farm, Groundwater Recharge Workshop (co-sponsored with The Nature Conservancy)
  - **December 2020** – (2 workshops) Status of Basin Setting conditions, education on Sustainable management Criteria terms, requirements and processes; Projects and Management Actions terms and next steps
  - **January 2021** – Well Monitoring Program Public Workshop to inform the public about and solicit applicants for the program
  - **July 2021** – (2 workshops) Current and Historical Groundwater Conditions, Historical, Current, and Projected Water Budgets, Draft Sustainability Goal, Draft Significant and Unreasonable Conditions
  - **October 2021** – (2 workshops) Public Draft GSP Review and Public Discussion

2.7.2.2 Soliciting Written Comments

In addition to soliciting feedback at all meetings described above, opportunities were provided to offer written comments on the GSP via an online comment form, email or letter. A series of chapter-specific review periods was initiated in April 2021, providing beneficial users the opportunity to provide iterative feedback. Table 2-9 presents the schedule used for this process. All comments received during these periods were admitted into the Administrative Record and the associated comment tracking system for subsequent review by the GSA Boards and beneficial users. The written comments and responses can be found in Appendix 2B and its associated subsections.

Table 2-9. GSP Review Schedule

GSP Chapter/Activity	Start Date	End Date	Duration, days
Public Draft Review	4/7/2021	5/5/2021	28
Chapter 1 – Introduction			
Chapter 2 – Plan Area			
Chapter 3 – Basin Setting			
Chapter 4 – Monitoring Networks			
Public Draft Review	7/16/2021	8/13/2021	28
Chapter 5 – Sustainable Management Criteria			
Chapter 6 – Projects and Management Actions			
Public Draft Review	9/13/2021	10/31/2021	48
Preface			
Executive Summary			
Revised Chapters 1 through 6			
Chapter 7 – Plan Implementation			
Chapter 8 – References and Technical Studies			
Technical Team Finalize GSP	11/1/2021	12/3/2021	33
Complete GSP			
GSP Adoption by Agencies and Submittal to DWR	12/3/2021	1/31/2022	59
Final Submitted Colusa Subbasin GSP			

2.7.3 Informing the Public about GSP Development Progress

2.7.3.1 Interested Parties List

Email distribution lists of GSA-specific beneficial users were developed for outreach supporting the GSP planning process. The lists are maintained and updated by the CGA and GGA Program Managers, respectively, and are summarized in Appendix 2C. (To protect sensitive information, actual contact information of interested parties is not appropriate to publish as part of this GSP). Any interested member of the public could be added to the lists by signing up via online entry options located on the CGA website and through email sign up options or requesting by phone for each GSA.

Tribal Engagement

As noted in the C&E Plan (Appendix 2E) and in Table 2-8 above, the Cachil DeHe Band of Wintun Indians of the Colusa Indian Community of the Colusa Rancheria is a federally recognized tribe of Wintun Indians from central California. The Tribe has been consistently identified as an Interested Party since the preliminary days of Subbasin governance (2015 – 2017) and has similarly, been a consistent entity on the Interested Parties list for both GSAs since their respective inception. A Tribal representative attended CGA and GGA meetings regularly from 2015 through December 2019, at which time, said representative departed Tribal employment. The CGA and GGA have continued their inclusive communication of all SGMA information to the Tribe; however, Tribal participation has been limited since January 2020. Likewise, the GSAs' inclusive communication of all SGMA information has been available to the Cortina Rancheria of Wintun Indians of California (Kletsel Dehe Wintun Nation); however, there has been no participation by a representative from the Cortina Rancheria in the GSP process.

2.7.3.2 Distribution of Meeting Information

Before each public meeting and workshop, agenda-based flyers were created in English and Spanish with key information provided. The flyers were emailed out to the Interested Party list, traditional media as well as to key outreach leads with various organizations and the member agencies of each GSA to ensure maximum distribution to the widest range of beneficial users feasible (Appendix 2C). Meeting and workshop flyers are presented in Appendix 2D.

2.7.3.3 Outreach and Branding

To provide Subbasin outreach materials with a consistent look and feel that ensure user awareness of messaging and a sense of organizational cohesion, the respective GSA Boards jointly recommended the development and ultimate approval of a Colusa Subbasin Logo and associated graphics standards to be used consistent on all outreach collateral and online materials. The new Colusa Subbasin logo has been included on this GSP and is also presented in Appendix 2D.

2.7.3.4 Traditional Media Outreach

In advance of each public meeting and workshop, press releases were issued to a local media contact list (Appendix 2C). Local media proved to be highly responsive and the Subbasin efforts collectively received media coverage for most public events described above. Related to this, the GSA Chairpersons wrote and the GSA's jointly approved, the release of an Op-Ed Piece for regional distribution regarding the nexus of the 2021 drought and SGMA planning and implementation (Appendix 2D).

2.7.3.5 Social Media Outreach

Based on a comprehensive outreach proposal submitted to and approved by the respective GSA Boards in October 2020, GSA staff launched social media sites on Facebook and Twitter:

- Facebook Page - https://www.facebook.com/search/top?q=Colusa%20Subbasin%20SGMA
- Twitter - https://twitter.com/colusasubbasin?lang=en

Through these sites, regular content updates were then conducted on average of a bi-monthly basis to ensure user interest and readability and to avoid information on said sites getting "stale." In addition to photographic images and SGMA / GSA / GSP content being regularly updated, the GSAs used Facebook Live to simulcast all events in the SGMA Series to ensure maximum availability for members of the public to view all outreach events from late 2020 through and including public review and subsequent GSA approval of the GSP.

2.7.3.6 GSA Websites

Throughout the planning process, the GSAs have maintained respective websites (as presented above).

These websites are populated with information about Subbasin-wide SGMA planning efforts. While the layout of these websites vary, in general, each includes the following:

- Reference documents regarding GSA creation, incorporation, governance and similar
- Reference documents regarding SGMA background information
- Calendar of public meetings and other upcoming events
- GSA Board, Executive Committee and TAC meeting agendas and materials including post meeting summaries and Zoom recordings (when available after March 2020)
- Information about past public meetings, including relevant meeting materials
- Links to external sites and research (e.g., Department of Water Resources SGMA portal, DWR Subsidence Studies) and other resources
- GSP Chapters, Appendices, Figures, Tables, Comment Forms and related materials
- Links to submit contact information into the Interested Parties Lists
- Reference and submission information for associated voluntary programs such as the Multi-benefit On-farm Managed Aquifer Recharge Program, and the Colusa Subbasin Well Monitoring Program and OpenET, an evapotranspiration data access project
- A link to the website of the respective other GSA
- Colusa Subbasin Social Media links
- Media links and strategy documents including press-releases and Op-Ed materials
- Information about other interbasin efforts
- GSP background documents
- Fact sheets and Subbasin maps

2.7.3.7 Beneficial User Input and Responses

As referred to above, the engagement opportunities described above provided various avenues for beneficial users to provide input on GSP development for the GSAs to be informed thereof. Appendices 2B and 2D present the input received and supports how this input influenced decision-making in GSP development.

CHAPTER 3
Basin Setting

Chapter 3 describes the basin setting, including the hydrogeologic conceptual model (HCM), current and historical groundwater conditions, and water budget information describing the movement of surface water and groundwater into, through and out of the Colusa (Subbasin). This chapter was prepared through a coordinated effort between the CGA and the GGA, the GSAs responsible for managing the Subbasin.

3.1 HYDROGEOLOGIC CONCEPTUAL MODEL

This section describes the Subbasin HCM. The HCM supports development and implementation of a GSP pursuant to the requirements of SGMA.

3.1.1 Regulatory Requirements

Title 23 Section 354.14 of the California Code of Regulations (23 CCR §354.14) requires that each GSP "*shall include a descriptive hydrogeologic conceptual model of the basin based on technical studies and qualified maps that characterizes the physical components and interaction of the surface water and groundwater systems in the basin*" and shall include written descriptions for the following HCM components:

- Regional geology and structure (Section 3.1.7)
- Lateral basin boundaries (Section 3.1.8.1)
- Definable bottom of the basin (Section 3.1.8.2)
- Principal aquifers and aquitards, including formation names, vertical and lateral extent, aquifer properties, restrictions to flow, water quality, and primary uses (Section 3.1.10)
- Any data gaps and uncertainties identified in the previously listed topics (Section 3.1.12)

In accordance with 23 CCR §354.14, the HCM shall also include maps of each of the following physical components of the HCM. All maps shall be informative, labeled, and include the datum (23 CCR §352.4(d)). Information regarding key data sources is also included on each of the maps.

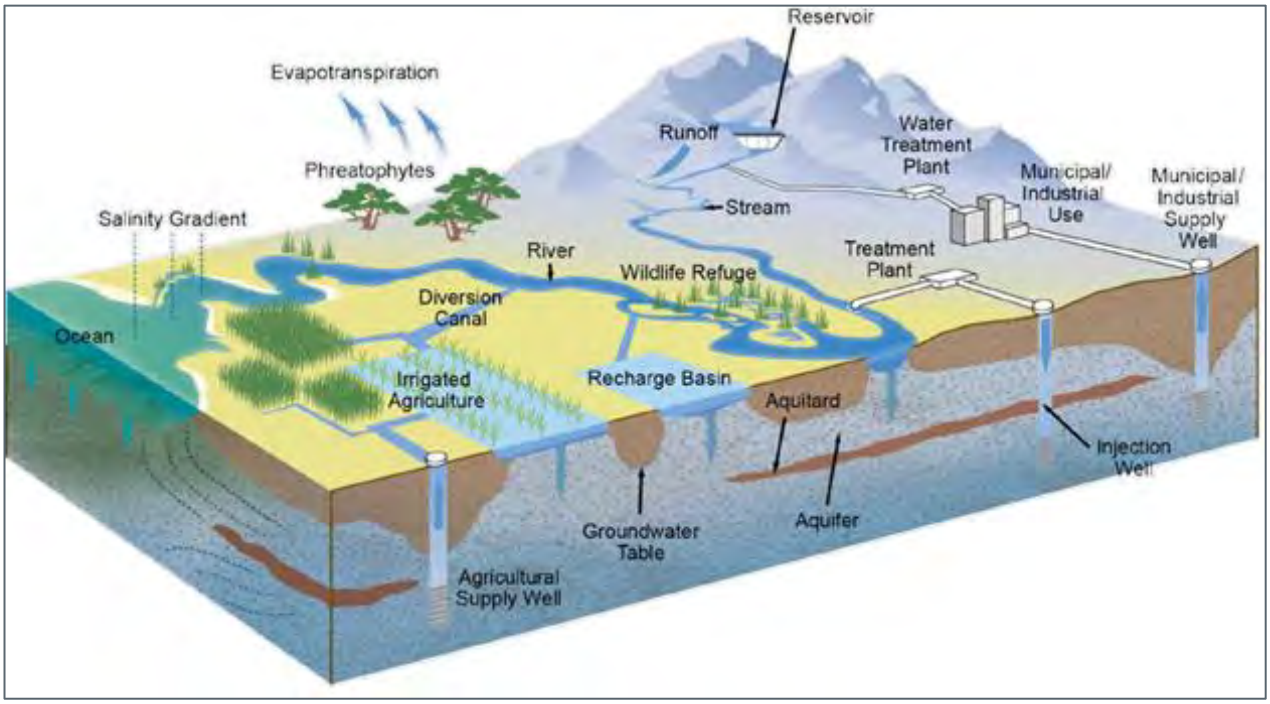
- Topography
- Surface geology and a minimum of two cross sections
- Soil properties
- Recharge and discharge areas
- Surface water features
- Sources and points of delivery of imported water

This section addresses the requirements using currently available data and information in accordance with the Department of Water Resources (DWR) Best Management Practice (BMPs) for the Sustainable Management of Groundwater: Hydrogeologic Conceptual Model BMP (DWR, 2016a). Additionally, components of this HCM have been compared to and updated based on information included in the California Central Valley Groundwater-Surface Water Simulation Model – Fine Grid (C2VSimFG), the selected integrated hydrologic model (IHM) chosen to support the Colusa Subbasin GSAs. This section provides a comparison of the HCM and IHM. Data gaps, uncertainties, and recommended actions are also presented in this section (Section 3.1.12).

3.1.2 Background Information

The HCM provides the general understanding of the hydrogeologic physical setting, characteristics, and processes that occur within the Subbasin and provides the foundation upon which the IHM and components of the water budget are based.

Figure 3-1 depicts a generalized HCM (DWR, 2016a). The main components of the HCM include surficial and subsurface features. Surficial features include topography, hydrology, water supply features, land use, soil types, and geologic outcrops. Subsurface features of the HCM include geologic formations and structures and the presence and characteristics of aquifers and aquitards. These HCM components, except for land use, are discussed in this chapter. Land use is discussed in both Chapter 2 Plan Area, and Section 3.3 Water Budget sections of this Colusa Subbasin GSP.



Reference: California Department of Water Resources, 2016, Best Management Practices for the Sustainability Management of Groundwater: Hydrogeologic Conceptual Model: California Department of Water Resources, December 2016.

Figure 3-1. Hydrogeologic Conceptual Model Representation

The Colusa Subbasin HCM was developed using information provided in a variety of existing studies, dissertations, reports, and datasets. Table 3-1 documents the primary data sources and references used to develop the HCM. All references and citations used for the Colusa Subbasin GSP are listed in Chapter 8.

Table 3-1. Hydrogeologic Data Sources

File Content	File Format	Responsible Agency	Source Reference	Website
Base of Fresh Water	PDF	USGS	Olmsted, F.H. and Davis, G.H., 1961, Geologic Features and Ground-Water Storage Capacity of the Sacramento Valley, California: U.S. Geological Survey in cooperation with the California Department of Water Resources Water Supply Paper WSP-1497, plate 5.	https://pubs.er.usgs.gov/
Bulletin 118 Groundwater Basin	GIS Shapefile	DWR	DWR, 2019, Bulletin 118 Basin Boundary GIS Data, v.6.1: California Department of Water Resources (DWR).	https://water.ca.gov/Programs/Groundwater-Management/Bulletin-118
Elevation DEM	GIS Raster	USGS	USGS, 2016, 1/3 arc-second National Elevation Dataset (NED) Digital Elevation Model (DEM): U.S. Geological Survey (USGS), 1x1-degree tiles N39W122, N39W123, N40W122, N40W123, downloaded 2016.	http://viewer.nationalmap.gov/
Geologic Structural Contours	PDF	USGS	Harwood, D.S. and Helley, E.J., 1987, Late Cenozoic Tectonism of the Sacramento Valley, California: U.S. Geological Survey Professional Paper PP-1359, plate 1.	https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
Geology	PDF	DWR	DWR, 2014, Geology of the Northern Sacramento Valley: prepared by the California Department of Water Resources Northern Region Office, Groundwater and Geologic Investigations Section.	https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Data-and-Tools/Files/Regional-Reports/Geology-of-the-Northern-Sacramento-Valley-California-June-2014.pdf
Geology	GIS Geodatabase	USGS	Helley, E.J. and Harwood, D.S., 1985, Geologic Map of the Late Cenozoic Deposits of the Sacramento Valley and Northern Sierran Foothills, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1790, scale 1:62,500.	Not Available Online
Geology	PDF	CGS[(a)]	Jennings, C.W. and Strand, R.G., 1960, Geologic Map of California, Olaf P. Jenkins edition, Ukiah Sheet: Department of Natural Resources Division of Mines and Geology (CDMG) Geologic Atlas Map GAM-24, third printing 1992, scale 1:250,000.	https://maps.conservation.ca.gov/cgs/publications/
Geology	PDF	CGS	Koenig, J.B., 1963, Geologic Map of California, Olaf P. Jenkins edition, Santa Rosa Sheet: California Department of Natural Resources Division of Mines and Geology Geologic Atlas Map GAM-22, scale 1:250,000.	https://maps.conservation.ca.gov/cgs/publications/
Geology	GIS Shapefile; PDF	DWR	DWR, 2009, Glenn-Colusa Irrigation District Test-Production Well Installation and Aquifer Testing: prepared by the California Department of Water Resources Northern District Groundwater Section in cooperation with Glenn-Colusa Irrigation District, March 2009, GIS shapefiles provided by DWR 2008.	http://wdl.water.ca.gov/pubs/geology/glenn-colusa_irrigation_district_test-production_well_installation_and_aquifer_testing__2009_/glenn-colusa_irrigation_district_test-production_well_installation_and_aquifer_testing__2009_.pdf
Groundwater Dependent Ecosystems	GIS Geodatabase; PDF	TNC	DWR, 2018, Summary of the "Natural Communities Commonly Associated with Groundwater" Dataset and Online Web Viewer: California Department of Water Resources, April 2018.	https://data.cnra.ca.gov/dataset/natural-communities-commonly-associated-with-groundwater
Hydrography - Hydrology and Watersheds	GIS Geodatabase	USGS	USGS, 2016, USGS National Hydrography Dataset (NHD) Downloadable Data Collection: U.S. Geological Survey National Geospatial Technical Operations Center (NGTOC), Region 1802.	http://viewer.nationalmap.gov/
Natural Communities Commonly Associated with Groundwater	GIS Shapefile	DWR	DWR, 2020, Natural Communities Commonly Associated with Groundwater (NCCAG) Dataset: California Department of Water Resources, California Department of Fish and Wildlife, and The Nature Conservancy.	https://gis.water.ca.gov/app/NCDatasetViewer/#
Soil Suitability for Recharge	GIS Shapefile	UCD &UC-ANR	University of California Davis (UCD) California Soil Resource Lab and University of California Division of Agriculture and Natural Resources (UC-ANR), 2017, Soil Agricultural Groundwater Banking Index (SAGBI), GIS shapefiles received 2017. O'Geen, A.T. et al, 2015, Soil Suitability Index Identifies Potential Areas for Groundwater Banking on Agricultural Lands: California Agriculture, Volume 69, Number 2, pp 75-84, April 2015.	https://casoilresource.lawr.ucdavis.edu/sagbi/
Soils	GIS Shapefile; Access Database	NRCS	NRCS, 2013 & 2017, Soil Survey Geographic Database (SSURGO): Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS), Colusa County (CA011), Spatial Data V3 (2013), Tabular Data V11 (2017).	http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx
Soils	GIS Shapefile; Access Database	NRCS	NRCS, 2014 & 2017, Soil Survey Geographic Database (SSURGO): Natural Resources Conservation Service Web Soil Survey, Glenn County (CA021), Spatial Data V5 (2014), Tabular Data V12 (2017).	http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx
Soils	GIS Map Package	ESRI	ESRI, 2017, NRCS Compiled 2017 SSURGO Downloader: Environmental Systems Research Institute (ESRI), Big Chico Creek - Sacramento River, Butte Creek, Honcut Headwaters - Lower Feather, Sacramento - Stone Corral, Upper Cache, and Upper Stony watersheds.	http://esri.maps.arcgis.com/apps/View/index.html?appid=cdc49bd63ea54dd2977f3f2853e07fff
Stream Gauge and Reservoir Stations	Tabular	CDEC	DWR, 2017, California Data Exchange Center (CDEC): California Department of Water Resources, downloaded 2017.	http://cdec.water.ca.gov/index.html
Stream Gauges	Tabular	USGS	USGS, 2017, National Water Information System (NWIS) - Web Interface: U.S. Geological Survey, downloaded 2017.	https://waterdata.usgs.gov/nwis
Water Quality Data	Tabular	SWRCB	SWRCB, 2020a, GeoTracker Groundwater Ambient Monitoring and Assessment: California State Water Resources Control Board.	http://geotracker.waterboards.ca.gov/gama
Water Quality Data	Tabular	USGS	USGS, 2020, National Water Information System (NWIS) - Web Interface: U.S. Geological Survey, download 2020.	https://waterdata.usgs.gov/nwis/qw
Wetlands	GIS Geodatabase	FWS	U.S. Department of the Interior, 2014, Classification of Wetlands and Deepwater Habitats of the United States: U.S. Department of the Interior (USDI) Fish and Wildlife Service (FWS), Washington D.C., FWS/OBS-79-31.	https://www.fws.gov/wetlands/data/data-download.html

(a) California Division of Mines and Geology is now the California Geological Survey.

3.1.3 Climate and Precipitation

The Subbasin has a Mediterranean climate with cool, wet winters and hot, dry summers. Regionally, temperature and precipitation vary with elevation, with lower temperatures and higher precipitation typically occurring at higher elevations. The region is subject to wide variations in annual precipitation, and experiences periodic dry periods. Summers can be hot, with temperatures commonly exceeding 100 degrees Fahrenheit.

Based on the historical data obtained from Western Regional Climate Center (WRCC) National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Network (COOP) stations in Colusa (Station 041948) and Orland (Station 046506), the recorded average monthly temperatures within the subbasin range from 46 to 80 degrees Fahrenheit, but the extreme low and high daily temperatures have been 15 and 120 degrees Fahrenheit, respectively (WRCC, 2020).

The average annual precipitation varies from about 21 inches in the northern portion of the subbasin to about 15 inches in the south. Due to the variable topographic relief of the subbasin, temperature and precipitation can vary greatly with location.

The Colusa station has recorded precipitation for water years 1949 through 2019 and the Orland station for 1905 through 2019. The water year starts October 1, ends on September 30, and is denoted by the calendar year of its end date. Figure 3-2 shows the annual water year precipitation measured at Colusa and Orland for water years 1949 through 2020. Water years missing more than 30 days of data during the rainy season were considered incomplete and were not included in this evaluation. The rainy season is interpreted to be October through April (Figure 3-2). Data was incomplete for water years 1952-1953, 1974, 1982, 1993-1998, and 2011-2013 at Colusa and water years 1906-1907, 1910, 1914, 1916-1920, 1941, 1981, 1994, 1996, and 2011-2012 at Orland. Historical precipitation shown on Figure 3-2 for these years is the minimum precipitation measured for the water year.

Multiple-year dry periods experienced in the Subbasin roughly correspond with state-wide multiple-year droughts. Multiple-year dry periods recorded within the Subbasin area include:

- 1949-1950
- 1954-1955
- 1959-1962
- 1964-1966
- 1971-1972
- 1976-1977
- 1987-1991
- 2007-2009
- 2012-2016

Figure 3-3 shows the exceedance curves for the Colusa and Orland precipitation data. The entire period of record except for water years with incomplete data was used for each station's exceedance curve. The figure shows the frequency at which a given level of annual precipitation was met or exceeded. The curve can be used to gauge how frequently the precipitation recorded in any given year was equaled or exceeded in the past. For example, the minimum historical precipitation of 8.15 inches recorded in Orland occurred in 1924 and was met or exceeded in 100 percent of years throughout Orland's period of record. Similarly, 90 percent of water years over Orland's period of record met or exceeded the 11.5 inches of precipitation measured in 2014.

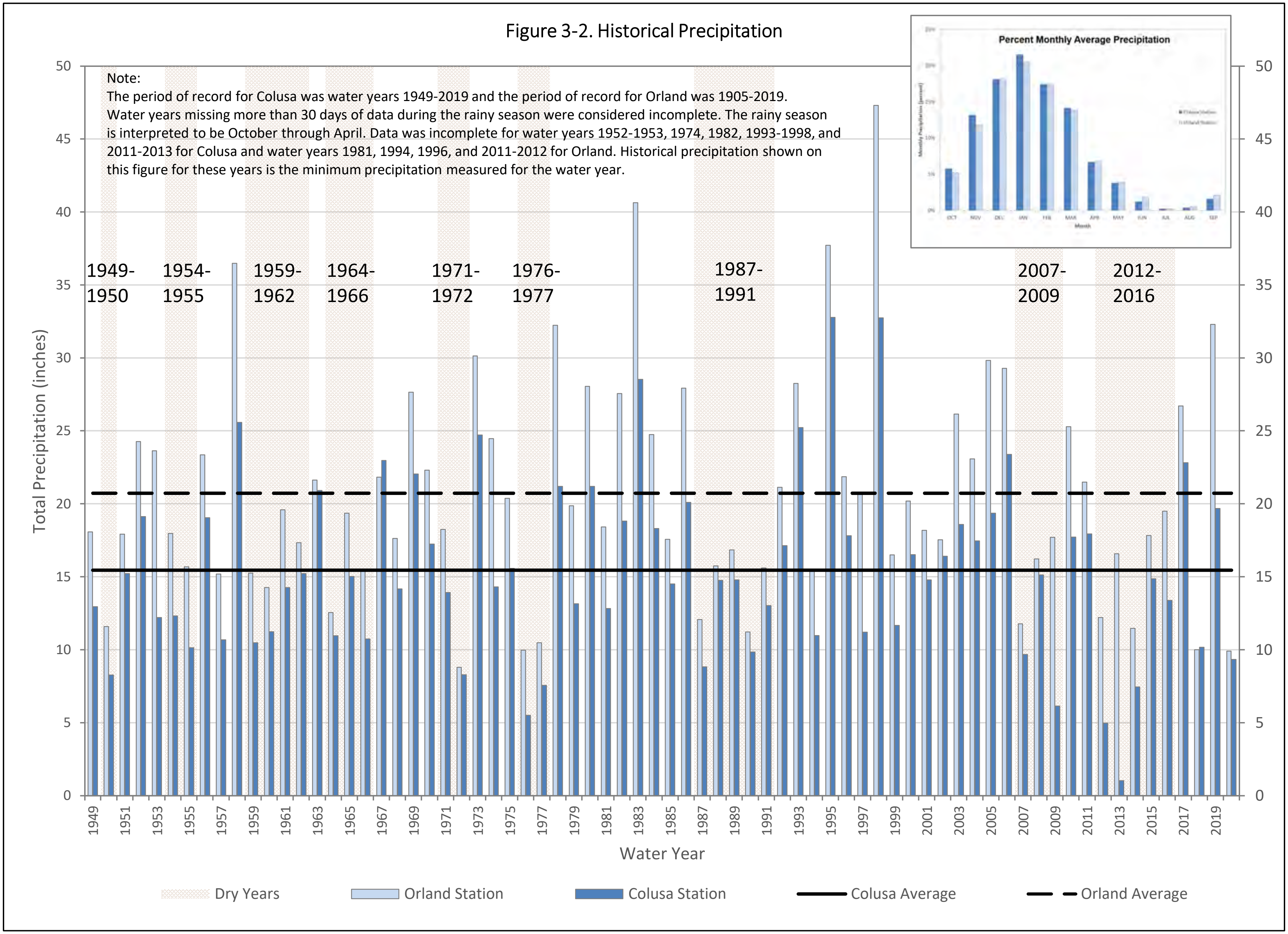


Figure 3-2. Historical Precipitation

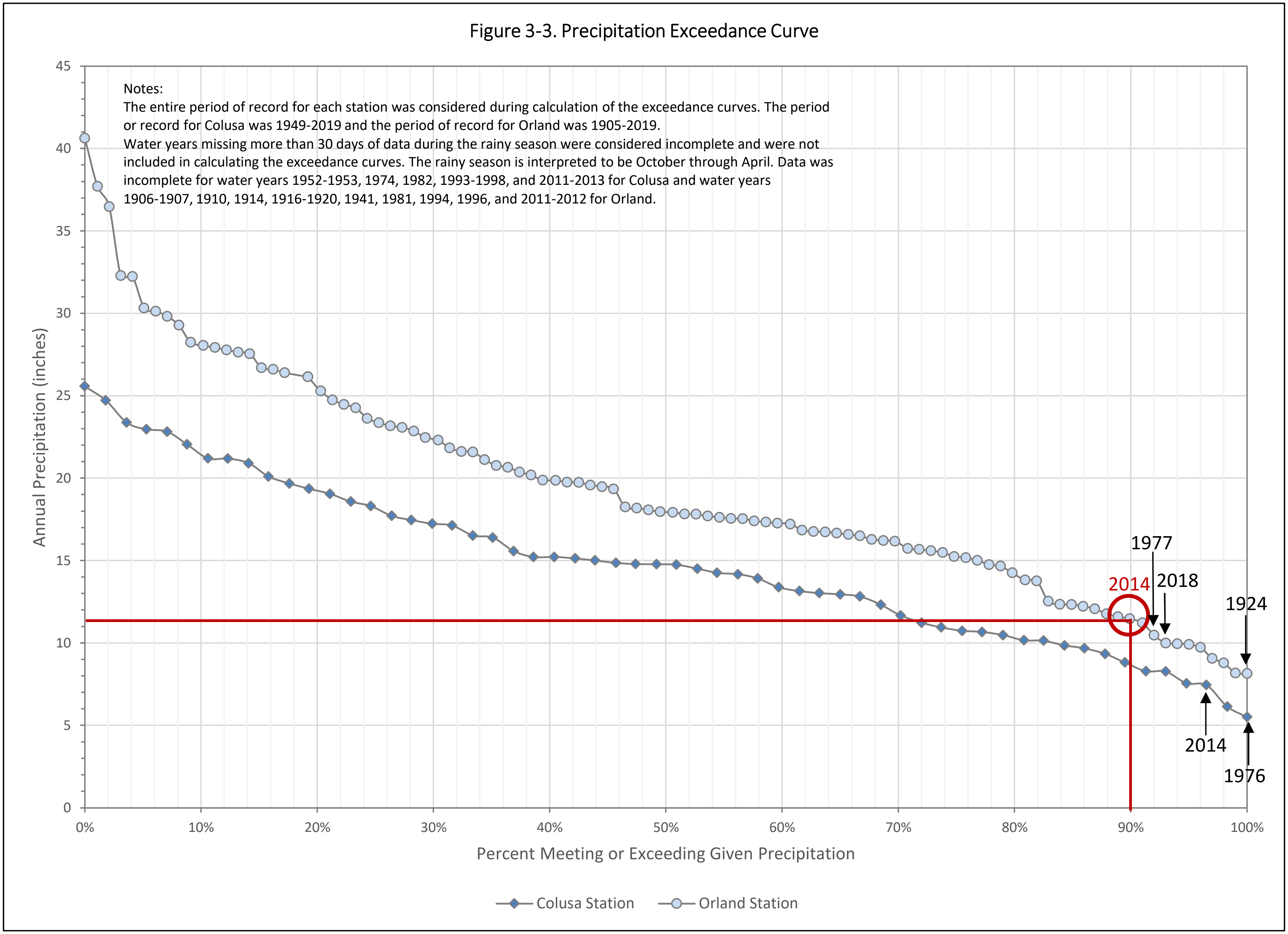


Figure 3-3. Precipitation Exceedance Curve
Notes:
The entire period of record for each station was considered during calculation of the exceedance curves. The period or record for Colusa was 1949-2019 and the period of record for Orland was 1905-2019.
Water years missing more than 30 days of data during the rainy season were considered incomplete and were not included in calculating the exceedance curves. The rainy season is interpreted to be October through April. Data was incomplete for water years 1952-1953, 1974, 1982, 1993-1998, and 2011-2013 for Colusa and water years 1906-1907, 1910, 1914, 1916-1920, 1941, 1981, 1994, 1996, and 2011-2012 for Orland.
Annual Precipitation (inches)
Percent Meeting or Exceeding Given Precipitation
1977
2018
2014
1924
2014
1976
Colusa Station
Orland Station

3.1.4 Topography

Figure 3-4 shows the topography of the Subbasin. The topography throughout the subbasin encourages drainage east towards the Sacramento River and south towards the San Joaquin-Sacramento River Delta (Delta). The western side of the subbasin is elevated and includes low foothills that transition to the higher elevation Coast Range. Streams from the Coast Range drain eastward through low alluvial plains towards the Sacramento River.

Elevations greater than 1,000 feet North American Vertical Datum of 1988 (NAVD 88) occur within the northwestern and the southwestern portion of the subbasin. These areas of high terrain are associated with the Coast Range foothills near Black Butte Lake and the northernmost extent of the Capay Hills. Minimum land surface elevations of less than 30 feet NAVD 88 occur in the southern portion of the subbasin between the Colusa Basin Drainage Canal System (Colusa Drain) and the Sacramento River. Elevations along the Sacramento River range from about 150 feet NAVD 88 at the northeast boundary of the subbasin to about 40 feet NAVD 88 near the southeast boundary of the subbasin.

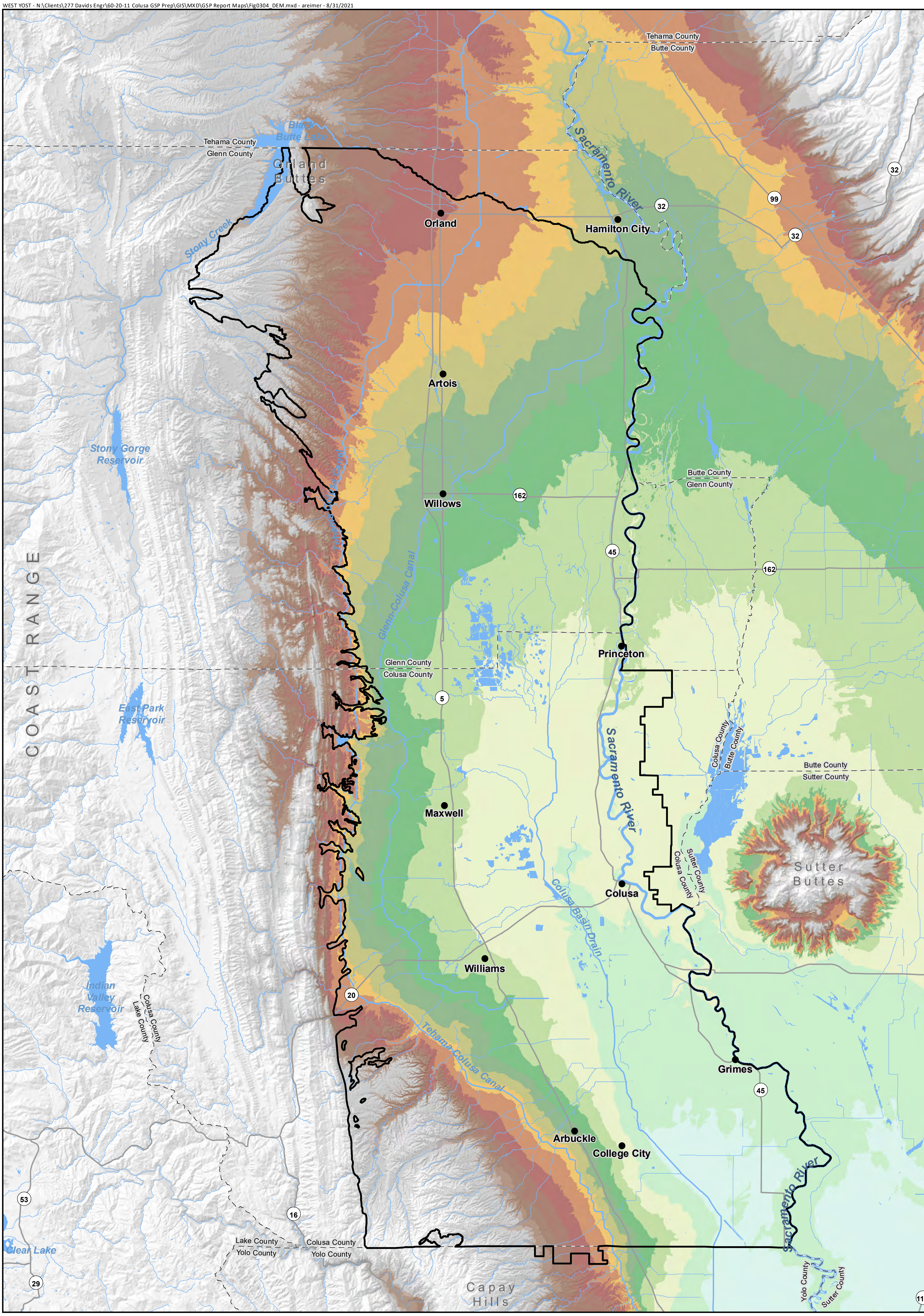
3.1.5 Hydrology

The physical hydrology of the Subbasin is influenced by the underlying geology, geomorphology and topography of the region and the Sacramento Valley's large agriculture industry. Chemical hydrology of waters within the Subbasin are similarly impacted by geology, lithology, and geomorphology, as different geologic and lithologic sediments can leach or filter chemicals into or out of groundwater solution. Hydrogeologic structures can also impact flow paths of waters within the subsurface and up to stream beds, allowing or impeding mixing of waters with different chemical signatures. Physical surface water hydrology is discussed in this section. Stratigraphic features that can impact water flow regime are discussed in Section 3.1.9. Groundwater quality is discussed in Section 3.1.10.3 and Section 3.2.5.

Figure 3-5 shows watersheds and natural waterways in the Subbasin. The Sacramento River is the principal stream in the subbasin and contributes significantly to the statewide water supply. Most of the streams within the region drain the Sierra Nevada to the east and the Coast Ranges to west and are tributary to the Sacramento River.

The drainage watersheds of these tributary streams within or adjacent to the Colusa Subbasin include:

- Big Chico Creek Sacramento River watershed (hydrologic unit code 08 [HUC08] 18020157), which drains into the Sacramento River at the northern boundary of the Subbasin;
- Upper Stony Creek watershed (HUC08 18020104), which drains into Stony Creek along the northern boundary of the Subbasin;
- Butte Creek watershed (HUC08 18020158), which drains into the west-central portion of the Subbasin, east of the Sacramento River;
- Honcut Headwaters – Lower Feather River watershed (HUC08 18020159), which drains into the Sacramento River south of the City of Colusa and flows along the Subbasin boundary; and
- Sacramento Stone Corral watershed (HUC08 18020104), which drains the Coast Range foothills west of the Subbasin, as well as the majority of the Subbasin, itself.



Source: USGS 1/3-arcsecond National Elevation Dataset (NED) Digital Elevation Model (DEM) N39W122, N39W123, N40W122, and N40W123.

Datums: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet. North American Vertical Datum of 1988, feet (NAVD 88).

Note:
1. Elevations greater than 1,000 ft NAVD 88 are shown as white on this map.

Colusa Subbasin

Land Surface Elevation (NAVD88, feet)

< 30	100 - 125	200 - 250	400 - 450
30 - 50	125 - 150	250 - 300	450 - 500
50 - 75	150 - 175	300 - 350	500 - 750
75 - 100	175 - 200	350 - 400	750 - 1,000
			> 1,000

N

0 2.5 5

Scale in Miles

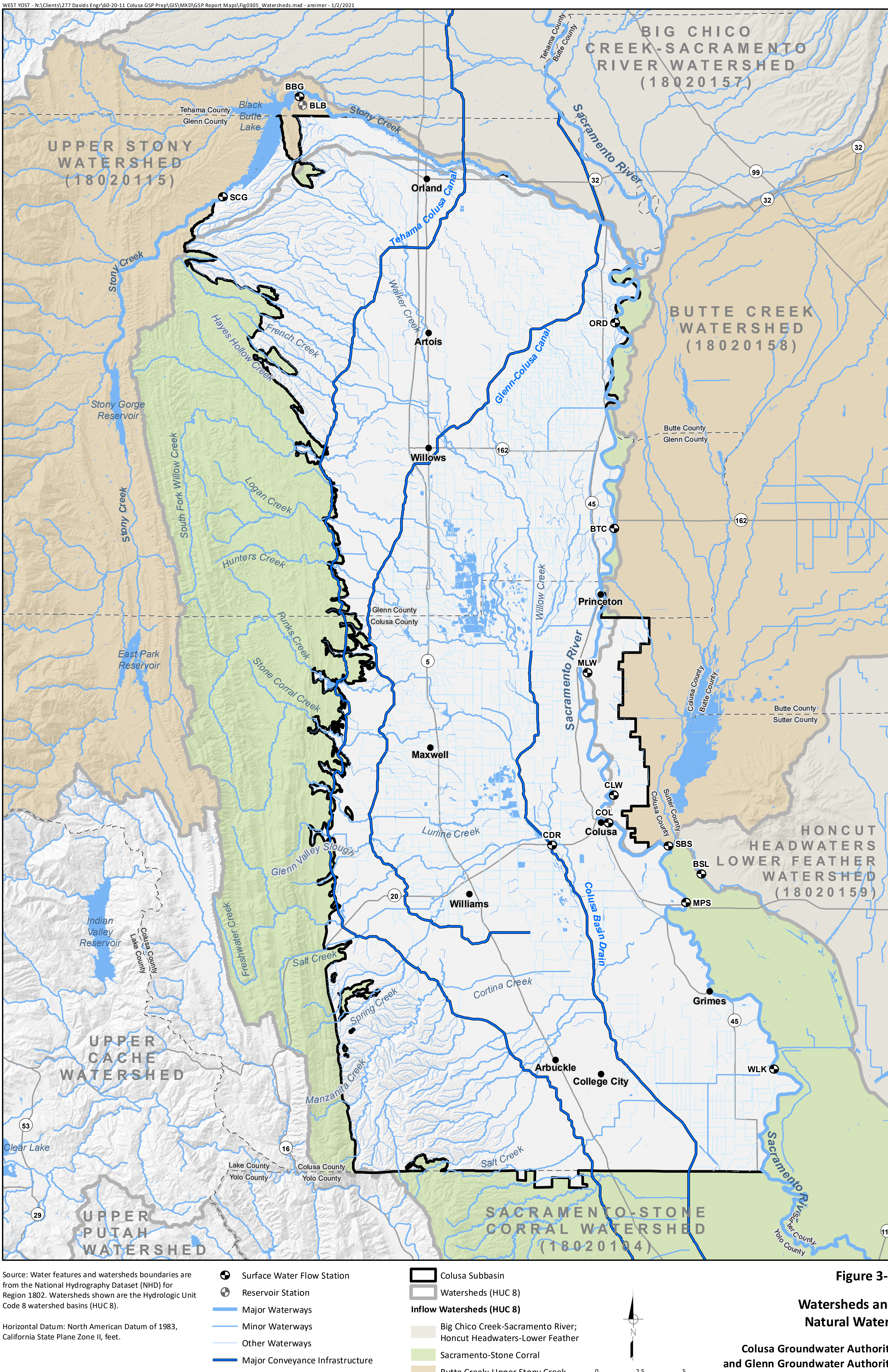
Figure 3-4

Topography

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan



Source: Water features and watersheds boundaries are from the National Hydrography Dataset (NHD) for Region 1802. Watersheds shown are the Hydrologic Unit Code 8 watershed basins (HUC 8).

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

- Surface Water Flow Station
- Reservoir Station
- Major Waterways
- Minor Waterways
- Other Waterways
- Major Conveyance Infrastructure
- Other Water Conveyance Infrastructure
- Water Bodies
- Colusa Subbasin
- Watersheds (HUC 8)

Inflow Watersheds (HUC 8)

- Big Chico Creek-Sacramento River; Honcut Headwaters-Lower Feather
- Sacramento-Stone Corral
- Butte Creek; Upper Stony Creek

0 2.5 5

Scale in Miles

Figure 3-5

Watersheds and Natural Waters

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan

The dominant north-northwesterly south-southeasterly structural trends in the Coast Range west of the Subbasin result in long narrow valleys and ridges. These topographic features have produced a drainage network that routes most of the Coast Range runoff to the Subbasin via Stony Creek, which flows north in the Coast Range through Stony Gorge Reservoir to Black Butte Lake before entering the Subbasin along its northern boundary and discharging into the Sacramento River. To the southwest in the Coast Range, similar geologic, geomorphic and topographic influences route most of the runoff through the Upper Cache Creek watershed in a southeasterly direction where it contributes to flows in Cache Creek. Cache Creek enters the Sacramento Valley south of the Subbasin in the Yolo Subbasin. As a consequence of the dominance of the Upper Stony and Upper Cache Creek watersheds in capturing most of the runoff from the higher elevations in the Coast Range, the remainder of the other Coast Range streams influent to the subbasin have relatively small catchment areas in low elevation areas of the Coast Range. These streams are intermittent and drain the foothills that border the Coast Ranges to the west.

Canals and drains intersect streams and creeks to provide a water supply and drainage network, which is shown on Figure 3-6. Major water features and conveyance infrastructure that serve agencies within the Subbasin include the Sacramento River, Stony Creek, Black Butte Lake, the Tehama-Colusa Canal, Glenn-Colusa Canal, and the Colusa Drain. The major water features and conveyance infrastructure are discussed in the following section. More detailed information regarding flows and volumes are discussed in the water budget chapter.

3.1.5.1 Natural Surface Waters and Conveyance Infrastructure

The regional watersheds and natural waterways are shown on Figure 3-5. The major natural waterways flowing into, through, or along the boundary of the Subbasin include the Sacramento River and Stony Creek. Many smaller intermittent streams drain the foothills that abut the Coast Ranges west of the Subbasin. Three major water conveyance infrastructures also exist within the subbasin. These are the Tehama-Colusa Canal, the Glenn-Colusa Canal, and the Colusa Drain. Smaller canal and channel systems transport water between the natural waterways and conveyance infrastructure. The natural and man-made water channels within the Subbasin are interconnected. Figure 3-5 and Figure 3-6 show the surface hydrology of the Subbasin. The major waterways are discussed in the following subsections.

3.1.5.1.1 Black Butte Lake and Stony Creek

The Upper Stony Creek watershed drains an approximately 770 square mile area of the Coast Range, foothills, and uplands, most of which is situated west of the Subbasin. Stony Creek south of the Glenn-Tehama County line defines the boundary between the Colusa and Corning Subbasins. The Stony Creek headwaters are in the Coast Range terrain of western Colusa County. Stony Creek flows north toward Stony Gorge Reservoir, which was constructed in 1928. Water discharged from Stony Gorge Reservoir continues northeast to Black Butte Lake, where most of the drainage within the Stony Creek watershed is eventually captured. According to data listed on the CDEC website and shown on Figure 3-7, storage within Black Butte Lake has been between 1,200 af and 140,000 af since 1963, when it was constructed. The lowest lake storage was recorded in Fall 1977, a critically dry year. Releases from Black Butte Lake, monitored by the USBR and available on CDEC, from 1996 to 2020 fluctuated between 0 and 24,000 cubic feet per second (cfs) (CDEC, 2020). Discharges from Black Butte Lake flow into either Stony Creek or canals that irrigate agricultural lands of the Colusa and Corning Subbasins. Stony Creek eventually drains into the Sacramento River. Historical streamflow in Stony Creek near Hamilton City from 1941 to 1963, prior to the construction of Black Butte Lake, ranged between 0 and 30,000 cfs.

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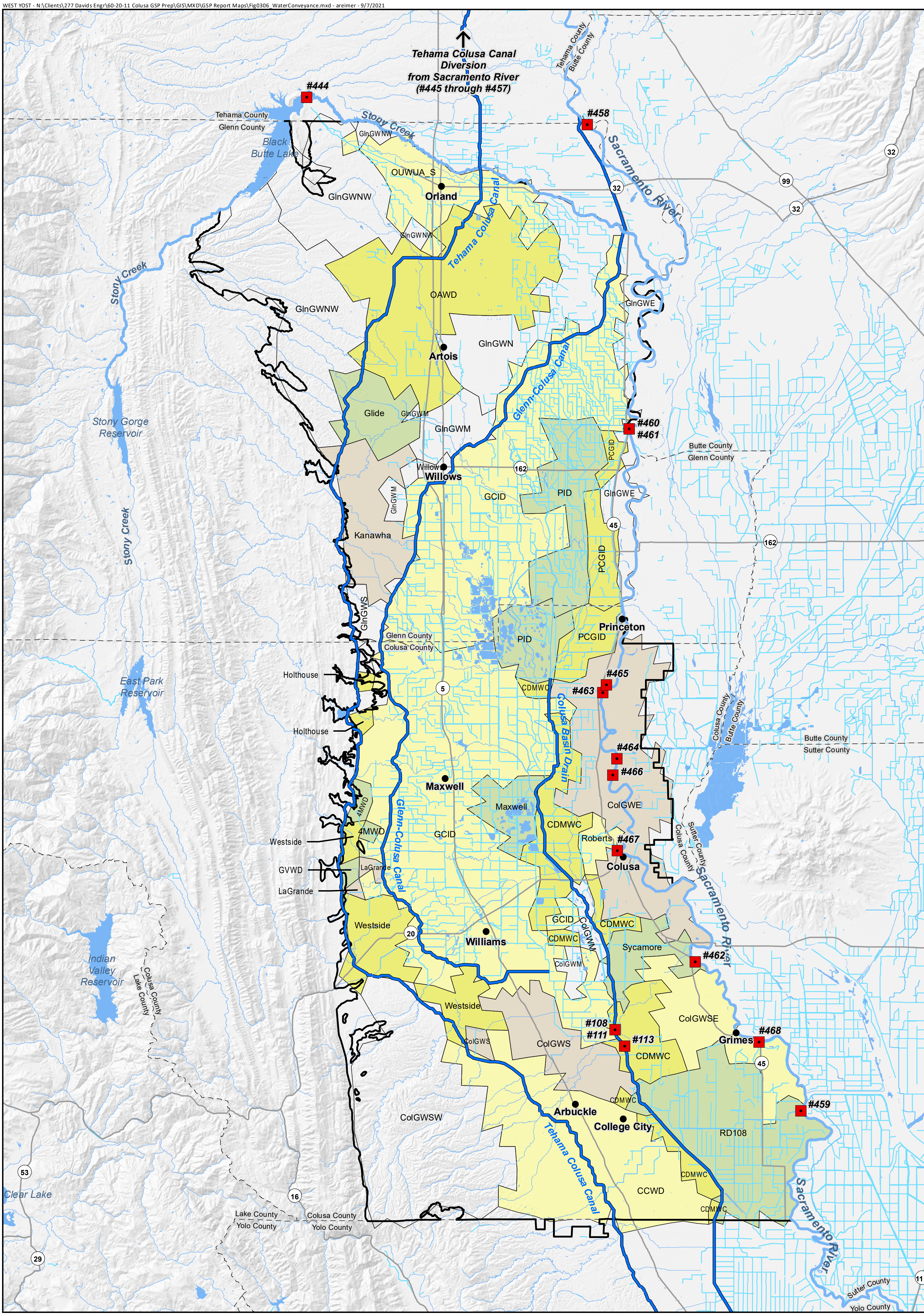


Source: Water features are from the National Hydrography Dataset (NHD) for Region 1802. Diversion points and model subareas were extracted from the C2VSimFG-Colusa hydrologic model.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Note:
1. Diversions 445 to 457 are located where the Tehama Colusa Canal diverts water from the Sacramento River and are not shown on this map.

Major Waterways
Minor Waterways
Major Conveyance Infrastructure
Other Conveyance Infrastructure
Water Bodies
Colusa Subbasin

Modeled Surface Water Diversion

Modeled Subareas that Receive Diverted Water

- 4MWD, GVWD, Glide, Maxwell, PID, RD108, Sycamore
- CCWD, ColGWSE, GCID, OUWUA_S, Roberts
- CDMWC, Holthouse, OAWD, PCGID, Westside
- ColGWE, ColGWS, Kanawha, LaGrande
- Subareas that Do Not Receive Delivered Water: ColGWM, ColGWSW, GlnGWE, GlnGWM, GlnGWN, GlnGWNW, GlnGWS, Willows

N

0 2.5 5

Scale in Miles

Figure 3-6

Water Conveyance Infrastructure

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan

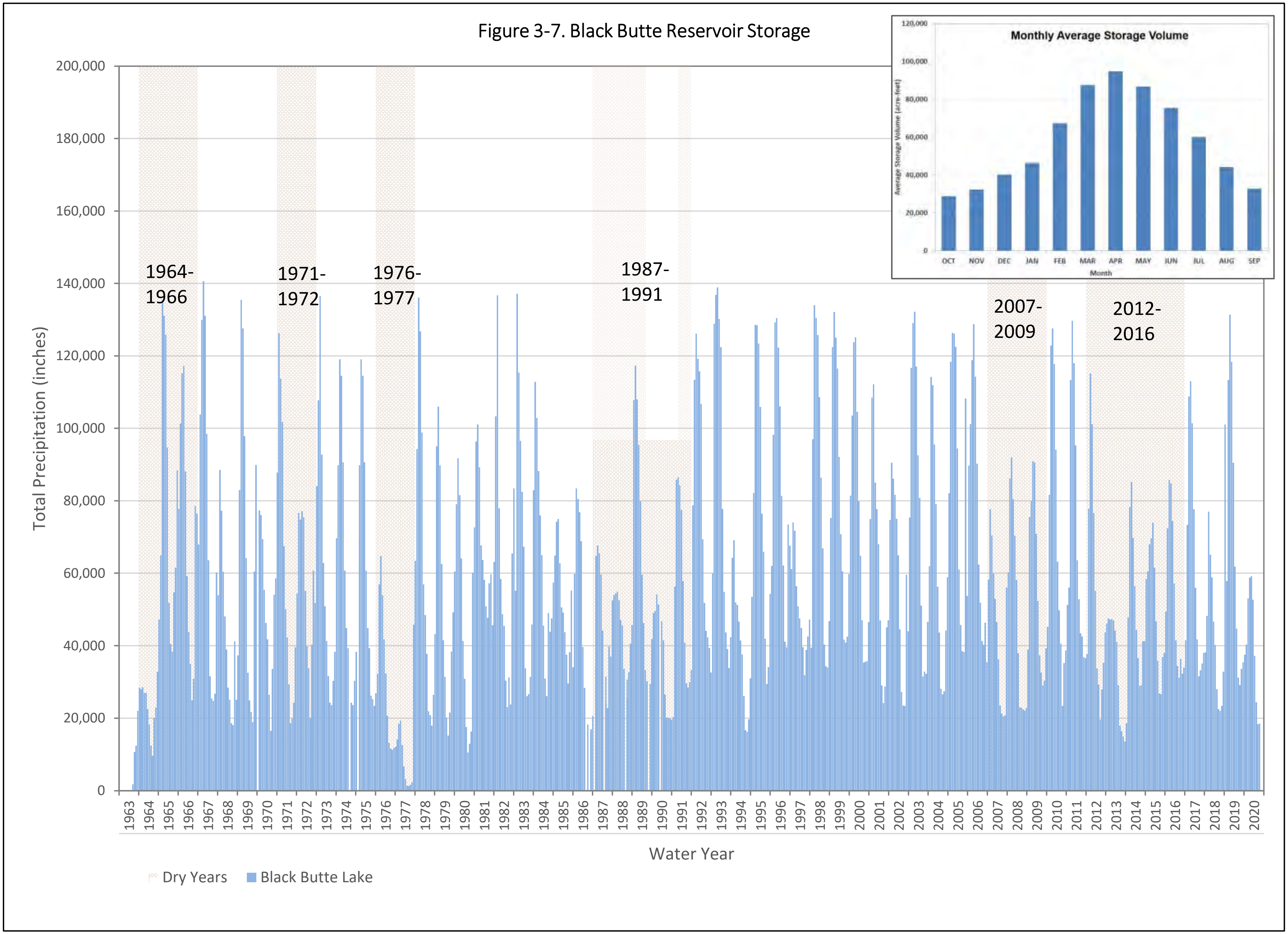


Figure 3-7. Black Butte Reservoir Storage
Total Precipitation (inches)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1964-1966
1971-1972
1976-1977
1987-1991
2007-2009
2012-2016
Water Year
Dry Years
Black Butte Lake
Monthly Average Storage Volume
Average Storage Volume (acre-feet)
120,000
100,000
80,000
60,000
40,000
20,000
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
Month

3.1.5.1.2 Sacramento River

The Sacramento River flows north to south along the eastern boundary of the Subbasin. The Sacramento River provides approximately 80 percent of the inflow to the Delta and is the largest and most important riverine ecosystem in the State of California (DWR, 2009a). In addition to providing flows to the Delta, the Sacramento River is the primary water source for irrigation water suppliers and certain landowners within the subbasin. Sacramento River stream flows measured at the Ord Ferry-Main Channel stream gage, in the northern part of the Subbasin, varied between 200 and 160,000 cfs during the 1984 to 2020 time period, with extreme low flows measured in the spring of 1990. River flows at Butte City (Station USGS 113890000) were record between 1939 and 2020 and ranged between 170,000 and 1,400 cfs. Stream flows measured at the stream gage below Wilkins Slough (Station USGS 11390500), south of Grimes, varied between 2,400 and 33,000 cfs for its entire period of record 1939 to 2020. Ord Ferry and Butte City are both located northwest of the Sutter Buttes and upstream of the confluence with Butte Creek, while Grimes is south of the Sutter Buttes. Figure 3-8 depicts the historical flows at these two locations. Flows at Wilkins Slough have historically remained fairly stable with the primary exceptions being critically dry years. Flows in the upstream stations are more seasonally and climatically variable and depict more of a response to dry years. Overall streamflows at all three stations have declined since 1995.

3.1.5.1.3 Tehama-Colusa Canal

The Tehama-Colusa Canal is operated and maintained by the Tehama-Colusa Canal Authority (TCCA), located near Willows, Glenn County. The TCCA service area covers approximately 150,000 acres and extends from Tehama County to Yolo County and provides irrigation water to farmers growing a variety of permanent and annual crops within the Subbasin. The Tehama-Colusa Canal originates north of the Subbasin at the Red Bluff Pumping Plant and Fish Screen in Tehama County, runs along the west side of the Colusa, and terminates south of the subbasin near Dunnigan Water District, Yolo County. Of the approximately 140 miles of TCCA water supply system, 75 miles of the Tehama-Colusa Canal traverses the Subbasin.

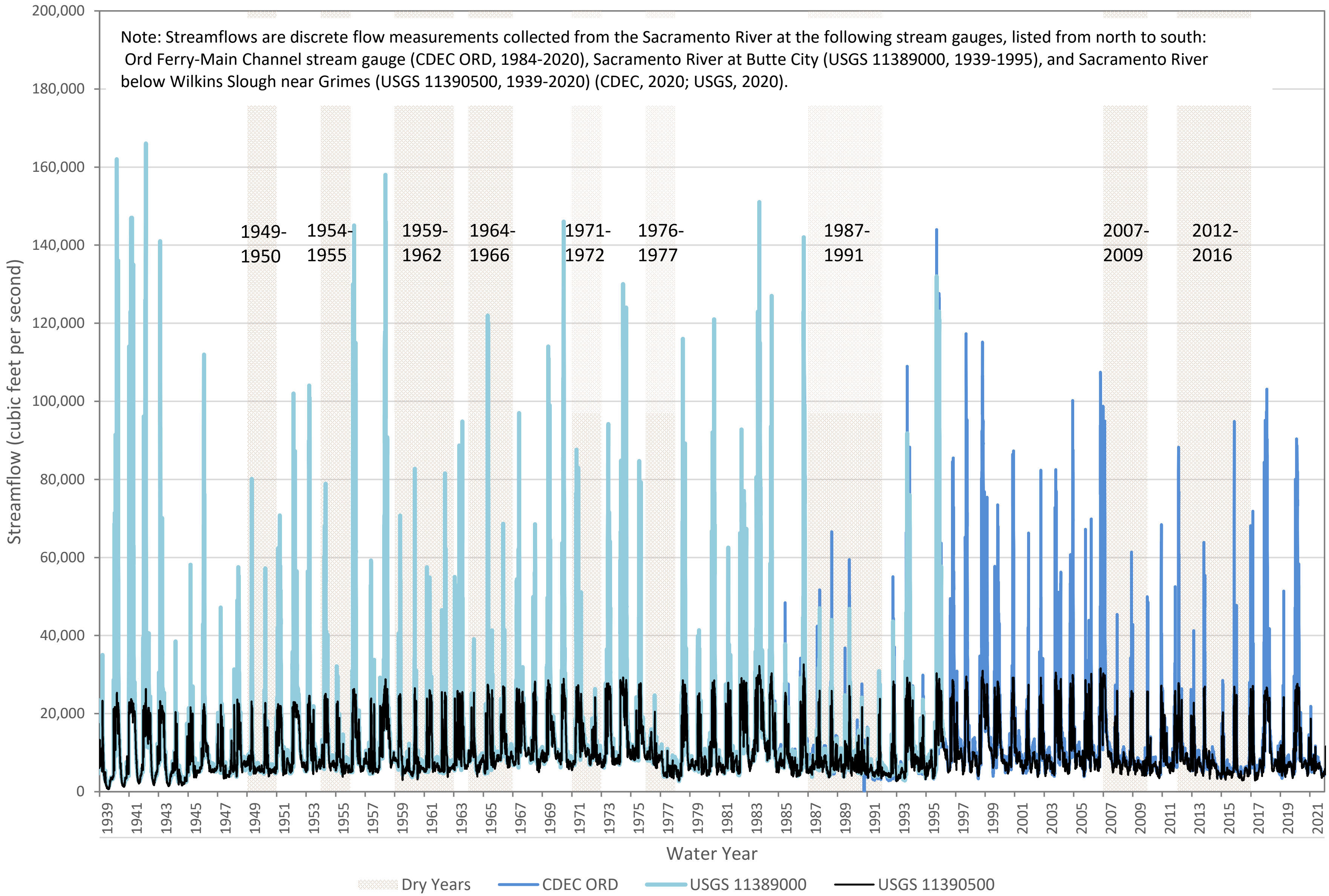
3.1.5.1.4 Glenn-Colusa Canal

The Glenn-Colusa Canal system is situated east of the Tehama-Colusa Canal and west of the Sacramento River. The Glenn-Colusa Canal originates on the Sacramento River north of the Subbasin and extends south of Williams, Colusa County, where it flows into the local canal system. The Glenn-Colusa Canal is operated by the Glenn-Colusa Irrigation District (GCID), located in Willows. GCID covers approximately 175,000 acres; of which, approximately 140,000 acres are farmed, making it the largest irrigation district in the Sacramento Valley (GCID, 2017). In addition to serving agricultural lands, GCID services approximately 1,200 acres of private habitat land and 20,000 acres of protected federal wildlife land. The main canal is approximately 65 miles long and conveys water into a complex system of nearly 1,000 miles of canals, laterals, and drains.

3.1.5.1.5 Colusa Basin Drainage Canal System

The Colusa Basin Drainage Canal System, or Colusa Drain, is a drainage system that transports rainfall runoff, agricultural runoff and return flows away from the agricultural lands in the Subbasin to the Sacramento River and the Tule Canal near Knights Landing, Yolo County. Many of the smaller natural streams of the region, including Willow Creek, drain into the Colusa Drain. Some of the water within the Colusa Drain is captured and reused prior to being discharged into the Sacramento River.

Figure 3-8. Sacramento River Streamflows



3.1.5.1.6 Other Streams

Walker Creek (near Artois) and Willow Creek (near Willows) are north-south trending streams largely contained within the subbasin (Figure 3-5). There are many ephemeral and intermittent streams that flow into or through the subbasin. These include ephemeral and intermittent streams that drain the foothills between the Subbasin and the higher elevation areas of the Coast Ranges. Historically, some of these streams were connected to springs at their headwaters or along their drainage reaches, where shallow groundwater would discharge into the channel. These foothill drainages and their tributaries are classified as part of the Sacramento-Stone Corral Watershed, as defined by the National Hydrology Dataset (NHD). The following streams comprise the Sacramento Stone Corral watershed, which bounds most of the Subbasin on its western side:

- Walker Creek
- Willow Creek
- French Creek
- Hayes Hollow Creek
- South Fork Willow Creek
- Logan Creek
- Hunters Creek
- Funks Creek
- Stone Corral Creek
- Lurline Creek
- Glenn Valley Slough
- Freshwater Creek
- Salt Creek (which flows past Williams, Colusa County)
- Spring Creek
- Manzanita Creek
- Cortina Creek
- Salt Creek (which flows past Arbuckle, Colusa County)
- Hambright Creek

Runoff in these ephemeral and intermittent streams generally begins in late fall when the rainy season starts and may continue until late spring. Inter-annual runoff patterns from streams such as these are highly variable, and many, if not all, of these streams flow into drainage canals within the subbasin. For example, Walker Creek and Willow Creek flow into the upstream end of the Colusa Drain, and other creeks, including Stone Corral Creek and both Salt Creeks, flow into the Colusa Drain's lower reaches (Figure 3-5).

3.1.5.2 Imported Water Sources and Points of Delivery

The primary surface water bodies through, or from, which imported waters are delivered to entities within the Subbasin include the Sacramento River and Stony Creek, with the Tehama-Colusa Canal and the Glenn-Colusa Canal being the primary conveyances of Sacramento River water. These surface water features, along with the regional and local water conveyance infrastructure, are shown on Figure 3-6. Water delivered via the Tehama-Colusa Canal, Sacramento River, Stony Creek, and other Central Valley Project contracts are managed by USBR.

Modeled points of surface water diversions included in the C2VSimFG-Colusa model and their delivery areas are shown on Figure 3-6 and listed in Table 3-2. The sources and delivery points for imported waters are described in more detail in the model development and calibration Technical Memorandum prepared by Woodard & Curran and Davids Engineering (2021) (Appendix 3D).

Table 3-2. Surface Water Diversions Delivered to Land

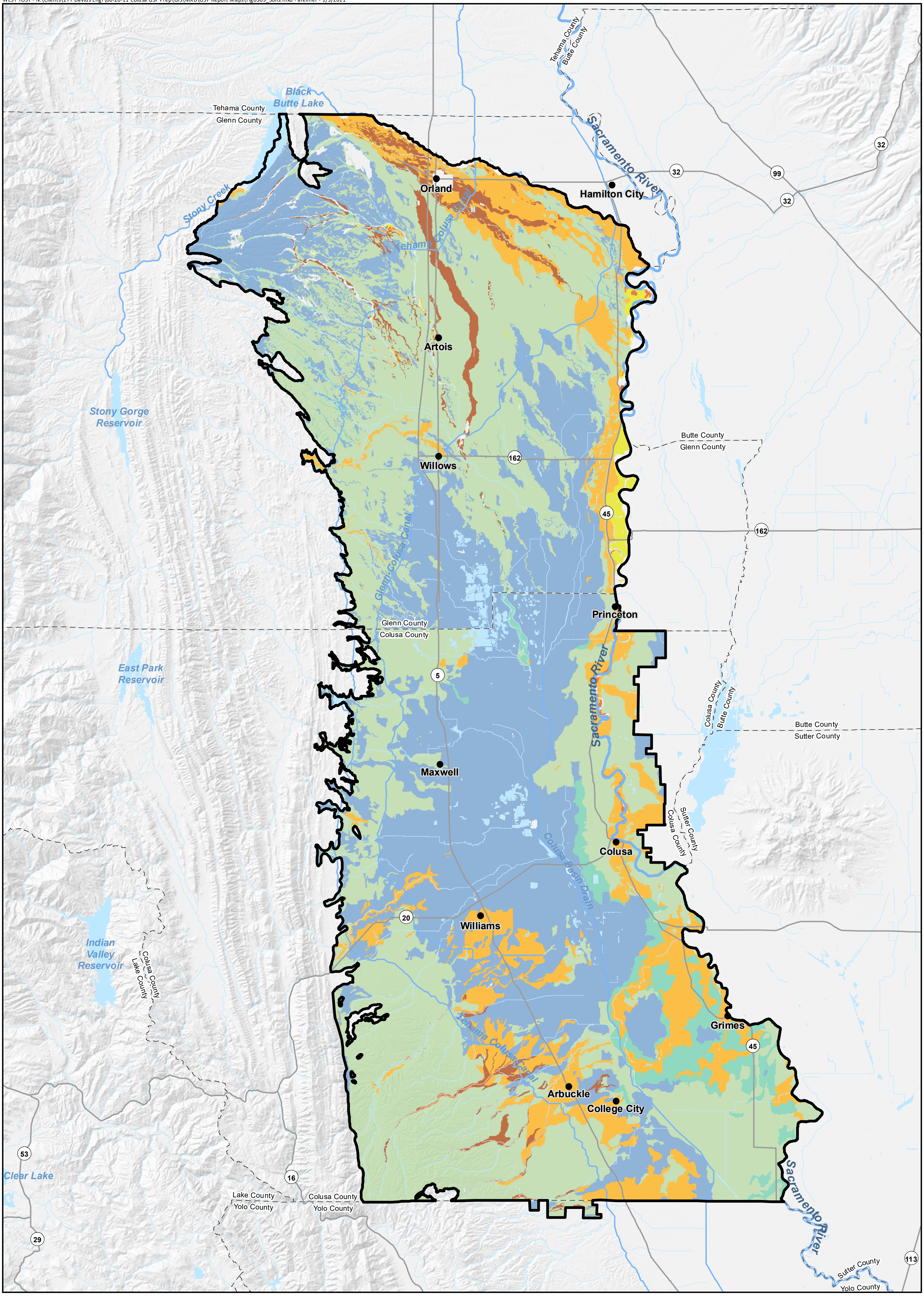
Model Diversion ID[(a)]	Description	Modeled Delivery Subarea	Data Source
444	Orland Unit Water Users' Association (OUWUA) (South Canal only)	OUWUA_S	USBR
445	Colusa County WD	CCWD	USBR
446	Orland-Artois WD (OAWD)	OAWD	USBR
447	Glenn-Colusa ID (Tehama-Colusa Canal)	GCID	USBR
448	Westside WD	Westside	USBR
449	Kanawha WD	Kanawha	USBR
450	Glide WD	Glide	USBR
451	La Grande WD	LaGrande	USBR
452	Davis WD	Westside	USBR
453	4-M WD	4MWD	USBR
454	Holthouse WD	Holthouse	USBR
455	Glenn Valley WD	GVWD	USBR
456	Cortina WD	CCWD; ColGWS	USBR
457	Myers-Marsh MWC	GCID; ColGWS	USBR
458	Glenn-Colusa ID Main Canal	GCID	USBR, GCIDWIS, and eWRIMS
459	Reclamation District #108	RD108	USBR
460	Princeton-Codora-Glenn ID	PCGID	USBR
461	Provident ID	PID	USBR
462	Sycamore MWC	Sycamore	USBR
463	Maxwell ID	Maxwell	USBR
464	Carter Mutual Water Company	ColGWE	USBR
465	Misc Sac River Riparian Diversions	ColGWE	USBR
466	Misc Sac River Riparian Diversions	ColGWE	USBR
467	Misc Sac River Riparian Diversions	ColGWE; Roberts	USBR
468	Andreotti, Arnold and Arthur, et al	ColGWSE	USBR
108	Colusa Drain to Princeton-Codora-Glenn ID, Provident ID, Maxwell ID for Ag (08N_SA1)	PID; PCGID	C2VSimFG Beta2
111	Colusa Drain to Colusa NWR (08S_PR)	CDMWC	C2VSimFG Beta2
113	Colusa Drain to Colusa Drain MWC for Ag (08S_PA)	CDMWC	C2VSimFG Beta2

(a) Diversion ID in the C2VsimFG-Colusa model. C2VsimFG-Colusa was adapted from the C2VSimFG Beta2 model.

3.1.6 Soils

According to DWR (1978), which summarizes work performed by the USGS (Bertoldi, 1974), most soils in the Subbasin are either: 1) "soils containing hardpan or other consolidated horizons that restrict the vertical flow of water, including soils over bedrock", such as occurs in the western upland areas; or 2) "soils containing clay in sufficient quantities to impede the vertical flow of water", such as occurs in the former flood basins of the Sacramento River. Exceptions to this generalization are the soils in the vicinity of Stony Creek and stream channel deposits adjacent to the Sacramento River, which have "few barriers to the vertical flow of water" (DWR, 1978). These general patterns are supported by more recent soil surveys conducted by the Natural Resources Conservation Service (NRCS). Areas containing soils with few barriers to vertical flow have higher potential to recharge the underlying aquifers.

Figure 3-9 contains the NRCS Soil Survey Geographic Database (SSURGO) hydrologic soil group designations. Much of the Subbasin is classified as hydrologic groups C and D, which are defined as soils with slow or very slow infiltration rates when saturated (NRCS, 1986). Slow infiltration rates, as defined by NRCS, can be due to the presence of fine-textured layers, clays with high shrink-swell potential, shallow water tables, or shallow soil layers underlain by near-impervious layers. The Stony Creek alluvial fan, the Sacramento River historic channel, and runoff areas of northern Dunnigan Hills contain hydrologic soil groups A and B, which are defined as areas with high and moderate infiltration rates when saturated, respectively, occasionally mixed with soil group D (NRCS, 1986). Soils classified as mixed D soils (A/D, B/D, or C/D) typically correspond to soils near shallow water tables. These mixed D soils exhibit very low infiltration rates when undrained (characteristic of soil group D), and the alternate level of infiltration when drained (characteristic of soil group A, B, or C).



Source: Soil Survey Geographic Database (SSURGO) soils were downloaded via the 2014 SSURGO Downloader for the Big Chico Creek - Sacramento River, Butte Creek, Honcut Headwaters - Lower Feather, Sacramento Stone Corral, Upper Cache, and Upper Stony watershed subbasins.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Note:
1. SSURGO soil designations outside of the study area are not shown in this map.

Study Area
Water

Hydrologic Soil Type

A
A/D
B
B/D
C
C/D
D

N

0 2.5 5
Scale in Miles

Figure 3-9

Soils

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

3.1.7 Geologic Framework

This section describes the geologic framework for the Subbasin, per the BMP (DWR, 2016a) and 23 CCR §354.14(b). The regional geologic and structural setting of the subbasin and surrounding area are described, including faults and other geologic structures that may influence groundwater flow and quality.

3.1.7.1 Regional Geologic History

Table 3-3 lists the geologic units within the Subbasin and characterizes their age, lithologic character, thickness, and water bearing character (WRIME, 2003a; WRIME, 2003b). Figure 3-10 shows detailed surface geologic mapping for the Subbasin and surrounding region, and the locations of five geologic cross sections through the Subbasin. Cross sections are provided on Figure 3-11 through Figure 3-13, and a three-dimensional (3D) representation of the HCM is provided on Figure 3-14. Figure 3-15 shows the Tehama and Tuscan Formation surficial outcrops and subsurface extents, including an approximation of the subsurface Tehama-Tuscan Transition Zone, in which Tehama and Tuscan Formation deposits are intermixed (DWR, 2009b). Figure 3-16 includes elevation contours for the top of the Cretaceous rocks. These contours represent the structural base of the freshwater aquifer system (Harwood and Helley, 1987).

The cross sections were developed based on DWR's Geology of the Northern Sacramento Valley report (DWR, 2014a). Some of the original DWR cross sections were expanded and new or extended cross sections were generated to provide a geologic representation of the subsurface throughout the entire Subbasin (Figure 3-10). The revised and new cross sections were based on land surface information, well completion reports, and other geologic references for the region. References to the data used to generate the cross sections are provided in Table 3-1 and Chapter 8. The cross sections were used to generate a 3D model of the post-Cretaceous water bearing formations, and for assessment of the groundwater monitoring network.

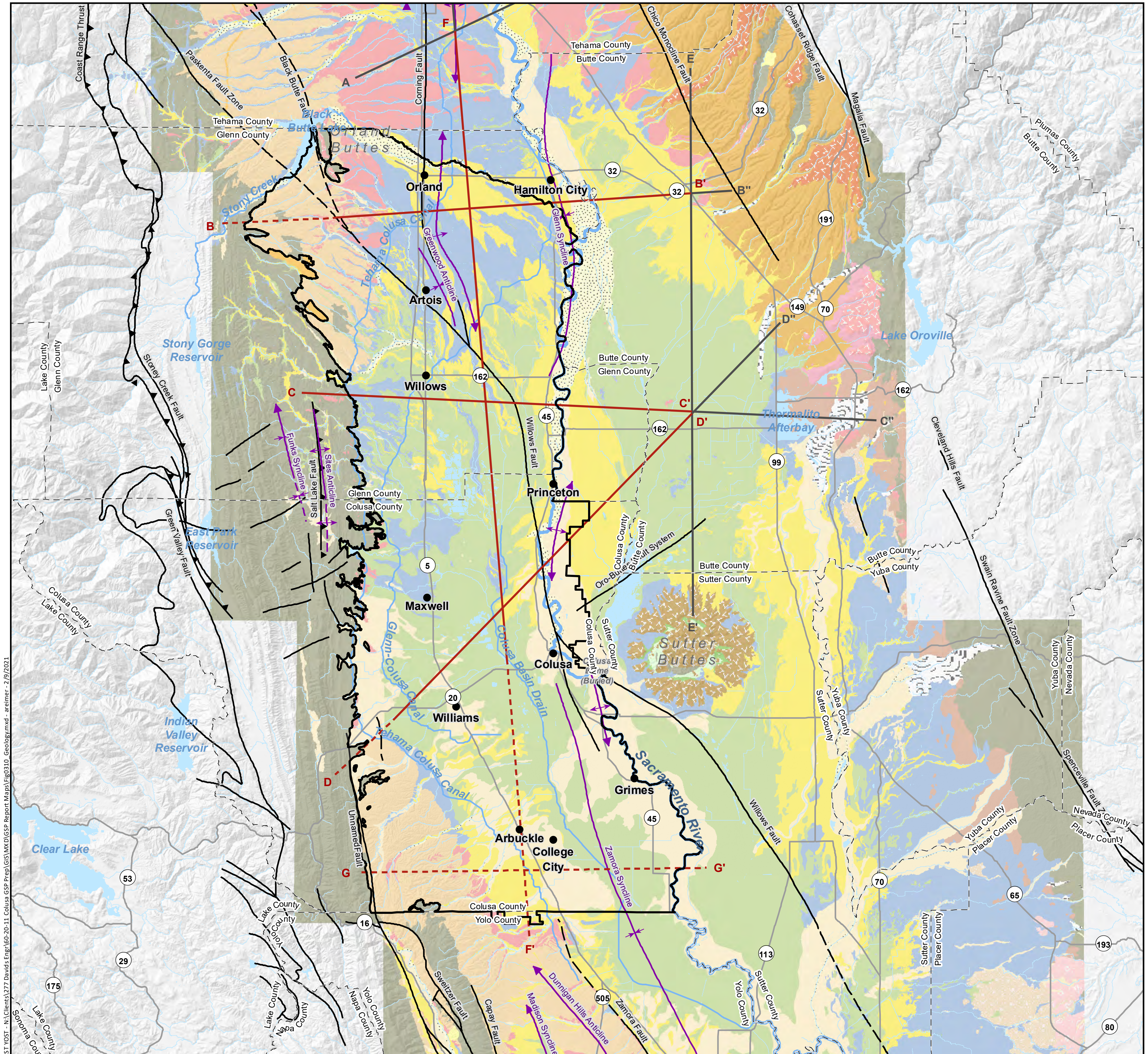
From the Late Jurassic (approximately 159 million years ago [Ma]) through the Miocene (approximately 23 Ma), much of what is now the Northern Sacramento Valley was a marine basin created in the forearc of the Pacific-North American plate subduction zone. The western boundary of the subbasin was formed by uplifting of volcanic, metamorphic and sedimentary rocks of marine origin, which would later become the Coast Ranges. This marine basin was bounded to the east by the Klamath-Sierran terrane formed during the Nevadan orogeny (approximately 155 Ma). Thick sequences of sediments eroded from the uplifted Klamath-Sierran terrane were deposited into the inland sea during the Cretaceous period. The resulting marine siltstones, sandstones, shales, and conglomerates comprise the Great Valley Sequence. Outcrops of the Great Valley Sequence define the western boundary of the Subbasin (Figure 3-10). The fresh groundwater-bearing formations overlie the Great Valley Sequence within most of the Subbasin, making it a major component of the structural base of the subbasin. The Great Valley Sequence is included in the pre-Paleogene and Cretaceous rocks referenced in the maps and within the report text. Figure 3-16 shows contours of the elevation of the top of the Cretaceous rocks in the Subbasin.

Table 3-3. Description of Geologic Units

Series		Unit	Lithologic Character	Thickness[a], ft	Water-Bearing Character
Quaternary	Holocene	Alluvium, Qa	Unconsolidated unweathered gravel, sand, silt, and clay[a].	80	Deposits are moderately to highly permeable with high permeability gravelly zones yielding large quantities to shallow wells[b]. Although deposits along Stony, Chico, and Thomes Creeks are important recharge areas[b], extensive water-bearing capacity is restricted by thickness and areal extent[a].
Quaternary	Holocene	Basin Deposits, Qb	Unconsolidated[e] fine-grained silts and clays, locally interbedded with stream and channel deposits along the Sacramento River[a].	150	Deposits are typically saturated nearly to the ground surface[b]. The low to moderate permeability results in yields of small quantity and poor groundwater quality to domestic wells[a,b].
Quaternary	Pleistocene	Modesto Formation, Qm	Poorly sorted[e] unconsolidated weathered and unweathered gravel, sand, silt, and clay[c].	200	Moderately to highly permeable[a].
Quaternary	Pleistocene	Riverbank Deposits, Qr	Poorly sorted[e] unconsolidated to semi-consolidated[c] pebble and small cobble gravels interlensed with reddish clay, sand, and silt[a].	200	Water-bearing capability is limited by thickness. These poorly to highly permeable deposits supply moderate groundwater amounts to domestic and shallow irrigation wells. Deeper irrigation wells may be supplied if the wells contain multiple perforation zones[a].
Quaternary	Pleistocene	Red Bluff Formation, Qrb	Highly weathered, sandy gravels[g].	30[g]	Water-bearing capability is limited by thickness. Fresh groundwater may occur as a perched aquifer[g].
Neogene & Quaternary	Pliocene & Pleistocene	Tehama Formation, Tte	Fluviatile moderately consolidated pale green, gray, and tan sandstone and siltstone enclosing lenses of sand and gravel; silt and gravel; and cemented conglomerate derived from the Coast Ranges[a,c].	2,000	Local high permeability zones within this characteristically low to moderate permeability unit, widespread distribution, and deep thickness cause this formation to be the principal water bearing unit in the area. Deep well yields are typically moderate, but are highly variable[b].
Neogene	Pliocene	Tuscan Formation, Tt	This series of volcanic flows, consolidated tuff breccia, tuffaceous sandstone, and volcanic ash derived from the Cascade Range interfingers with the Tehama Formation as it westerly grades into volcanic sands, gravels, and clays[a,b]. The formation is divided by layers of thin tuff or ash units into four lithologically similar units A-D[a].	1,500	Within this formation, moderately to highly permeable volcanic sediments are hydraulically confined by layers of tuff breccias and clays[b]. Units A and B are the primary water-bearing zones and are composed of volcanic conglomerate, sandstone, and siltstone layers interbedded with lahars. Stratigraphically higher, the massive lahar deposits of unit C confine groundwater in the permeable beds of units A and B1.
Neogene	Pliocene	Nomlaki Tuff Member	Tuff breccias and white tuffs of dacitic composition. This member of the Tehama and Tuscan Formations serves as an important stratigraphical marker bed in northern Sacramento Valley[e].	60[e]	Poorly permeable.
Neogene	Miocene	Neroly Formation, Tn	Marine to non-marine tuffaceous andesitic sandstone interbedded with tuffaceous shales and tuff layers. Contains local conglomerate lenses[c].	500	This formation of variable permeability contains interstitial fresh water under confined conditions(d), however, deposits of the Neroly Formation are typically located below the base of fresh water.
Neogene	Miocene	Upper Princeton Valley Fill, Tupg	Non-marine sandstone containing mudstone, conglomerate, and sandstone conglomerate interbeds[c].	1,400	Largely non-water bearing or contains interstitial confined fresh to brackish water[g].
Neogene	Miocene	Lovejoy Basalt, Tl	Black, dense, hard microcrystalline basalt[c].	65	Largely non-water bearing.
Paleogene	Eocene	Ione Formation, Ti	Marine gravels[f], sandstone with claystone, and carbonaceous interbeds[g].	500(f)	Largely non-water bearing or contains interstitial confined fresh to brackish water.
Paleogene	Eocene	Lower Princeton Submarine Valley Fill, Tlpg	Marine conglomerate and sandstone interbedded with silty shale[c].	2,400	Largely non-water bearing or contains saline water.
Cretaceous		Great Valley Sequence, JKgvs	Marine siltstone, shale, sandstone, and conglomerate[c].	15,000	Largely non-water bearing or contains saline water[b].
Pre-Cretaceous		Basement Complex, pTb	Metamorphic and igneous rocks.	n/a	May contain groundwater, mainly saline, in fractures and joints.

Source: This table was originally included as part of the hydrogeologic conceptual model for the Stony Creek Fan IGSM (WRIME, 2003)[h]. The table has been revised and expanded to include the hydrogeologic conceptual model units for the study area represented in this report.

(a) Department of Water Resources web page (www.wq.water.ca.gov).
(b) Department of Water Resources, Bulletin 118-6, 1978.
(c) Department of Water Resources, Bulletin 118-7 (Draft, not published).
(d) Department of Water Resources, Sacramento River Basin-Wide Water Management Plan-Draft, 2000.
(e) Department of Water Resources, Groundwater Levels in the Sacramento Valley Groundwater Basin, Glenn County, 1997.
(f) Springhorn dissertation, 2008.
(g) Department of Water Resources, Geology of the Northern Sacramento Valley, 2014.
(h) WRIME, Stony Creek Fan Integrated Groundwater and Surface Water Model (SCFIGSM) Hydrogeology and Conceptual Model, 2003.



Northern Sacramento Valley Geology Cross Section Used for the Hydrogeologic Conceptual Model

Section Extension or New Cross Section

Northern Sacramento Valley Geology Cross Section Not Used for the Hydrogeologic Conceptual Model

Study Area

0 4 8

Scale in Miles

Geologic Structures

- Anticline
- Syncline
- Plunging Anticline
- Plunging Syncline
- Doubly Plunging Anticline
- Double Plunging Syncline
- Fault
- Thrust Fault

Geologic Units

- Stream Channel Deposits (Holocene)
- Alluvial Deposits (Holocene)
- Basin Deposits (Holocene)
- Landslides (Quaternary)
- Modesto Formation (Pleistocene)
- Riverbank Formation (Pleistocene)
- Red Bluff Formation (Pleistocene)
- Turlock Lake Formation (Pleistocene)
- Volcanic Rocks and Lacustrine Deposits of Sutter Buttes (Pleistocene - Pliocene)
- Basaltic Rocks (Pleistocene - Pliocene)
- Tehama Formation (Pliocene)
- Nomlaki Tuff Member (Pliocene)
- Putah Tuff Member (Pliocene)
- Tuscan Formation (Pliocene)
- Laguna Formation (Pliocene)
- Sutter Formation of Williams and Curtis (1977) (Pliocene - Oligocene)
- Channel Deposits (Pliocene - Miocene)
- Mehrten Formation (Pliocene - Miocene)
- Lovejoy Basalt (Miocene)
- Ione Formation (Eocene)
- Sedimentary Rocks in Sutter Buttes Area (Eocene)
- Metamorphic, Igneous, and Sedimentary Rocks (pre-Paleogene)
- Tailings

Source:

1. California Department of Water Resources, 2014, Geology of the Northern Sacramento Valley: prepared by the California Department of Water Resoures Northern Region Office, Groundwater and Geologic Investigations Section, updated September 2014.
2. Helley, E.J. and Harwood, D.S., 1985, Geologic Map of the Late Cenozoic Deposits of the Sacramento Valley and Northern Sierran Foothills, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1790, scale 1:62,500, GIS geodatabase.
3. Jennings, C.W. and Strand, R.G., 1960, Geologic Map of California, Olaf P. Jenkins Edition, Ukiah Sheet: Department of Natural Resources Division of Mines and Geology, third printing 1992, scale 1:250,000.
4. Koenig, J.B., 1963, Geologic Map of California, Olaf P. Jenkins Edition, Santa Rosa Sheet: California Department of Natural Resources Division of Mines and Geology, scale 1:250,000.
5. Springhorn, S.T., 2008, Stratigraphic Analysis and Hydrogeologic Characterization of Cenozoic Strata in the Sacramento Valley near the Sutter Buttes: Master of Science Dissertation, California State University, Chico, 2008.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Notes:

1. The Helley and Harwood mapping is used where available and is supplemented or revised using geologic mapping from the California Department of Natural Resources Division of Mines and Geology documents and information provided in the Springhorn dissertation (2008)
2. Geologic structures are dashed where approximated.

Figure 3-10

Geologic Map

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan

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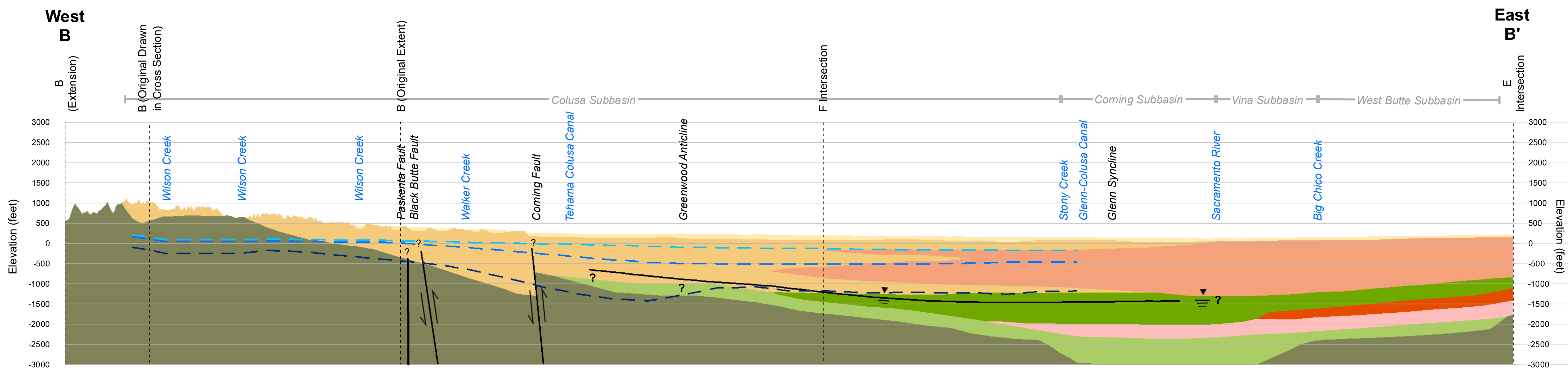
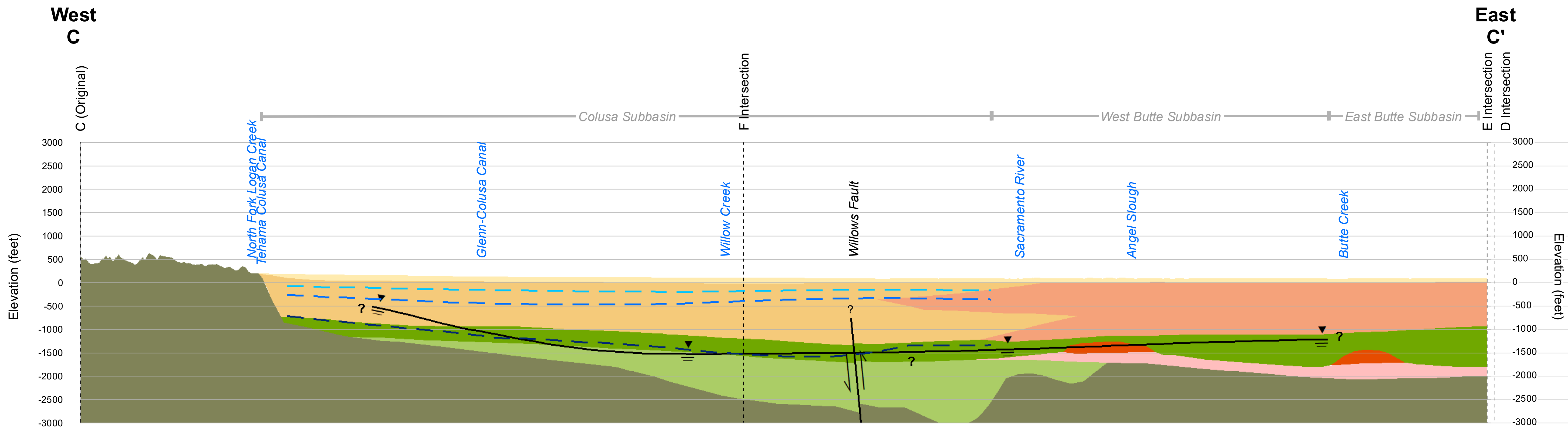
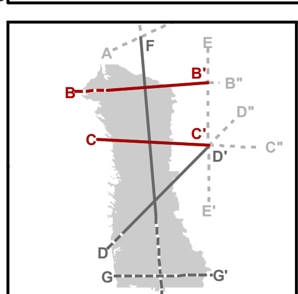


Cross Section B-B'



Cross Section C-C'



Inset Map Symbology

- Selected NSV Geology Cross Section Used for HCM
- Selected Section Extension or New Cross Section
- NSV Geology Cross Section Used for HCM
- Section Extension or New Cross Section
- NSV Geology Cross Section Not Used for HCM
- Colusa Subbasin

Cross Section Symbology

- Fault
- Base of Fresh Water (~2,000 mg/L TDS)
- Base of Model Layer 1 and Modeled Unconfined Aquifer
- Base of Model Layer 2 and Modeled Confined Aquifer Pumping
- Base of Model Layer 3 and Modeled Base of Fresh Water (~3,000 mg/L TDS)

Geologic Units

- Alluvium
- Tehama Formation
- Tuscan Formation
- Upper Princeton Valley Fill
- Lovejoy Basalt
- Ione Formation
- Lower Princeton Valley FIll
- Cretaceous Rocks (pre-Paleogene)

Notes:
1. Elevations are in North American Vertical Datum of 1988, feet (NAVD 88).
2. Cross sections shown are digitized versions of the cross sections included in the Department of Water Resources (DWR) Geology of the Northern Sacramento Valley, California report (DWR, 2014). Existing cross sections were extended and new cross sections were added, as needed, to provide coverage for the entire Colusa Groundwater Subbasin.
3. Cross sections B, C, and D were not digitized beyond their intersection with section E.
4. Base of fresh water was digitized from Olmsted and Davis (1961) and is not shown beyond the extent of the original base of freshwater contouring. Base of fresh water was defined by Olmsted and Davis as approximately 2,000 mg/L of total dissolved solids (TDS).
5. The preliminary approximation of the base of the groundwater subbasins within the study area is based on geologic formation boundaries.

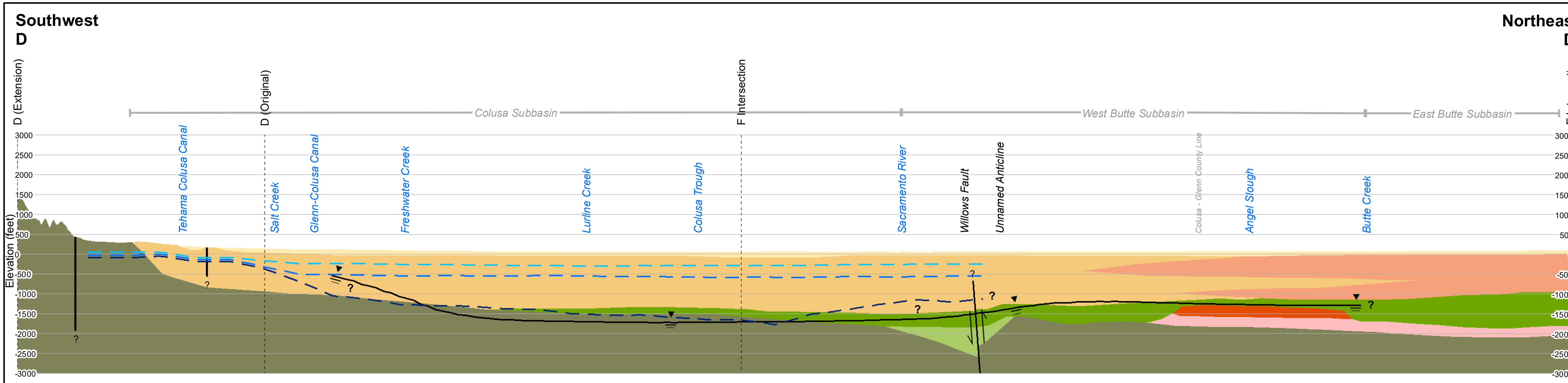
0 1.25 2.5
Scale in Miles

Vertical Exaggeration: 5.28

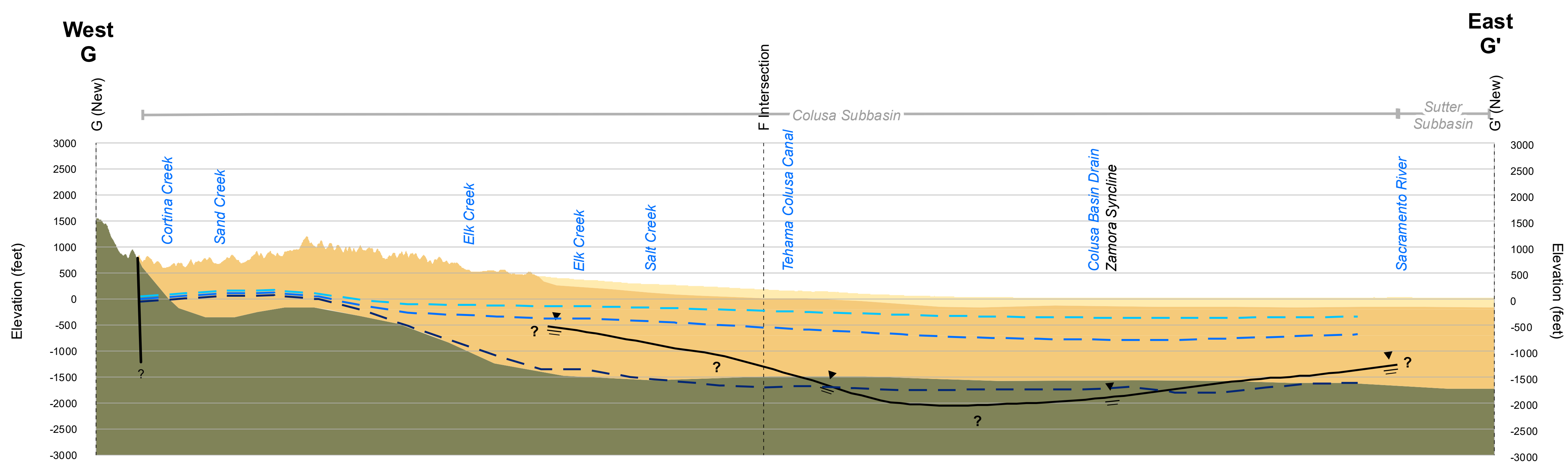
Figure 3-11

Cross Sections B-B' and C-C'

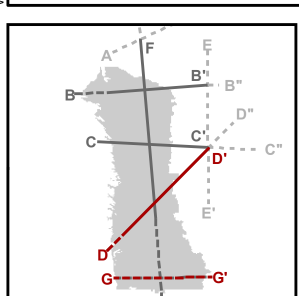
Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan



Cross Section D-D'



Cross Section G-G'



Inset Map Symbology

- Selected NSV Geology Cross Section Used for HCM
- Selected Section Extension or New Cross Section
- NSV Geology Cross Section Used for HCM
- Section Extension or New Cross Section
- NSV Geology Cross Section Not Used for HCM
- Colusa Subbasin

Cross Section Symbology

- Fault
- Base of Fresh Water (~2,000 mg/L TDS)
- Bottom of Model Layer 1 and Modeled Base of Unconfined Aquifer
- Bottom of Model Layer 2 and Modeled Base of Confined Aquifer Pumping
- Bottom of Model Layer 3 and Modeled Base of Fresh Water (~3,000 mg/L TDS)

Geologic Units

- Alluvium
- Tehama Formation
- Tuscan Formation
- Upper Princeton Valley Fill
- Lovejoy Basalt
- Ione Formation
- Lower Princeton Valley FIll
- Cretaceous Rocks (pre-Paleogene)

Notes:
1. Elevations are in North American Vertical Datum of 1988, feet (NAVD 88).
2. Cross sections shown are digitized versions of the cross sections included in the Department of Water Resources (DWR) Geology of the Northern Sacramento Valley, California report (DWR, 2014). Existing cross sections were extended and new cross sections were added, as needed, to provide coverage for the entire Colusa Groundwater Subbasin.
3. Cross sections B, C, and D were not digitized beyond their intersection with section E.
4. Base of fresh water was digitized from Olmsted and Davis (1961) and is not shown beyond the extent of the original base of freshwater contouring. Base of fresh water was defined by Olmsted and Davis as approximately 2,000 mg/L of total dissolved solids (TDS).
5. The preliminary approximation of the base of the groundwater subbasins within the study area is based on geologic formation boundaries.

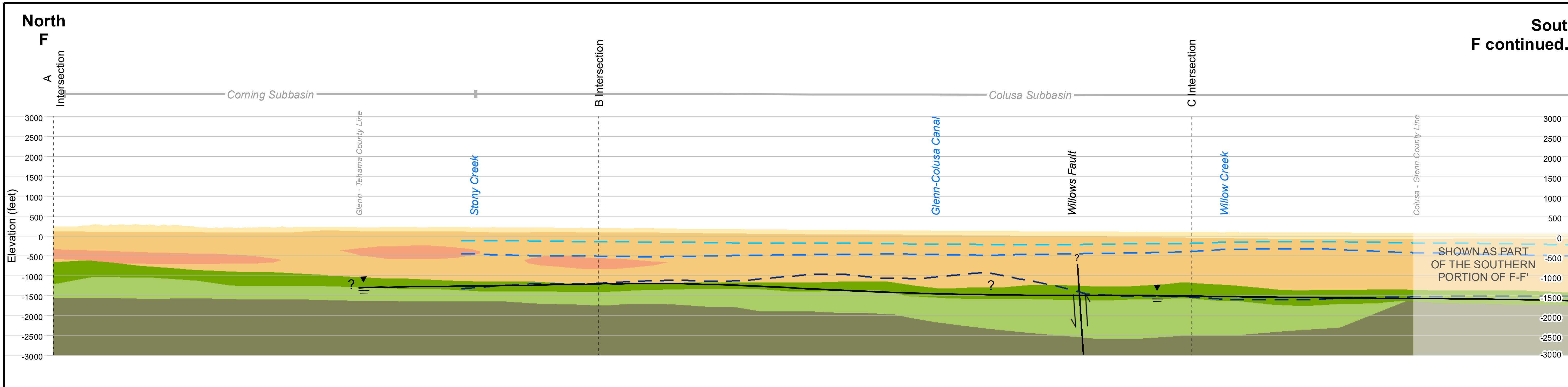
0 1.25 2.5
Scale in Miles

Vertical Exaggeration: 5.28

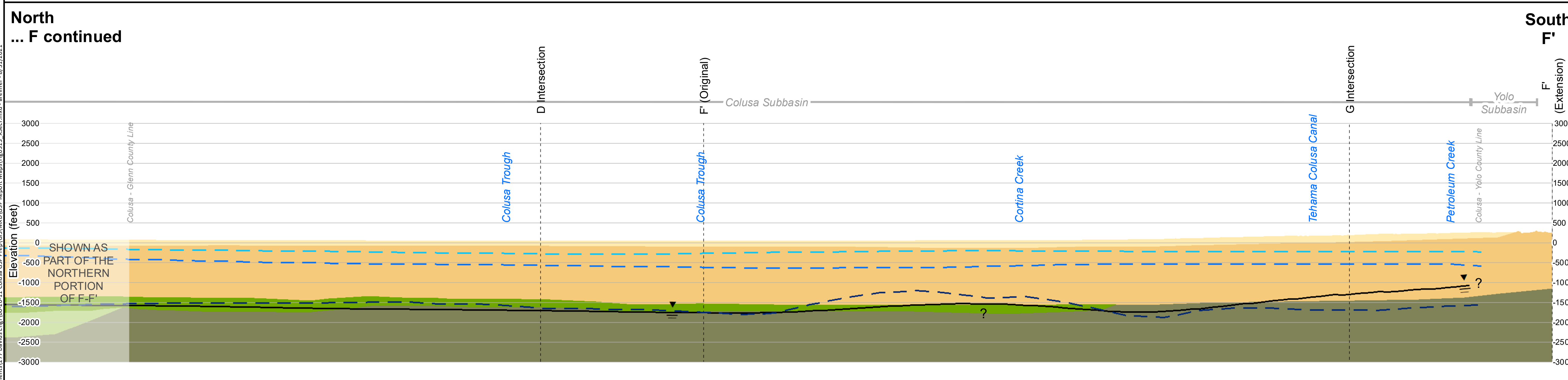
Figure 3-12

Cross Sections D-D' and G-G'

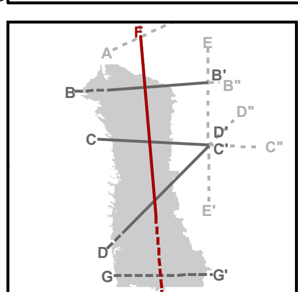
Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan



Cross Section F-F' Northern Portion



Cross Section F-F' Southern Portion



Inset Map Symbology

- Selected NSV Geology Cross Section Used for HCM
- Selected Section Extension or New Cross Section
- NSV Geology Cross Section Used for HCM
- Section Extension or New Cross Section
- NSV Geology Cross Section Not Used for HCM
- Colusa Subbasin

Cross Section Symbology

- Fault
- Base of Fresh Water (~2,000 mg/L TDS)
- Bottom of Model Layer 1 and Modeled Base of Unconfined Aquifer
- Bottom of Model Layer 2 and Modeled Base of Confined Aquifer Pumping
- Bottom of Model Layer 3 and Modeled Base of Fresh Water (~3,000 mg/L TDS)

Geologic Units

- Alluvium
- Tehama Formation
- Tuscan Formation
- Upper Princeton Valley Fill
- Lovejoy Basalt
- Ione Formation
- Lower Princeton Valley FIll
- Great Valley Sequence

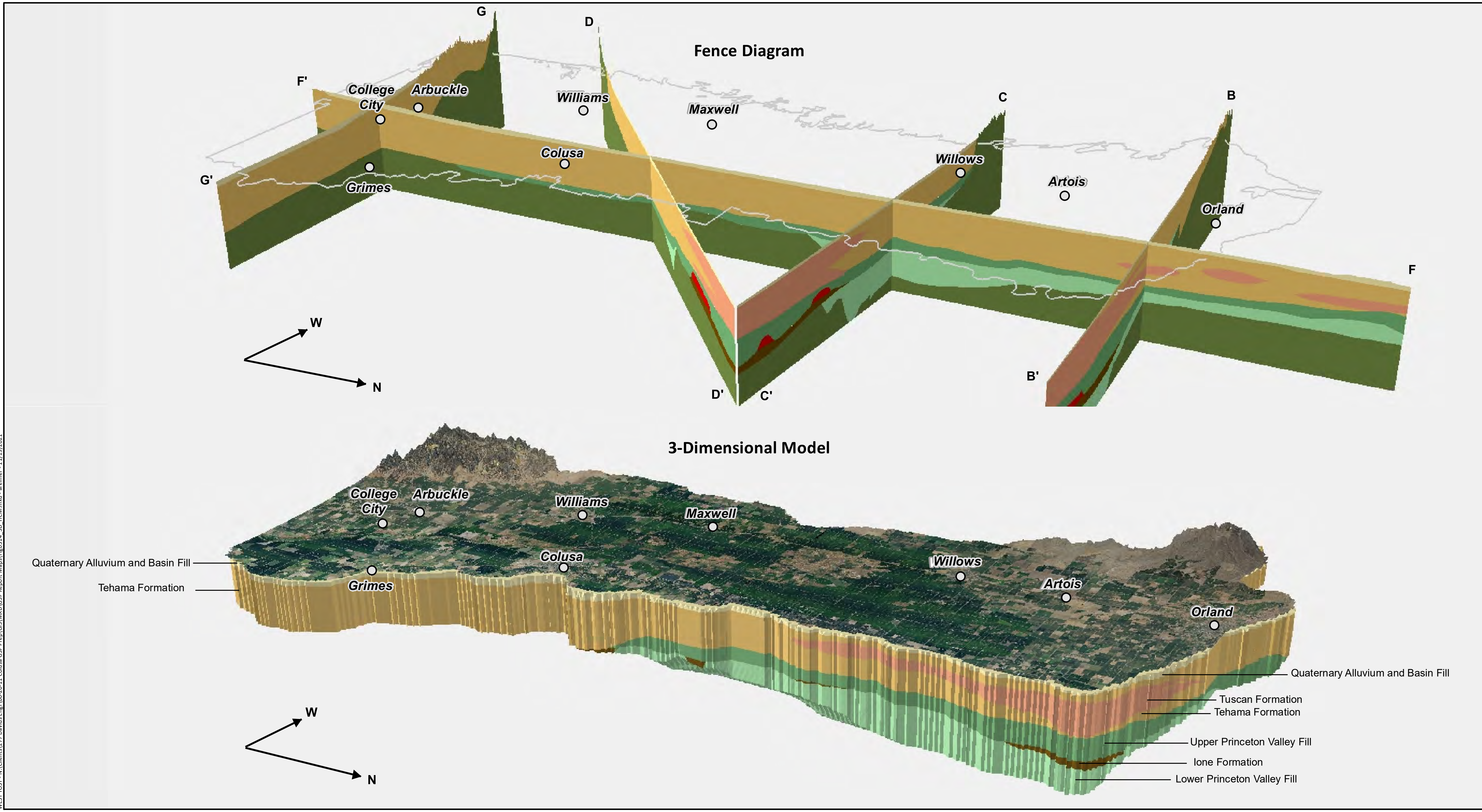
Notes:
1. Elevations are in North American Vertical Datum of 1988, feet (NAVD 88).
2. Cross sections shown are digitized versions of the cross sections included in the Department of Water Resources (DWR) Geology of the Northern Sacramento Valley, California report (DWR, 2014). Existing cross sections were extended and new cross sections were added, as needed, to provide coverage for the entire Colusa Groundwater Subbasin.
3. Cross sections B, C, and D were not digitized beyond their intersection with section E.
4. Base of fresh water was digitized from Olmsted and Davis (1961) and is not shown beyond the extent of the original base of freshwater contouring. Base of fresh water was defined by Olmsted and Davis as approximately 2,000 mg/L of total dissolved solids (TDS).
5. The preliminary approximation of the base of the groundwater subbasins within the study area is based on geologic formation boundaries.

0 1.25 2.5
Scale in Miles
Vertical Exaggeration: 5.28

Figure 3-13

Cross Section F-F'

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan



Datums: North American Datum of 1983, California State Plane Zone II, feet. North American Vertical Datum of 1988, feet.

Notes:
1. Vertical exaggeration is 10x.
2. Elevations are in North American Vertical Datum of 1988, feet (NAVD 88).
3. The fence diagram and 3-dimensional (3D) model are based on the cross sections included in the California Department of Water Resources (DWR) Geology of the Northern Sacramento Valley, California report (DWR, 2014) and have been updated and expanded upon based on available well completion reports to represent the water-bearing formations.
4. The 3D model excludes the Lovejoy Basalt.

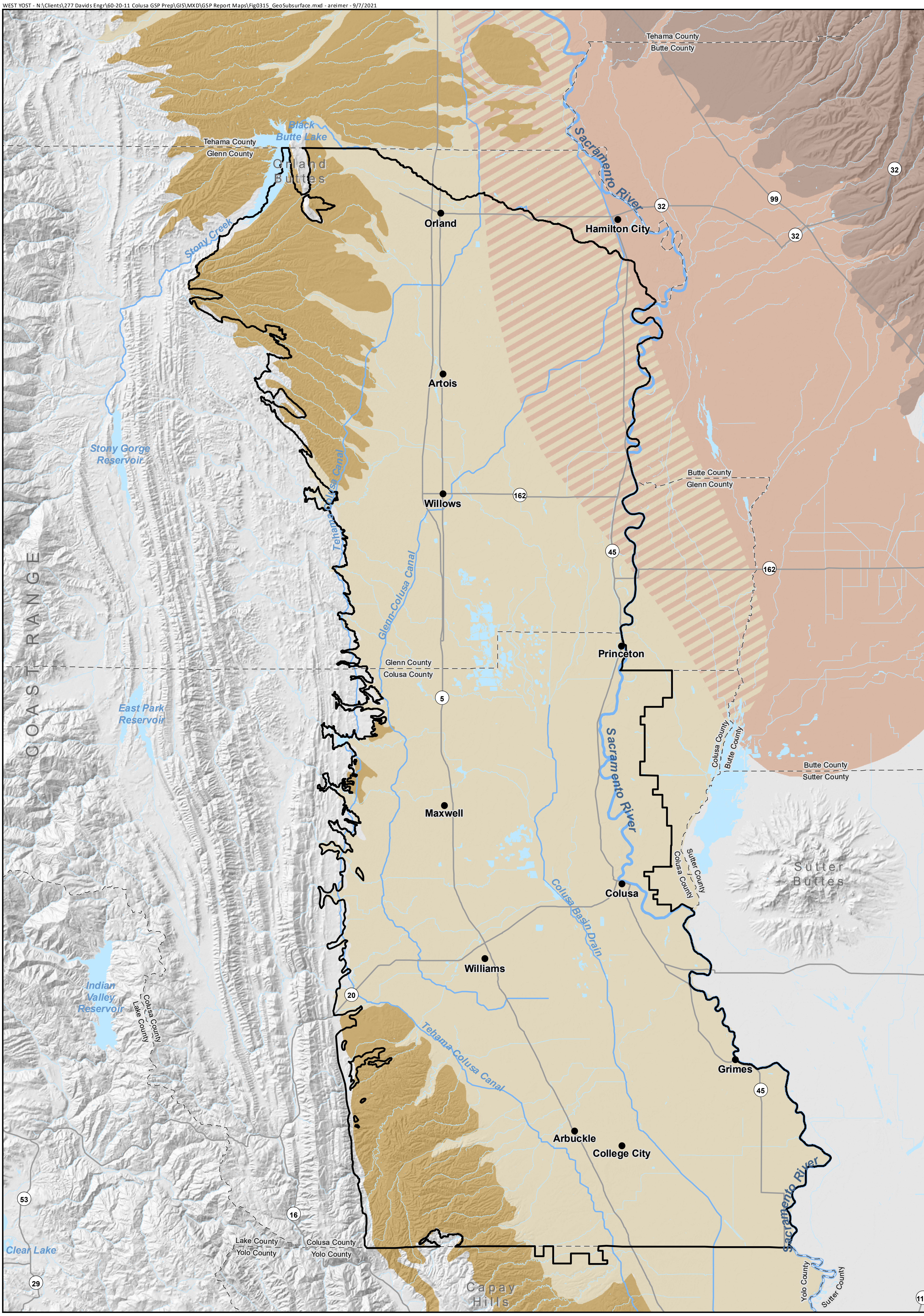
Hydrogeologic Formation

- Quaternary Alluvium and Basin Fill
- Tehama Formation
- Tuscan Formation
- Upper Princeton Valley Fill
- Lovejoy Basalt
- Ione Formation
- Lower Princeton Valley Fill
- Cretaceous Rocks (pre-Paleogene)

Figure 3-14

3D Hydrogeologic Conceptual Model

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan



Source: DWR, 2009, Glenn-Colusa Irrigation District Test-Production Well Installation and Aquifer Testing: prepared by the California Department of Water Resources (DWR) Northern District Groundwater Section in cooperation with Glenn-Colusa Irrigation District, March 2009, GIS shapefiles provided by DWR 2008.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

- Colusa Subbasin
- Tuscan Outcrop
- Tehama Outcrop
- Tehama-Tuscan Subsurface Transition Zone
- Tehama Subsurface
- Tuscan Subsurface

N

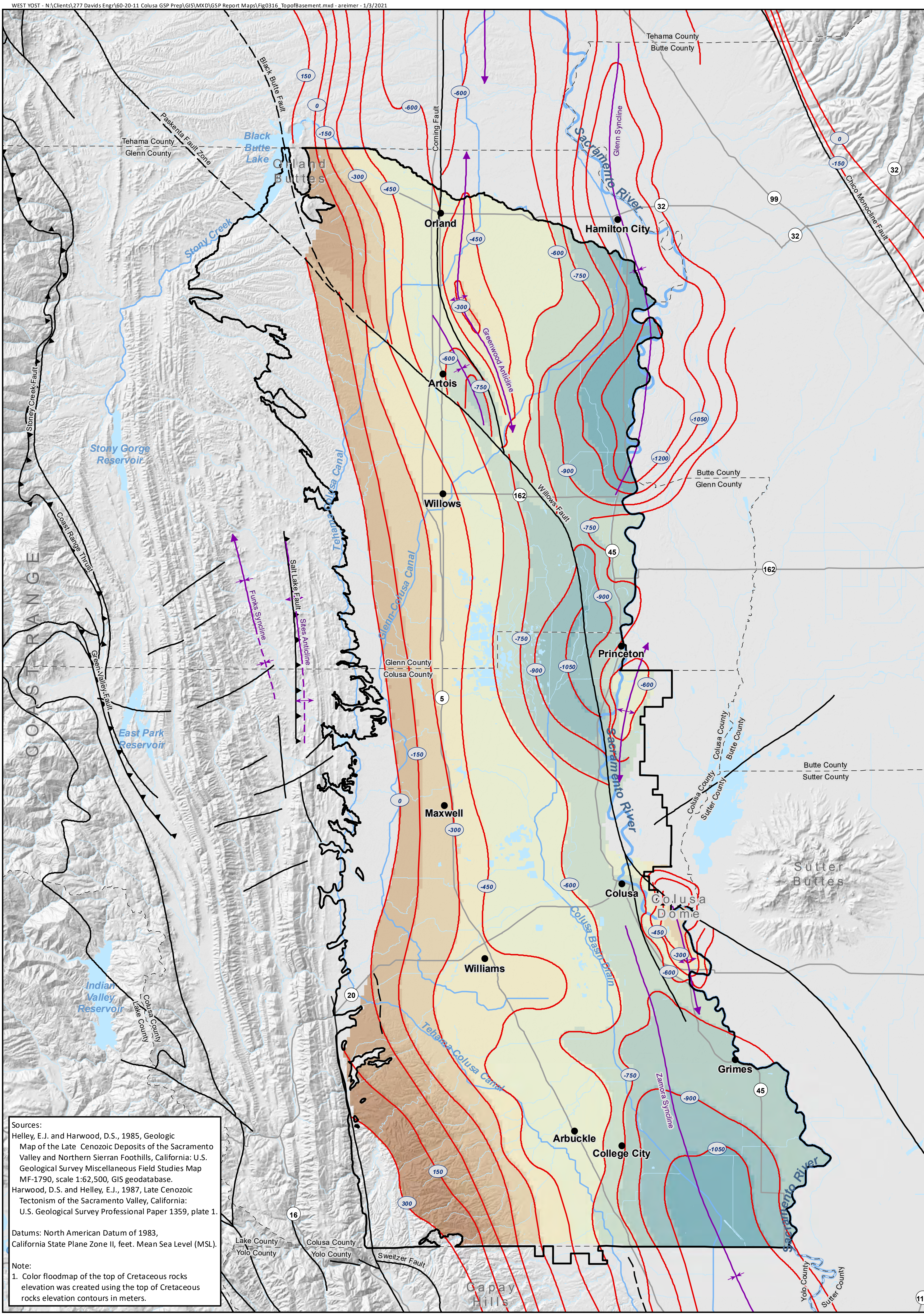
0 2.5 5
Scale in Miles

Figure 3-15

Extent of Tehama and Tuscan Formations

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

WEST YOST - N:\Clients\277 Davids Engr\60-20-11 Colusa GSP Prep\GIS\MXD\GSP Report Maps\Fig0316_TopofBasement.mxd - areimer - 1/3/2021



Sources:
Helley, E.J. and Harwood, D.S., 1985, Geologic Map of the Late Cenozoic Deposits of the Sacramento Valley and Northern Sierran Foothills, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1790, scale 1:62,500, GIS geodatabase.
Harwood, D.S. and Helley, E.J., 1987, Late Cenozoic Tectonism of the Sacramento Valley, California: U.S. Geological Survey Professional Paper 1359, plate 1.

Datums: North American Datum of 1983, California State Plane Zone II, feet. Mean Sea Level (MSL).

Note:
1. Color floodmap of the top of Cretaceous rocks elevation was created using the top of Cretaceous rocks elevation contours in meters.

- Anticline, Certain
- Syncline, Certain
- Plunging Anticline, Certain
- Plunging Syncline, Certain
- Doubly Plunging Anticline, Certain
- Anticline, Approximate
- Syncline, Approximate
- Fault, Certain
- Thrust Fault, Certain
- Fault, Approximate
- Top of Cretaceous Rocks Elevation Contours (MSL, meters)
- Colusa Subbasin

Top of Cretaceous Rocks Elevation (MSL, meters)

- < -1,050
- -1,050 - -900
- -900 - -750
- -750 - -600
- -600 - -450
- -450 - -300
- -300 - -150
- -150 - 0
- 0 - 150
- > 150

0 2.5 5
Scale in Miles

Figure 3-16

Top of Cretaceous Rocks Structural Contours Map

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

The shoreline of the sea migrated westward throughout the Paleogene period due to continued subduction of the Pacific plate beneath the North American plate. During this period of regression, drainage from ancestral mountain ranges located north of the Subbasin eroded a submarine valley into the marine deposits (DWR, 2014a; Redwine, 1984). This valley, called the Princeton Submarine Valley, extends from the northern end of what is now the Sacramento Valley towards the City of Woodland in Yolo County, south of the Subbasin. Continued regression of the inland sea and ongoing drainage from the surrounding ancestral hills resulted in a mix of marine and continental deposits filling the Princeton Submarine Valley and surrounding basin. The incised nature of the Princeton Submarine Valley within the Great Valley Sequence can best be seen in the west to east trending Cross Sections B-B', C-C', and D-D' on Figure 3-11 and Figure 3-12. Cross Section F-F', on Figure 3-13, approximately follows the axis of the valley.

The lowest extents of the submarine valley were unconformably filled with Lower Princeton Valley Fill deposits during the Eocene. The Lower Princeton Valley Fill, deposited via turbidity flows, consists of interbedded sandstones and shale (DWR, 2014a; Springhorn, 2008). The Lower Princeton Valley Fill was conformably overlain by the Ione Formation in the Eocene (approximately 40 Ma) via stream drainage from the Sierra Nevada. The western extent of the Ione Formation is characterized by shallow marine deposition in the remnants of the inland sea, while the eastern extent of the formation is characterized by non-marine deltaic deposition (Redwine 1984; Springhorn, 2008). The Ione Formation unconformably overlies the Great Valley Sequence and crystalline and metasedimentary rocks near the eastern portion of the Sacramento Valley and is used as a marker bed to distinguish the Upper and Lower Princeton Valley Fill deposits.

Around this time, the tectonic regime of the northern Sacramento Valley began transitioning from a subduction zone to a transform zone as the Mendocino Triple Junction (composed of the Pacific, North America, and Juan de Fuca-Gorda plates) approached the Subbasin from the south. The transition from subduction to transform movement resulted in the creation of faults and folds, many of which are north-south trending due to the direction of compression applied by the transform system.

Volcanic activity during the Miocene resulted in the deposition of the Lovejoy Basalt (approximately 16.4 Ma), which unconformably overlies the Ione Formation and older formations, where they exist (Figure 3-11 and Figure 3-12). These basaltic flows originated near Honey Lake in the eastern Sierras and flowed westward, following channels towards and through what is now the northern Sacramento Valley (Helley and Harwood, 1985). Due to its distribution as flows in preexisting channels, the presence of Lovejoy Basalt is widespread but discontinuous.

Unconformably overlying the Lovejoy Basalt and older formations is the Upper Princeton Valley Fill. Upper Princeton Valley Fill was originally thought to have been deposited in Late Miocene to Oligocene, however age dating of the Lovejoy Basalt has constrained the age of the Upper Princeton Valley Fill to the Miocene epoch (approximately 16.4 Ma) (Springhorn, 2008). Upper Princeton Valley Fill consists of sandstone, with occasional interbeds of mudstone and conglomerate deposited in a fluvial floodplain system (Redwine, 1984). Because of its depositional history, groundwater within the Upper Princeton Valley Fill is fresh to brackish in quality.

Uplift of the Coast Ranges in the Pliocene epoch eventually gave form to the Sacramento Valley as it exists today. Alluvial, fluvial, and floodplain deposits derived from the Coast Ranges eventually accumulated as the Tehama Formation along the western side of the valley, while volcanic activity within the southern Cascade Ranges produced basalt and andesite flows that would eventually become reworked into the Tuscan Formation. The Tehama and Tuscan Formations were deposited concurrently during the late Pliocene to Pleistocene, interfingering with one another beneath the valley floor in what is referred to as the Tehama-Tuscan Transition Zone (Figure 3-15). The interlayering of the Tehama and Tuscan Formations can be seen in Cross Sections B-B’, C-C’, D-D’, and F-F’ (Figure 3-11 through Figure 3-13). The Tuscan Formation appears as isolated lenses in north-south trending Cross Section F-F’, but these lenses are integral with the main body of the Tuscan Formation, as depicted in the west-east trending cross sections. In the late Pliocene epoch, volcanic activity within the southern Cascade Range caused the widespread deposition of the Nomlaki Tuff across the northern Sacramento Valley. The Nomlaki Tuff has been radiometrically dated to 3.4 Million Years Ago (Ma) (Evernden, 1964) and provides an age constraint on the Tehama and Tuscan Formations because it is found in the basal deposits of both formations. The age of the upper boundary of the Tuscan Formation is further constrained to 1.5 Ma based on age dating of a rhyolite flow that overlies the Tuscan Formation near Mineral, Tehama County (Lydon, 1968).

Additional faults and folds were created as the Mendocino Triple Junction continued to move northward. These include the Corning Fault, Glenn Syncline, Greenwood Anticline, and an assortment of domes and buttes within the Subbasin. The Sutter Buttes are thought to have formed in part due to the compressional tectonics associated with the migration of the Mendocino Triple Junction (Hausback and Nilsen, 1999). The most recent Sutter Buttes volcanism occurred approximately 2 Ma (Hausback and Nilsen, 1999).

Quaternary geologic deposits are characterized by alluvial pediments and fans, and basin floodplain deposits of the Red Bluff Formation (an erosional surface, or pediment), Riverbank Formation, Modesto Formation, and basin deposits. These are collectively referred to as “Alluvium” on the cross sections found on Figure 3-11 through Figure 3-13 because of their limited thicknesses relative to the older formations (Table 3-3).

The Red Bluff Formation is a thin sand and gravel deposit resting on a pediment or erosional surface on the Tehama Formation (Figure 3-10). The Red Bluff Formation was formed when the Sacramento Valley was a closed drainage basin, which resulted in lacustrine depositional environments. The Red Bluff Formation is thought to represent the paleoshores of this ancient lacustrine system (DWR, 2014a; Springhorn, 2008). The age of the Red Bluff Formation is constrained to 0.6 to 1.09 Ma by radiometrically determined ages of the Rockland ash bed and the Deer Creek basalt, respectively (Harwood et. al., 1981; Harwood and Helley, 1987; Lanphere et. al., 1999). This constrains the age of the Tehama Formation to be no younger than 0.6 to 1.09 Ma.

Lacustrine environments resulting from the basin’s internal drainage during deposition of the Red Bluff Formation also resulted in the deposition of diatomaceous clays similar to the Corcoran Clay of the San Joaquin Valley. This diatomaceous clay layer within the Sacramento Valley is referred to as the Turlock Lake Formation (Harwood and Jaworowski, 1985). This indicates that potentially subsidence-prone compressible sediments of approximately 0.6 to 1.09 Ma age are located near the top of the Tehama Formation. Boreholes east and south of the Sutter Buttes have encountered the Turlock Lake Formation. While similar sediment lithologies have been encountered in boreholes west of the Sutter Buttes, Turlock Lake Formation has not yet been identified in boreholes within the Subbasin. One borehole drilled near the Colusa Drain near Zamora in Yolo County, referred to as the USGS Zamora borehole, encountered a diatomaceous clay layer of about 10-feet thick at an approximate depth of 534 to 544 feet with properties similar to those of the diatomaceous clay from the Corcoran Clay of the San Joaquin Valley (Page, 1998; Page and Bertoldi, 1983).

The limited fresh groundwater found within the Red Bluff Formation tends to be present under perched conditions (DWR, 2014a). The Red Bluff Formation is therefore not further discussed in the following sections of this report.

Glacial activity during the Pleistocene epoch resulted in the Riverbank and Modesto Formations (Busacca et. al., 1989). The age of the Riverbank Formation ranges from 0.13 to 0.45 Ma and corresponds to the Illinoisan and older glacial stages. The age of the Modesto Formation ranges from approximately 0.01 to 0.042 Ma and correlates to the Wisconsin glacial stage.

The youngest deposits of the Subbasin consist of Holocene-aged basin deposits and stream channel deposits.

3.1.7.2 Primary Freshwater-Bearing Formations

The geologic formations forming the freshwater aquifer comprise a single aquifer system. The geologic formations comprising the freshwater aquifer system are discussed below.

3.1.7.2.1 Tuscan Formation

Tuscan Formation deposits are characterized by their Cascade Range origin and volcanic signature. This extensive series of basaltic and andesitic volcanic flows, consolidated tuff breccia, tuffaceous sandstone, and volcanic ash is primarily located on the northeastern portion of the Sacramento Valley. Figure 3-10 and Figure 3-15 show the approximate surface and subsurface extents of the Tuscan Formation in the vicinity of the Subbasin. The Tehama-Tuscan Transition Zone is also visible in the 3D hydrogeologic conceptual model shown on Figure 3-14. The Tuscan Formation comprises the oldest freshwater aquifer in the eastern half of the northern Sacramento Valley. The Tuscan Formation is exposed on the eastern side of the Sacramento Valley and occurs as interfingering layers with the Tehama Formation at depth near the center of the Sacramento Valley. This interfingering of the Tehama Formation with Tuscan Formation units is referred to as the Tehama-Tuscan Transition Zone (Figure 3-15). In the Subbasin, these deposits occur at depths greater than the depths of most existing domestic wells.

Moderately to highly permeable volcanic sediments are hydraulically confined by layers of tuff breccias and clays within the Tuscan Formation. The Tuscan Formation contains four map units, which are designated A through D, with A being the oldest (DWR, 2006a). The low permeability lahar, or mudflow, deposits of Unit C are confining beds for the underlying older Tuscan Units A and B. Although Unit C contains permeable volcanic sandstone and conglomerate interbeds, this unit is characterized by an overall low yield of water to wells within the Subbasin. Units A and B are much coarser-grained than the overlying Unit C, and they are the primary water-bearing zones of the eastern Sacramento Valley. The lower Tuscan Formation (Tuscan Units A and B) is present at depths below 700 feet in the northeastern part of the Subbasin and consists of volcanic conglomerate, sandstone, siltstone, and interbedded lahars overlain by tuffaceous breccias, sandstone and conglomerate. Tuscan Unit D is not present within the Subbasin.

The permeability of the Tuscan Formation varies, and irrigation wells range in well yield from 7 to 4,000 gallons per minute (gpm).

3.1.7.2.2 Tehama Formation

Figure 3-10 and Figure 3-15 show the approximate surface exposures and subsurface extents of the Tehama Formation. The Tehama Formation forms the oldest, deepest, and thickest part of the freshwater aquifer in the western half of the northern Sacramento Valley. The Tehama Formation consists of up to nearly 2,000 feet of moderately compacted silt, clay, and silty fine sand enclosing thin, discontinuous lenses of sand and gravel deposited in a fluvial (river-borne) environment (DWR, 2006a; Olmsted and Davis, 1961). Based on the mineralogy of surface exposures, the sediments were derived from erosion of the Coast Ranges and Klamath Mountains to the west and northwest. They were deposited under floodplain conditions on the west side of a broad valley of low relief (Brown and Caldwell, 2007; Russell, 1931).

The Tehama and Red Bluff Formations are exposed at the land surface on the western side of the Sacramento Valley, in the northwest, and the southwest. The outcrop of the Tehama and Red Bluff Formations and pinchout of the younger valley sediments coincide with an increase in terrain, as seen in Figure 3-4. There are few wells drilled in these areas and local residents report that existing wells yield little groundwater. Geologic mapping shows outcropping of older Cretaceous-aged sedimentary rocks in the northwestern portion of the subbasin near the Orland Buttes and west of the Tehama-Colusa Canal (Figure 3-10). Based on these observations, the Tehama Formation is relatively thin and has a low permeability where it outcrops. The Tehama Formation is buried beneath younger sediments to the east and interfingers with the Tuscan Formation throughout the Tehama-Tuscan Transition Zone in the northeast portion of the Subbasin (Figure 3-15).

The permeability of the Tehama Formation varies but is generally less than in the overlying unconsolidated alluvial deposits. Because of the thickness of the producing zones, production from the Tehama Formation can be up to several thousand gallons per minute per well (DWR, 2006a), but is typically less than that exhibited by the Tuscan Formation.

3.1.7.2.3 Riverbank and Modesto Formations

The late Pleistocene-aged Riverbank and Modesto Formations uncomfortably overlie the Tuscan and Tehama Formations. The thickness of the formation ranges from less than 10 feet to nearly 200 feet across the valley floor (DWR, 2006a; Helley and Harwood, 1985). These formations consist of loose to moderately compacted silt, silty clay, sand and gravel deposited in alluvial depositional environments during periods of world-wide glaciation (DWR, 2006a; Lettis, 1988; Weissmann et. al., 2002). The formations were deposited in response to changes in base level and increased precipitation during the glacial periods. The increased stream gradients and precipitation resulted in greater stream discharge and competency than observed today. The greater competency of the streams led to scouring of stream channels in preexisting geologic deposits, followed by transport, deposition and burial of sands and gravels in the channels as the glacial cycles progressed.

Figure 3-10 shows the spatial distribution of the Riverbank and Modesto Formation in the Subbasin. The formations are exposed at the land surface along the channels of creeks and along the western margin of the Subbasin, where they form a series of coalescing alluvial fans, emanating from the mouths of the creeks. The Riverbank and Modesto Formations typically form terraces along stream channels. The oldest terraces occur furthest from the channel and at the highest elevations. Successively younger terraces are incised into the next oldest deposit and, therefore, occur closer to the stream channel and at lower elevations. The Riverbank Formation forms the older terrace deposits that occur at a higher topographic level. In the Stony Creek Fan area, these terraces are well-defined, but they are absent or poorly defined along other minor streams in the Subbasin.

The Riverbank Formation consists of poorly to highly permeable pebble and small cobble gravels interbedded with reddish clay, sand, and silt. The Modesto Formation consists of moderately to highly permeable gravels, sands, and silts. The Riverbank Formation is distinguished from the Modesto Formation by interbedded clay layers. These formations contain fresh water (DWR, 2006a; Harwood and Helley, 1987).

Wells penetrating the sand and gravel units of the Riverbank and Modesto Formations produce up to about 1,000 gpm; however, the production varies depending on local formation thickness (DWR, 2006a). Wells screened in the Riverbank and Modesto Formations are generally domestic and shallow irrigation wells (DWR, 2006a).

3.1.7.2.4 Stream Channel and Basin Deposits

Holocene stream channel and basin deposits are the youngest sediments in Subbasin, with ages of roughly 10,000 years or younger (Helley and Harwood, 1985). The stream channel and basin deposits consist of up to 80-foot sections of unconsolidated clay, silt, sand, and gravel reworked from older formations by streams. According to DWR (2006a), which also refers to these deposits as younger alluvium, these deposits form a shallow, unconfined aquifer of moderate to high permeability, but with limited capacity due to the relatively restricted lateral and vertical extents of the deposits.

Holocene flood basin deposits are very young surficial deposits formed during flood events when streams overtopped their natural levees, flooding the surrounding area. As the flood water spread, the current velocity and stream competency decreased, resulting in deposition of silts, clays, and fine sands. Flood basin deposits reach thicknesses of up to 150 feet and may be interbedded with stream channel deposits (DWR, 2006a). Because of their low permeability, limited extent, and generally poor water quality, flood basin deposits are typically not used for groundwater production (DWR, 2006a).

3.1.7.3 Geologic Structures

Figure 3-16, from Harwood and Helley (1987), shows the structural contours in meters delineating the top of the Cretaceous marine sedimentary rocks in the vicinity of the Subbasin. The shaded color intervals on Figure 3-16 conform to the structural contours of the top of the Cretaceous rocks. The structural contours were based on the Cretaceous rocks because the resulting surface produces a single structural datum throughout the western Sacramento Valley. This datum helps reveal some of the geologic structures (folds and faults) that affect the Subbasin.

Figure 3-10 shows the significant structural features near the Subbasin, including, but not limited to the Willows Fault, Corning Fault, Glenn Syncline, and the Zamora Syncline in addition to other smaller unnamed geologic structures. These structural features affect geologic units at least as young as the Red Bluff Formation, which indicates that structural deformation was occurring as recently as 0.45 Ma – the oldest potential age of the overlying Riverbank Formation – and may be continuing at present (Harwood and Helley, 1987).

3.1.7.3.1 Faults

Faults may affect groundwater flow by bringing geologic materials with different hydraulic properties into contact across the fault plane or by fracturing the materials, which could either increase or decrease permeability, depending on the degree of fracturing and other geologic processes, such as mineralization, active within the fault zone. The fault might, therefore, act as a boundary or barrier affecting the lateral flow of groundwater between adjacent areas and might act as a conduit allowing vertical or lateral flow within the fault zone. The faults that were analyzed as part of this report include the Zamora Fault, Willows Fault, Corning Fault, Black Butte Fault, and the Paskenta Fault. These faults are shown on Figure 3-10 and discussed in the following subsections.

3.1.7.3.1.1 Zamora Fault

The Zamora Fault is a northwest-trending, east-dipping normal fault mapped along the eastern edge of Dunnigan Hills, south of the Subbasin. The Dunnigan Hills escarpment is partially attributed to the displacement along the Zamora Fault (Harwood and Helley, 1987). Local topography and geology indicate that the fault may extend further northward towards Arbuckle.

3.1.7.3.1.2 Willows Fault

The Willows Fault is a north-south trending reverse fault that dips 74 degrees to the east and extends from near Stockton, San Joaquin County to the north end of the Sacramento Valley (Harwood and Helley, 1987). The reverse movement of the fault juxtaposes Mesozoic-aged marine formations against the Tehama Formation, as seen in portions of Cross Sections B-B', C-C', and D-D', and the northernmost portion of Cross Section F-F' (Figure 3-11 through Figure 3-13). Additionally, there is evidence that the Willows Fault influenced not only the position of the Lower Princeton Valley Fill thalweg, but also offset the fill during deposition (Redwine, 1984). Displacement along the Willows Fault is approximately 1,600 feet at the top of the Cretaceous rocks and approximately 1,560 feet at the top of the Eocene formations (Harwood and Helley, 1987). The most recent activity along the Willows Fault affects the lower Tehama Formation. The slip rate on the Willows Fault is estimated to be 0.00055 inches per year (McPherson and Garven, 1999).

Groundwater elevations exhibit a localized lowering of the water levels where the northern extent of the Willows Fault splits into the Black Butte and Paskenta Fault zones. This is discussed more in the Existing and Historical Groundwater Conditions sections of the GSP (Section 3.2).

3.1.7.3.1.3 Corning Fault

The Corning Fault is an offshoot of the Willows Fault that extends north of Artois, Glenn County. It is a north-trending reverse fault of similar structure to the Willows Fault, which has no surface expression, but offsets the Pleistocene-age Red Bluff Formation and the underlying Tehama Formation (Harwood and Helley, 1987). Additionally, Late Cretaceous deposits in the region exhibit offsets of approximately 1,000 feet due to the Corning Fault (Helley and Hardwood, 1985), which can be seen in Cross Section B-B' (Figure 3-11). William Lettis and Associates (2002) concluded that "the Corning Fault is an active seismic source" with an estimated slip rate between 0.0008 and 0.002 inches per year.

3.1.7.3.1.4 Black Butte Fault

The Black Butte Fault is a northwest trending fault that separates the Orland Buttes from Black Butte Lake. Movement along the fault may have caused the uplift of the Orland Buttes (Russell, 1931). Mapping by Helley and Harwood (1985) included on Figure 3-10 depicts the Black Butte Fault as a northward offshoot of the Willows Fault, much like the Corning Fault.

3.1.7.3.1.5 Paskenta Fault

Displacement along the Paskenta Fault impacts the Cretaceous rocks but has not been observed within the Tehama and younger formations, constraining its most recent activity to approximately 3.3 Ma (DWR, 2014a). There are two main interpretations of the geologic nature of the Paskenta Fault zone. One interpretation is that the fault zone is a northwest trending, left lateral, transtensional strike slip fault (Moxon, 1990). The other interpretation is that the fault zone originated as an east-striking north-dipping normal fault zone that has been subjected to uplift and tilting to its current northwest trend (DWR, 2014a; Jones et. al., 1969; Moxon, 1990). Additionally, some studies represent the fault zone as truncating near Black Butte Lake or transitioning into an anticlinal form while others have mapped the fault as a splay fault from the Willows Fault, as shown on Figure 3-10 (DWR, 2014a).

3.1.7.3.2 Folds

Folds may affect groundwater conditions because folding causes the elevation and thickness of geologic units to vary from place to place. Synclines are typically characterized by thickening of younger units near the axis of the fold and potential exposure of older more consolidated units near the margins of the fold. Anticlines are the opposite and can expose less permeable rock formations along their axis and may exhibit thickening of younger less consolidated formations near their margins. Additionally, the permeability and other material properties of sedimentary rocks, such as the Tehama Formation, are typically naturally anisotropic due to the alignment of mineral grains along bedding planes during deposition of the sediments. This alignment of the mineral grains results in higher permeability along rather than across bedding planes, which typically results in a maximum permeability horizontally and a minimum permeability vertically. Subsequent folding of bedding planes causes a reorientation of the direction of the mineral grains, and therefore a reorientation of the maximum and minimum permeability direction, which may affect groundwater flow rates and directions. The folds that were analyzed as part of this report include the Zamora Syncline, the Glenn Syncline, and the Greenwood Anticline. These folds are shown on Figure 3-10 and discussed in the following subsections.

3.1.7.3.2.1 Zamora Syncline

The Zamora Syncline is located in the subsurface east of Arbuckle, Colusa County and extends into Yolo County (Figure 3-10). The Zamora Syncline has no topographic expression, which means that the thickness of post-Cretaceous sediments, including the Tehama Formation, is greater along the axis of the syncline than on the limbs. This means that the aquifer thickness is greatest along the axis of the syncline. The effects of the Zamora Syncline on the older Cretaceous formations can be seen on Figure 3-16, where the elevation of the top of the Cretaceous formations is depressed west and south of College City, Colusa County.

3.1.7.3.2.2 Glenn Syncline

The Glenn Syncline is located near Hamilton City, Glenn County and was formed during the same compressional regime as the Corning Fault (DWR, 2014a). The Glenn Syncline roughly follows the direction of the Sacramento River (Figure 3-10). The effects of the Glenn Syncline on the Cretaceous formations can be seen in the elevation contours of the top of the Cretaceous rocks on Figure 3-10, where a depression in the top of the Cretaceous formations corresponds to the axis of the Glenn Syncline. Folding of the geologic formations along the Glenn Syncline can also be seen in Cross Section B-B’ (Figure 3-11). Due to the vertical exaggeration of the cross section, folding is not as evident as the presence of the Princeton Submarine Valley, but a slight depression can be seen in the Great Valley Sequence and Upper Princeton Valley Fill near the Glenn Syncline.

3.1.7.3.2.3 Greenwood Anticline

The Greenwood Anticline and an unnamed syncline are located near Artois, Glenn County. These structures are on opposing sides of the Corning Fault and mimic the change in strike directions displayed by the Corning Fault (Helley and Harwood, 1985). It is believed that the Greenwood Anticline and the unnamed syncline coincided with the formation of the Corning Fault, under the same tectonic stress regimes (DWR, 2014a). Comparing Figure 3-10 and Figure 3-16, highs in the top of the Cretaceous formations are associated with the locations of the anticlines.

3.1.7.3.3 Orland Buttes

The Orland Buttes are located along the eastern shore of Black Butte Lake in Glenn County. The buttes are composed of Cretaceous rocks capped by Lovejoy Basalt, which were thought to have been uplifted due to movement along the Black Butte Fault (Russell, 1931). Seismic refraction data and a recent study by Williams Lettis and Associates (2002), however, suggest that the Orland Buttes were exposed via uplift and subsequent eastward tilting along a blind west-dipping thrust fault.

3.1.7.3.4 Sutter Buttes

The Sutter Buttes rise about 2,080 feet above the Sacramento Valley floor east of Colusa and are composed of igneous, metasedimentary and metavolcanic rocks about 2.4 to 1.4 Ma in age (Harwood and Helley, 1987). The formation of the Sutter Buttes occurred in two phases. The first phase caused Upper Cretaceous and Lower Paleogene formations to be arched into a dome rising above land surface during a period of magma injection. This was followed by rapid erosion and heavy faulting of the dome structure, causing the relatively older formations to be exposed prior to the second phase. The second phase consisted of explosive volcanism, producing the rampart tuffs and breccias surrounding the Sutter Buttes. Like many of the other geologic structures of the region, the Sutter Buttes express characteristics representative of the stress regime produced by the Mendocino Triple Junction (Harwood and Helley, 1987).

3.1.7.3.5 Colusa Dome

The Colusa Dome is a subsurface structure located approximately six miles west-southwest of the Sutter Buttes (Harwood and Helley, 1987). The dome is oblong in shape, approximately 12 miles long in the north-south direction and approximately 3 miles wide. Formation of the Colusa Dome, proposed by Harwood and Helley (1987), is due to both drag on the Willows Fault and/or a related south-trending fault splay and localized magmatic intrusion, potentially during the same period as the formation of the Sutter Buttes. The Colusa Dome is associated with uplift of Cretaceous to Eocene formations. Uplift of the Cretaceous rocks can be seen on Figure 3-16. The Cretaceous rocks have been uplifted to approximately 1,500 feet below ground surface (bgs) while the younger Eocene deposits have been uplifted to approximately 500 feet bgs (Springhorn, 2008; Williams and Curtis, 1977).

3.1.8 Basin Boundaries

Per the BMPs (DWR, 2016a) and 23 CCR §354.14(b), the lateral basin boundaries can be defined as geologic, hydrologic, or structural features that significantly affect groundwater flow. The lower boundary of the basin can be defined based on physical properties (such as depth to bedrock) or geochemical properties (such as base of fresh water).

3.1.8.1 Lateral Boundaries

Historically, the lateral boundaries of the Subbasin were defined hydrologically and consisted of Stony Creek to the north, the Sacramento River to the east, Cache Creek to the south, and the foothills of the North Coast Ranges to the west. The hydrologic rationale for these boundaries is that the streams are, or may be, coincident with groundwater divides (boundary zones of either converging or diverging groundwater flow) and the low-permeability Coast Ranges rocks create a barrier to groundwater flow at their contact with the alluvial sediments of the Subbasin.

The modified Subbasin extents have defined the southern boundary to be the Colusa-Yolo County line and the southern extent of the Colusa County Water District, both of which are jurisdictional boundaries (DWR, 2016d). The northern boundary is Stony Creek, where the Subbasin exists within Glenn County, and the Glenn-Tehama County line where Stony Creek exists in Tehama County. Stony Creek and the Coast Ranges comprise the western extent of the Subbasin. The Sacramento River demarks the eastern boundary of the Subbasin with the exception of lands within Colusa County east of the Sacramento River and west of Reclamation District 1004, which were added after the groundwater basin boundary modifications of 2018 (DWR, 2019).

3.1.8.2 Vertical Boundaries

Figure 3-16 provides elevation contours of the top of Cretaceous-age rocks within the Subbasin (Harwood and Helley, 1987). These contours provide one approximation of the physical base of the principal aquifer in the Subbasin (Harwood and Helley, 1987). Harwood and Helley (1987) contoured the top of the igneous crystalline and metasedimentary rocks where depth information was available and contoured the top of the Cretaceous rocks where wells were not deep enough to reach the crystalline and metasedimentary rocks. The contours on Figure 3-16 do not account for the post-Cretaceous Lower Princeton Valley Fill and Ione Formation, which were deposited in marine environments, or the Upper Princeton Valley Fill, which can contain fresh or brackish groundwater, and are therefore not considered part of the fresh groundwater aquifer system (Redwine, 1984). These formations lie above the elevation contours shown on Figure 3-16.

The base of the groundwater subbasins can also be defined chemically as the base of fresh water. The map in Figure 3-17 and the cross sections in Figure 3-11, Figure 3-12, and Figure 3-13 depict the base of fresh water as defined by USGS (Olmsted and Davis, 1961). According to Olmsted and Davis (1961), the base of fresh water is where specific conductance of the water exceeds 3,000 micromhos, or approximately 2,000 milligrams per liter (mg/L) total dissolved solids (TDS). DWR is preparing an updated map of the base of freshwater within the Central Valley, which will be based on a TDS concentration of 1,000 mg/L, as defined the SWRCB maximum contamination level (MCL) for TDS (DWR, 2016a). The base of fresh water defined by C2VSim is defined by a TDS concentration of 3,000 parts per million (ppm) (3,000 mg/L) and was based on available geophysical logs (DWR, 2020a). The differences in the definition of the "base of fresh water" is a data gap that will be addressed in future versions of the HCM, as more recent studies are issued, and an industry standard is adopted. Data gaps and uncertainties associated with the base of freshwater and recommendations to address them are discussed in Section 3.1.12.

The cross sections shown on Figure 3-11 through Figure 3-13 contain an approximate delineation of the vertical extent of the subbasin. The physical base of the subbasin was defined as the base of the Tuscan or Tehama Formations. This definition excludes Cretaceous-age formations, post-Cretaceous age sediments of marine origin (Lower Princeton Valley Fill and the Ione Formation). The post-Cretaceous, non-marine Upper Princeton Valley Fill is excluded because it can contain brackish groundwater, where saline waters from the marine deposits mix with freshwater from the continental deposits. This delineation is similar to the delineation based on the chemically defined basin extent, except near the western margins of the Subbasin where brackish groundwater occurs above the Upper Princeton Valley Fill in the Tehama Formation.

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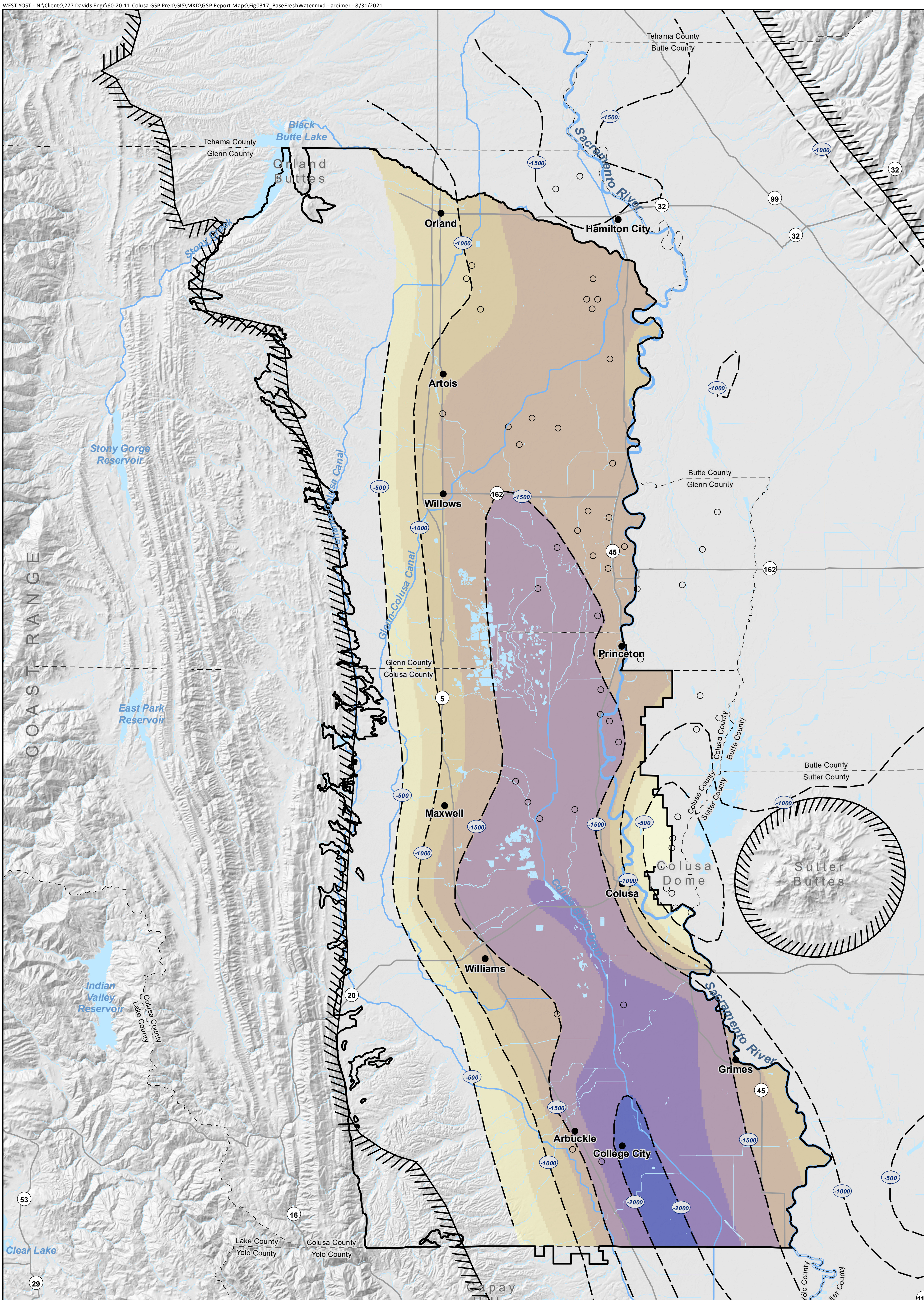

Source: Olmsted, F.H. and Davis, G.H., 1961, Geologic Features and Ground-Water Storage Capacity of the Sacramento Valley, California: prepared by U.S. Geological Survey in cooperation with the California Department of Water Resources, Water Supply Paper 1497, plate 5.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Vertical Datum: Mean Sea Level (MSL).

Note:
1. Fresh water is defined as having a specific conductance less than 3,000 micromhos (approximately 2,000 mg/L of total dissolved solids)

○ Well Used for Contouring

Colusa Subbasin

Base of Fresh Water Elevation Contour (feet, dashed where

Edge of Sierra Nevada, Cascade Range, and Coast

Elevation of Base of Fresh Water (MSL, feet)

- > -500
- -750 - -500
- -1000 - -750
- -1,250 - -1,000
- -1,500 - -1,250
- -1,750 - -1,500
- -2000 - -1,750
- <-2,000

0 2.5 5
Scale in Miles

Figure 3-17

Base of Fresh Water

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

3.1.9 Stratigraphic and Structural Features Potentially Affecting Flow

Stratigraphic and structural features that could potentially impact groundwater flow were introduced in Section 3.1.7.3. The structures discussed below are not necessarily subbasin boundaries but may impede or enable groundwater flow within the aquifer system.

3.1.9.1 Topography

Topographic relief impacts flows at shallower depths in the aquifer system, for example where permeable beds pinch out on elevated topography and the older, less permeable units are exposed on the surface.

3.1.9.2 Faults

Geologic investigations have shown displacement of the hydrogeologic formations along the Willows and Corning Faults. This is evident in the cross sections of Figure 3-11 through Figure 3-13. These faults may act as barriers or conduits to fresh groundwater flows. Deep-seated faults that intersect base of freshwater boundary may impact water quality if the fault zone sediments are relatively permeable compared to the native formations. Fault zone sediments with higher permeability will encourage groundwater mixing of the deeper brackish or saline waters and shallower fresh groundwater.

Displacement along the Paskenta Fault zone has not been observed in the fresh groundwater bearing hydrogeologic formations, however, measured and interpolated water levels near the Paskenta and Willows Fault zones near Artois, Glenn County exhibit a consistent localized lowering of the groundwater elevations along the trace of the fault. Additional study of the groundwater conditions would be needed to determine if the fault is acting as a conduit for flow along the fault trace, is impeding flows traverse to the fault, or both. Faults that act as conduits to groundwater flow can lead to degradation of water quality if contaminated or low-quality waters are mixed with freshwater sources.

3.1.9.3 Folds

Synclines are the folding in of the stratigraphic formations, deepening younger formations along the axis of the syncline and potentially exposing the older formations along the margins. Synclines can indicate locations of increased permeability or aquifer connectivity. This is seen within the subbasin near the Zamora Syncline where the Tehama Formation is characterized by highly pervious, loose, and well bedded layers (DWR, 2006a). Folds can also cause reorientation of naturally anisotropic units causing decreased permeability within the aquifer; however, this effect on permeability has not yet been quantified within the subbasin.

3.1.9.4 Stratigraphic Pinchouts

Stratigraphic pinchouts can occur at different scales. At a geologic scale, pinchouts can be found at the lateral extents of the formation, where the formation thickness tapers out. Examples of this within the study include the overlapping fingers of the Tehama and Tuscan Formations throughout the transition zone (Figure 3-15) or where the alluvial and basin deposits truncate against the uplands of the Coast Ranges (Figure 3-10). Pinchout can also be seen in the cross sections on Figure 3-11 through Figure 3-13.

Pinchouts can also occur at a larger scale. Structured heterogeneity of a geologic formation can result in higher permeable sediment occurring within lower permeable material. The Tehama Formation is especially heterogeneous given its depositional history of alluvial and fluvial deposits and is composed of predominantly fine-grained sediments enclosing discontinuous lenses of sand and gravel, which by definition are pinchouts.

3.1.9.5 Manmade Features

Structural features that may impact groundwater flow are not limited to naturally occurring geologic structures. Subsurface manmade features can also act to impede or encourage groundwater flow. Sediment mixing or digging may inhibit shallow groundwater flows. Structures with leaky subsurface infrastructure, such as basements, may impede natural groundwater flow by trapping shallow groundwater within the structure. Conversely, manmade structures that can encourage groundwater flows include boreholes such as water wells, oil and gas wells, or exploratory drilling shafts. Groundwater can use unsealed or leaky boreholes to quickly move vertically through the aquifer system. This can impact not only groundwater levels, but also groundwater quality.

3.1.10 Principal Aquifers and Aquitards

The Subbasin is underlain by one principal aquifer with interconnected unconfined, semiconfined, and confined zones.

Shallow groundwater in the Subbasin occurs under unconfined conditions in the Holocene stream channel deposits, except where these units are overlain by Holocene basin deposits, creating semiconfined to confined conditions (DWR, 1978). At greater depths, groundwater occurs under semiconfined to confined conditions in a single heterogeneous aquifer system, composed of predominantly fine-grained sediments enclosing discontinuous lenses of sand and gravel. The aquifer properties, including hydraulic conductivity and degree of confinement are dependent on the properties of the fine-grained units (Bertoldi et. al., 1991; Williamson et. al., 1989). The physical, chemical, and hydraulic hydrogeologic properties of the principal aquifer are discussed in the following subsections.

Most of the fresh groundwater within the Subbasin is contained within the Tehama Formation. The fraction of fresh groundwater contained within the Tehama Formation decreases in the northeastern portion of the Subbasin, where sediments of the Tuscan Formation are more prevalent (Figure 3-15). The interface between the Tehama Formation and Tuscan Formation, referred to in this report as the Tehama-Tuscan Transition Zone, has been documented as mixed Tehama and Tuscan Formation sediments (DWR, 2009b). These mixed sediment zones grade into the Tehama and Tuscan Formations and probably result in continuity of flow between the Tehama and the Tuscan Formations.

There are no defined principal aquitards within the Subbasin, however, the formations deposited under alluvial conditions or volcanic flows with lahars, such as the Tehama and Tuscan Formations, respectively, tend to consist of thick low-permeability sediments interbedded with interconnected channels or lenses of higher-permeability sediment. The low-permeability sediments may impede vertical groundwater flows, but generally do not separate the aquifer system into separate, definable principal aquifers.

3.1.10.1 Physical and Structural Properties

The lateral extent of the principal aquifer is the same as the lateral extent of the subbasin and is discussed in Section 3.1.8.1.

The principal aquifer extends to the base of fresh water, which is discussed in Section 3.1.8.2.

The unconfined to semi-confined portion of the principal aquifer primarily consists of Riverbank and Modesto Formations, as well as the overlying Holocene stream channel and basin deposits. These sediments can be up to approximately 200 feet thick and are comprised of unconsolidated to semi-consolidated materials. These sediments are found throughout the subbasin but pinch out near the western margin of the Subbasin where the foothills and uplands of the Coast Ranges commence, and the Tehama Formation outcrops. Geologic mapping and well records support that the Tehama Formation is relatively thin where it outcrops and does not produce much groundwater. This is discussed more in Section 3.1.7.2.2.

The confined portion of the principal aquifer consists of the Tehama Formation, Tuscan Formation, and to a lesser extent, the Upper Princeton Valley Fill. The Tehama Formation is the primary water-bearing formation within the principal aquifer. The Tehama Formation is heterogeneous with discontinuous sand and gravel lenses. Thicknesses of the Tehama Formation can be as much as approximately 2,000 feet (Olmsted and Davis, 1961). The Tehama Formation exists throughout the Subbasin but pinches out along the western margin of the Subbasin with the Coast Ranges and also to the east within the Tehama-Tuscan Transition Zone (Figure 3-15). The Tuscan Formation is composed of interbedded lahars, conglomerate, volcanic sandstone, and volcanic ash layers and can be found at depths greater than 700 feet bgs. The Tuscan Formation within the subbasin exists almost solely within the Tehama-Tuscan Transition Zone but can be found as far east as the foothills of the Sierra Nevada Mountain Range. The Upper Princeton Valley Fill is located at depths greater than 1,000 feet bgs where it exists within the subbasin and is predominantly composed of sandstone. Table 3-4 contains the ranges of vertical and horizontal hydraulic conductivity, transmissivity, storativity, and specific yield values for the principal aquifer's unconfined and confined hydrogeologic units as listed in published reports on aquifer testing. Analytical models such as the Theis or Hantush-Jacob methods commonly enable the estimation of transmissivity and storativity from aquifer test data. Transmissivities can then be used to determine hydraulic conductivity of a water-bearing unit. Hydraulic conductivities are a measure of the aquifer's ability to transmit water horizontally or vertically. Aquifer materials generally have higher horizontal hydraulic conductivity than vertical hydraulic conductivity. Confining units are generally the limiting factor when evaluating vertical movement of water through the aquifer system.

Horizontal hydraulic conductivity of the unconfined to semi-confined zone ranges from 10 to 229 feet per day (ft/day).

A typical horizontal hydraulic conductivity of the Tehama Formation is approximately 27 ft/day. Within the permeable units of the Tuscan Formation (Units A and B), horizontal hydraulic conductivities range from 11 to 88 ft/day. One study estimated horizontal hydraulic conductivity within the confining unit of the Tuscan Formation (Unit C) to be 321 to 571 ft/day (Brown and Caldwell, 2013), an order of magnitude larger than those estimated within the more permeable units. Typically, the horizontal hydraulic conductivity of low-permeability strata is lower than that of its more permeable counterparts. This discrepancy in hydraulic conductivity values may be due to aquifer testing conducted within highly permeable zones within Unit C. More investigation into the discrepancy is recommended, as discussed in Section 3.1.12.2.

Vertical hydraulic conductivity for the confining unit in the Tehama-Tuscan Transition Zone was estimated to be 0.0036 ft/day based on data obtained during an aquifer test using a multiple completion observation well with separate completions perforated above and below the confining unit (West Yost, 2012).

Table 3-4. Hydraulic Properties

Hydraulic Property per Source	Unconfined to Semi-Confined	Confined (Tehama Formation)	Confined (Tuscan Formation)		
			Unit C	Unit B	Unit A
Transmissivity, ft²/day					
Stony Creek Fan Aquifer Performance Testing[a]	--	2,466 - 4,727	--	2,705 - 8,902	2,705 - 8,902
Tuscan Aquifer Investigation[b]	--	--	11,550 - 20,540	2,322 - 3,078	12,230 - 23,650
Horizontal Hydraulic Conductivity, ft/day					
Stony Creek Fan Aquifer Performance Testing[a]	--	26.6	--	11.4 - 13.2	11.4 - 13.2
Stony Creek Fan Feasibility Study[c]	10 - 229	--	--	--	--
Tuscan Aquifer Investigation[b]	--	--	321 - 571	66 - 88	41 - 79
Vertical Hydraulic Conductivity, ft/day					
Stony Creek Fan Aquifer Performance Testing[a]	--	--	0.0036	--	--
Storativity, unitless					
Stony Creek Fan Aquifer Performance Testing[a]	--	0.0003 - 0.001	--	0.0009 - 0.003	0.0009 - 0.003
Tuscan Aquifer Investigation[b]	--	--	0.0003 - 0.0005	0.00004 - 0.00009	0.00004 - 0.001
Specific Yield, unitless					
USGS Water Supply Paper 1497[d]	0.034 - 0.185	--	--	--	--

(a) West Yost, 2012
(b) Brown and Caldwell, 2013
(c) Montgomery Watson Harza (unpublished) via WRIME, 2003
(d) Olmsted and Davis, 1961

Water released from storage within confined aquifer systems is characterized by the storativity of the aquifer units. Storativity is estimated to range from 0.0003 to 0.001 for the Tehama Formation and 0.00004 to 0.003 for the Tuscan Formation. Storativity of Unit A of the Tuscan Formation (the deepest unit) is generally higher than that of Unit B (Brown and Caldwell, 2013), but still lower than that of the Tehama Formation. Storativity values are not reported for the unconfined portion of the Tuscan Formation.

Specific yield represents the water released from drainage from the pore space between the individual grains that comprise the aquifer sediment. Specific yield is only specified for the unconfined portion of the principal aquifer. Specific yield for the unconfined portion of the principal aquifer is approximately 0.034 to 0.185 (3.4 percent to 18.5 percent) (Olmsted and Davis, 1961).

Structural properties that could impact groundwater flows within the principal aquifer are discussed in more detail in Section 3.1.9.

3.1.10.2 Primary Uses

There are approximately 90 public water service agencies that provide potable water within the Subbasin (Figure 2-4). These stakeholders include municipalities, water agencies, irrigation districts, wildlife refuges, and reclamation districts. Not shown are private and domestic pumpers located in the "white-space" of the Subbasin and State small water systems. The primary uses of groundwater within the principal aquifer include agricultural, irrigation, domestic, industrial, and municipal supply (DWR, 2006a).

3.1.10.3 Water Quality

Historical groundwater quality concerns within the Subbasin include locally elevated levels of salinity, TDS, adjusted sodium absorption ratio, boron, nitrate, and manganese (DWR, 2006a; Wood Rodgers, 2008). Many of the entities within Glenn and Colusa Counties that monitor groundwater for quality either use wells that have multiple or long perforated intervals that access groundwater from both the unconfined and confined portions of the principal aquifer, or report water quality results from their wells collectively, without specifying what depth(s) the well was screened in. This data gap is discussed in more detail in Section 3.1.12 of this report.

Recent groundwater quality concerns within the Subbasin include salinity, boron, nitrate, heavy metals, including arsenic, and hexavalent chromium. High concentrations of sodium, chloride, and sulfate, all of which are related to salinity have been observed south of Maxwell (CH2MHILL, 2016a; RD 108, 2008) and could negatively impact agricultural applications. Elevated concentrations of boron within Colusa County have already impacted agricultural practices (GCID, 1995). In contrast, boron concentrations measured in select groundwater wells within Glenn County have not exceeded the United States Environmental Protection Agency (USEPA) agricultural water quality goal for boron of 750 micrograms per liter (µg/L) (USEPA, 1986; USGS, 2018). Elevated salinity levels throughout much of Colusa County, nitrates near Orland and Willows, arsenic near Grimes, and iron and manganese near Williams and Colusa are of concern with respect to drinking water MCLs (CH2MHILL, 2016a). Arsenic, especially, has been a constituent of concern for Grimes, Colusa, and the surrounding area. Local agencies have been working to mitigate arsenic contamination in groundwater in this area. Drinking water supply wells near Willows, Glenn County, have experienced high concentrations of hexavalent chromium (California Water Service, 2016).

There are also several active groundwater contamination cleanup sites in the Subbasin. These primarily include leaky storage tanks and unauthorized releases of contaminants such as petroleum hydrocarbons, nitrate, pesticides and herbicides including dicamba, and solvents. Most of these cleanup sites impact the unconfined portion of the principal aquifer, but there is a risk that the contamination could migrate into the deeper, more heavily pumped portions of the aquifer. The largest contamination site is the Orland Dry Cleaner site, a tetrachloroethylene (PCE) plume that extends approximately two miles southeast of the source location in Orland, Glenn County (Department of Toxic Substances Control [DTSC], 2020; SWRCB, 2020b). In 2007, PCE contamination was recorded at depths of 127 feet bgs (DTSC, 2020).

More detail regarding existing and historical groundwater quality issues and trends is provided in Section 3.2 of this GSP.

3.1.11 Groundwater Inflows and Outflows

Groundwater inflows and outflows between the Subbasin and neighboring groundwater subbasins depend on fixed aquifer hydraulic properties and the prevailing groundwater gradients, which are influenced by time-dependent natural recharge and discharge patterns, aquifer interactions with streams, the effects of pumping, and the effects of managed and unmanaged recharge. These inflows and outflows are discussed further in the following subsections.

3.1.11.1 Groundwater Underflow

Groundwater underflow occurs as outflow across the boundary of the Colusa and Yolo Subbasins under the influence of the generally southeasterly to southerly groundwater flow gradient. The boundary between the Colusa and Yolo Subbasins is jurisdictional and has no influence on the flow of groundwater. Groundwater underflow as inflow occurs along the boundary of the Colusa and Corning Subbasins, along Stony Creek. Groundwater underflow may occur as either outflow or inflow across the eastern hydrologic border of the Subbasin, where the Subbasin is bound by either the Sacramento River or the jurisdictional boundary of R.D. 1004. How groundwater levels impact interconnected surface waters is discussed in Section 3.2.7.

The magnitude of these underflows is not currently quantified but is anticipated to be a relatively small component of the water budget for the Subbasin and neighboring groundwater subbasins. Significant influences on these inflows and outflows include groundwater gradients across subbasin boundaries, stream stage in the Sacramento River, Stony Creek and Butte Creek, and the timing, location, and magnitude of groundwater pumping, managed recharge, and unmanaged recharge, which includes recharge due to agricultural practices and precipitation.

Underflow across the western boundary of the Subbasin is negligible due to the low permeability of the Coast Range rocks.

3.1.11.2 Groundwater Recharge Areas

The primary sources of groundwater recharge in the Subbasin are deep percolation – the movement of water from land surface to the aquifer – of precipitation and applied water. Other volumetrically less important sources include deep percolation resulting from domestic and municipal uses.

3.1.11.2.1 Agricultural Recharge

Much of the Subbasin is devoted to agriculture; many of the agricultural fields are irrigated with surface water supplies from the Tehama-Colusa Canal, the Glenn-Colusa Canal, and other irrigation water supply systems, which provide Sacramento River water from outside of the subbasin boundaries (Figure 3-6). Water applied to agricultural lands has a significant contribution to groundwater recharge.

3.1.11.2.2 Soil Suitability for Groundwater Recharge

Recharge occurs throughout the Subbasin, but at variable rates depending on topography, soil properties and the underlying geology, as introduced in Sections 3.1.4, 3.1.6, and 3.1.7, respectively. Figure 3-18 shows potential recharge areas based on the Soil Agricultural Groundwater Banking Index (SAGBI) (O'Geen et. al., 2015). SAGBI was developed to provide a measure of soil suitability for recharge on agricultural lands while maintaining the viability of soils and crops, and groundwater quality. The index was developed considering five major factors (O'Geen et. al., 2015):

1. Deep percolation;
2. Root zone residence time;
3. Topography;
4. Chemical limitations; and
5. Soil surface conditions.

As depicted on Figure 3-18, the index also includes the assumption that soils with restrictive layers would be made more permeable through deep tillage. The index ranges from very poor to excellent over the Subbasin.

Soils with indices in the moderately good to excellent range correspond to hydrologic soil groups A through C, as discussed in Section 3.1.6, and are mostly located over younger alluvial fan and stream channel deposits, including those of Stony Creek and other small streams draining the Coast Ranges, and younger stream channel deposits located along the Sacramento River (Figure 3-9 and Figure 3-10).

3.1.11.2.3 On-Farm Multi-Benefit Managed Aquifer Recharge and Shorebird Habitat Program

In 2018, CGA in cooperation with The Nature Conservancy (TNC) implemented a pilot managed aquifer recharge program. During this program, farmers worked with TNC to create temporary wetlands using existing water conveyance infrastructure and available flows during fall and winter migration periods. The program sought to increase groundwater recharge in severely disadvantaged communities while providing habitat for migratory birds. Various factors including water availability, soil suitability, and farming practices were evaluated for participating farmers. The pilot project areas are delineated on Figure 3-18.

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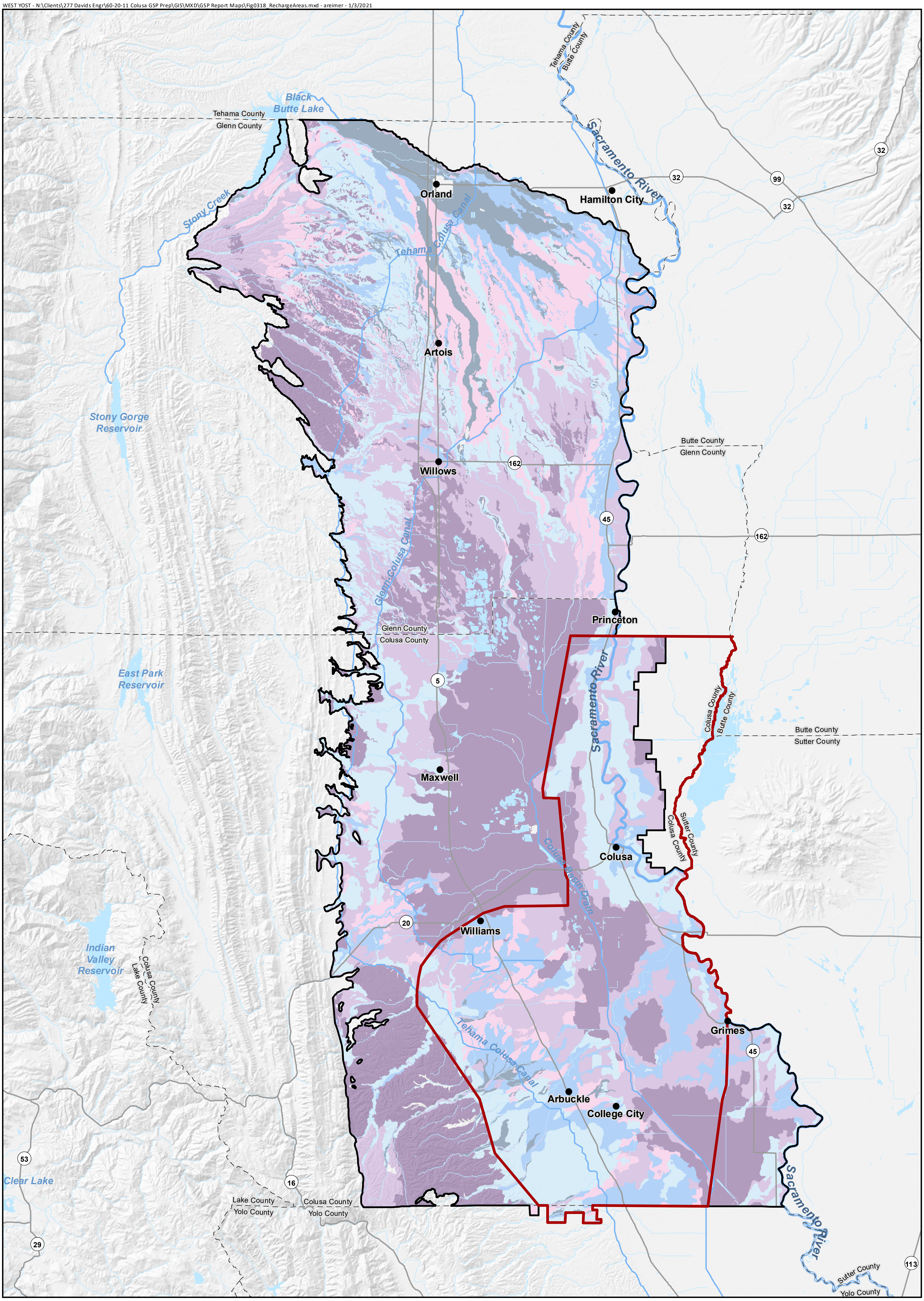


Source: O'Geen, A.T. et. al., 2015, Soil Suitability Index Identifies Potential Areas for Groundwater Banking on Agricultural Lands: California Agriculture, Volume 69, Number 2, pages 75-84, April 2015, GIS files provided November 2017.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Note:
1. Modified Soil Agricultural Groundwater Banking Index (SAGBI) suitability groups assume that soils with restrictive soil layers have been modified by deep tillage.

Colusa Subbasin

Colusa Multi-Benefit Groundwater Recharge Project Area (2020)

Soil Agricultural Groundwater Banking Index with Assumed Deep Tillage Modification

- Excellent
- Good
- Moderately Good
- Moderately Poor
- Poor
- Very Poor

N

0 2.5 5

Scale in Miles

Figure 3-18

Locations of Potential Recharge

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan

3.1.11.3 Groundwater Discharge Areas

Groundwater discharges in the Subbasin include:

- Discharges to streams, drains, seeps and springs;
- Losses to the atmosphere through uptake and consumption by wetland or riparian vegetation (phreatophytes), deeply rooted crops, and bare soil evaporation under shallow water table conditions; and
- Groundwater pumping.

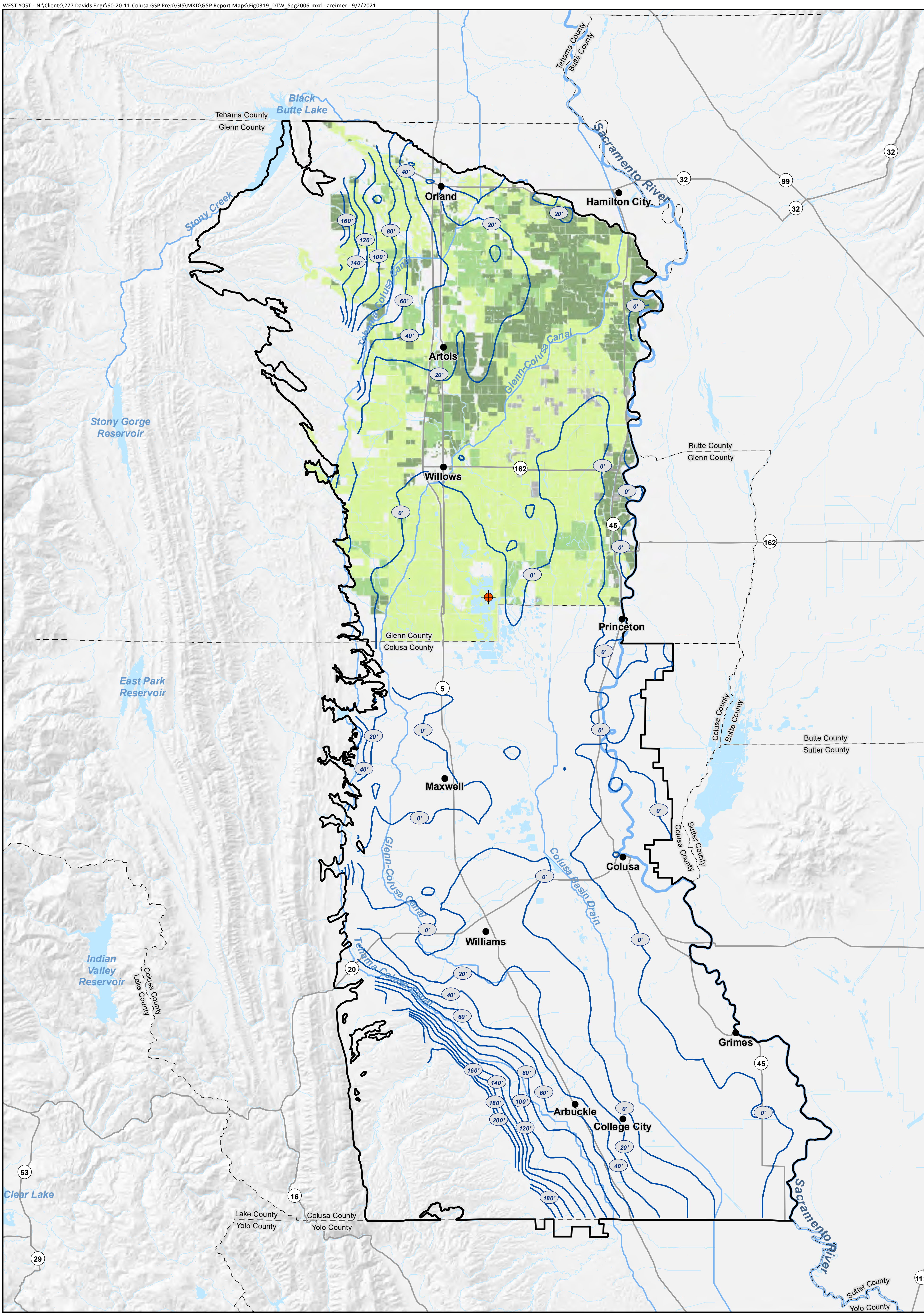
Figure 3-19 and Figure 3-20 show depth to groundwater during the spring of 2006 (prior to the multiple year droughts of 2007-2009 and 2012-2015) and the spring of 2017 (after the multiple year droughts), respectively.

Areas with depth to groundwater close to land surface may indicate potential zones of groundwater discharge that can be expressed as flowing artesian wells, or through discharge to ponds, springs, wetlands, streams and canals. Discharges can also occur through evapotranspiration from riparian or phreatophytic vegetation, and from bare soil evaporation.

Approximately 25 springs can be identified from historical USGS topographic maps of the subbasin. Most of these springs are unnamed and located in the Subbasin occur near the western boundary. Location indicates that the springs historically discharged from the Tehama, Riverbank, or Modesto Formations and stream channel alluvium. A number of these springs have been developed for agricultural use by landowners locally (apparent on satellite imagery). Data regarding discharge and water quality was not found for incorporation into this GSP.

In the spring of 2006, the largest of these potential discharge zones was in a low elevation area of the Subbasin aligned along a north-northwesterly trend extending from the Colusa-Yolo County line into the southern half of Glenn County (Figure 3-19). The axis of the southerly part of this zone was aligned with the Colusa Drain, which is an indication that the Colusa Drain received groundwater discharge in spring 2006. Shallow depths to water in spring of 2006 also were evident along the Sacramento River, indicating that some reaches of the Sacramento River may have received groundwater discharges in spring 2006. The extent of potential groundwater discharge areas in the spring of 2017 was similar but more limited.

Comparison of the depth to groundwater contours to land use shows that many areas with shallow depths to groundwater correspond to the areas of rice cultivation and wildlife refuges. Ponded agricultural fields tend to be in areas that contain a high percentage of silts and clays, which restrict, yet do not negate the vertical flow of water into or out of the groundwater system. A portion of the groundwater would therefore discharge into the ponded water and a portion would discharge into unlined irrigation canals, drains, or ephemeral stream channels.



Source: Water levels were obtained from the California Department of Water Resources Water Data Library. Water source information was obtained from DWR Land Use Survey. Water source data for Glenn County was surveyed in 2003. Colusa County was surveyed in 2003 for land use but not water use.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

Note: Colusa County was not surveyed for water use within 3 years of 2006 for comparison to the spring 2006 groundwater level contours.

Well 18N02W18D001-004M

Spring 2006 Depth to Water Contours (feet, 20-foot Interval)

Colusa Subbasin

Water Source (2003)

- Surface Water
- Mixed Surface and Groundwater
- Groundwater
- Unknown

0 2.5 5

Scale in Miles

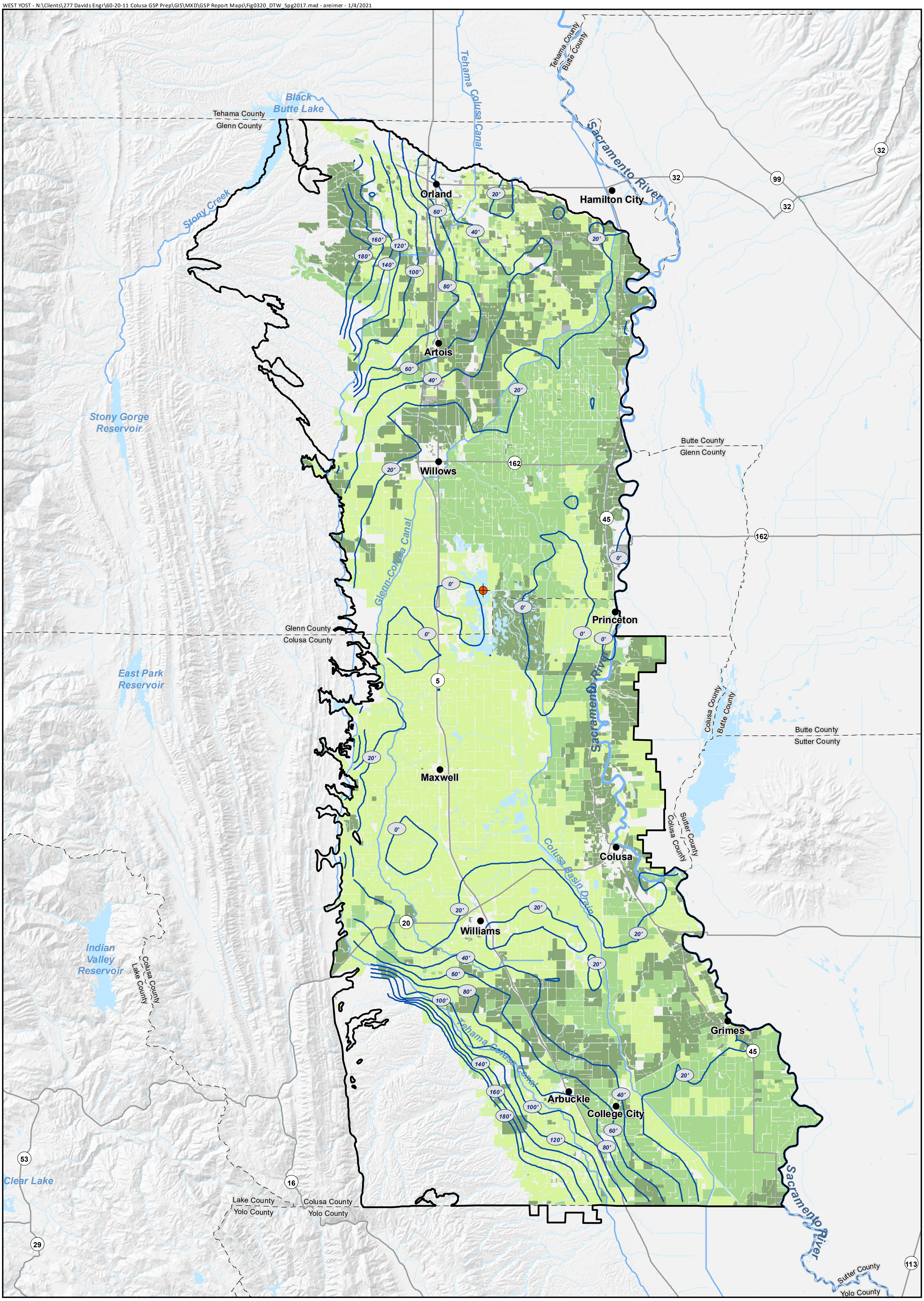
Figure 3-19

Depth to Groundwater Contours Spring 2006

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan



Well 18N02W18D001-004M

Spring 2017 Depth to Water Contours (feet, 20-foot Interval)

Colusa Subbasin

Water Source (2014)

Surface Water

Mixed Surface and Groundwater

Groundwater

Unknown

Source: Water levels were obtained from the California Department of Water Resources Water Data Library. Water source information was obtained from DWR Land Use Survey. Water source data for Glenn and Colusa Counties were marked as provisional, 2014.

Horizontal Datum: North American Datum of 1983, California State Plane Zone II, feet.

0 2.5 5

Scale in Miles

Figure 3-20

Depth to Groundwater Contours Spring 2017

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan

The potential for flowing artesian conditions is evident in the historical groundwater level measurements for some monitoring wells in the Subbasin. Figure 3-21 is a hydrograph for a multiple completion well located north of the Sacramento National Wildlife Refuge, west of Princeton. As seen on the hydrograph, the groundwater within the deep completion (18N02W18D001) historically has a higher potentiometric head than the groundwater within the shallower completions. This indicates a potential for upward flow of groundwater from the deeper confined water-bearing units to the shallower confined water-bearing units. Starting in 2014 and continuing through the first half of 2020, however, the depth to groundwater within the deepest completion has decreased significantly, indicating a reversal in the vertical flow direction. This period corresponds to the multiple year droughts of 2007 to 2009 and 2012 to 2016. Although the overall depths to groundwater were greater in the latter half of 2020, the vertical flow direction quickly reverted back to pre-2014 conditions. Generally speaking, groundwater pumping increases during periods of drought, when surface water deliveries are diminished. This causes a lowering of groundwater levels and may result in cones of depression surrounding the groundwater extraction wells. When sufficient surface water supplies exist, pumping decreases, and the groundwater levels revert to their previous vertical gradient regime, as evidenced in the hydrographs. Groundwater levels can take much longer to recover than the vertical gradient regime.

Groundwater pumping within the subbasin serves municipal, domestic, irrigation, commercial, and environmental needs. Figure 3-19 and Figure 3-20 show the irrigation districts, reclamation districts, municipal water agencies, and wildlife refuges within the Subbasin and the water supply source identified by DWR in 2014 (DWR, 2014b). DWR surveys of groundwater extraction for the Subbasin reported approximately 310,000 af for agricultural applications, 14,000 af for municipal and industrial consumption, and 22,000 af for environmental wetland use (DWR, 2006a). There are also many unmetered domestic and small agricultural wells located throughout the Subbasin. Colusa County estimates approximately 1,200 af of groundwater extraction from domestic wells (Wood Rodgers, 2008) across the entire County. A more detailed discussion of the water budget is discussed in Section 3.3 of this GSP. For GSP development, groundwater pumping by rural residential wells was estimated using the C2VSimFG-Colusa model, and was calculated based on residential demand after accounting for any other available water supplies and separately accounting for agricultural demand (see Appendix 3D for additional information). More detailed discussion of the GSP water budget and groundwater pumping estimates is provided in Section 3.3 of this GSP.

While the municipalities rely on groundwater to serve their residents, much of the agricultural lands within the Subbasin divert surface water supplies for irrigation. Some of the farmlands use a mix of surface water supplies and groundwater (Figure 3-19 and Figure 3-20). The primary groundwater pumping areas for irrigation correspond to farmlands that do not receive surface water supplies. An example of this includes farmlands that are not part of an existing irrigation district.

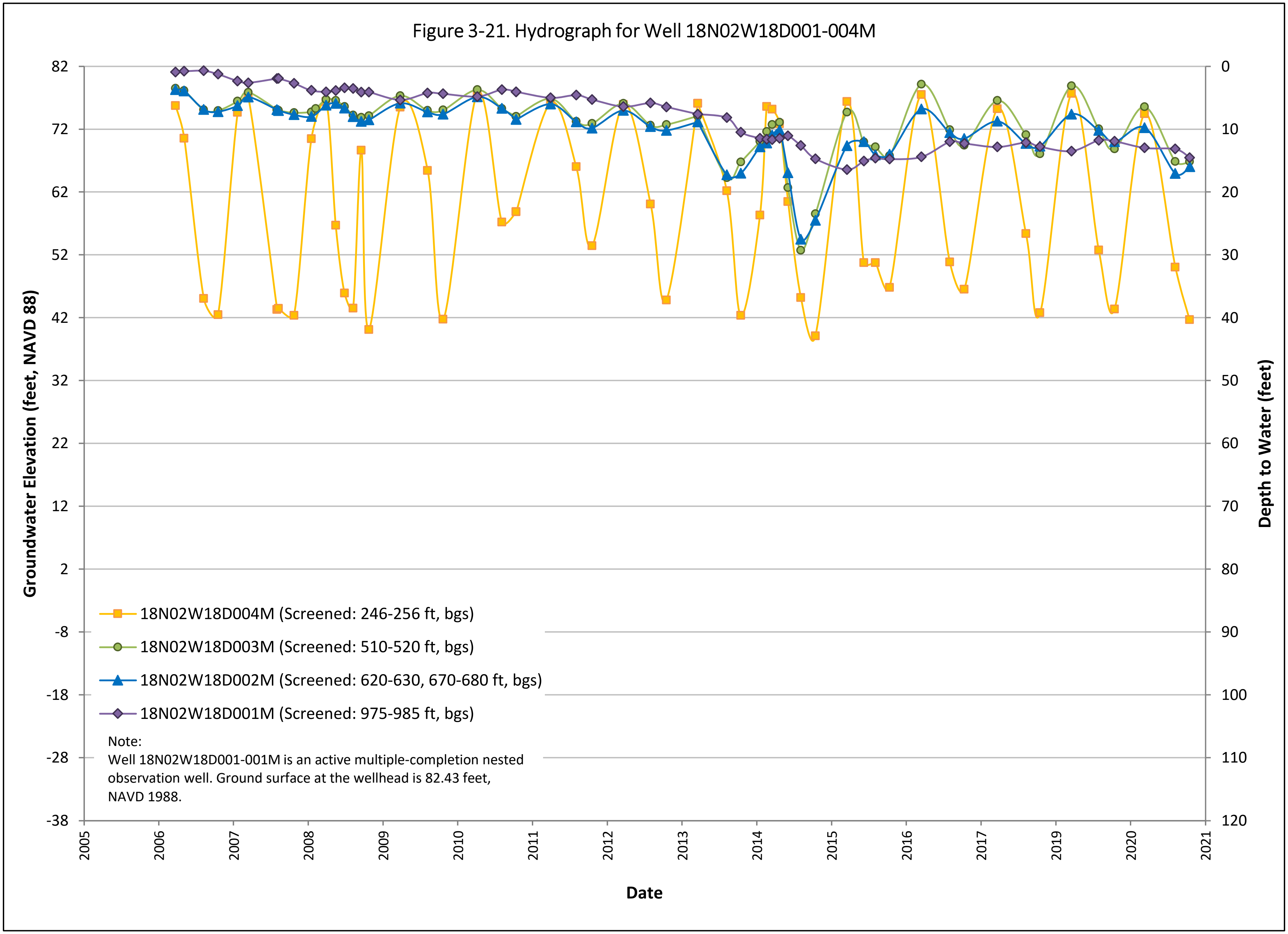


Figure 3-21. Hydrograph for Well 18N02W18D001-004M
Groundwater Elevation (feet, NAVD 88)
Depth to Water (feet)
Date
82
72
62
52
42
32
22
12
2
-8
-18
-28
-38
0
10
20
30
40
50
60
70
80
90
100
110
120
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
18N02W18D004M (Screened: 246-256 ft, bgs)
18N02W18D003M (Screened: 510-520 ft, bgs)
18N02W18D002M (Screened: 620-630, 670-680 ft, bgs)
18N02W18D001M (Screened: 975-985 ft, bgs)
Note:
Well 18N02W18D001-001M is an active multiple-completion nested observation well. Ground surface at the wellhead is 82.43 feet, NAVD 1988.

3.1.12 Data Gaps, Uncertainty, and Recommended Actions

BMPs for the HCM (DWR, 2016a) state that "the HCM should be developed and periodically updated as part of an iterative process as data gaps are addressed and new information becomes available". The different components of the HCM were evaluated for data gaps, uncertainty, and unresolved discrepancies identified through comparison with the C2VSimFG. These topics and recommended future actions are discussed in more detail in the following subsections. More information regarding C2VSimFG and how it was used for the Subbasin can be found in Appendix 3D.

The data gaps in the HCM and some recommended actions to address the data gaps are discussed in the following sections. The following data gaps have been identified:

- Lateral and vertical extent of geologic units and the principal aquifer, specifically with regard to the Tehama-Tuscan transition zone, volcanic and plutonic formations related to the Colusa Done and Sutter Buttes, Turlock Lake Formation or similar highly compressible clayey deposits, and thickness of the Tehama Formation in the upland areas of western Colusa Subbasin and near the Zamora Syncline.
- Vertical extent of the base of fresh water.
- Hydraulic parameters of the principal aquifer.
- Groundwater quality of the principal aquifer, specifically with regard to the source and vertical migration of contaminated waters.
- Groundwater levels within the principal aquifer, specifically pertaining to the western margins of the Subbasin where there is a lack of monitoring locations and the unconfined shallow water table (e.g., near Orland where an increase of drying shallow domestic wells is currently occurring).
- Location and discharge of springs.

3.1.12.1 Extent of Geologic Units, Principal Aquifer, and Base of Fresh Water

Uncertainties in the thickness and extent of the principal aquifer, geologic formations, and base of fresh water have been identified in the following areas of the subbasin:

1. Tehama-Tuscan Transition Zone;
2. West and south of the Sutter Buttes;
3. Northwestern upland area, west of Orland;
4. Southwestern upland area, west of Arbuckle; and
5. Near the Zamora Syncline, east of Williams and College City.

There is uncertainty regarding the extent and depths of the Tehama and Tuscan Formations within the Tehama-Tuscan Transition Zone. Previous geologic mapping shown on the cross sections (Figure 3-11 through Figure 3-13) and Figure 3-15 depict thick depositions of Tehama and Tuscan within the Transition Zone, but the borehole data delineating the thickness and extent of units and the degree to which Tehama and Tuscan Formation sediments are intermixed is limited.

Springhorn (2008) identified the lands west and south of the Sutter Buttes, along the Sacramento River and surrounding area, as an area with gaps in information regarding subsurface lithologic extent and how it impacts groundwater quality, primarily arsenic. The investigations conducted for this GSP agree that the area is a data gap.

Additionally, there is some concern regarding the extent and thickness of the Turlock Lake Formation or a similar diatomaceous clay layer within or near the Subbasin. The compressible Turlock Lake Formation sediments may lead to land subsidence and reduction in aquifer storage. The Turlock Lake Formation and a similar diatomaceous clay layer is present in boreholes east and south of the Sutter Buttes and was encountered in a borehole near Zamora in Yolo County. Additional subsurface investigations in the areas west and south of the Sutter Buttes is recommended to better understand the extent of these sediments.

The base elevation of the uppermost three C2VsimFG model layers is overlain on the cross sections (Figure 3-11 through Figure 3-13). The modeled layers for C2VSimFG are based on groundwater conditions and pumping, not geologic units, but can be compared with the extent of the geologic units comprising the principal aquifer. The principal aquifer is also characterized by the extent and thickness of the freshwater-bearing geologic formations within the subbasin. Therefore, the extent of the geologic formations, principal aquifer, mapped base of freshwater and extent of the model layers are all related. Discrepancies between these datasets highlight uncertainty in the underlying datasets, the methods used to interpolate the base of fresh water, and the methods used to interpolate the thicknesses of geologic formations between locations with known data. Available information in the northwest uplands indicate that the Tehama Formation in that area is relatively thin compared to the rest of the subbasin and has low groundwater yield. The geologic mapping and cross section B-B' shown on Figure 3-10 and Figure 3-11 support this theory. The modeled base of fresh water, however, shows the principal aquifer as approximately 1,000 feet thick. This contradicts the available geologic data and verbal reports from residents of the area. Olmsted and Davis (1961) did not map the base of fresh water in this area. Table 3-5 provides a comparison of the four model layers with the principal aquifer and geologic formations.

Table 3-5. Comparison of Modeled Layers with Principal Aquifer and Geologic Units

C2VSimFG Model Layer Number	C2VSimFG Model Layer Description	Principal Aquifer	Geologic Formation
1	Unconfined Freshwater Aquifer Zone with Pumping	Unconfined Zone	Holocene Basin Fill and Stream Channel Deposits Modesto Formation Riverbank Formation Tehama Formation (minimal)
2	Confined Freshwater Aquifer Zone with Pumping	Confined Zone	Tehama Formation Tuscan Formation
3	Confined Freshwater Aquifer Zone with Little Pumping	Confined Zone	Tehama Formation Tuscan Formation Upper Princeton Valley Fill (partial)
4	Confined Saline Aquifer	--	Upper Princeton Valley Fill (partial) Ione Formation Lower Princeton Valley Fill

Uncertainty is even greater in the southwestern upland area than the northwest upland area. In addition to minimal available well logs, there are no mapped isolated outcrops of older Cretaceous-aged rocks within the southern uplands to indicate uplift of older bedrock formations. Cross sections D-D’ and G-G’, which cut through the southwestern upland area, show the reverse discrepancy along the west margin of the Subbasin (Figure 3-12). Cross sections D-D’ and G-G’ show the modeled base of the aquifer to be much shallower than the mapped freshwater-bearing geologic units.

The Tehama Formation thickens near the Zamora Syncline, however available data that identifies the base of the Tehama Formation in this area is scarce. The modeled based of fresh water from C2VSimFG and the mapped base of fresh water from Olmsted and Davis (1961) both indicate that fresh water exists at depths greater than those shown on cross section G-G’ (Figure 3-12).

Other locations where the modeled or mapped base of fresh water does not coincide with the freshwater-bearing formations can be seen on the cross sections (Figure 3-11 through Figure 3-13). For example, near the Corning Fault on cross section B-B’, near Sacramento River on cross section D-D’, or between Cortina Creek and the Tehama-Colusa Canal on cross section F-F’. Additionally, input from residents and additional groundwater quality studies support that the base of fresh water is shallower than reported along fault zones (e.g., Willows Fault) and near the Sutter Buttes, where the freshwater-bearing geologic formations are thinner and shallower.

Additional subsurface data will be collected to help delineate the base of the geologic formations in the aforementioned areas. The vertical extents of these geologic units will be updated through evaluation of DWR’s forthcoming texture model developed as part of the Sacramento Valley Simulation Model (SVSim); inspection of geophysical logs from oil and gas wells; aeromagnetic surveys; passive seismic or other geophysical investigation surveys, such as controlled source audio-frequency magnetotellurics (CSAMT); in-depth evaluation of available well completion reports (most of which may not be deep enough to characterize the base of the Tehama and Tuscan Formations, but may be sufficient to better define the Tehama-Tuscan Transition Zone); information from new boreholes; and/or other methods or data sources that may characterize the subsurface stratigraphy.

Different agencies have chosen different TDS concentration thresholds to define the base of fresh water. These different threshold concentrations used to classify fresh water versus saline water is a contributing factor in the discrepancy between all of the mapped depth to base of fresh water. Olmsted and Davis (1961) used a threshold of approximately 2,000 mg/L while C2VSimFG assumes a threshold of 3,000 ppm (approximately 3,000 mg/L of TDS, DWR, 2020a), and DWR is preparing an updated analysis of the base of freshwater within the Central Valley, which will be based on a TDS concentration of 1,000 mg/L, the MCL for TDS (DWR, 2016a). The new DWR analysis will be used to update the HCM and the freshwater threshold concentration used by that analysis will supersede all previous mapped thresholds.

Once additional, more recent information is evaluated the geologic and base of freshwater extents in the HCM can be updated and the relevant C2VSimFG model inputs can be adjusted to better represent the principal aquifer in these areas. Further improvements to the HCM can be conducted using oil and gas well logs, the proposed future DWR airborne electromagnetic survey data (AEM), and any new theses or studies regarding hydrogeology or geochemistry in the greater Colusa Subbasin area.

3.1.12.2 Hydraulic Parameters

Hydraulic parameter estimates will be updated and refined by performing additional pumping tests, and reanalyzing existing test data in cases in which parameter estimates are outside of expected ranges. Pumping tests will use pumping wells and dedicated monitoring wells discretely screened in either the unconfined or confined portion of the principal aquifer in order to better quantify hydraulic parameters per the principal aquifer's unconfined or confined condition.

The hydraulic properties of Tuscan Formation Unit C will be further investigated to verify the high hydraulic conductivities reported for Unit C and their applicability in the Subbasin.

3.1.12.3 Groundwater Quality

23 CCR §354.14(b)(4)(D) states that "general water quality of the principal aquifers" shall be included in the HCM. Future groundwater quality characterization efforts will utilize wells with known construction. The wells used to characterize groundwater quality discussed in this plan are all drilled within the principal aquifer but have not been identified as representing the unconfined or confined conditions. Identifying well depths and construction information would be beneficial in order to better understand groundwater quality and the potential spatial trends and movement of contaminants within the principal aquifer. GSAs should keep in mind the Human Right to Water and how it could be managed via water quality degradation projects implemented under the Colusa Subbasin GSP.

Coordination with local agencies, public water systems and domestic pumpers west and south of the Sutter Buttes and near Williams is encouraged to better understand the extent and potential movement of arsenic and salinity concentrations. Further investigation regarding the potential for mobilization of brackish waters or naturally occurring constituents of concern is recommended. The proposed DWR AEM survey is anticipated to be able to characterize shallow freshwater-saline water interface(s).

3.1.12.4 Groundwater Level Measurements

Groundwater elevation contours shown on Figure 3-19 and Figure 3-20 imply that the faulting could be impacting the localized groundwater flow regime. Additional water level measurements collected from the greater Artois area and westward would allow better evaluation of groundwater conditions in the area. More data could shed light on if the localized groundwater lows are due to the fault zone or some other factor such as localized pumping. The same applies to the Willows Fault near Colusa and the Sutter Buttes, where uncertainty exists regarding how the fault zone could impact migration of deep brackish to saline water into the freshwater aquifer system.

Most of the wells monitored for groundwater elevations are greater than 100 feet deep. This presents a data gap in understanding the shallow, unconfined groundwater elevations that many domestic and agricultural irrigation supply wells extract from. Recent conversations with domestic pumpers near the greater Orland area have indicated that many domestic wells have gone and are going dry as a result of the ongoing drought. DWR has recently started mapping and recording reports of drying wells and more published data is being made available. Glenn County and Colusa County are also recording reports of wells that have gone dry or have other issues. Maps of reported wells in Glenn County are regularly updated and available to the public at: https://arcg.is/10nmyT2. Coordination between the GSAs, public monitoring agencies, public water systems, domestic pumpers, and other stakeholders that depend on shallow groundwater wells has already started and evaluation of shallow water levels is currently ongoing. Regular monitoring of shallow wells and recording of drying wells will provide information to better characterize the extent and magnitude of groundwater lowering within the shallow portion of the principal aquifer.

3.1.12.5 Springs

According to historical USGS topographical maps, springs exists throughout the western margin of the Subbasin. However, their location, if they still exist, and their characteristics such as source waters, use, and flow discharge and frequency are not well reported. Better understanding the spring flows from the

Coast Range foothills will help shed light on the shallow groundwater regime of the western area of the Subbasin, as well as provide insight into the ephemeral and intermittent streams and potentially help delineation of groundwater dependent ecosystems and habitats. Additional evaluation, potentially including field survey of the spring locations, communication with local residents and stakeholders, and monitoring of surface discharge is recommended.

3.2 EXISTING AND HISTORICAL GROUNDWATER CONDITIONS

This section describes the existing and historical groundwater conditions of the Subbasin to support development and implementation of the GSP pursuant to the requirements of SGMA. This plan section was prepared through a coordinated effort between the GSAs responsible for managing the Subbasin.

3.2.1 Regulatory Requirements

Title 23 Section 354.16 of the California Code of Regulations (23 CCR §354.16) requires that the GSP "*shall provide a description of current and historical groundwater conditions in the basin, including data from January 1, 2015, to current conditions, based on the best available information*" and shall include descriptions for conditions related to the six undesirable results listed under SGMA:

- Groundwater elevations (Section 3.2.2)
- Groundwater storage (Section 3.2.3)
- Seawater intrusion (Section 3.2.4)
- Groundwater quality issues (Section 3.2.5)
- Land subsidence (Section 3.2.6)
- Interconnected surface water systems (Section 3.2.7)
- Groundwater-dependent ecosystems (Section 3.2.8)

This section addresses these requirements using currently available data and information in accordance with the information provided by DWR and listed in the California Code of Regulations.

3.2.2 Groundwater Elevations

Appendix 3A contains the location map and historical hydrographs for the 50 wells within the Subbasin. The hydrograph wells contain a mix of active water supply wells and dedicated observation wells. The hydrograph wells are constructed to different depths within the principal aquifer and represent conditions within the unconfined to confined zones. Appendix 3B contains historical groundwater elevation contour maps for spring and fall of calendar years 2006 (wet conditions), 2015 (critical conditions), 2017 (wet conditions), and 2020 (dry conditions). Most of the wells used in contouring are screened at depths greater than 100 feet and represent groundwater levels in the semiconfined to confined part of the principal aquifer. This presents a data gap in mapping shallow groundwater elevations that would impact domestic and agricultural irrigation supply wells, discussed in Section 3.1.12, and would potentially impact environmental water users.

3.2.2.1 Temporal and Spatial Trends

Figure 3A-1 of Appendix 3A shows the locations of historical monitoring wells within the subbasin. A hydrograph representative of typical historical and seasonal groundwater level trends within the Subbasin is shown on Figure 3-22. Historical water levels, measured between approximately 1975 and 2005, were overall increasing or stable from year to year. Since about 2007, however, there has been a general decline in water levels. Many wells with historical measurements (Appendix 3A) recovered to pre-2006 conditions after the 2012 to 2016 multiple-year drought but are still below their historical average. With the current ongoing dry years, it is expected that water levels will continue to decline.

The Subbasin has a Mediterranean-type climate with wet winters and dry summers. Seasonal trends in groundwater elevations reflect these seasonal climatic changes. During the dry season when there is an increase in groundwater pumping, depth to groundwater increases, and during the rainy season when there is a decrease in demand and groundwater recharge rates are higher, depth to groundwater decreases. These seasonal fluctuations in groundwater elevations can be seen in the hydrograph on Figure 3-22 as the “peaks” and “valleys”, respectively, of the water level line. The magnitude of the seasonal drawdown and recovery depends on hydrologic conditions (e.g., dry or wet years) and human influence such as demand and available water supply sources.

Well 13N01W07G001M (Figure 3-22) is screened in the unconfined to semi-confined portion of the principal aquifer. Groundwater levels declined during the droughts of 1976 to 1977, 1987 to 1991, 2007 to 2009, and 2012 to 2016 and either stabilized or recovered after these dry years. The most notable recovery periods occurred around 1983, which was both a wet year and when water users added more surface water to their supply portfolios, and after the 1987 to 1991 drought. Groundwater recharge increased after the introduction of surface waters due to a decrease in groundwater pumping and the addition of applied surface waters for agricultural use. Event signatures such as these are less notable in shallow wells located near surface waters, where flows in perennial streams or irrigation canals may smooth out impacts to groundwater levels.

Regional groundwater flow within the Subbasin is generally eastward from the margins of the Sacramento Valley toward the Sacramento River and southward towards the Sacramento-San Joaquin Delta. The regional groundwater flow trends are typified by groundwater conditions in 2006. Figures 3B-1 and 3B-2 of Appendix 3B shows the groundwater elevations in spring and fall of 2006, before the onset of the multiple-year droughts of 2007 to 2009 and 2012 to 2016. For most of the subbasin, the groundwater flows in a southeasterly direction, consistent with typical regional trends. South of Arbuckle, however, groundwater flows northeast down from the uplands before turning southeast and down the valley. This flow pattern is repeated in spring and fall 2015, which represent conditions during a multiple-year drought period (Figure 3B-3 of Appendix 3B).

Groundwater pumping has resulted in localized cones of depression that disrupt the regional groundwater flow trends. Changes in land use and multiple-year droughts have led to increased groundwater pumping. These changes in groundwater pumping have created new cones of depression and enlarged existing cones of depression. The regional groundwater gradient and direction were affected by cones of depression in areas of heavy groundwater pumping, which can be seen on the spring and fall 2015 contour maps (Figures 3B-3 and 3B-4 of Appendix 3B).

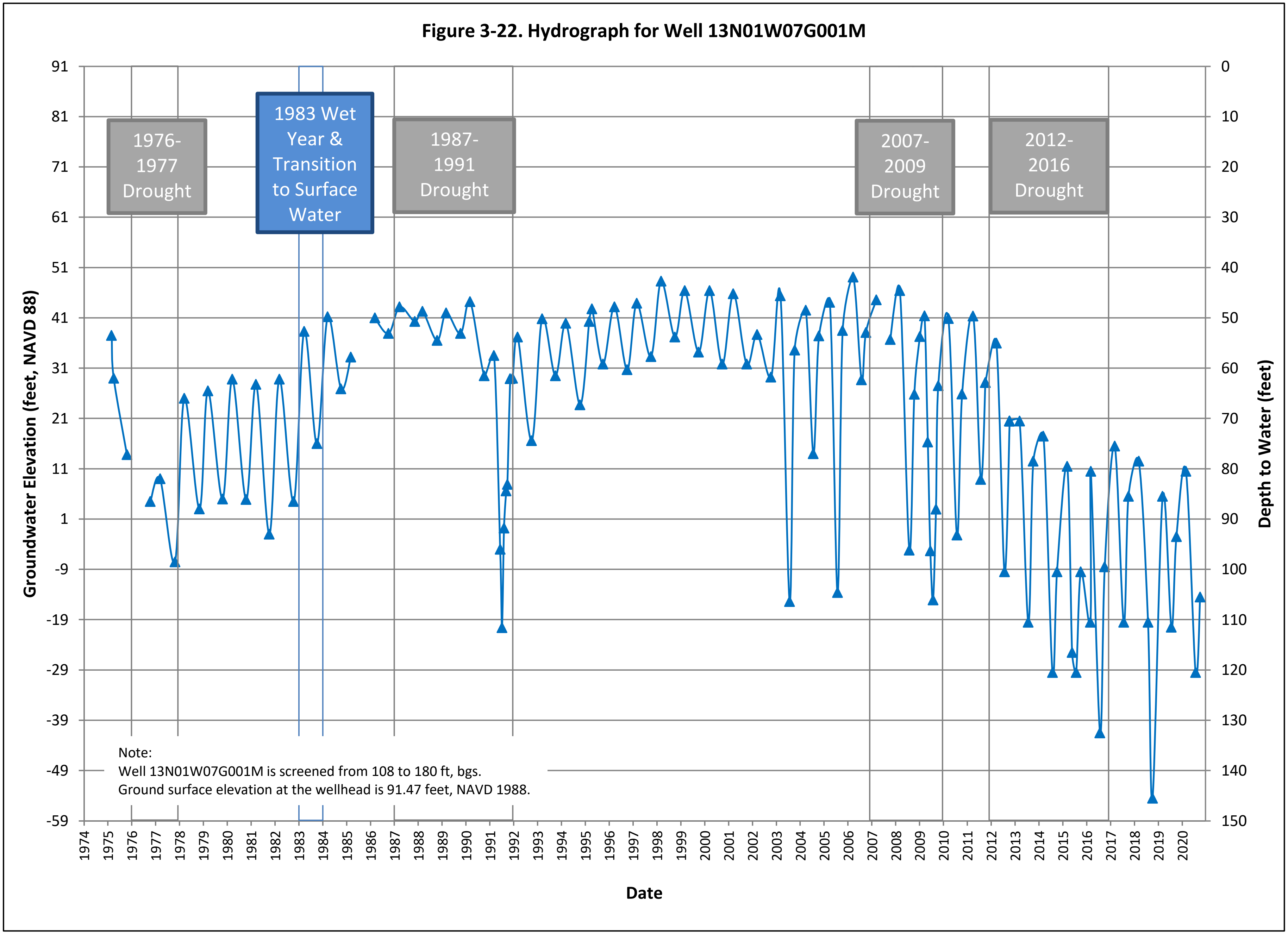


Figure 3-22. Hydrograph for Well 13N01W07G001M
1976-1977 Drought
1983 Wet Year & Transition to Surface Water
1987-1991 Drought
2007-2009 Drought
2012-2016 Drought
Groundwater Elevation (feet, NAVD 88)
Depth to Water (feet)
Date
Note:
Well 13N01W07G001M is screened from 108 to 180 ft, bgs.
Ground surface elevation at the wellhead is 91.47 feet, NAVD 1988.

Groundwater elevations throughout the Subbasin declined over the prolonged dry period after 2006 but recovered in 2017. Figure 3-23 is a groundwater elevation change map that compares spring 2006 (pre-drought) to spring 2017 (post-drought) conditions. Negative changes in groundwater elevations indicate decreases in the spring groundwater elevations from 2006 to 2017, which highlights areas that had not fully recovered from the multiple-year drought between 2007 and 2016. The primary areas with groundwater declines were in the northwestern part of the Subbasin near, and west of, the Glenn County communities of Orland and Artois, and in the southern part of the Subbasin near the Colusa County communities of Williams, Arbuckle, and College City.

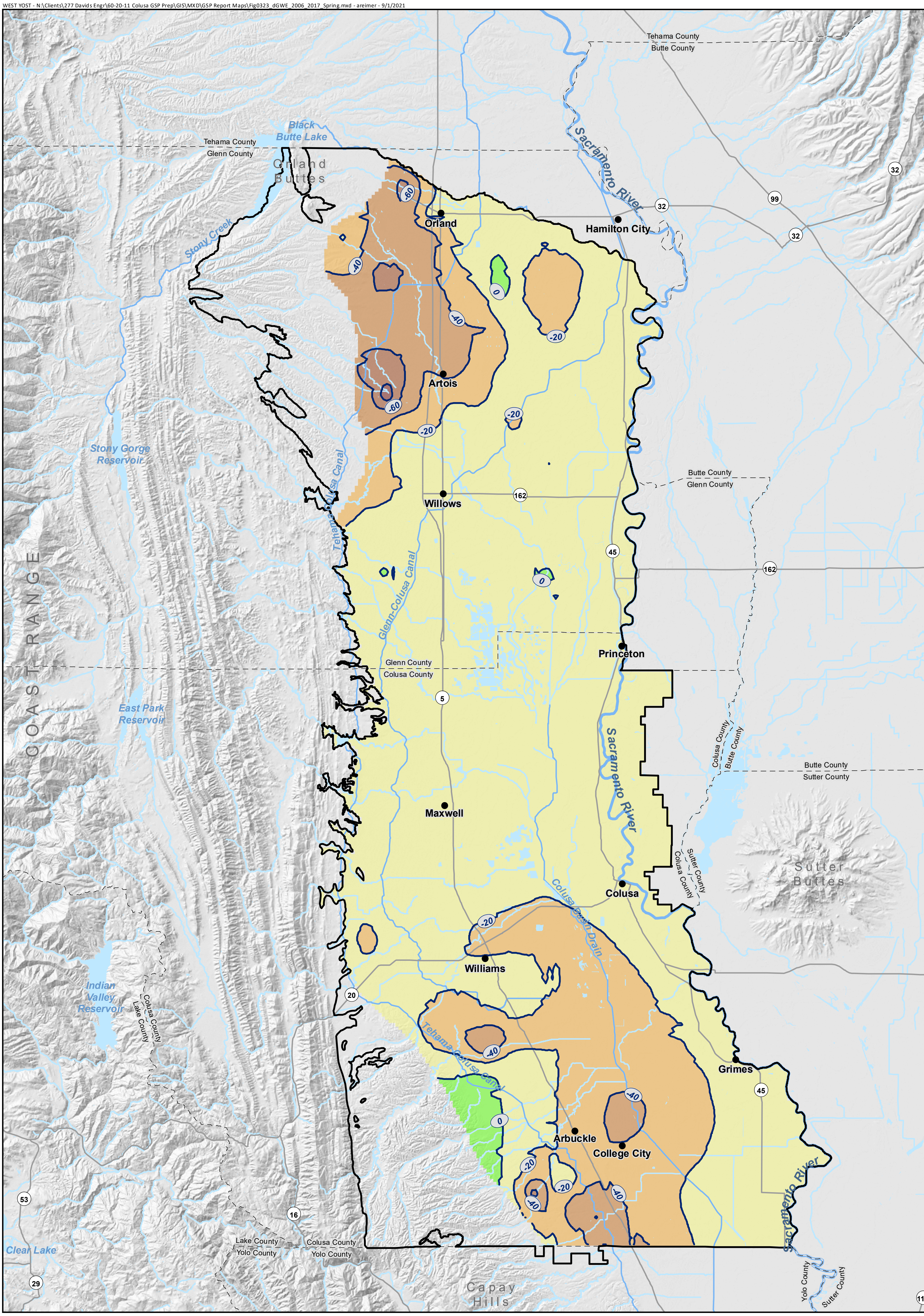
Current groundwater elevations are shown on Figure 3-24 and Figure 3-25 for spring and fall 2020, respectively. Current groundwater levels are similar to those measured in 2017, indicating that regional groundwater levels have been relatively stable since the end of the previous multiple-year drought. However, since the end of the previous multiple-year drought, the Subbasin has experienced alternating years of average or dry conditions. These climatic patterns are starting to have an impact on groundwater levels. Shallow groundwater levels are of particular concern. Many shallow domestic and agricultural irrigation wells in Glenn County have been going dry. Monitoring of shallow wells and coordination with public water systems, domestic pumpers and monitoring agencies is in-progress to characterize the magnitude and rate of shallow groundwater level decline. Data gaps and recommendations are discussed in Section 3.1.12.

3.2.2.2 Lateral and Vertical Flow Gradients

The lateral groundwater gradient has historically been relatively stable over time and typically increases with increasing terrain slope. Typical lateral flow gradients within the Subbasin are approximately 0.001 in the valley and approximately 0.01 in the uplands. Impacts due to pumping are the exception to the typical gradients and disrupt both local and regional gradients. Changes in hydraulic parameters due to reduction in storage or compression of aquifer materials to land subsidence can result in long-term impacts to the lateral and vertical hydraulic gradients.

The vertical groundwater gradients within the principal aquifer provide insight into pumping stresses within the aquifer. Vertical groundwater gradient also helps in the identification and assessment of areas where groundwater discharge and recharge may occur and supports the understanding of interconnections between the surface water features and the groundwater system. Figure 3-26, Figure 3-27, and Figure 3-28 contain hydrographs for multiple-completion nested monitoring wells in order from north to south. The well locations are shown on Figure 3A-1 of Appendix 3A. Well 22N03W24E001-003M is located just south of Stony Creek near the Tehama-Colusa Canal. A downward vertical gradient has consistently been observed at 22N03W24E001-003M (Figure 3-26), indicating that there is potential groundwater recharge from surface sources. This is consistent with other multiple-completion wells in the area.

Well 18N02W18D001-004M, shown on Figure 3-27, is located just north of the Glenn and Colusa County border. Before 2014, the well exhibited an upward flow gradient, with potential for upward groundwater from the deeper confined aquifer zone towards a shallower semi-confined aquifer zone. After 2014, in the midst of the prolonged dry period, the gradient began to transition. The vertical gradients in 18N02W18D001-004M after 2014 show potential for downward flow during the rainy season and upward flow during the dry season.



Change in Groundwater Elevation Contour (20-Foot Interval)

Colusa Subbasin

Change in Groundwater Elevation: Spring 2006 to Spring 2017

- < -80
- -80 to -60
- -60 to -40
- -40 to -20
- -20 to 0
- > 0

Horizontal Datum: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Notes:

1. Negative change in groundwater elevation indicates a decrease in the spring groundwater elevation and an increase in the seasonal depth to water, from 2006 to 2017.

N

0 2.5 5

Scale in Miles

Figure 3-23

Change in Groundwater Elevation Spring 2006 to Spring 2017

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan

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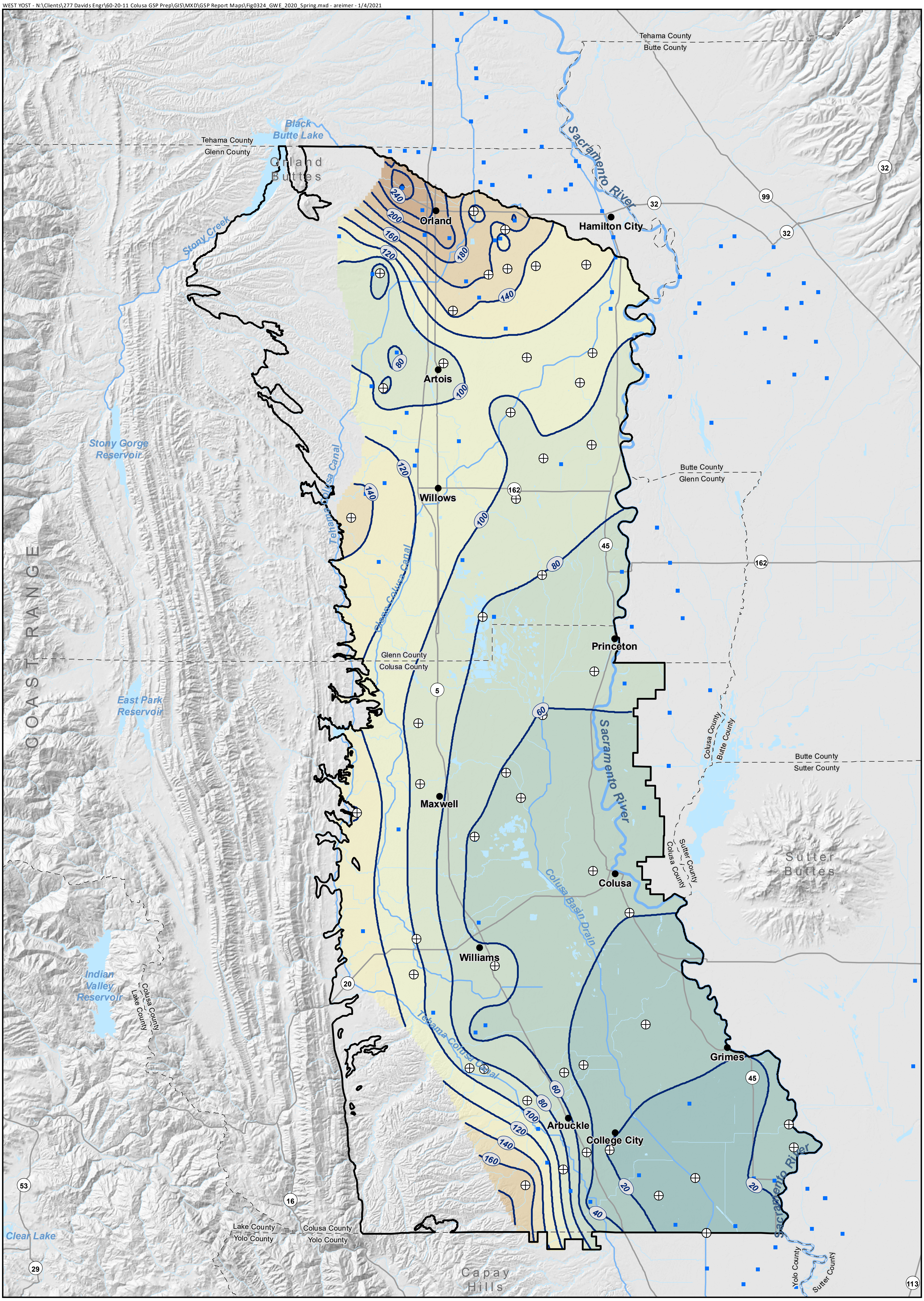

Groundwater Elevation (ft)

260 - 280	140 - 160	20 - 40
240 - 260	120 - 140	0 - 20
220 - 240	100 - 120	-20 - 0
200 - 220	80 - 100	-40 - -20
180 - 200	60 - 80	
160 - 180	40 - 60	

- Well Used for Contouring
- Monitoring Network Wells
- Groundwater Elevation Contour (20-Foot Interval)
- Colusa Subbasin

Horizontal Datum: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Vertical Datum: North American Vertical Datum of 1988, feet (NAVD 88).

N

0 2.5 5

Scale in Miles

Figure 3-24

Groundwater Elevation Contours Spring 2020

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin Groundwater Sustainability Plan

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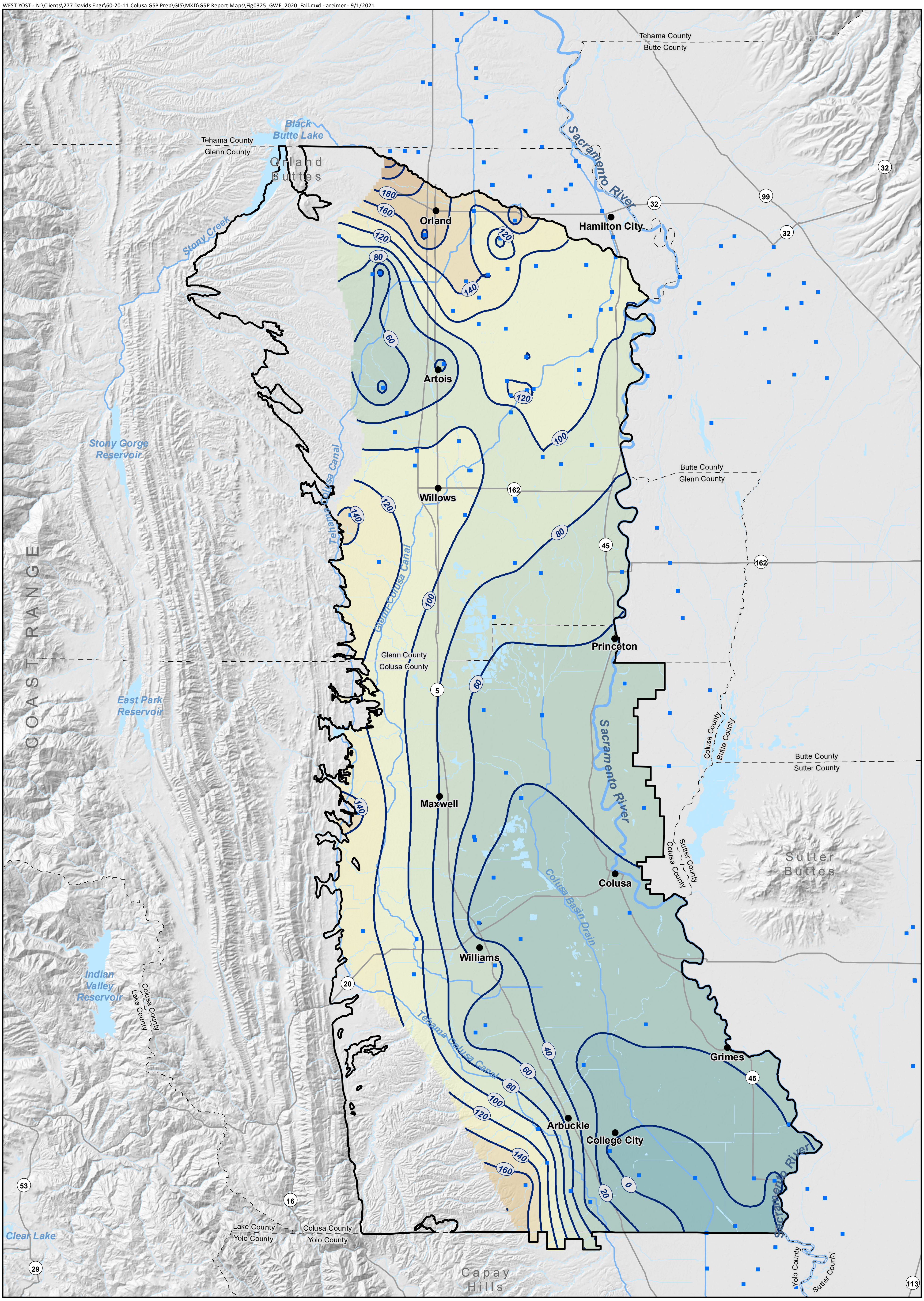

Groundwater Elevation (ft)

- 260 - 280
- 240 - 260
- 220 - 240
- 200 - 220
- 180 - 200
- 160 - 180
- 140 - 160
- 120 - 140
- 100 - 120
- 80 - 100
- 60 - 80
- 40 - 60
- 20 - 40
- 0 - 20
- -20 - 0
- -40 - -20

- Well Used for Contouring
- Groundwater Elevation Contour (20-Foot Interval)
- Colusa Subbasin

Horizontal Datum: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Vertical Datum: North American Vertical Datum of 1988, feet (NAVD 88).

N

0 2.5 5
Scale in Miles

Figure 3-25

Groundwater Elevation Contours Fall 2020

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

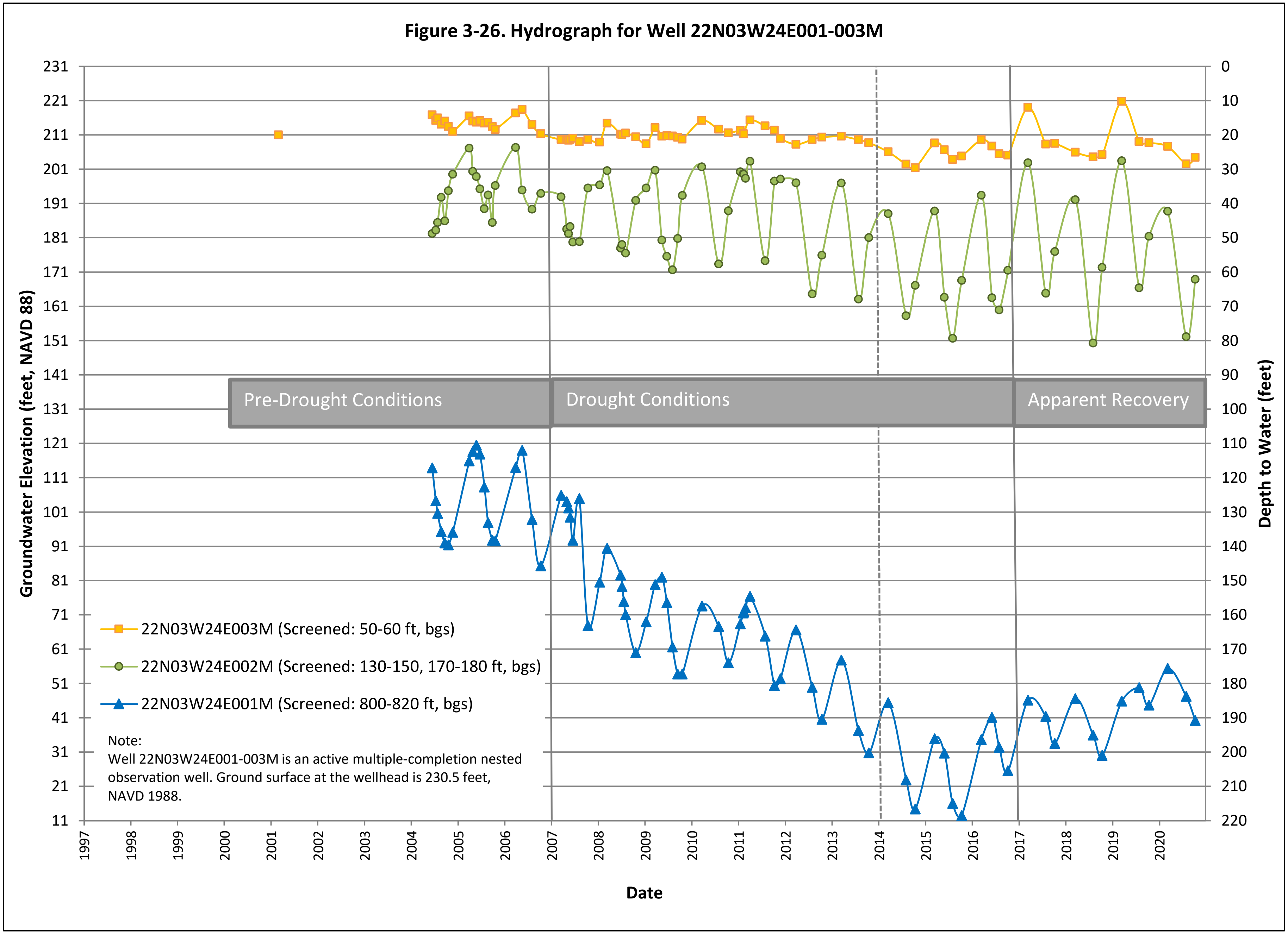

Figure 3-26. Hydrograph for Well 22N03W24E001-003M
Groundwater Elevation (feet, NAVD 88)
Depth to Water (feet)
Date
Pre-Drought Conditions
Drought Conditions
Apparent Recovery
22N03W24E003M (Screened: 50-60 ft, bgs)
22N03W24E002M (Screened: 130-150, 170-180 ft, bgs)
22N03W24E001M (Screened: 800-820 ft, bgs)
Note:
Well 22N03W24E001-003M is an active multiple-completion nested observation well. Ground surface at the wellhead is 230.5 feet, NAVD 1988.
231
221
211
201
191
181
171
161
151
141
131
121
111
101
91
81
71
61
51
41
31
21
11
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
1997
1998
1999
2000
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2018
2019
2020

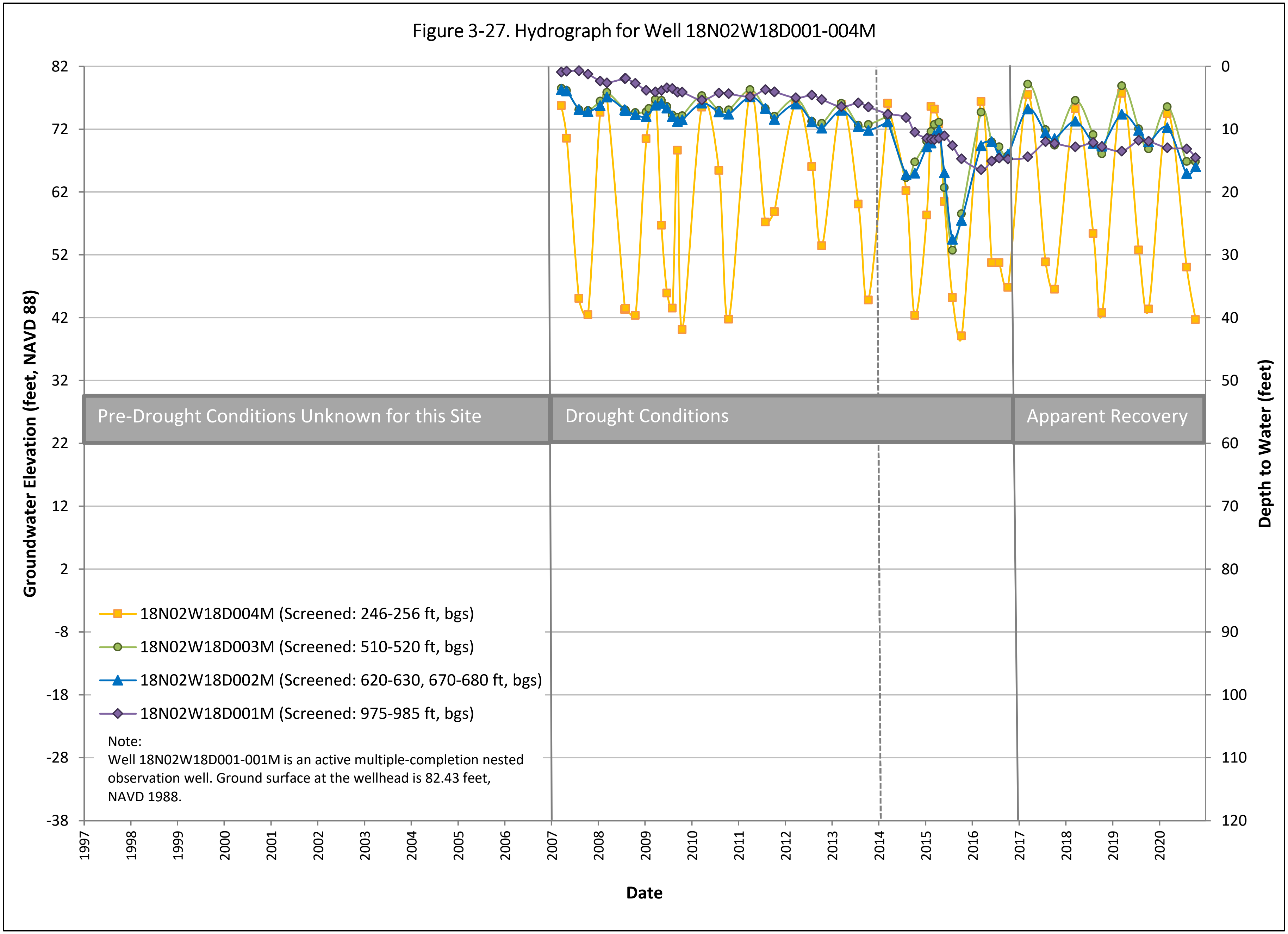


Figure 3-27. Hydrograph for Well 18N02W18D001-004M
Groundwater Elevation (feet, NAVD 88)
Depth to Water (feet)
82
72
62
52
42
32
22
12
2
-8
-18
-28
-38
0
10
20
30
40
50
60
70
80
90
100
110
120
Pre-Drought Conditions Unknown for this Site
Drought Conditions
Apparent Recovery
18N02W18D004M (Screened: 246-256 ft, bgs)
18N02W18D003M (Screened: 510-520 ft, bgs)
18N02W18D002M (Screened: 620-630, 670-680 ft, bgs)
18N02W18D001M (Screened: 975-985 ft, bgs)
Note:
Well 18N02W18D001-001M is an active multiple-completion nested observation well. Ground surface at the wellhead is 82.43 feet, NAVD 1988.
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Date

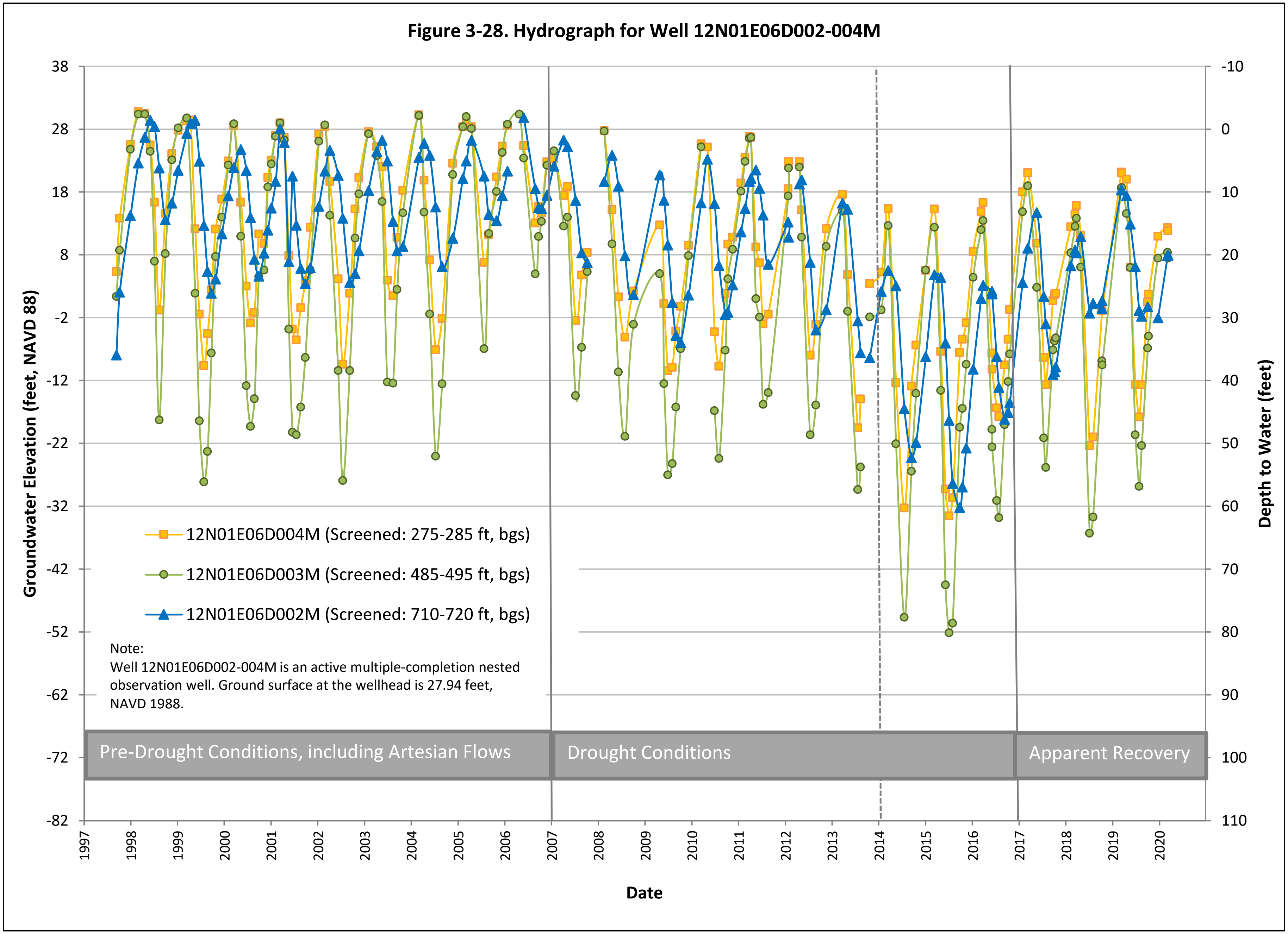


Figure 3-28. Hydrograph for Well 12N01E06D002-004M
Groundwater Elevation (feet, NAVD 88)
Depth to Water (feet)
Date
12N01E06D004M (Screened: 275-285 ft, bgs)
12N01E06D003M (Screened: 485-495 ft, bgs)
12N01E06D002M (Screened: 710-720 ft, bgs)
Note:
Well 12N01E06D002-004M is an active multiple-completion nested observation well. Ground surface at the wellhead is 27.94 feet, NAVD 1988.
Pre-Drought Conditions, including Artesian Flows
Drought Conditions
Apparent Recovery
38
28
18
8
-2
-12
-22
-32
-42
-52
-62
-72
-82
-10
0
10
20
30
40
50
60
70
80
90
100
110
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Variable vertical gradients also occurred in well 12N01E06D002-004M (Figure 3-28), located on the Colusa and Yolo County line. Prior to the prolonged dry period between 2007 and 2016, the vertical gradients and groundwater elevations measured in the well showed potential for seasonal flowing artesian conditions. The potentiometric head of the confined aquifer system rose above land surface during the wet season. During the start of the multiple-year drought, the vertical gradient was upward from the deep zone and downward from the shallow zone towards the middle zone. This may have been due to the majority of groundwater pumping occurring at depths similar to the middle completion of the monitoring well. During the latter half of the multiple-year drought, the vertical gradient reversed during the wet season, with vertical gradients showing potential for flow from the shallow towards the deeper zones. After 2016, the vertical gradients returned to pre-drought conditions, but at generally lower groundwater elevations.

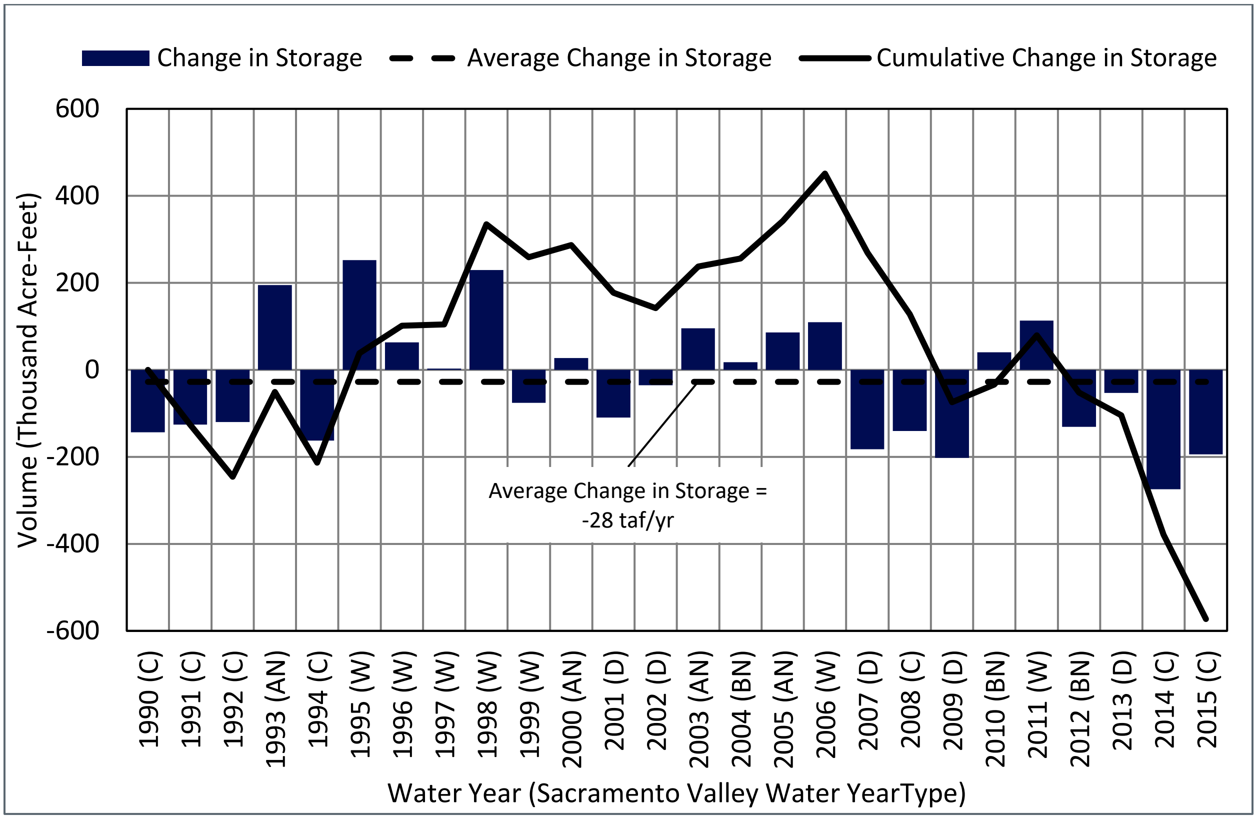
3.2.3 Estimate of Groundwater Storage

The current groundwater storage volume within the Subbasin, above the crystalline basement rocks and base of freshwater, is estimated to be between about 26 million acre-feet (maf) and 140 maf based on an analysis using contouring of Spring 2020 groundwater levels, an average saturated thickness, and an assumed average specific yield range of 0.034 to 0.185, taken from Olmsted and Davis (1961). This range in groundwater storage volume reported in this GSP is low due the lack of groundwater elevation data within the upland areas of the subbasin and uncertainty regarding the depth to the base of freshwater. Recent groundwater modeling conducted to support development of this GSP suggests average specific yield values for the full saturated thickness in the subbasin (i.e., from the regional water table to the base of fresh water) fit within the range provided by Olmsted and Davis (1961).

Prior to the groundwater basin boundary modification process concluded by DWR in 2019, DWR Bulletin 118 estimated the aquifer storage capacity within the upper 200 feet of the Subbasin to be approximately 13 maf (DWR, 2006a). The Subbasin at the time was bounded by Stony Creek to the north, Sacramento River to the east, Cache Creek to the south, and the uplands of Dunnigan Hills and the foothills of the Coast Ranges to the west. Currently, the Subbasin excludes the areas south of the Colusa-Yolo County boundary and includes a portion of the former West Butte Subbasin east of the Sacramento River within Colusa County. Taking into account the area of the current Subbasin extent and a specific yield estimate of 0.071 within the unconfined zone, as reported in Bulletin 118 (2006a), approximately 10.3 maf of storage capacity is estimated within the upper 200 feet of the current subbasin extent.

The average annual change in storage was -28 thousand acre-feet per year (taf/yr) over the historical water budget period of 1990 to 2015. This indicates that, on average, more groundwater has left the Subbasin than entered, resulting in an average net reduction in groundwater stored in the Subbasin. Figure 3-29 summarizes the annual change in storage and the cumulative change in storage in the Subbasin aquifer system over the historical water budget period. A decrease in groundwater storage occurred during critically dry (C), dry (D), and below normal (BN) water years. This is most evident between 2007 and 2015, when the region experienced a series of consecutive, multiple-year droughts. While critically dry, dry, and below normal water years almost always correspond with a decrease in storage, above normal (AN) and wet (W) water years do not always result in an increase in groundwater storage. On average, the Subbasin’s storage volume is influenced more by dry years than wet years. This is likely due to both a greater reliance on groundwater supply during dry years when surface water is less readily available and the relatively slow nature of deep percolation to recharge the groundwater system during wet years. Most of the groundwater inflows and outflows within the Subbasin are exchanged directly with the land and surface water system overlying the Subbasin groundwater system. More information regarding the groundwater storage calculations can be found in the water budget section of this GSP

(Section 3.3) and the model development and calibration Technical Memorandum prepared by Woodard & Curran and Davids Engineering (2021) (Appendix 3D).



Reference: Woodard & Curran and Davids Engineering. 2021. C2VSimFG-Colusa Model Development and Calibration Technical Memorandum: (Appendix 3D).

Figure 3-29. Change in Groundwater Storage

3.2.4 Seawater Intrusion

The Subbasin is located approximately 30 miles from the legal Sacramento-San Joaquin River Delta boundary, and even farther from the brackish delta estuaries. Additionally, the 2019 Basin Prioritization study by DWR found that the Subbasin has not exhibited any impacts of seawater intrusion within the past 20 years (DWR, 2020b). Seawater intrusion is neither occurring nor anticipated to occur in the subbasin over the planning horizon and thus further discussion of seawater intrusion is not included in this GSP.

3.2.5 Groundwater Quality

Groundwaters within the subbasin are mixed calcium, magnesium, and sodium bicarbonate waters (DWR, 2004a, 2006a, 2006b). The northern portion of the subbasin is dominated by calcium bicarbonate water, while increased sodium content has been observed near the Sutter Buttes and west towards Williams, resulting in localized occurrences of mixed sodium and magnesium bicarbonate waters south of Princeton, near Williams, Colusa, Grimes, and Arbuckle, and south towards Yolo County (DWR, 2006a).

Groundwater quality concerns within the Subbasin include locally elevated levels of salinity, TDS, adjusted sodium absorption ratio, arsenic, boron, hexavalent chromium, iron, manganese, and nitrate (DWR, 2006a; Wood Rodgers, 2008; California Water Service, 2016; SWRCB, 2020a). The following subsections discuss the occurrence of these constituents of concern within the subbasin.

Monitoring and regulatory programs exist for the major constituents of concern within the Subbasin. These include programs managed by the U.S. Geological Survey, State of California Department of Water Resources and the State Water Resources Control Board, Central Valley Salinity Coalition, and Central Valley Regional Water Quality Control Board. This section summarizes groundwater quality information from these existing programs. The California Safe Drinking Water Act addresses the regulation and control of public water systems in the State of California, including enforcing provisions of the federal Safe Drinking Water Act. The federal government first granted primary enforcement responsibility to the State in 1978. The State Water Resources Control Board Division of Drinking Water (DDW) is the agency responsible for enforcement in Colusa and Glenn Counties, including the entire Subbasin.

Chapter 4 describes the proposed monitoring network for monitoring the potential mobilization of brackish or saline water from below the freshwater aquifer or along faults in the vicinity of the Sutter Buttes.

3.2.5.1 Major Naturally Occurring Constituents

All groundwater contains dissolved constituents that are products of natural processes of the hydrologic cycle. Rainfall contains only small concentrations of dissolved constituents. Upon reaching the land surface, dissolution of minerals contributes dissolved ions to the water. Calcium, magnesium, and sodium are the major cations (positively charged ions) typically found in groundwater, and sulfate and chloride, which, along with bicarbonate, are the major anions (negatively charged ions). The bicarbonate ion is formed by dissolution of carbon dioxide from the atmosphere and released by organic processes in the soil. Dissolved carbon dioxide contributes to the dissolution of minerals as water is recharged. The quantity of dissolved salts depends on the specific surface area of the aquifer material, the solubility of the minerals present, the pH and oxidation-reduction potential (Eh) of the system, and the residence time of the water in the subsurface aquifer.

3.2.5.1.1 Salinity

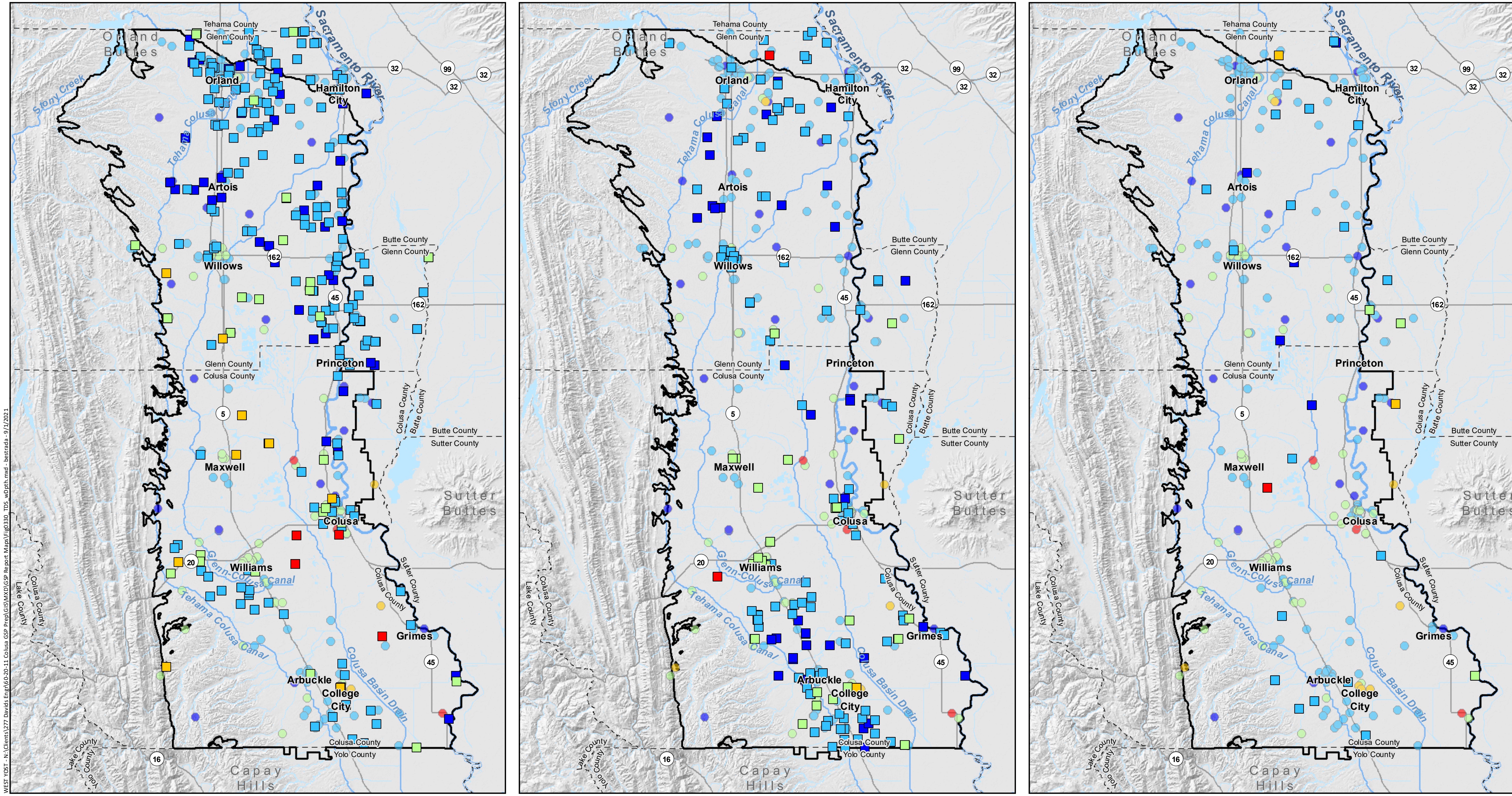
Salinity of groundwater can be characterized by the measured TDS concentration and/or the electrical conductivity (EC) value, which is easily measured in the field and can be used as a proxy for TDS. TDS has three secondary drinking water MCLs, which are established for aesthetic consumer acceptance: recommended limit (500 mg/L), upper limit (1,000 mg/L), and short-term limit (1,500 mg/L). The recommended MCL is the threshold for a “higher degree of consumer acceptance”, the upper MCL indicates the limit for which it is reasonable to provide an alternate water source, and the short-term MCL water is “acceptable only for existing community water systems on a temporary basis pending construction of treatment facilities or development of acceptable new water sources” (22 CCR §64449).

TDS concentrations throughout the subbasin range from less than 100 mg/L to more than 1,500 mg/L, the short-term secondary MCL defined by Title 22 California Code of Regulations (SWRCB, 2018b). Figure 3-30 shows TDS concentrations detected in wells of varying depths. Wells with unknown depth and construction information are shown on all three panels of Figure 3-30. TDS concentrations of more than 500 mg/L, the recommended secondary MCL, have been detected in wells throughout the subbasin, but mostly in wells south of Artois. The highest concentrations of TDS have been measured in the area surrounding the cities of Maxwell, Colusa, and Williams.

Wells Less Than 200 ft Deep

Wells 200 to 700 ft Deep

Wells Greater Than 700 ft Deep



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Source: Total dissolved solid (TDS) concentration and well depth information was downloaded from GeoTracker Groundwater Ambient Monitoring and Assessment Program (GAMA) and U.S. Geological Survey (USGS) National Water Information System (NWIS), 2020.

Horizontal Datum: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Note:
1. TDS concentrations shown are the maximum detected at that location.
2. The drinking water standards (2018) secondary maximum contaminant level for TDS is 500 mg/L (recommended), 1,000 mg/L (upper limit), and 1,500 mg/L (short term).

Colusa Subbasin

Maximum TDS Concentration (mg/L) in Wells with Known Depth

- < 250
- 250 - 500
- 500 - 1,000
- 1,000 - 1,500
- > 1,500

Maximum TDS Concentration (mg/L) in Wells with Unknown Depth

- < 250
- 250 - 500
- 500 - 1,000
- 1,000 - 1,500
- > 1,500

N

0 4 8

Scale in Miles

Figure 3-30

Historical Concentrations Total Dissolved Solids

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan

Wells screened in the unconfined to semi-confined zone of the aquifer (i.e., in wells less than 200 feet deep) in the central and southern portion of the Subbasin had the highest number of wells with elevated TDS concentrations. TDS concentrations in the shallow wells southwest of Colusa have consistently been greater than 2,000 mg/L over a 20-year period. The wells southwest of Colusa with unknown depth have historically had TDS concentrations between 649 mg/L and 1,820 mg/L between 1957 and 2011. The wells northeast of Maxwell have consistently had TDS concentrations above 1,000 mg/L over a 20-year period.

Wells with depths greater than 200 feet near Maxwell, Colusa, and Williams have historically had TDS concentrations less than 1,000 mg/L, with the exception of the deep well southeast of Maxwell. This well is a multiple-completion nested monitoring well with completions set at 378 feet, 775 feet, 1,236 feet, and 1,481 feet deep. In 2011, TDS concentrations in the deepest completion had the lowest TDS concentration (approximately 260 mg/L) while the second-deepest completion well had the highest TDS detection (approximately 930 mg/L). The two shallowest completions in the well had TDS concentrations of approximately 520 mg/L. In 2016, the second-shallowest completion well had the highest TDS concentration (approximately 1,640 mg/L), while the shallowest completion well had the lowest concentration (approximately 530 mg/L). The deepest completion was not measured in 2016.

The shallow well west of Grimes shown in Figure 3-30 is shown with an elevated TDS symbol because of a single TDS measurement of 2,040 mg/L taken in 1975. This older measurement may not be representative of current conditions in the area. Similarly, the wells near College City and other locations with TDS detections greater than 1,000 mg/L tend to be wells with a single measurement and may not represent current or consistent TDS concentrations for those locations.

Many of the wells located in or near urban areas exhibit TDS concentrations above the 500-mg/L recommended secondary MCL. This includes wells with unknown depths in the areas of Williams, Maxwell, Williams, Colusa, Arbuckle, and College City. Public supply wells deeper than 200 feet near Williams and Willows exhibited an increasing trend in TDS concentrations (Dupuy, et. al., 2019; Jurgens, et. al., 2020).

3.2.5.1.2 Major Cations and Anions

The primary cations within the Subbasin are calcium, magnesium, and sodium. The highest calcium concentrations within the Subbasin have been measured in wells between Colusa and Williams, where concentrations have been recorded above 100 mg/L. Elevated sodium concentrations have been detected in wells throughout the Subbasin but tend to be higher in the area surrounding Williams and Colusa. In Colusa, sodium concentration levels are often an order of magnitude greater that of magnesium or calcium. Magnesium concentrations are typically between 10 and 30 mg/L. Wells near Willows, Williams, and Arbuckle have shown an increasing trend in magnesium concentrations over the past decade (DWR, 2021b; SWRCB, 2020a; USGS, 2020).

The ratio of calcium to sodium is much higher in the northern part of the subbasin compared to the southern part of the subbasin. This aligns with the spatial trend in water type, with calcium bicarbonate waters being characteristic of northern Glenn County and sodium bicarbonate waters generally characterizing Colusa County.

As a general rule, the ratio of sodium to calcium and magnesium concentrations in groundwater increases with residence time. This is due to cation exchange, which can be thought of as a natural water softening process that occurs when groundwater containing calcium and magnesium comes in contact with clay containing exchangeable sodium. The longer the water is in contact with the aquifer, the higher the ratio of sodium to calcium and magnesium, and the softer the water. This relationship may be obscured by other factors, including geologic heterogeneities that may cause variation in the sodium concentrations, independent of the residence time of the groundwater, and saline water intrusion. These factors, notwithstanding the relative concentrations of sodium, calcium and magnesium in the wells, may also help to delineate recharge and discharge zones, and potential mobilization of brackish or saline water.

The subbasin waters are mixed bicarbonate waters. Other major anions distributed throughout the subbasin include chloride and sulfate. The spatial distribution of the high concentrations of chloride and sulfate is similar to that of elevated concentrations of TDS and sodium, with the highest concentrations detected in the general Maxwell-Colusa-Williams area and south towards Arbuckle (Figure 3-30). Sulfate concentrations in this area have been measured above the 250-mg/L recommended secondary MCL, with the southern wells showing a long-term increasing trend in sulfate concentrations (SWRCB, 2020a). Groundwater samples in the past decade have generally contained chloride concentrations below the 250-mg/L recommended secondary MCL throughout the Subbasin (DWR, 2021b; SWRCB, 2020a). Anthropogenic sources of chloride and sulfate include wastewater effluent, septic discharge, industrial use, landfill leachate, and agricultural runoff.

3.2.5.2 Other Naturally Occurring Constituents

Naturally occurring constituents that could constrain the use of groundwater within the Subbasin for potable supply, and which have been detected in wells regionally throughout the Sacramento Valley, include arsenic, boron, iron, manganese, and hexavalent chromium. Boron can also be detrimental to plants.

3.2.5.2.1 Arsenic

Arsenic is a naturally occurring constituent in groundwater and commonly occurs at concentrations ranging from 10 to 50 µg/L in the western United States, where it is typically associated with alluvial-lacustrine basin-fill deposits and volcanic rocks and sediments (Welch, et. al., 1988). The primary MCL for arsenic in drinking water is 10 µg/L (SWRCB, 2018a).

Grimes and Princeton have had violations of the 10 µg/L drinking water MCL, which is both the State of California and federal standard. Arsenic has been detected near Grimes at concentrations as high as about 28 µg/L (measured in 2012). A federal program was initiated to install filters on water connections and reduce the arsenic concentration (Glenn County, 2005). Recent concentrations of arsenic in wells near Grimes have been less than 20 µg/L, however, there have been detections of high levels of arsenic in wells near the Sutter Buttes. The elevated arsenic concentrations near Grimes were determined to be due to natural conditions (Glenn County, 2005), potentially including proximity to the Sacramento River stream channel, Sutter Buttes, Willows Fault, and the Colusa Dome.

3.2.5.2.2 Boron

Boron is a naturally occurring element that is associated with the marine deposits of the Coast Ranges. Anthropogenic sources of boron include industrial waste discharges, municipal wastewater, and agricultural practices (SWRCB, 2017). Fire retardant manufacturing, storage, and use throughout Glenn and Colusa Counties could be an anthropogenic source of boron in the aquifer system. Boron in groundwater is most likely in the form of boric acid. Boron is a necessary component to plant growth in small amounts, but some plants are sensitive to the presence of boric acid in waters and may exhibit adverse effects if exposed to boron concentrations higher than the plant’s tolerance.

Elevated concentrations of boron reported by GCID within Colusa County have impacted agricultural practices (GCID, 1995). According to GCID (1995), groundwater underlying the northern portion of the GCID service area has boron concentrations suitable for irrigation. Additionally, boron measured in select groundwater wells within Glenn County has not exceeded the USEPA agricultural water quality goal for boron of 750 µg/L (USEPA, 1986; USGS, 2020). In contrast, elevated levels of boron have been detected in the southern portion of the GCID service area (GCID, 1995).

3.2.5.2.3 Iron and Manganese

Iron and manganese in groundwater are naturally occurring via weathering from subterranean sediment. Anthropogenic sources include landfill leachate, sewage discharge, and industrial effluent. Iron concentrations exceeding the 300-µg/L secondary MCL have been reported in water supply wells near Orland, Willows, Delevan, Williams, Colusa, and Arbuckle within the past decade (DWR, 2021b; SWRCB, 2020a). Williams and Colusa have experienced long-term increasing trends in iron concentrations, although the most recent concentrations have been lower than during previous years (USEPA, 2020; CH2MHILL, 2016a).

Elevated manganese concentrations above the 50-µg/L secondary MCL have been reported near the cities of Williams and Colusa, and northeast of Artois, near the Sacramento River (USEPA, 2020). According to the Northern Sacramento Valley (Four Valley) Drinking Water Strategy Document (Glenn County, 2005), there have been customer complaints near Williams and Colusa related to iron and manganese in drinking water.

3.2.5.2.4 Hexavalent Chromium

Chromium typically occurs in in the trivalent state, which is nearly insoluble. Geochemical conditions in recharge zones or the aquifer can oxidize trivalent chromium to hexavalent chromium, which is soluble, mobile in groundwater, and a carcinogen. Naturally occurring chromium minerals are associated with serpentinite and other Coast Range rocks. Over geologic time, these rocks have been eroded, transported by streams, and incorporated in the basin fill sediments of the Subbasin. Anthropogenic sources of hexavalent chromium are mostly related to industrial use and waste.

There is currently no MCL for hexavalent chromium. The SWRCB implemented a 10-µg/L primary MCL for hexavalent chromium on July 1, 2016. On May 31, 2017, the Sacramento Superior Court ruled that the SWRCB must withdraw the 10-µg/L hexavalent chromium MCL and develop a new MCL after assessing the economic feasibility of compliance, especially for smaller public water systems. The 10-µg/L hexavalent chromium MCL was withdrawn on September 11, 2017. The SWRCB has not published a timeline for issuing the new MCL, but the new MCL is anticipated to be announced in late 2021.

Drinking water supply wells near Willows have experienced high concentrations of hexavalent chromium (California Water Service, 2016). Hexavalent chromium in a well west of Willows has not been detected at concentrations below 20 µg/L since 2016 and was detected at 40.1 µg/L in July 2020 (SWRCB, 2020a). Hexavalent chromium concentrations greater than 20 µg/L have also been detected in wells midway between Williams and Arbuckle, and near Colusa, within the past decade (DWR, 2021b; SWRCB, 2020a).

3.2.5.3 Non-Point Sources of Groundwater Pollution

Non-point sources of groundwater pollution are diffuse discharges that occur over a wide area. The major non-point source groundwater constituent of concern in the Subbasin is nitrate.

3.2.5.3.1 Nitrate

Nitrate is a naturally occurring compound that forms when nitrogen and oxygen combine in the soil. Nitrate occurs naturally in groundwater or can be introduced through a variety of land uses, including row crop agriculture, irrigated agriculture, and various waste disposal practices. Typical waste materials resulting in nitrate pollution include animal manures from commercial poultry, dairy, hog and beef operations; wastewater treatment plant effluent applied to land; household wastes disposed of in septic systems; and landfill leachate.

Small amounts of nitrate in groundwater are normal, but larger concentrations can result in serious health problems. The 45-mg/L MCL for nitrate (quantified as nitrate) is considered by the State and Federal governments to be the maximum concentration that can be safely consumed from a public water system. Excessive nitrate consumption can lead to health problems, including irritation of gastrointestinal tract and bladder, and methemoglobinemia, or blue baby syndrome, so named because affected infants take on a bluish tinge. Blue baby syndrome is caused when nitrate is converted to nitrite by bacterial activity in the stomach. Typically, in adults, these bacteria are destroyed by stomach acid. The stomachs of infants (especially less than 3 months of age in humans) are not fully developed and do not produce strong acids. This allows the bacteria to survive, leading to the buildup of nitrite in the blood. The nitrite oxidizes the ferrous iron in the blood to ferric iron, thereby limiting its ability to carry oxygen to the cells. The syndrome is readily treated if diagnosed.

Nitrate detections are widespread in the Subbasin but are mostly low concentrations, typically meeting drinking water standards, with the exception of the northern portion of Glenn County and the area near Willows (CH2MHILL, 2016a; Wood Rodgers, 2008). According to the Sacramento Valley Water Quality Coalition Groundwater Quality Report (CH2MHILL, 2016a), only 2 percent of the 359 total wells analyzed within Glenn and Colusa Counties had nitrate concentrations above the 45-mg/L MCL and the average nitrate concentration was 8.3 mg/L.

3.2.5.4 Point Sources of Groundwater Pollution

Point sources of groundwater pollution are discrete discharges that occur at a single identified location. Discharges from point sources can be either a single discharge event or have occurred continuously over a period of time. Point sources of groundwater pollution often require monitoring and cleanup programs.

There are several active groundwater contaminant cleanup sites in the Subbasin. These mostly include leaky storage tanks and unauthorized releases of contaminants such as petroleum hydrocarbons, nitrate, pesticides and herbicides. The largest contamination site is the Orland Dry Cleaner site, a perchloroethylene (PCE) plume within the Subbasin that extends approximately two miles southeast of the source location in Orland (DTSC, 2020; URS Corporation Americas, 2020). PCE is a dense non-aqueous phase liquid, meaning it is denser than water, with a moderate to high mobility rating (SWRCB, 2017). Long-term temporal trends of PCE concentrations in most of the monitoring wells show concentrations stabilizing or decreasing since the start of sampling in 2003 (URS Corporation Americas, 2020).

3.2.6 Land Subsidence

Differential land subsidence and associated earth fissuring resulting from groundwater withdrawal have had significant consequences in several California groundwater basins. Land subsidence can cause structural damage to wells, foundations, roads, bridges, and other infrastructure, as well as impacting surface water flows by reducing conveyance capacity and potentially changing flow gradients within canals, natural streams, and floodplains. Inelastic land subsidence may also negatively impact groundwater storage capacity. Land subsidence has been measured within the Subbasin, however, it is yet to be determined if the subsidence measured within the Subbasin has measurably impacted storage capacity.

The 1976-1977 drought was the first time that more groundwater than surface water was used for agricultural irrigation in the Sacramento Valley. Drilling and pump contractors reported that in the summer of 1977 many wells were discovered to have broken casings, and the demand for new and replacement wells could barely be met (Borchers, et. al., 1998).

The risk of significant land subsidence impacts depends on a complex array of variables including: the degree of new groundwater development, especially in areas or at depths not previously exploited; changing land use, which could bring to light an effect that would otherwise go unnoticed; and the mineral composition and consolidation history of the aquifer skeleton.

Land subsidence due to groundwater withdrawal is triggered by decreases in pore pressure in a confined aquifer system containing clay layers (typically, montmorillonite clay). The decrease in pore pressure increases the effective stress on the aquifer skeleton. If this effective stress exceeds the maximum stress to which the aquifer skeleton has been subjected in the past, the clay layers will undergo permanent compaction. Highly compressible clays, such as montmorillonite, have not been reported within Subbasin boreholes. They have, however, been encountered in boreholes south of the Sutter Buttes (see discussion regarding lacustrine deposits and the Turlock Lake Formation in Section 3.1.7.1). Additionally, a borehole drilled near the Colusa Drain, near Zamora in Yolo County (south of the Subbasin), at 12N1E34Q1 contained a silty, diatomaceous, kaolinitic clay with a compression index of 1.22 and coefficient of consolidation of 4.98 square feet per year. These values are comparable to samples of diatomaceous clay from the Corcoran Clay of the San Joaquin Valley, and indicate a high susceptibility to compaction (Page, 1998). The core sample was collected at a depth of 534 to 544 feet.

Figure 3-31 shows the measured land surface displacement from resurvey of Sacramento Valley benchmarks between 2008 and 2017 (DWR, 2018a). Figure 3-32 includes the annual rate of subsidence from 2018 to 2019, as calculated from interferometric synthetic aperture radar (InSAR) imagery surveys (TRE ALTAMiRA, 2020). Appendix 3C contains the location map and ground surface displacement charts measured in five extensometers located within the counties of Colusa and Glenn.

Land subsidence has been reported and measured in the Arbuckle area of Colusa County. A 2015 NASA report based on InSAR survey evaluation showed isolated land subsidence of up to approximately 0.5 feet west of Arbuckle (Farr et. al., 2015). Data from a repeat survey of the Sacramento Valley Height-Modernization Project benchmarks also indicates a decrease in land surface elevation by as much as 2 feet between 2008 and 2016 near Arbuckle (Ehorn, 2016). A resurvey of those benchmarks conducted in 2017 showed a total displacement of 2.14 feet since 2008. This equates to approximately 0.24 feet, or approximately 3 inches, of subsidence per year between 2008 and 2017, on average. Subsidence calculated by TRE ALTAMiRA from InSAR imagery showed up to more than 2 inches of subsidence occurring between 2018 and 2019 within the greater Arbuckle area (Figure 3-32).

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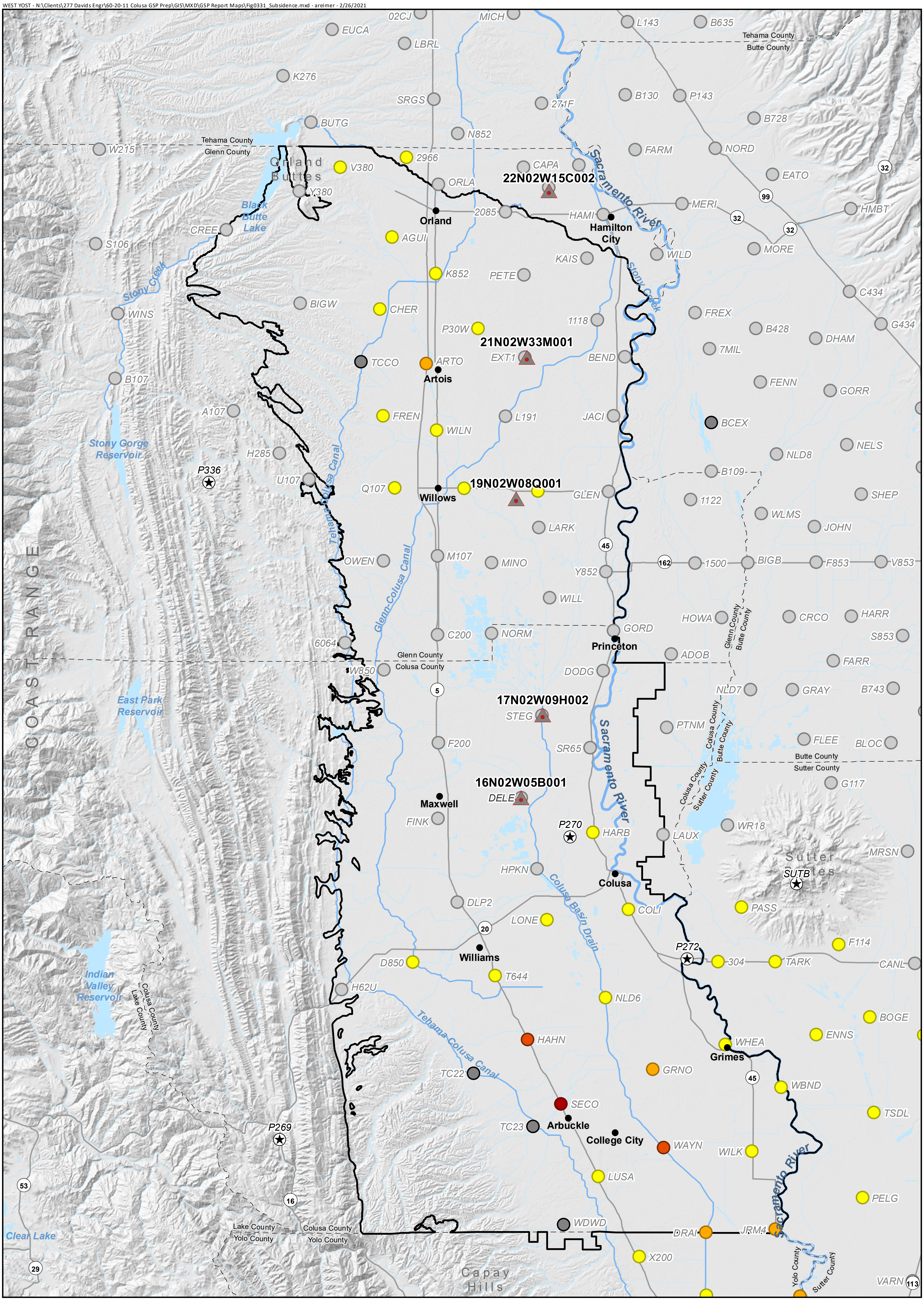

Source: Extensometers and continuous GPS stations were obtained from DWR and USGS. Benchmarks and displacement data were obtained from a resurvey report puublished by DWR (2020).

Datums: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Extensometer

Continuous GPS Station

Colusa Subbasin

Sacramento Valley Benchmark Subsidence Measured Between 2008 and 2017

- > 2 ft
- 1 - 2 ft
- 0.5 - 1 ft
- 2 inches - 0.5 ft
- < 2 inches
- New Benchmark or Not Surveyed

N

0 2.5 5

Scale in Miles

Figure 3-31

Measured Subsidence 2008 to 2017

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin
Groundwater Sustainability Plan

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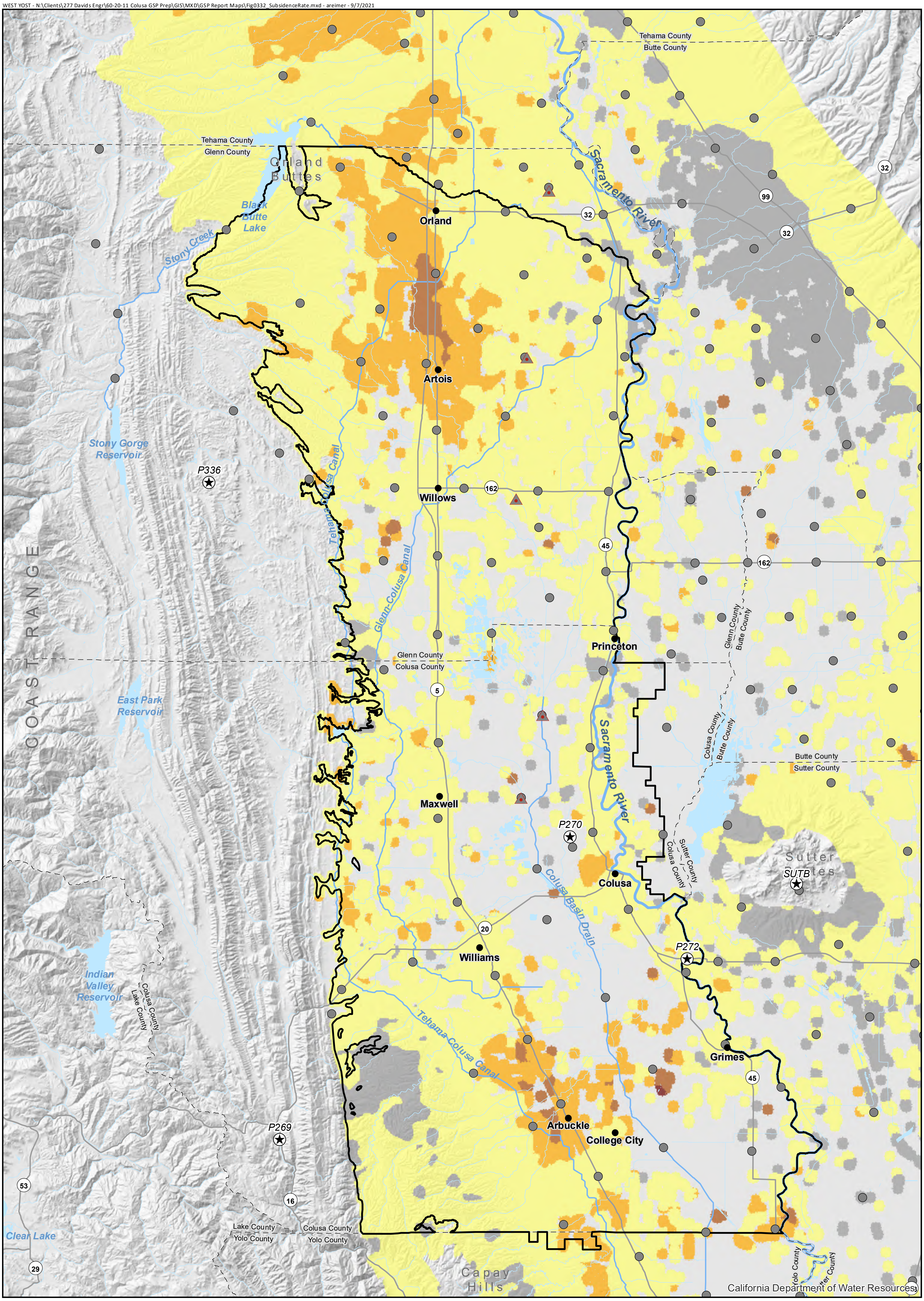


Source: TRE ALTAMiRA, 2020, InSAR Land Surveying and Mapping Services in Support of the DWR SGMA Program, Vertical Displacement v2019 Annual Rate 2018-09-01 to 2019-09-01, March 2020.

Datums: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

- Extensometer
- Continuous GPS Station
- Sacramento Valley Subsidence Benchmark
- Colusa Subbasin

Annual Subsidence Rate (inches per year) Between September 2018 and September 2019

- > 2
- 1 - 2
- 0.5 - 1
- 0 - 0.5
- Uplift or No Subsidence

N

0 2.5 5

Scale in Miles

Figure 3-32

Annual Subsidence Rate 2018 to 2019

Colusa Groundwater Authority and Glenn Groundwater Authority

Colusa Subbasin

Groundwater Sustainability Plan

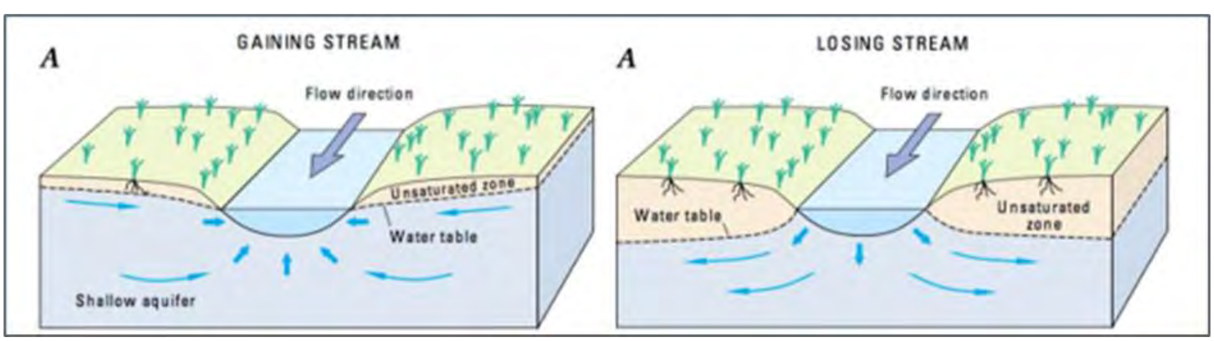
Land subsidence is not exclusive to the Colusa County portion of the subbasin; repeat surveys of benchmarks in Glenn County showed small amounts of land subsidence southwest of Orland occurring between 2008 and 2017 (Ehorn, 2016; DWR, 2018a). One benchmark located near Artois had a measured displacement of 0.59 feet, or approximately 7 inches. InSAR imagery from 2018 to 2019 showed approximately 1.5 inches of subsidence occurring between Orland and Artois.

Extensometer measurements have also recorded ground displacement in the Subbasin. Appendix 3C contains a map of the extensometer locations (Figure 3C-1 of Appendix 3C) and ground displacement measured within extensometers in or near the subbasin. Seasonal displacements of ±0.3 inches have been recorded in these extensometers. Most of the subsidence measured in the extensometers has been elastic, meaning the aquifer materials are not permanently compressed. Potential inelastic displacement may have occurred in extensometers 21N02W33M001M, northeast of Artois, and 16N02W05B001M, east of Maxwell, during the multiple-year droughts (Figure 3C-5 and Figure 3C-2 of Appendix 3C, respectively). Potential inelastic subsidence occurred in 21N02W33M001M between 2007 and 2010, and between 2008 and 2016 in 16N02W05B001M. Measured seasonal fluctuations in displacement within both of these boreholes have since stabilized.

3.2.7 Interconnected Surface Waters

Traditionally, water resource managers have tended to address surface water and groundwater systems as distinct and separate. However, most surface water bodies (e.g., rivers, streams, drains and lakes) are connected to the groundwater system to some degree so that changes to surface water bodies (either gains or losses) can affect flows in aquifer systems, and vice versa. Additionally, changes in land use, irrigation methods, and management of surface water storage and conveyance infrastructure can impact surface water and groundwater systems.

Figure 3-33 illustrates the typical range of groundwater-surface water interactions in the absence of groundwater pumping. Streams interact with groundwater in three basic ways: streams gain water from inflow of groundwater through the streambed (gaining stream); they lose water to groundwater by outflow through the streambed (losing stream); or they do both, gaining in some reaches and losing in other reaches (Winter, et. al., 1998). Also, whether a given reach is gaining or losing can vary with time in response to changing hydrological conditions. The upper, high elevation reaches of a stream may tend to be losing while the lower reaches may tend to be gaining. If the stream is connected to the groundwater system, meaning that it is physical contact with the groundwater system, then the gains and losses depend on the stage of the stream, the groundwater level, and the streambed conductance. If the stream is disconnected from the groundwater system, meaning that the stream is separated from the groundwater system by an unsaturated zone, then the gains and losses are independent of the groundwater level.



Reference: U.S. Geological Survey. 2021.

Figure 3-33. Conceptual Example of Gaining and Losing Streams

Groundwater pumping can lead to streamflow depletion, potentially reducing supplies for human and ecosystem water uses (USGS, 2012). When groundwater is pumped, the water table near the well declines, forming a cone of depression. Initially the decline is accounted for by a change in aquifer storage surrounding the well. As pumping continues, the cone of depression expands, and begins to capture groundwater that would have otherwise discharged to the stream. The pumping may lower groundwater levels enough to cause induced infiltration from the stream, changing the once gaining reach of the stream to a losing reach. The streamflow depletion is the sum of the captured groundwater discharge that would otherwise have reached the stream, plus the induced infiltration caused by the groundwater pumping (Barlow and Leake, 2012).

After pumping is stopped, groundwater levels will not recover immediately. Instead, groundwater will flow towards the cone of depression at a rate dictated by the hydraulic properties of the aquifer and the hydraulic gradient directed radially inward towards the well. The rate will gradually decline with the hydraulic gradient. The existence of residual drawdown in the aquifer after pumping ceases means that streamflow depletion can continue after pumping stops.

The duration of streamflow depletions caused by pumping depends on the spatial scale: the greater the distance between groundwater pumping and affected stream, the longer the timescale. As a consequence, the ultimate effects of pumping can occur significantly after pumping starts, or even after pumping has ceased. The timescales involved in aquifer responses to pumping and other stresses can be on the order of decades, making it difficult to associate cause with effect. Monitoring for potential impacts may be ineffective because, by the time effects are observed, it may be too late to take in action, and the effects may persist for decades. In general, the longer the timeframe for effects to be observed at a given monitoring point, the longer those effects will persist, if the pumping resulting in the effects is halted immediately. Also, the effects of pumping on stream depletions are cumulative, with the effects of each pumping cycle in each well imposed on the next.

3.2.7.1 Simulated Stream Gains and Losses

The Subbasin integrated hydrologic model, C2VSimFG-Colusa, was used to analyze historical stream gains (water that enters the stream from the groundwater system) and losses (water that enters the groundwater system from the stream; also referred to as seepage) in waterways that flow within or along the boundaries of the Subbasin. The modeled streams include the Sacramento River, Stony Creek, and the Colusa Drain.

Table 3-6 includes the breakdown of the modeled net stream gain (stream gains minus stream losses) for each stream by water year type. Table 3-7 includes stream gain and loss statistics for the modeled streams. Simulated Sacramento River conditions were mostly net gaining, with the exception of 1998, where the Sacramento River experienced net loss of approximately 13 taf. The median net gain along the Sacramento River was approximately 72 taf/yr. The net stream gain in the Sacramento River was lower during wet years, when there would be more surface flow, and higher in the dry years, when surface waters would be in short supply. Simulated conditions in the Colusa Drain indicate net stream gain of approximately 115 taf/yr on average between 1990 and 2015, with net gains occurring in all years including critically dry years. Contrary to simulated Sacramento River conditions, net stream gain in the Colusa Drain were higher during wet years than during dry conditions. Stony Creek always experienced annual net losses between 1990 and 2015. Stream losses were greatest during critically dry and dry years.

A detailed assessment of projected stream gains and losses is presented in Appendix 3G. The analysis considers the Sacramento River, Stony Creek, and the Colusa Drain individually and collectively, and evaluates temporal patterns of gain and loss over the 50-year projected (future) water budget period (described in Section 3.3, below). Under projected future conditions without climate change, average net stream gains (stream gains minus stream losses) are projected to be approximately 125 taf/yr in aggregate for the Sacramento River, Stony Creek, and the Colusa Drain combined. With the potential effects of climate change[1], net stream gains are projected to remain positive but to decrease by about 48 taf/yr, or by 38 percent, with respect to the projected future conditions without climate change. However, viewed in the relation to the average Sacramento River flow above the Feather River confluence of approximately 11,700 taf/yr the projected change is roughly one half of one percent. These simulated net stream gains are less than the typical ±2.5% accuracy of annual volume measurements when calculated from current meter-based stage-discharge functions (Clemmens and Wahlin, 2006). Consequently, these simulated net stream gains are not significantly different than the uncertainty of average annual streamflows along these waterways, and cannot be measured directly from stream gage measurements with certainty. This will continue to be evaluated and addressed as part of continued work to fill data gaps and part of ongoing monitoring to be reported in annual reports.

Table 3-6. Modeled Net Stream Gain 1990-2015 by Water Year Type

Water Year Type	Number of Years Evaluated	Net Stream Gain, taf		
		Colusa Drain	Stony Creek	Sacramento River
Critical Dry	7	109	-38	91
Dry	5	109	-30	86
Below Normal	3	104	-31	57
Above Normal	4	121	-33	47
Wet	7	127	-28	26

Note: Total gains, losses and net stream gains will not exactly match values reported elsewhere in this GSP due to different methods of extracting data from C2VSimFG-Colusa.

Table 3-7. Modeled Net Stream Gain 1990-2015 Statistics

	Colusa Drain		Stony Creek		Sacramento River	
	Net Stream Gain, taf	Year	Net Stream Gain, taf	Year	Net Stream Gain, taf	Year
Minimum	82	2010	-55	1992	-13	1998
Maximum	152	1999	-21	2006	117	2007
Median	115	1997	-31	2011	72	2000
Average	115	--	-32	--	62	--

Note: Total gains, losses and net stream gains will not exactly match values reported elsewhere in this GSP due to different methods of extracting data from C2VSimFG-Colusa.

[1] Results are from the C2VSimFG-Colusa model "Projected Future Conditions with 2070 Climate Change and without Projects" scenario, in which projected precipitation, evapotranspiration, and surface water supplies are adjusted to reflect the estimated effects of climate change based on the 2070 Central Tendency climate change datasets provided by DWR to support GSP development. Climatological, hydrological, and water operations datasets, change factors, and the DWR Climate Change Resource Guide are available at: https://data.cnra.ca.gov/dataset/sgma-climate-change-resources.

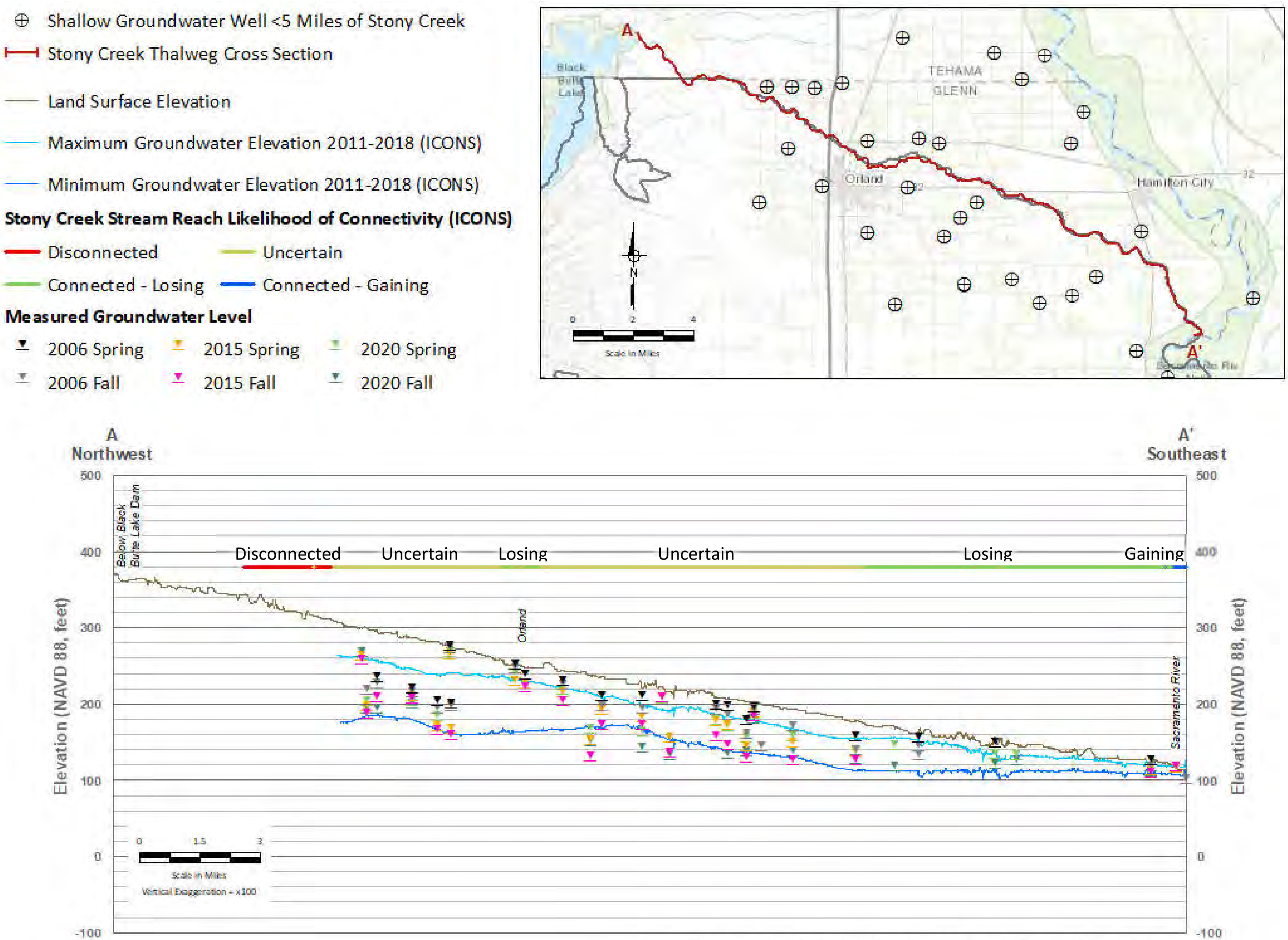
3.2.7.2 Stony Creek Thalweg Analysis

A thalweg analysis was conducted for Stony Creek, where local historical water level measurements were compared to streambed elevation of Stony Creek's thalweg to evaluate for stream-aquifer connectivity and to compare those results with results of the *Interconnected Surface Water in California's Central Valley* (ICONS) study (TNC, 2021). Shallow wells less than 200 feet deep and within 5 miles of surface water features are the criteria used to identify representative groundwater level wells to be used as a proxy for surface water depletion and stream-aquifer interaction monitoring, discussed in Chapter 4 and Chapter 5. Figure 3-34 shows a cross section, A-A', that follows the thalweg of Stony Creek. Superimposed onto the cross section are the spring and fall 2006, 2015, and 2020 groundwater level measurements from 31 shallow wells (less than 200 feet deep) within 5 miles of the creek. Also shown in the cross section are the ICONS datasets:

- Minimum groundwater elevation measured between 2011 and 2018: depicted as a light blue interpolated potentiometric water surface.
- Maximum groundwater elevations measured between 2011 and 2018: depicted as a medium blue interpolated potentiometric water surface.
- Stream likelihood of connectivity based on the average groundwater elevations measured between 2011 and 2018: depicted as a graded rainbow-colored horizontal line above land surface where red indicates disconnected stream reaches, yellow are reaches with uncertain connectivity, green indicates connected and potentially losing reaches, and dark blue are connected and potentially gaining stream reaches.

The measured groundwater levels roughly match the interpolated surface of the ICONS minimum and maximum groundwater elevation datasets. The most notable discrepancies occur just southeast of Orland, where measured groundwater levels appear deeper than the interpolated minimum groundwater elevation, and just northwest of Orland, where measured groundwater levels appear shallower than the maximum interpolated groundwater elevation. None of the measured groundwater levels are at higher elevation than the streambed land surface which suggests that no part of Stony Creek is gaining. This, however, could be due to the spatial density of the shallow groundwater wells. Additionally, there is no active stream gage on Stony Creek below Black Butte Lake.

Further evaluation of locations, quantity and timing of stream depletions through additional monitoring and/or construction of additional shallow or multiple-completion monitoring wells near surface waters (e.g., Stony Creek, Sacramento River, and the Colusa Drain) comparing observed groundwater levels with stream discharge or river stage information would provide more insight into stream-aquifer interactions and a subsequent detailed analysis of potential impacts to beneficial users and uses.



Data Source: The Nature Conservancy, California. ICONS: Interconnected Surface Water in California's Central Valley, Version 1.0.1. https://icons.codefornature.org/. March 2021.

Figure 3-34. Thalweg Analysis

3.2.8 Groundwater Dependent Ecosystems

GDEs are defined as “ecological communities of species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface” (23 CCR § 351(m)). As described in TNC’s guidance for GDE analysis (Rohde et al. 2018), a GDE’s dependence on groundwater refers to reliance of GDE species and/or communities on groundwater for all or a portion of their water needs. TNC has identified hundreds of freshwater species that are located in the Subbasin, based on analysis of the California Freshwater Species Database version 2.0.9 within the Subbasin boundary (Appendix 2B-2). While there are data gaps in understanding how many of these species utilize or depend on groundwater, the GSAs conducted an initial evaluation of potential GDEs in the Subbasin using the best available information at the time of GSP development. As described in Chapter 7 of this GSP, the GSAs have also planned several studies that will expand monitoring of GDEs and help to increase understanding of the potential impacts of land use planning and well permitting on GDEs in the Subbasin.

Natural communities commonly associated with groundwater (NCCAG) within the State of California were mapped by TNC (2018b) and Klausmeyer, et. al. (2018). The NCCAG mapping provided an initial indication of the location, habitat type, and impacted vegetation for potential GDE areas within the Subbasin. The majority of the potential GDE vegetation areas include cottonwood (31 percent), bulrush (21 percent), willow (15 percent), and oak (13 percent) habitat areas. Arundo, or giant reed, accounts for four percent of NCCAGs initially identified within the Subbasin.

Preliminary screening of the potential GDEs within the Subbasin was conducted to help prioritize areas for further mapping, evaluation, and monitoring of GDEs during implementation of the Colusa Subbasin GSP. The preliminary screening supported the assessment of data gaps, evaluation of existing monitoring networks, which could potentially be used for GDE monitoring, and development of PMAs.

The GSAs will seek to work with resource agencies, stakeholders, beneficial users and the public to refine the understanding of GDEs in the Subbasin, fill data gaps, and develop PMAs with consideration of GDEs.

Under the preliminary screening, a score of 1 (less likely to be a GDE) to 4 (more likely to be a GDE) was applied to the NCCAG areas based on depth to groundwater, proximity to surface waters, and proximity to irrigated croplands. Figure 3-35 shows the relationship between the score and ranking criteria.

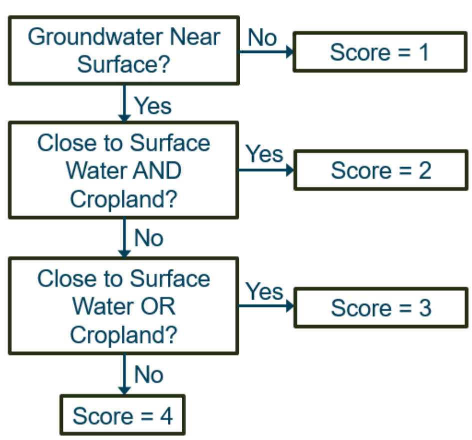


Figure 3-35. GDE Scoring Criteria

Average spring groundwater level data from 2014 to 2018 indicates that shallow groundwater levels (i.e., within 30 feet of ground surface) exists throughout most of the subbasin. A depth to water (DTW) of 30 feet based on the average DTW for 2014 to 2018 was used as one of the primary criteria in the initial screening of potential GDEs. The use of a 30-foot DTW criterion to screen potential GDEs is based on reported maximum rooting depths of California phreatophytes and is consistent with guidance provided by TNC (Rohde et al., 2018) for identifying GDEs. The use of shallow groundwater data over the 5-year 2014 to 2018 time period was deemed appropriate because it provided a more conservative (i.e., more inclusive) indicator of potential GDEs than the use of a data from a single year. The 30-foot DTW contour is shown on Figure 3-36. Depths to shallow groundwater east of the contour are less than 30 feet. Based on the scoring criteria presented in Figure 3-35, east of the 30-foot contour line is shallow groundwater and so will be evaluated using the next criteria while land west of the contour line receives a score 1 (less likely to be a GDE) and is not evaluated with additional criteria.

Areas within 150 feet of surface waters, including canals, ditches, and perennial streams, were considered to have access to surface waters. Additionally, areas within 150 feet of irrigated rice paddies and 50 feet of other irrigated croplands were considered to have access to surface waters. The leftmost and middle panels of Figure 3-36 include the areas within 150 feet of surface waters, 150 feet of rice croplands, and 50 feet of other irrigated croplands. Vegetation within these areas is assumed to have access to surface water and/or agricultural runoff and percolation and therefore receive a score of 2 if they are close to both surface water and agricultural lands (i.e., they are more likely to be a GDE than lands without shallow groundwater, but still not very likely) or a score of 3 if they are close to either surface waters or agricultural lands (i.e., they only have one source of water from surface practices or natural flows). GDEs include vegetation and habitat that are wholly dependent on groundwater. Closer proximity to available surface waters decreases the likelihood that a vegetated wetland or potential GDE habitat area is a GDE. The exception to this could be locations where surface waters gain a significant amount of water from groundwater. The Sacramento River and the Colusa Drain are both under net-gaining conditions, where surface waters annually gain water from the aquifer system (Section 3.2.7). These net-gaining conditions along surface water corridors could increase the likelihood of GDEs regardless of the scoring exercise results presented here.

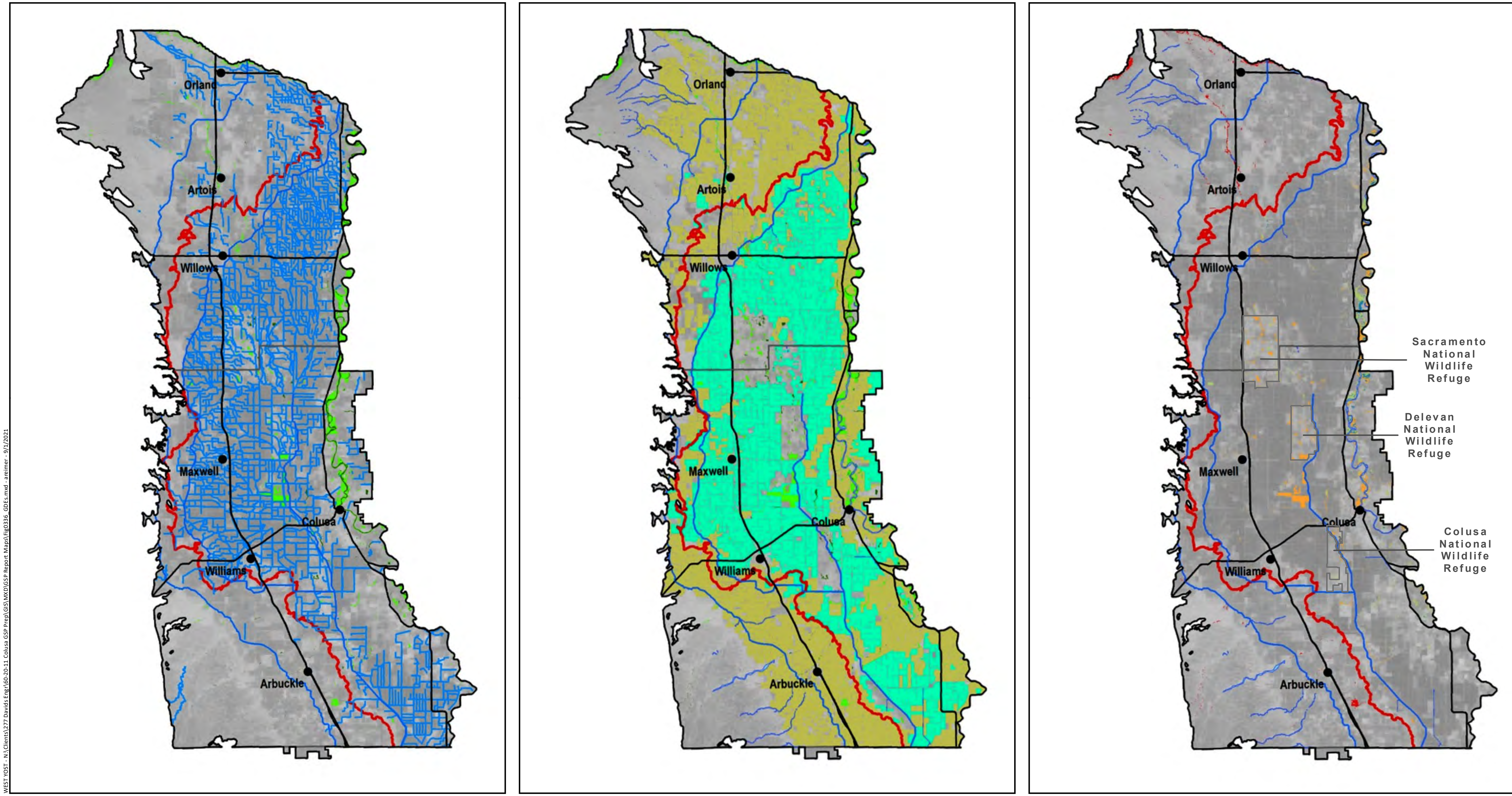
Vegetated lands that have access to shallow groundwater and not near either surface waters or irrigated agricultural lands receive a score of 4 (i.e., the only water source available for vegetation consumption is groundwater).

The rightmost panel of Figure 3-36 shows the scores for the potential GDE areas within the Subbasin. Table 3-8 includes the acreages per GDE score. Most of the NCCAG lands within the Subbasin were designated a score of 2, which is on the lower end of likelihood of being classified as a GDE due to proximity to both surface waters and irrigated croplands. The majority of the high scores (i.e., score of 3 or 4, or a high likelihood of being a GDE) occur along the Sacramento River corridor, within the wildlife refuges, and in non-agricultural lands surrounding some of the streams, such as along Willows Creek and south of Delevan Wildlife Refuge. Groundwater level data is lacking in the uplands west of Orland and west of Arbuckle. There is potential for GDEs to be present in these areas, especially near seeps and springs, but the data is lacking in order to determine their existence. This data gap is discussed in Section 3.1.12

Table 3-8. GDE Likelihood Scores

Score	Score Description	Approximate Acreage
1	Less Likely	2,540
2	--	8,710
3	--	5,580
4	More Likely	920

Within 150 ft of Surface Waters | Within 150 ft of Rice and 50 ft of Other Irrigated Croplands | GDE Liklihood Scores



Source: Wetland and vegetation areas are from the Natural Communities Naturally Associated with Groundwater (NCCAG) datasets and associated reports prepared by The Nature Conservancy (2018).

Horizontal Datum: North American Datum of 1983 (NAD 83), California State Plane Zone II, feet.

Note:
1. GDE liklihood scores were obtained via comparison of NCCAG ares with proximity to surface waters and irrigated croplands.

- Colusa Subbasin
- Spring Depth to Water 30 ft Contour
- Proximity to Surface Waters (Within 150 ft)
- Proximity to Irrigated Rice Croplands (Within 150 ft)
- Proximity to Other Irrigated Croplands (Within 50 ft)
- NCCAG Vegetation and Wetlands

GDE Liklihood Score
- 4 (High Liklihood)
- 3
- 2
- 1 (Low Liklihood)

N

0 4 8
Scale in Miles

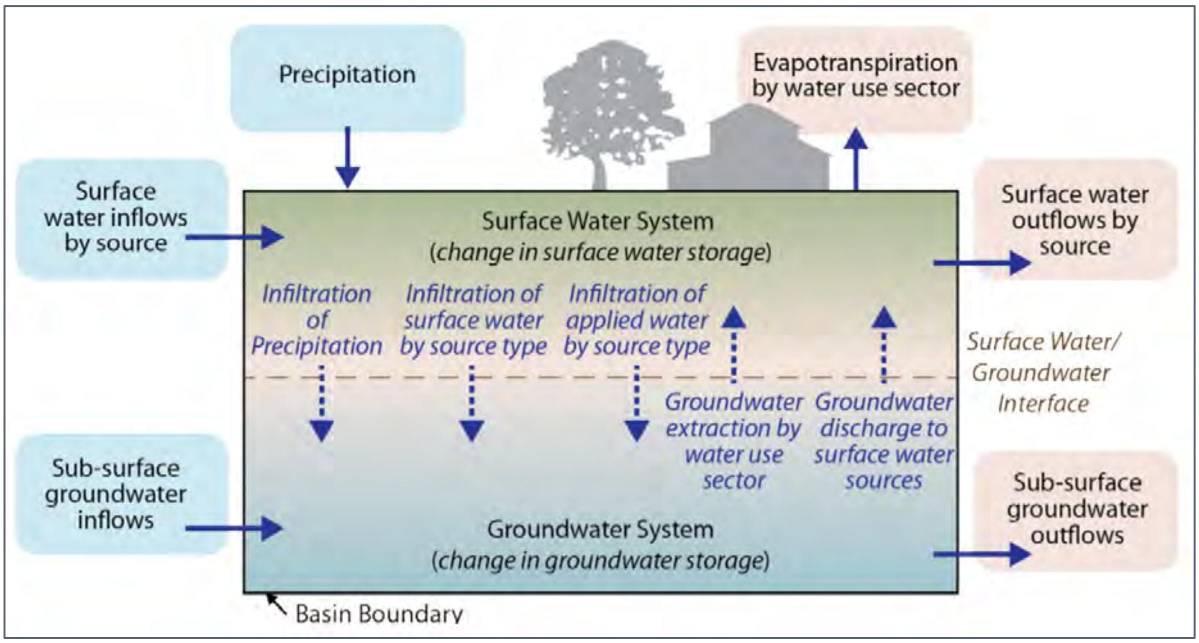
Figure 3-36

Groundwater Dependent Ecosystems

Colusa Groundwater Authority and Glenn Groundwater Authority
Colusa Subbasin
Groundwater Sustainability Plan

3.3 WATER BUDGET INFORMATION

This section describes historical, current, and projected water budgets developed for the Subbasin in accordance with §354.18 of the GSP Emergency Regulations. According to §354.18, the water budgets were prepared using the best available information and best available science to quantify and provide an understanding of historical and projected hydrology, water demands, water supplies, land use, population, climate change, groundwater and surface water interaction, and subsurface groundwater flow. The water budgets support GSP development in a number of ways, including assessing the sustainable yield of the subbasin, development of sustainable management criteria, and evaluating the need for projects and management actions to ensure sustainable operation of the Subbasin. Components of the water budgets are depicted in Figure 3-37.



Notes: Boundary fluxes are shown as solid blue arrows, with inflows and outflows indicated by blue and red captions, respectively. Internal fluxes are indicated by dashed blue arrows. The two primary storage mechanisms are the surface water storage and groundwater storage systems.

Figure 3-37. Water Budget Components (DWR 2016)

Water budgets were developed considering hydrology, water demand, water supply, land use, population, climate change, surface water - groundwater interaction, and subsurface groundwater inflows and outflows to and from neighboring groundwater basins. Water budget results are reported on a water year basis spanning from October 1 of the prior year to September 30 of the current year. All water budget values are expressed in average annual volumes, with annual volumes presented in tabular form in Appendix 3E (for the entire Subbasin) and in Appendix 3F (for 32 subareas within the Subbasin).

3.3.1 Selection of Hydrologic Periods

The GSP Emergency Regulations require evaluation of water budgets over a minimum of 10 years for the historical water budget, using the most recent hydrology for the current water budget, and 50 years of hydrology for the projected water budget. Hydrologic periods were selected for each water budget category listed below based on consideration of the best available information and science to support water budget development and consideration of the ability of the selected periods to provide a representative range of wet and dry conditions:

- **Historical** – The 26-year period from water years[2] 1990 to 2015 was selected based on the level of confidence in historical input data and information to support water budget development considering land use, surface water availability, hydrology, and other factors.
- **Current Conditions** – Historical water budget information for 2015 represents the most recent hydrology developed for GSP analysis (i.e., precipitation, evapotranspiration, stream inflows). To provide a broader basis for understanding current water budget conditions, a water budget scenario combining most recently available land use (2013 and 2015, representing non-curtailment [Shasta Non-Critical] and curtailment [Shasta Critical] years[3], respectively) and urban demands (average of 2006-2015) over 50 years of historical hydrology was developed. The period selected was 1966 to 2015. An advantage of evaluating the current conditions water budget over a representative 50-year period is that the results provide a baseline for evaluation of the projected water budgets.
- **Future Conditions** – Consistent with the current conditions water budget, the hydrologic period selected as the basis for the projected water budgets was 1966 to 2015.

Selection of the 50-year hydrologic period for the current and projected water budget scenarios was based primarily on three considerations:

- C2VSimFG, the primary tool used to develop the water budgets, has hydrologic information from water years 1922 to 2015.
- The average Sacramento Valley Water Year Index[4] values for the 50-year period from 1966 to 2015 and the 104-year period from 1906 to 2019 (1906 is the first year for which the index is available) are both 8.1. This indicates that the selected 50-year period is similar on average to the entire period of record for the Sacramento Valley watershed. (Figure 3-38). This is important because the major source of surface water in the Subbasin is the Sacramento River.

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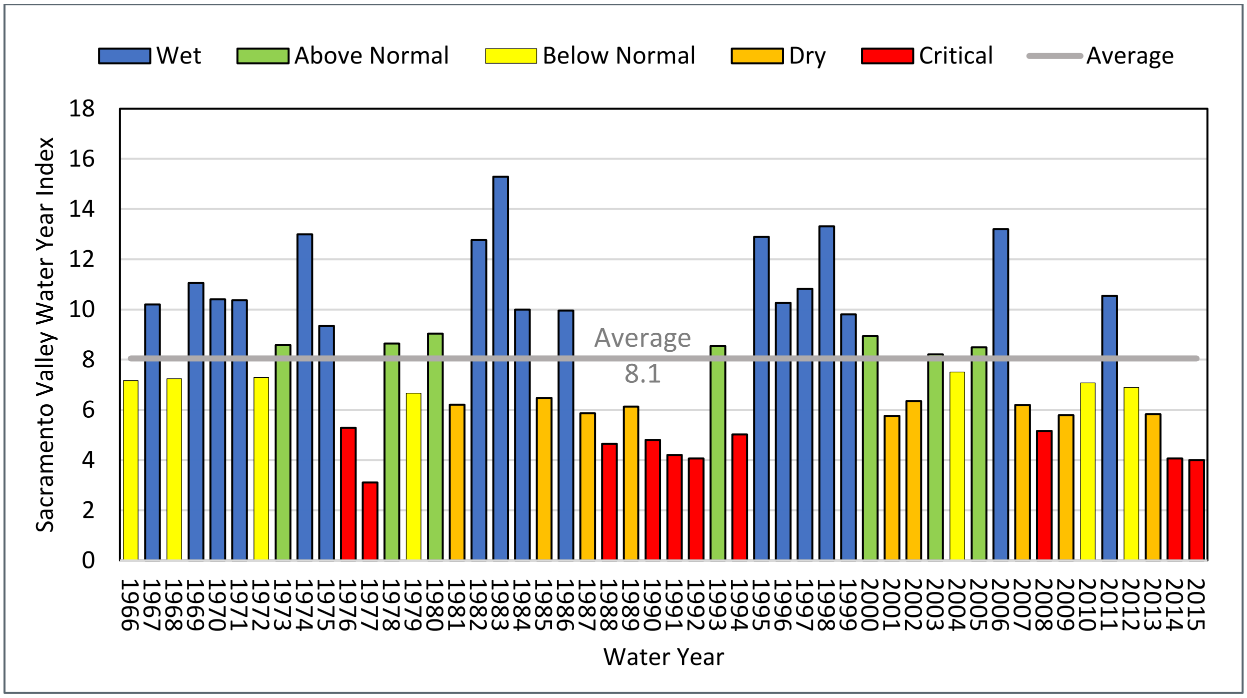
[2] A water year is defined as the period from October 1 of the prior year to September 30 of the current year. For example, water year 2000 refers to the period from October 1, 1999, to September 30, 2000.

[3] In general, Shasta Critical conditions are declared when the forecast inflow to Lake Shasta for a particular water year is equal to or less than 3.2 million acre-feet. In Shasta Critical years, the Sacramento River Settlement Contractors in the Colusa Subbasin (and elsewhere in the Sacramento Valley) are subject to 25% water supply reductions, significantly reducing surface water supplies available to the subbasin in those years. In turn, the reduction of surface water supplies results in a reduction of cropped farmland.

[4] The Sacramento Valley Water Year Index classifies water years as wet, above normal, below normal, dry, or critical based on Sacramento River unimpaired flows. Additional details describing the Sacramento Valley Water Year Index are available from the California Data Exchange Center .

- The selected period includes a combination of wet and dry cycles, including relatively wet periods in the early 1970’s, mid 1980’s, and late 1990’s and dry periods in the late 1970’s, early 1990’s, and from approximately 2007 to 2015.

Additionally, annual precipitation for the 1966 to 2015 period averaged approximately 19.4 inches per year, as compared to 18.0 inches for the 1906 to 2018 period indicating slightly wetter conditions than the entire period of record for the Sacramento Valley Index.



Notes: The average index is 8.1, which is the same as the average for the entire period of record from 1906 through 2019.

Figure 3-38. Sacramento Valley Water Year Index and Water Year Types for a 50-year Period from 1966 to 2015

3.3.2 Use of the C2VSimFG Integrated Hydrologic Model

Development of the Integrated Water Flow Model (IWFM) began under the direction and funding of the DWR in 2001. The fine-grid application of IWFM, the California Central Valley Groundwater-Surface Water Simulation Model (C2VSimFG), became publicly available in 2012. The model has been updated over time to simulate historical conditions through water year 2015. The model performs calculations on a monthly time step with monthly input data (i.e., precipitation, stream inflow, surface water diversions) and some annual input data (i.e., land use). Refinements to the model over time include additional crop types to better represent ponded crops (i.e., rice and wetlands), recalibrated soil parameters, and elemental land use. Development and calibration of the C2VSimFG-Colusa[5] model used for water budget analyses in the Subbasin are described in more detail in Appendix 3D.

[5] Version BETA2 of C2VSimFG was used for C2VSimFG-Colusa.

To prepare water budgets for this GSP, historical C2VSimFG-Colusa results for water years 1990 to 2015 have been relied upon, and four additional baseline scenarios have been developed to represent current and projected (future) conditions utilizing 50 years of hydrology (described previously). Specific assumptions associated with these scenarios are described in the following section.

3.3.3 Water Budget Assumptions

Assumptions utilized to develop the historical, current, and projected water budgets are described below and summarized in Table 3-9. Assumptions are listed for the analysis period, hydrology (including stream inflows and precipitation), land use, and water supplies (including surface water diversions and water demands).

In the historical simulation, surface water supplies implicitly reflect historical surface water transfers and any effects of transfers on groundwater pumping. In the current conditions and future conditions scenarios, possible future water transfers (unrelated to GSP projects) were considered but not simulated, as they were considered to be highly speculative. GSP implementation will follow the principle of adaptive management, with continued monitoring and refinement of the basin setting, and with implementation of projects and/or management actions in response to changes in Subbasin conditions that may occur depending on future water transfers and other factors potentially affecting surface water supplies and groundwater pumping.

Table 3-9. Summary of Water Budget Assumptions Used for Historical, Current Conditions, Future Conditions, and Future Conditions with Climate Change at Two Times in the Future (i.e., 2030 and 2070)

Water Budget	Analysis Period	Hydrology	Land Use	Water Supplies
Historical Simulation	1990-2015	Historical	Historical	Historical
Current Conditions Baseline	2016-2065	Historical (1966-2015)	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively, for water diversions; 2006-2015 average for urban demands
Future Conditions, No Climate Change Baseline	2016-2065	Historical (1966-2015)	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively, for water diversions; 2006-2015 average for urban demands
Future Conditions, 2030 Climate Change Baseline	2016-2065	Historical (1966-2015), adjusted based on 2030 climate change with central tendency	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively	Same as Current (see above), adjusted for 2030 climate change

Table 3-9. Summary of Water Budget Assumptions Used for Historical, Current Conditions, Future Conditions, and Future Conditions with Climate Change at Two Times in the Future (i.e., 2030 and 2070)

Water Budget	Analysis Period	Hydrology	Land Use	Water Supplies
Future Conditions, 2070 Climate Change Baseline	2016-2065	Historical (1966-2015), adjusted based on 2070 climate change with central tendency	Current (2013 and 2015) used for Shasta Non-Critical and Shasta Critical, respectively	Same as Current (see above), adjusted for 2070 climate change

3.3.3.1 Historical

A historical water budget was developed to support understanding of past aquifer conditions, considering surface water and groundwater supplies utilized to meet demands. The historical water budget was developed using C2VSimFG-Colusa and incorporates the best available science and information. Historical water supplies and aquifer response have been characterized by water year type based on DWR's Sacramento Valley Water Year Index.

As described previously, water years 1990 to 2015 were selected to provide a minimum of ten years across a range of hydrologic conditions. This period includes relatively wet years in 1995, 1998, 2006, and 2011 as well as dry conditions between 1990 and 1992, in 1994, between 2007 and 2009, and between 2013 and 2015.

Development of the historical water budget is described in greater detail in Appendix 3E. Model inputs and historical water budget results were summarized for 32 distinct subareas within the Subbasin. These subareas, described in Appendix 3F, approximately represent regions of the subbasin that share a common water supplier (e.g., an irrigation or water district service area), a common governing agency (e.g., a county or city), and a common primary water supply source (e.g., areas with access to surface water or areas with access to only groundwater, i.e., "groundwater" areas). Subareas were delineated within the C2VSimFG-Colusa model to support development of model inputs and to support quality control and calibration of model outputs. Specific data and information used to create model inputs are summarized in Appendix 3D.

Information utilized to develop the historical water budget includes:

- **Analysis Period** – Water years 1990 to 2015
- **Stream Flows** – Data from C2VSimFG-Colusa were used as best-estimates for inflows and outflows from rivers, streams, and other waterways traversing the Subbasin or along the boundary. The Sacramento River is the major surface water inflow to the subbasin. Stony Creek also provides inflow to the region along the northern boundary. Flows were estimated using C2VSimFG-Colusa which simulates the Sacramento River, Stony Creek, and Colusa Drain in the Subbasin.

- **Land Use** – Land use characteristics for agricultural, native, and urban (including rural residential) lands were estimated annually based on a combination of DWR land use surveys and county agricultural commissioner cropping reports. DWR land use data were available for 1993, 1998, 2003, 2009, and 2014. Urban land use areas were also verified against urban spheres of influence identified from city and county planning documents.
- **Agricultural Water Demand** – Agricultural irrigation demands were estimated using C2VSimFG-Colusa, which simulates crop growth and water use on a monthly basis, considering crop type, evapotranspiration, root depth, soil characteristics, and irrigation practices. For ponded land uses (rice and managed wetlands), pond depths and pond drainage are also considered to simulate demands.
- **Urban and Industrial Water Demand** – Urban and industrial demands and per capita water use over time were estimated based on a combination of pumping data provided by the State Water Resource Control Board (Small Supplier Conservation Reports) and Urban Water Management Plans (UWMPs). Estimates of population were based on data from the Department of Finance and from UWMPs.
- **Surface Water Diversions** – Surface water diversions were estimated based on a combination of reported diversions by water suppliers and Bureau of Reclamation records. In some cases, agricultural water demand was estimated for areas known to receive surface water but for which reported diversion data were not available. Deliveries of surface water supplies were configured to simulate actual surface water deliveries, to the extent possible with available data, and thus implicitly reflect historical surface water transfers and any effects of transfers on groundwater pumping.
- **Groundwater Pumping** – For urban water suppliers, historical pumping was estimated from reported pumping volumes over time. Pumping for large irrigation districts was developed from reported data and private pumping for landowners was calculated automatically within the model by first estimating the total demand and then subtracting surface water deliveries to calculate estimated groundwater pumping required to meet the remaining demand.

3.3.3.2 Current Conditions

The current conditions water budget was developed as a baseline to evaluate projected water budgets considering future conditions and is based on 50 years of hydrology along with the most recent information describing land use, urban demands, and surface water supplies. The 50-year hydrologic period was selected rather than the most recent year for which historical water budget information is available to allow for direct comparison of potential future conditions to current conditions. The use of a representative hydrologic period containing wet and dry cycles supports the understanding of variability and uncertainty in groundwater conditions over time, establishment of sustainable management criteria, and development of projects and management actions to avoid undesirable results.

The current water budget estimates current inflows, outflows, and change in storage for the subbasin using 50 years of representative hydrology and the most recent water supply, water demand, and land use information.

Information utilized to develop the current conditions baseline water budget include:

- **Analysis Period** – The 2016-2065 analysis period was simulated based on 50 years of historical hydrology representing the period from 1966 to 2015. Table 3-10 identifies the projected water years and corresponding historical water years and water year types that were assigned for mapping historical hydrologic data to the current conditions scenario. Hydrologic model inputs for years 2016-2065 were based on these historical water year assignments to achieve a future hydrologic period of that is representative and consistent with historical hydrology over the 1965-2015 period.

- **Stream Inflows** – Inflows of surface water into the subbasin were estimated utilizing the same information as for the historical water budget.
- **Land Use** – Land use for agricultural, native, and urban (including rural residential) lands was estimated annually using the most recent land use information. Specifically, 2013 and 2015 land use were mapped to the 50-year analysis period, with 2015 land use applied to critically dry years corresponding to Shasta Critical years and 2013 land use applied to all other years. Shasta Critical years were identified based on annual inflow to Shasta Lake. Annual inflow to Shasta Lake is a reasonable indicator of surface water supplies and associated changes in diversion curtailments within the subbasin, which are primarily from the Sacramento River.
- **Agricultural Water Demand** – Agricultural irrigation demands were estimated using C2VSimFG-Colusa, in the same manner as the historical water budget. The same general assumptions used for simulating all crops (including rice and managed wetlands) in the historical water budget were also used in the current conditions baseline water budget.
- **Urban and Industrial Water Demand** – Urban and industrial demands were estimated based on recent per capita water use and projected 2050 population. Specifically, average per capita water use for recent years (2006 to 2015) was reduced based on projected 2050 values in the Willows UWMP.
- **Surface Water Diversions** – For the current conditions scenario, historical diversions were applied to the future, with 2015 diversions used in Shasta Critical years and 2013 diversion used in Shasta Non-Critical years. Shasta Critical Conditions were simulated for the following five years throughout the 50-year simulation period: 2026, 2027, 2041, 2064, and 2065. Simulated diversions in the Subbasin in those Shasta Critical years were on average approximately 30 percent less than the simulated diversions in Shasta Non-Critical years.
- **Groundwater Pumping** – Pumping to meet urban demands was estimated based on an average of recent years, as described above. Pumping to meet agricultural and managed wetlands demands was estimated using C2VSimFG-Colusa as described previously for the historical water budget.

Table 3-10. Summary of Projected Water Years and Assigned Historical Water Year

Projected Water Year	Assigned Historical Water Year	Sacramento Valley Water Year Type	Projected Water Year	Assigned Historical Water Year	Sacramento Valley Water Year Type
2016	1966	BN	2041	1991	C
2017	1967	W	2042	1992	C
2018	1968	BN	2043	1993	AN
2019	1969	W	2044	1994	C
2020	1970	W	2045	1995	W
2021	1971	W	2046	1996	W
2022	1972	BN	2047	1997	W
2023	1973	AN	2048	1998	W
2024	1974	W	2049	1999	W
2025	1975	W	2050	2000	AN
2026	1976	C	2051	2001	D
2027	1977	C	2052	2002	D
2028	1978	AN	2053	2003	AN
2029	1979	BN	2054	2004	BN
2030	1980	AN	2055	2005	AN
2031	1981	D	2056	2006	W
2032	1982	W	2057	2007	D
2033	1983	W	2058	2008	C
2034	1984	W	2059	2009	D
2035	1985	D	2060	2010	BN
2036	1986	W	2061	2011	W
2037	1987	D	2062	2012	BN
2038	1988	C	2063	2013	D
2039	1989	D	2064	2014	C
2040	1990	C	2065	2015	C

Note: Sacramento Valley Water Year Type is based on the Sacramento Valley Water Year Index and is classified into five types: Wet (W), Above Normal (AN), Below Normal (BN), Dry (D), and Critical (C).

3.3.3.3 Future Conditions Scenarios

Three projected (future conditions) baseline water budgets were developed considering a range of future conditions that may occur. The scenarios consider future planned land use changes (i.e., development), along with changes in climate, including precipitation, surface water inflows, and evapotranspiration. These baselines provide information regarding changes in subbasin conditions (e.g., groundwater storage) that may occur in the future over a series of wet and dry cycles.

The projected water budget estimates potential future inflows, outflows, and change in storage for the subbasin using 50 years of representative hydrology (including modifications based on climate change projections), the most recent water supply and water demand, and planned future land use information.

Information utilized to develop the future conditions baseline water budgets include:

- **Analysis Period** – The 2016-2065 analysis period was simulated based on 50 years of historical hydrology representing the period from 1966 to 2015. Table 3-10 identifies the projected water years and corresponding historical water years and water year types that were assigned for mapping historical hydrologic data to the future conditions scenarios. Hydrologic model inputs for years 2016-2065 were based on these historical water year assignments to achieve a future hydrologic period of that is representative and consistent with historical hydrology over the 1965-2015 period.
- **Stream Inflows**
  - Future Conditions, No Climate Change – Inflows of surface water into the subbasin were estimated utilizing the same information as for the historical water budget.
  - Future Conditions, 2030 Climate Change – Precipitation, evapotranspiration, and surface water supplies were adjusted to reflect climate change based on the 2030 Central Tendency climate change datasets provided by DWR to support GSP development.
    - For precipitation and evapotranspiration, monthly change factors were applied to historical values to estimate potential future conditions.
    - For stream flows, DWR estimates of stream inflows were utilized where available; for streams without direct estimates of inflows, inflows were estimated using streamflow change factors applied at the watershed scale.
  - Future Conditions, 2070 Climate Change – Precipitation, evapotranspiration, and surface water supplies were adjusted to reflect climate change based on the 2070 Central Tendency climate change datasets provided by DWR to support GSP development.
    - For precipitation and evapotranspiration, monthly change factors were applied to historical values to estimate potential future conditions.
    - For stream flows, DWR estimates of stream inflows were utilized where available; for streams without direct estimates of inflows, inflows were estimated using streamflow change factors applied at the watershed scale.
- **Land Use** – Land use for agricultural, native, and urban (including rural residential) lands was estimated annually using the most recent land use information and modified based on planned development according to County General Plan documents.
  - Future Conditions, No Climate Change – Land use was assumed to be similar to the current conditions water budget scenario.
  - Future Conditions, 2030 Climate Change – 2013 and 2015 land use data were mapped to the 50-year analysis period considering 2030 central tendency climate change projections. 2015 land use was applied to extreme dry years and 2013 land use applied to all other years. 2013 and 2015 land use data were modified to reflect planned development, generally resulting in an increase in urban land through development of previously undeveloped (i.e., native) lands.
- **Future Conditions, 2070 Climate Change** – 2013 and 2015 land use data were mapped to the 50-year analysis period considering 2070 central tendency climate change projections. 2015 land use was applied to Shasta Critical years and 2013 land use applied to all other (Shasta Non-Critical) years. 2013 and 2015 land use data were modified to reflect planned development, generally resulting in an increase in urban land through development of previously undeveloped (i.e., native) lands.