Sacramento Valley Groundwater Assessment

Active Management – Call to Action

TECHNICAL SUPPLEMENT

Prepared for

Northern California Water Association

Prepared by

Davids Engineering
Macaulay Water Resources
West Yost Associates

June 2014

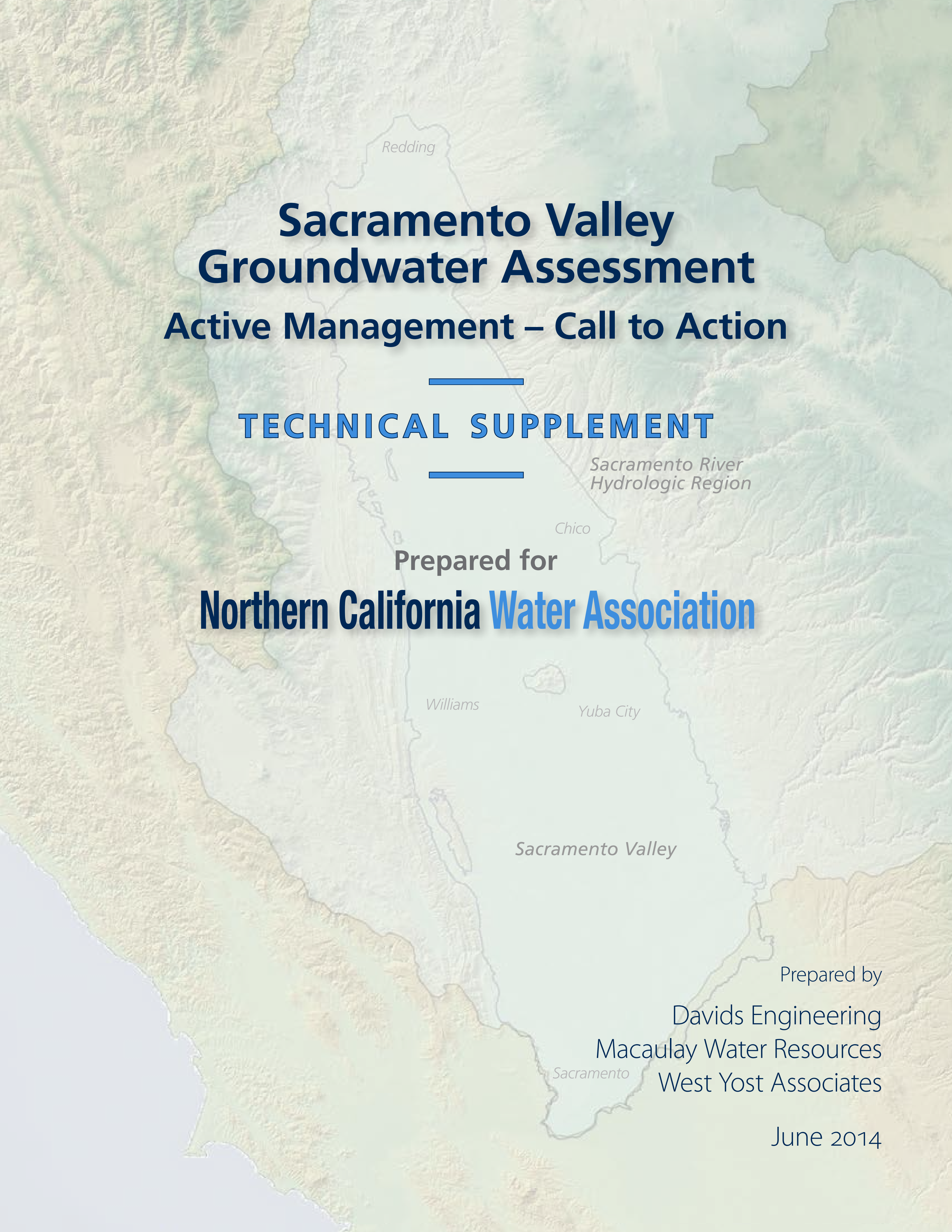


Table of Contents

Executive Summary 4

Chapter 1: Introduction **7**

1.1 Introduction and Purpose 7

1.2 Study Area 9

1.3 Report Organization 9

1.4 Terminology 10

Chapter 2: General Assessment of Groundwater Resources and Management 11

2.1 Groundwater Basins and Groundwater Source Areas 11

2.2 State of Groundwater Conditions 12

2.2.1 Groundwater Occurrence and Movement 12

2.2.2 Groundwater Level and Storage Trends 14

2.2.3 Quality 18

2.2.4 Land Subsidence 19

2.2.5 Fractured-Rock Aquifers 20

2.3 Entities Managing Groundwater 20

Chapter 3: Understanding Groundwater Resources 21

3.1 Monitoring 21

3.1.1 Groundwater Level Monitoring 24

3.1.2 Groundwater Quality Monitoring 24

3.2 Modeling 26

3.3 Groundwater Quality Assessment 28

3.4 Land Use & Water Use and Supply Information 29

3.4.1 Land Use Information 29

3.4.2 Water Use Information 31

3.5 Concept of Capture and Implications to Groundwater Management 33

3.5.1 Considerations Involving Stream-Aquifer Interaction 35

3.6 Recent Changes in the Sacramento Valley Groundwater Balance: Background 36

3.7 Sacramento Valley Water Balance 37

3.8 Recent Trends in Water Balance Parameters 41

3.8.1 Water Consumption and Corresponding Water Demands 41

3.8.2 Surface Water and Groundwater Supplies 46

3.8.3 River and Stream Accretions 47

3.8.4 Deep Percolation 48

3.8.5 Increasing Adoption of Pressurized On-Farm Irrigation Systems 48

3.9 Regional Impacts within the Sacramento Valley 51

Chapter 4: Institutional Approaches to Groundwater Management 52

4.1 Groundwater Management Plans, Including Basin Management Objectives 52

4.2 County Ordinances 54

4.2.1 Colusa County Ordinance 55

4.2.2 Butte County Ordinance 55

4.2.3 Glenn County Ordinance 56

4.2.4 Tehama County Ordinance 56

4.3 Integrated Regional Water Management Plans 56

4.4 Regional Board Waste Discharge Requirements 58

Chapter 5: Regional Sustainability and Self-Sufficiency for Managing Water Supplies 59

5.1 Introduction 59

5.2 Sustainability Defined 59

5.3 Sustainability, Self-Sufficiency and Groundwater 60

5.4 Vulnerability: Still Learning 61

5.5 Recent Water Management Successes 63

5.5.1 South Sutter Water District 63

5.5.2 Yuba County Water Agency 64

5.5.3 Yolo County Flood Control and Water Conservation District – Active Groundwater Management in Yolo County 66

5.5.4 Northern Sacramento County 67

Chapter 6: Conclusions and Recommendations 69

6.1 Conclusions 69

6.1.1 Data Collection, Monitoring and Modeling 69

6.1.2 Water Management 70

6.1.3 Water Supplies 70

6.1.4 Land Use 70

6.1.5 Other 71

6.2 Recommendations 71

6.2.1 Increase Data Collection, Monitoring and Modeling 71

6.2.2 Improve Water Management Activities 72

6.2.3 Augment Water Supplies 72

6.2.4 Address Land Use 73

6.2.5 Other 73

Appendix A: Bibliography 75

Appendix B: List of Tables 79

Appendix C: List of Figures 80

Appendix D: Adopted Groundwater Management Plans in the Sacramento Valley 82

Executive Summary

This report provides technical support to NCWA's June 2014 short report, *Sacramento Valley Groundwater Assessment, Active Management – Call to Action*. Our groundwater resources are an essential regional asset, contributing fundamentally to the economy, social well-being and the environment of the Sacramento Valley. Further, the physical connections between surface water and groundwater systems within the Valley demand that the two be managed conjunctively to continue to meet water demands within Sacramento Valley and statewide on a sustainable basis.

This report provides an overview of the Sacramento Valley's groundwater resources and the evolving efforts to better understand and actively manage the region's water resources. In 2003, the Department of Water Resources (DWR) issued Bulletin 118 Update 2003 regarding groundwater throughout California. This report serves a complement to, and to a certain extent an update to, much of the information in that bulletin as it relates to the Sacramento Valley. Further, this report and the NCWA June 2014 short report provide conclusions and recommendations for future action. This report provides a comprehensive overview of the various ongoing programs and actions in the Sacramento Valley to better understand and actively manage groundwater resources for the benefit of the Sacramento Valley.

This year we face unprecedented drought conditions, following a decade of relatively dry years and increasing demands on our groundwater resources. These increasing demands have two principal causes. The reduced availability of surface water during dry years brings a predictable shift towards greater use of groundwater. The second is expanding and intensifying agricultural land use within the Sacramento Valley, much of that supported exclusively by groundwater supplies, together with increasing urban water demands, leading to increased reliance on groundwater even in "normal" years.

This report contains a great deal of technical information, a compilation of what is known from both monitoring and modeling. New information, in addition to what is known about total storage and water levels, is coming in on a regular basis. Sacramento Valley Water leaders are actively confronting many vulnerabilities to their water supplies. This leadership and investment has yielded many successes.

Here is what we know to be true:

- Sacramento Valley groundwater is a finite resource.

- The Sacramento Valley's groundwater systems are large and typically span boundaries delineating counties, water supplier districts and other political jurisdictions. Additionally, the systems are interconnected to varying degrees, have different physical characteristics from place to place, and generally react slowly to changes in stresses. The combination of these conditions calls for both local and regional management and short- and long-term perspectives.

- The Sacramento Valley's groundwater and surface water systems are interconnected, so that management actions and associated stresses on one affect have the potential to affect the other.

- Availability and management of surface water supplies are influenced by the unpredictability of Nature and limited storage, control, and conveyance facilities. Groundwater conditions are generally more predictable and slower to change than surface water supplies and can be developed in closer proximity to specific water demands, so groundwater is often the resource relied upon to secure reliable annual water supplies. Because of this, effective management of groundwater resources is essential to ensure sustainable resources both in the short term and long term.

In addition, Sacramento Valley water leaders understand that water supply reliability is linked to a healthy economy and a healthy environment. It is these factors that set forth the goal that modern water management describes as "sustainable water resources." As addressed in NCWA's July 2011 report, *Efficient Water Management* *for Regional Sustainability in the Sacramento Valley*, the essential indicators of sustainability are a vibrant and growing economy, reliable high-quality surface water and groundwater supplies, stable groundwater levels to protect water supplies and stream ecological values, preservation and enhancement of fish and wildlife habitat, and the preservation of agricultural productivity. The 2011 Sustainability Report concluded that all our water use efficiency initiatives need to contribute to maintaining or improving these indicators of sustainability, and started an important dialogue within the Sacramento Valley on what measures should be considered to assure the long-term sustainability of our economy and environment.

The technical material presented in this report leads to a number of conclusions and recommendations in Chapter 6. They highlight:

- Data collection, monitoring and modeling
- Water management activities
- Water supplies
- Land use
- Other (including declining river and stream accretions)

The water supply and environmental stresses of the current drought are focusing more attention on groundwater, our essential drought reserve when surface supplies are limited. We summarize on the following pages what appear to be important long-term trends going on within the Sacramento Valley that affect our groundwater resources. It is not yet possible to separate such trends from the impacts of the current drought. Real-time monitoring alone does not tell the full story since groundwater responses to changes in use are slow to appear. No matter what the combined impacts of these trends and the increased use of groundwater during drought times, the current stresses on our groundwater reserves need to be addressed.

None of the issues facing groundwater and overall water supply sustainability in the Sacramento Valley are easy. Still, the region is early enough in its recognition of its water management challenges that there is time to take action, but it must be soon. Failure to take action in time has resulted in undesirable groundwater stresses in many regions throughout the West and the Plain States. We can do better.

Chapter 1: Introduction

1.1 Introduction and Purpose

This report provides an overview of the Sacramento Valley's groundwater resources and the evolving efforts to better understand and actively manage the resources to provide sustainable benefits for the Sacramento Valley and California. Over the past few decades, a number of water agencies in the Sacramento Valley have substantially increased their active management of surface and groundwater resources. This report describes several of those active management successes, as well as identification of long-term vulnerabilities and recommendations for the future.

California is in a third consecutive dry year, with severe, widespread drought conditions existing throughout the state including the Sacramento Valley and watershed. These conditions are likely to challenge and reveal even more than we have learned historically regarding the nature and limits of Sacramento Valley groundwater resources and the effectiveness of management responses.

This report is intended to serve as a **call to action**, with the extraordinary stresses of the current drought and guided by the considerations listed below:

- Sacramento Valley groundwater is a finite resource.
- Driven by economic growth, increasing environmental demands, changing land use and other forces, water demands in the Sacramento Valley and California are increasing, directly and indirectly resulting in increased groundwater development and use in the Sacramento Valley.
- Sustainable groundwater resources are necessary to meet the Sacramento Valley's long-term water demands for all beneficial purposes (see Figure 1-1).
- Several subregions within the Sacramento Valley have taken action to reverse historic falling groundwater levels, with several case studies contained in this report. In all cases, local agencies have invested in local water infrastructure and increased the amount and distribution of surface water.
- Long-term trends indicating threats to groundwater sustainability need to be identified, understood and tracked.
- The Sacramento Valley's groundwater and surface water systems are interconnected, so that stresses on one affect the other.
- There have been increased demands on all water resources within the Sacramento Valley, including new environmental demands over the past 30 years, the intensification of irrigated agriculture including the expansion of tree crops, and continued residential development.
- 2014 began with state and local declarations of drought emergencies. As of the release of this report, record low deliveries from both the State Water Project and the federal Central Valley Project were confirmed and the State Water Resources Control Board had begun to issue notices of curtailments to some water rights holders in the state, including some in the Sacramento Valley.
- The Sacramento Valley's groundwater systems are large, interconnected and can react slowly to changes in stresses, calling for local and regional management with vision encompassing both short- and long-term views.
- Effective management of groundwater resources is essential to ensure sustainable groundwater resources.

The utilization and preservation of the Sacramento Valley's groundwater resources through active management is critical to the economic, social and environmental fabric of the region. The region's water users have managed surface water and groundwater conjunctively for many years to ensure reliable and affordable water supplies and groundwater sustainability within the region. As regional pressures on water demands and supplies increase, water resources managers must continue to pursue increasingly effective conjunctive management strategies to ensure regional sustainability and self-sufficiency, while at the same time, enabling the region to continue contributing substantially to statewide water supplies and the overall economy.

In 2003, the Department of Water Resources (DWR) issued Bulletin 118 Update 2003 regarding groundwater throughout California. This report serves a complement to that bulletin and provides a comprehensive overview of the various programs and actions in the Sacramento Valley to better understand and actively manage the groundwater resources for the benefit of the Sacramento Valley.

CH2MHill (for NCWA) has developed a Groundwater Quality Assessment Report (GAR) in anticipation of pending requirements of the Central Valley Regional Water Quality Control Board (CVRWQCB) Irrigated Lands Program (ILP). The GAR is a regional-level analysis designed to aid in the initial prioritization of water quality monitoring and implementation activities, and assessment of data adequacy. It provides the foundation and framework for the long-term program of monitoring and implementation that is required under the ILP. The GAR is posted to the NCWA web site at norcalwater.org/groundwater-quality-report.

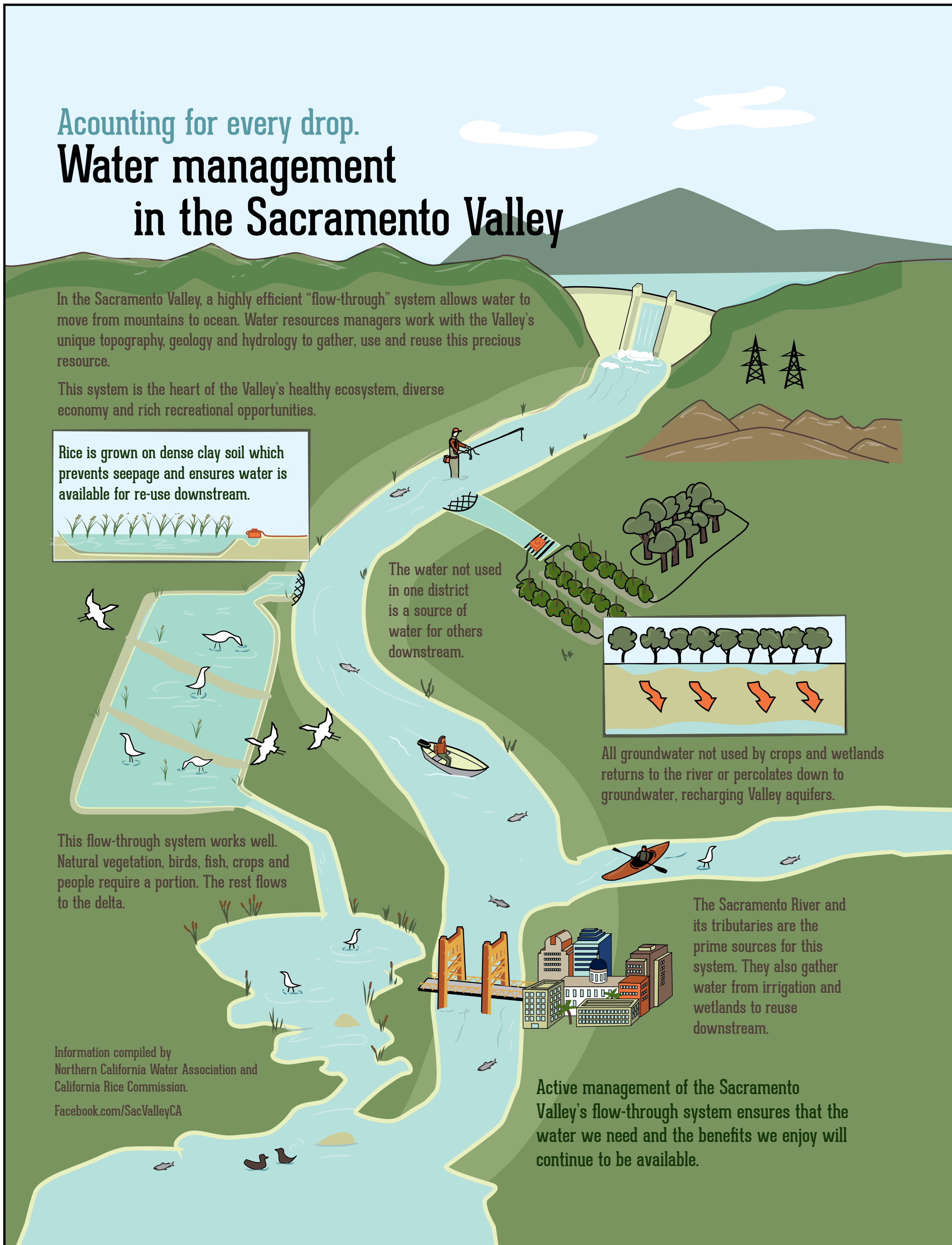


Figure 1-1 Water Management in the Sacramento Valley

1.2 Study Area

The geographic area covered by this report is that delineated in DWR Bulletin 118 Update 2003 as it relates to the Sacramento Valley, and shown in Figure 1-2 below. It consists of DWR's designated Redding Area Groundwater Basin, the Sacramento Valley Groundwater Basin and adjacent volcanic bedrock groundwater source areas, which together are synonymously referred to in this report as the Sacramento Valley Study Area or Region. While the focus of this report is primarily on the two alluvial groundwater basins, the report also addresses basic information and areas of vulnerability for the groundwater source area.

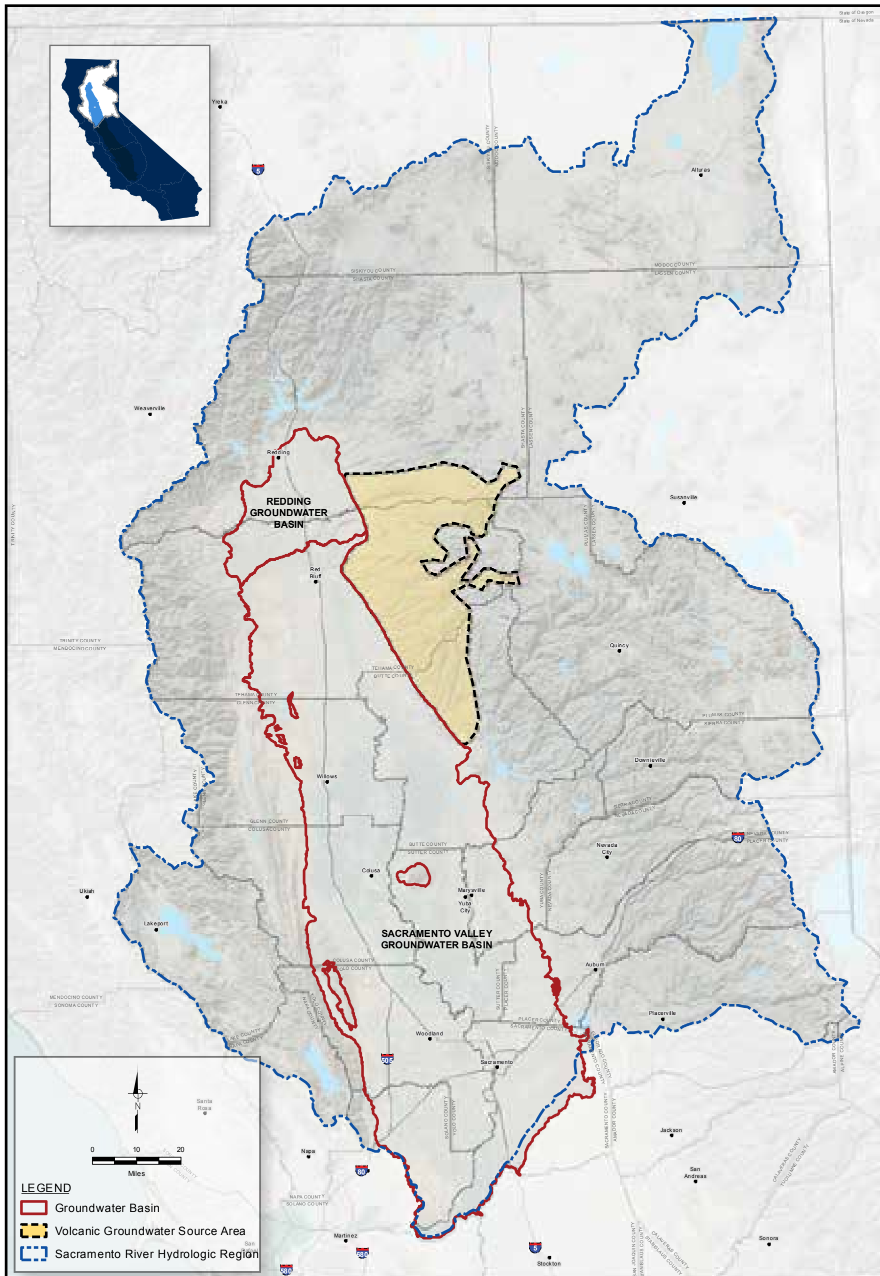


Figure 1-2 Study Area

1.3 Report Organization

There are five additional chapters that follow this introduction, each with supporting figures. The report concludes with a reference list / bibliography of information used in preparing this report, so that readers are able to pursue more details as desired. Chapters 2, 3 and 4 contain detailed technical information and analysis to support the report conclusions and recommendations set forth in Chapter 6. Here is a short summary of the subject of each of the following chapters:

- **Chapter 2** provides a general assessment of groundwater resources and management in the Sacramento Valley, describing groundwater basins, groundwater conditions, and a list of those entities that have some responsibility for managing groundwater resources.

- **Chapter 3** provides more detail on data availability, monitoring, modeling, an ongoing groundwater quality assessment, the reporting of land use and water supplies, and the important elements of the interactions between surface water and groundwater. The chapter also provides an assessment of recent changes in the region's water balance, which has implications for sustainability.

- **Chapter 4** assesses the institutional approaches to groundwater management in the Sacramento Valley at different levels of government.

- **Chapter 5** addresses the concept of sustainability and its application to the water supplies and demands of the Sacramento Valley. Consistent with the purpose of this report, sustainability is addressed in the context of water management tools. Chapter 5 also describes what is known so far regarding 2014 drought conditions. The chapter ends with descriptions of examples of recent successes in groundwater management within the Sacramento Valley.

- **Chapter 6** provides conclusions and recommendations for future actions. The recommendations are founded on concerns regarding long-term vulnerability and the overall goal of sustainability of the region's groundwater resources in contributing to meeting the long-term water needs of the region.

- **Appendix A** is a bibliography of relevant reports and information that provides support to this report.

- **Appendix B** is a list of tables in this report.

- **Appendix C** is a list of figures in this report.

- **Appendix D** is a tabular summary of adopted groundwater management plans in the Sacramento Valley.

1.4 Terminology

Following are definitions for abbreviations and technical terms used in this report:

- **CVP**: Central Valley Project

- **C2VSim**: California Central Valley Groundwater-Surface Water Simulation Model

- **DWR**: California Department of Water Resources

- **ET**: Evapotranspiration

- **Groundwater Source Area**: DWR Bulleting 118 Update 2003 defines groundwater source areas as, "An area where groundwater may be found in economically retrievable quantities outside of normally defined groundwater basins, generally referring to areas of fractured bedrock in foothill and mountainous terrain where groundwater development is based on successful well penetration through interconnecting fracture systems." Previous versions of Bulletin 118 assigned numbers to these bedrock areas. These numbers were retired in the Bulletin 118 Update 2003 to help clarify that bedrock groundwater source areas are not groundwater basins.

- **MAF**: Million acre-feet

- **NCWA**: Northern California Water Association

- **QO**: Quantifiable Objectives

- **SWP**: State Water Project

- **TAF**: Thousand acre-feet

- **USDA**: U.S. Department of Agriculture

- **USBR**: U.S. Bureau of Reclamation

- **NWS**: National Weather Service

- **Gaining Stream**: A stream or reach of a stream that gains water through inflow of groundwater.

- **Induced Infiltration**: Stream losses caused by lowering of groundwater levels in response to groundwater pumping. Induced infiltration transforms a gaining reach of a stream into a losing reach.

- **Losing Stream**: A stream or reach of a stream that loses water through outflow of groundwater.

- **Residual Drawdown**: Region of lowered groundwater levels persisting in an aquifer after pumping stops. Residual drawdowns tend to diminish with time at rates determined by the hydraulic properties of the aquifer.

- **Streamflow Depletion**: The sum of captured groundwater discharge that would have reached the stream in the absence of groundwater pumping and induced filtration caused by the groundwater pumping.

Chapter 2: General Assessment of Groundwater Resources and Management

2.1 Groundwater Basins and Groundwater Source Areas

The Sacramento Valley's groundwater basins and 24 subbasins are listed in Table 2-1 and shown on Figure 2-1.

Figure 2-1 also shows the location of selected groundwater source areas as delineated in DWR Bulletin 118 Update 2003. The largely volcanic terrain to the east and northeast of the Sacramento Valley constitutes an extensive groundwater source area, yielding economically retrievable quantities of groundwater from fractured or otherwise permeable volcanic bedrock (DWR, 2003). However, only DWR's delineated groundwater source areas underlying watersheds that are directly tributary to the Sacramento River are included in the study area as shown on Figure 2-1. Other contiguous parts of DWR's mapped volcanic rock groundwater source area underlie watersheds that drain to other river systems, such as the upper Feather River. These areas are less directly connected to the Sacramento Valley and are not specifically addressed in this report.

Other bedrock areas on the periphery of the Sacramento Valley are not designated groundwater source areas and are not addressed in this report. However these areas do support limited groundwater production, which is crucial for the local inhabitants.

5-6 Redding Area Basin

5-6.01 Bowman Subbasin
5-6.02 Rosewood Subbasin
5-6.03 Anderson Subbasin
5-6.04 Enterprise Subbasin
5-6.05 Millville Subbasin
5-6.06 South Battle Creek Subbasin

5-21 Sacramento Valley Basin

5-21.50 Red Bluff Subbasin
5-21.51 Corning Subbasin
5-21.52 Colusa Subbasin
5-21.53 Bend Subbasin
5-21.54 Antelope Subbasin
5-21.55 Dye Creek Subbasin
5-21.56 Los Molinos Subbasin
5-21.57 Vina Subbasin
5-21.58 West Butte Subbasin
5-21.59 East Butte Subbasin
5-21.60 North Yuba Subbasin
5-21.61 South Yuba Subbasin
5-21.62 Sutter Subbasin
5-21.64 North American Subbasin
5-21.65 South American Subbasin
5-21.66 Solano Subbasin
5-21.67 Yolo Subbasin
5-21.68 Capay Valley Subbasin

Table 2-1 Groundwater Basins and Subbasins of the Sacramento Valley

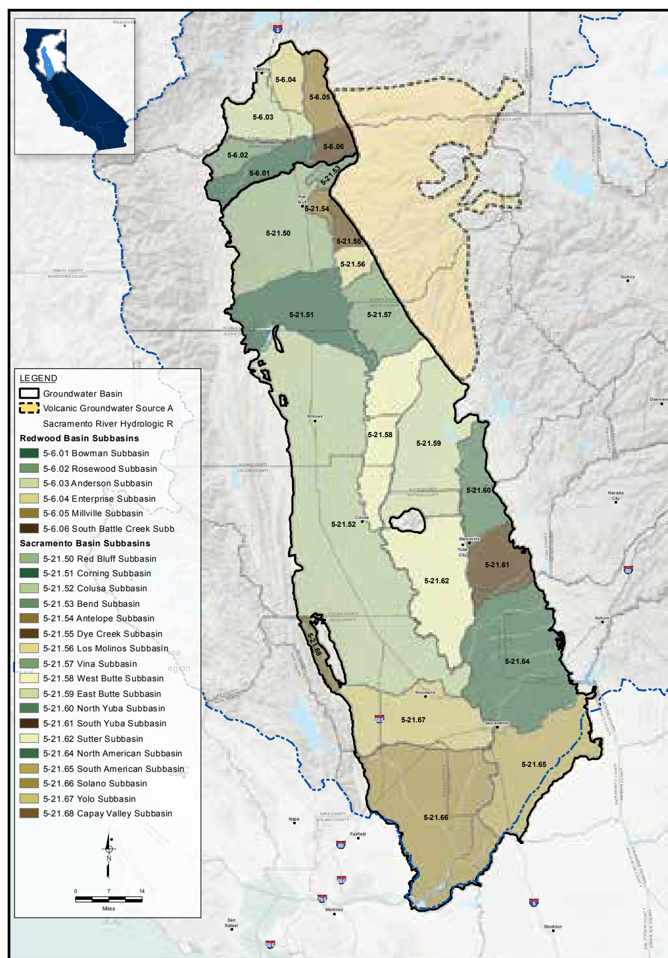


Figure 2-1 Sacramento Valley Alluvial Groundwater Basins and Subbasins

2.2 State of Groundwater Conditions

Groundwater conditions have been characterized by DWR (McManus, September 16, 2013 presentation to NCWA) using these criteria:

- Groundwater Occurrence and Movement
- Groundwater Level and Storage Trends
- Quality
- Land Subsidence

These conditions reflect the present extent of land use change, the corresponding increase in water use throughout the Sacramento Valley, and the increasing reliance on groundwater.

2.2.1 Groundwater Occurrence and Movement

Groundwater occurs in the saturated pore space of the valley-fill aquifers underlying the Sacramento Valley and in fractures and other permeable textural features of the volcanic bedrock groundwater source area outcropping on the northeastern flank of the valley (Figure 2-2).

The principal geologic formations comprising the freshwater valley-fill aquifers include various near-surface Holocene to Pleistocene deposits ranging from less than 10,000 years to approximately 2.6 million years in age underlain by older Pleistocene to Miocene formations ranging from approximately 2.6 million years to as much as ten million years in age. The younger deposits are dominated by alluvial and fluvial sediments of mixed provenance, including sedimentary, metamorphic, intrusive igneous and extrusive igneous source areas bounding the valley. The younger formations include the Modesto and Riverbank Formations, and the Turlock Lake Formation in the southeastern Sacramento Valley. The older deposits are predominately comprised of alluvial and fluvial sediments of the Tehama and Laguna Formations and volcaniclastic sediments of the Tuscan and Mehrten Formations. These freshwater-bearing formations are underlain by tens of thousands of feet of valley filling sedimentary rocks deposited in marine environments. These marine rocks contain saline water and are exploited for natural gas.

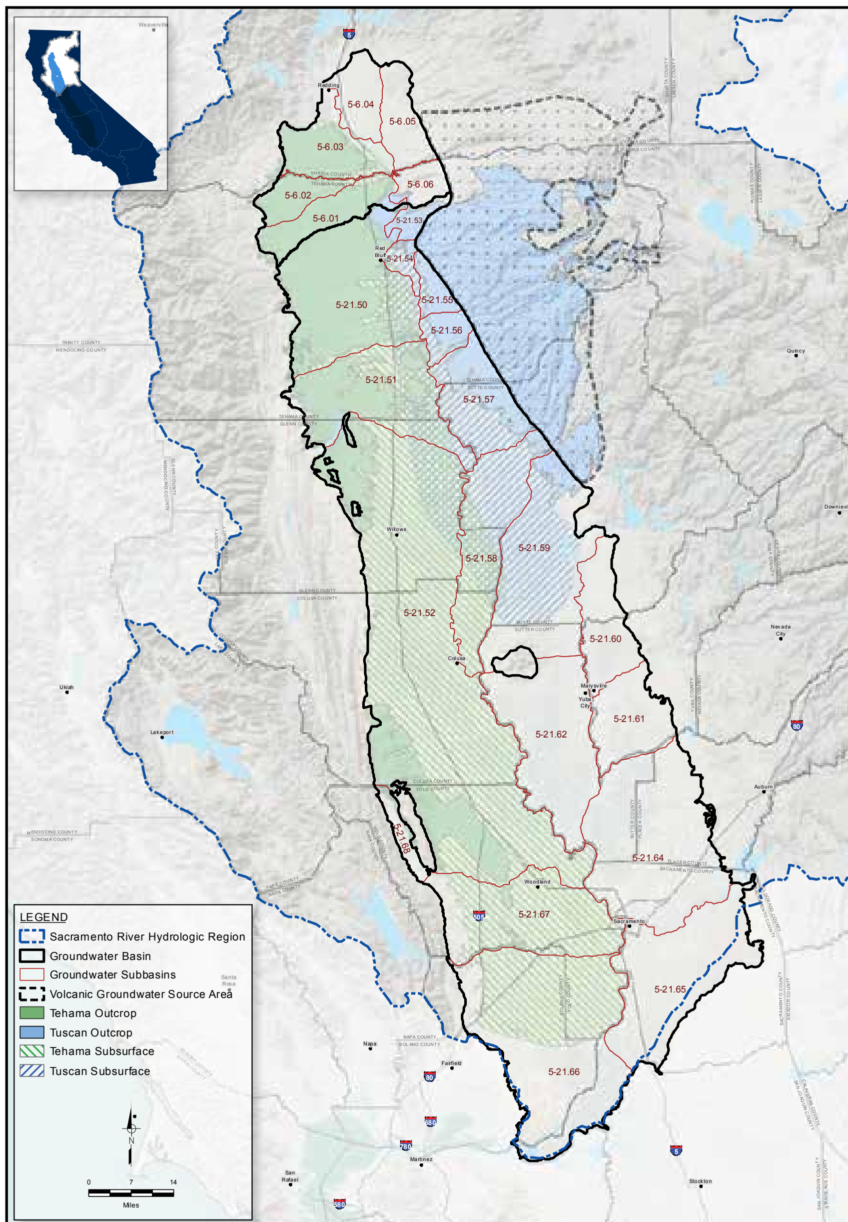


Figure 2-2 Extents of the Tuscan and Tehama Formations

The volcanic bedrock groundwater source area is contiguous with the valley-fill aquifers of the northeastern Sacramento Valley and is comprised of the Tuscan Formation and related andesitic and basaltic volcanic rocks.

The freshwater aquifers comprised of the younger formations extend to depths up to 200 feet and are commonly exploited for domestic uses. Well yields from these formations are typically relatively low because of the limited thickness of the formations. The freshwater aquifers comprised of the older formations extend to depths up to several thousand feet, but the aquifer intervals exploited by wells in the older formations are usually less than 600 feet below ground surface, because additional depth is not necessary to achieve adequate yields for typical agricultural and municipal uses. In a limited number of cases, agricultural and municipal wells exploit deeper intervals of the aquifer, either to meet specific water quality goals or to manage the impact of pumping on other groundwater users and the hydrologic system as a whole.

Well yields in the volcanic bedrock groundwater source area are highly variable depending on whether or not a given well penetrates a permeable structure within the bedrock. Well yields are less reliable than in the valley-fill aquifers because the storage capacity of permeable features in the volcanic bedrock groundwater source area is limited and subject to relatively rapid depletion, if precipitation is insufficient.

Groundwater ages range from a few tens of years in the shallowest aquifers to more than 10,000 years in the deepest parts of the freshwater aquifer. The range of groundwater ages reflects the residence time of water in the aquifer. Generally, groundwater moves through the shallower parts of the aquifer system relatively rapidly, and the distances between recharge and discharge areas are relatively short. This leads to relatively short residence times and correspondingly young ages. In contrast, groundwater movement in deeper parts of the aquifer system is generally slower, and the distances between recharge and discharge areas are relatively long. This leads to relatively long residence times and correspondingly older ages. One reason for the relatively slower movement of groundwater at greater depths in the aquifer is the general lack of groundwater pumping below roughly 600 to 700 feet below ground surface. Increased pumping at these depths would increase groundwater flow velocities, decrease the residence time in the aquifer and lead to younger ages of the water. Changes in the age of the groundwater in response pumping would not necessarily signal overdrafting of the resource, defined here as unacceptable reductions in storage over time, because such changes in storage are dependent on the ongoing balance between recharge and discharge fluxes, not the residence times of individual water molecules.

The vast difference between the age of the groundwater and the formations comprising the aquifer underscores the fact that groundwater is an integral part of the hydrologic cycle and is continually moving through the aquifer from areas of recharge to areas of discharge. Although many volumes of groundwater have moved through the aquifer system over the life of the Sacramento Valley, this volume is only a small fraction of the total flow through the Sacramento Valley hydrologic system, because groundwater flows are greatly exceeded by stream flows.

Groundwater flow is generally from areas of higher elevation to areas of lower elevations at rates typically ranging from a fraction of a foot per day to a few feet per day. In the volcanic bedrock groundwater source area, local groundwater flow velocities can be much higher, ranging up to hundreds of feet per day in scoriaceous zones and open conduits in volcanic rock. Flow rates averaged over large volumes of the volcanic bedrock groundwater source area probably overlap the range of flow rates in the alluvial aquifers, because of scoriaceous zones, open fractures, and conduits form only a small fraction of the rock volume, and individual permeable features may not be continuous or extensively interconnected over large distances.

Figure 2-3 shows groundwater elevation contours in the Sacramento Valley for spring 2010. Spring water levels typically represent the highest annual groundwater levels (DWR, 2013). As with topographic contours, arrows drawn perpendicular to the groundwater elevation contours indicate the general direction of groundwater flow. Groundwater flow is generally from the northern end of the valley towards the Sacramento-San Joaquin Delta and from the margins of the valley towards its center, consistent with the topography of the basin. Although not depicted on Figure 2-3, these flow patterns are locally modified by groundwater pumping, recharge and underflow from adjacent areas. These local groundwater flow patterns would be apparent with finer scale mapping of localized areas within the valley.

Groundwater flow mapping is not available for the volcanic bedrock groundwater source area due to the paucity of groundwater level monitoring data. However, based on the fact that the area comprises watersheds directly influent to the Sacramento Valley, topographic gradients are directed towards the valley. Groundwater flow generally follows topography, and it is likely that the general flow direction in the volcanic bedrock groundwater source area is towards the valley with underflows reaching the valley-fill aquifers. Locally, flow directions probably vary with the local topography and the spatial distribution and orientation of permeable bedrock structures. Likewise, groundwater pumping and recharge influence local flow patterns in the volcanic bedrock groundwater source area.

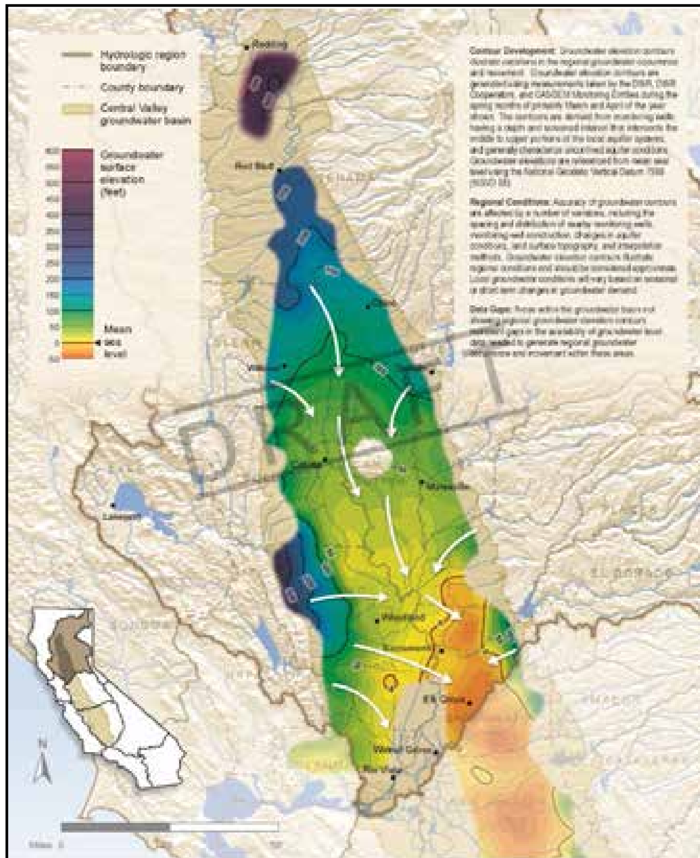


Figure 2-3 Spring 2010 Groundwater Elevation Contours in the Sacramento Valley

2.2.2 Groundwater Level and Storage Trends

The Sacramento Valley has been extensively developed for irrigated agriculture. Surface water is used for irrigation in many areas according to established surface water rights, but high quality groundwater is generally readily available throughout the Valley, and in most areas can be pumped economically. Therefore, land suitability and other economic conditions pose the main constraints to agricultural development, not water supply.

Whether land is irrigated with surface water or groundwater has very significant implications to the balance of the groundwater system. In general, in areas with surface water supplies, typically little or no groundwater is pumped and the net effect of irrigation is recharge to the groundwater system in the form of deep percolation of applied water. (This may be offset to some degree in cases where despite surface water being available, some growers choose to use groundwater due to certain advantages it affords. See Section 3.8.5 for further discussion of this topic.) By contrast, in areas that rely wholly or predominantly on groundwater, only a portion of the water pumped percolates back to the groundwater system, typically resulting in net extraction of groundwater. These typically dominant irrigation-related factors together with other groundwater recharge and discharge processes determine whether the groundwater balance is sustained over time, as reflected in changes in groundwater levels and storage.

A widely held perception based on historical observations is that the Sacramento groundwater basin is drawn down seasonally due to irrigation pumping, but generally recovers each year because, on an annual basis, groundwater pumping and other groundwater discharges are matched by groundwater recharge from deep percolation of applied water and precipitation, leakage from canals and streams, and other recharge sources. However, in recent years, groundwater level monitoring performed by DWR reveals that groundwater levels in some areas of the Sacramento Valley have not fully recovered. These are typically areas that have been developed for irrigation that are completely or predominantly dependent on groundwater as a supply source.

These downward trends are expected to be exacerbated by the current drought. Future droughts, changes in land and water use, and climate change present a serious risk that these trends will continue, threatening the sustainability of the groundwater system with serious consequences for all beneficial uses of groundwater and surface water. Surface water beneficial uses are at risk because in many areas of the Sacramento Valley stream flow has historically been sustained by groundwater accretions, particularly during the dry summer months. As groundwater levels are drawn down, accretions to streams decline and streams may even begin to lose water by leakage into the aquifer. The types of interactions between streams and aquifers and the implications of drawdown are discussed further in Section 3.5.

DWR Northern Region Office maintains a website (www.water.ca.gov/groundwater/data_and_monitoring/northern_region/GroundwaterLevel/gw_level_monitoring.cfm) that documents changes in groundwater levels in numerous groundwater wells across the region for the time period from spring 2004 through spring 2013. The wells monitored are categorized as shallow (less than 200 feet), intermediate (200 - 599 feet), and deep (600 feet and greater). Agricultural and municipal wells typically pump from the intermediate depth zone and account for the majority of pumpage in the Sacramento Valley. In contrast, the large number of domestic wells used to supply rural residences account for only a small fraction of the pumpage but are typically much shallower and their performance is therefore more susceptible to changes in groundwater levels. The groundwater level trend maps demonstrate that groundwater levels have declined in all three depth zones over the last decade. The intermediate depth zone experienced the greatest decline in groundwater levels, which approached 30 feet in some areas of the groundwater basin.

DWR has calculated annual and cumulative changes in groundwater storage based on observed changes in groundwater levels for the period Spring 2005 through Spring 2010 (Table 2-2). These calculations reveal that recent annual changes in groundwater levels and storage have been positive or negative in any given year, but on a cumulative basis have been negative. The estimated cumulative change in groundwater storage between spring 2005 and spring 2010 ranges between -686 thousand acre-feet (TAF) and -1,666 TAF depending on the assumed specific yield used for the calculation. This equates to an estimated average annual change in groundwater storage of between -137 TAF and -333 TAF in the basin during this period. This is shown graphically in Figure 2-4, taken from the draft 2013 Update to the California Water Plan (at the time our report was prepared, the final 2013 Update along with final figures had not been released). This figure shows the changes in groundwater levels within the Sacramento Valley from Spring 2005 to Spring 2010. A number of areas within the Sacramento Valley show groundwater

Sacramento Valley Groundwater Basin Spring 2005-10 Change in Storage Estimates

Reporting Areas (Acres): 3,070,427

Non-Reporting Areas (Acres): 1,052,799

Period Spring – Spring	Average Change in Groundwater Elevation (feet)	Estimated Change in Storage in TAF Assuming Specific Yield=0.07	Assuming Specific Yield = 0.17
2005 – 2006	2.3	503	1,222
2006 – 2007	-4.3	-929	-2,225
2007 – 2008	0.1	15	36
2008 – 2009	-1.8	-378	-918
2009 – 2010	0.5	102	249
2005 – 2010 (total)	-3.2	-686	-1,666

Note: Changes in groundwater elevation and storage are calculated for reporting area only.

Table 2-2 Recent Annual Changes in Storage in the Sacramento Valley Groundwater Basin

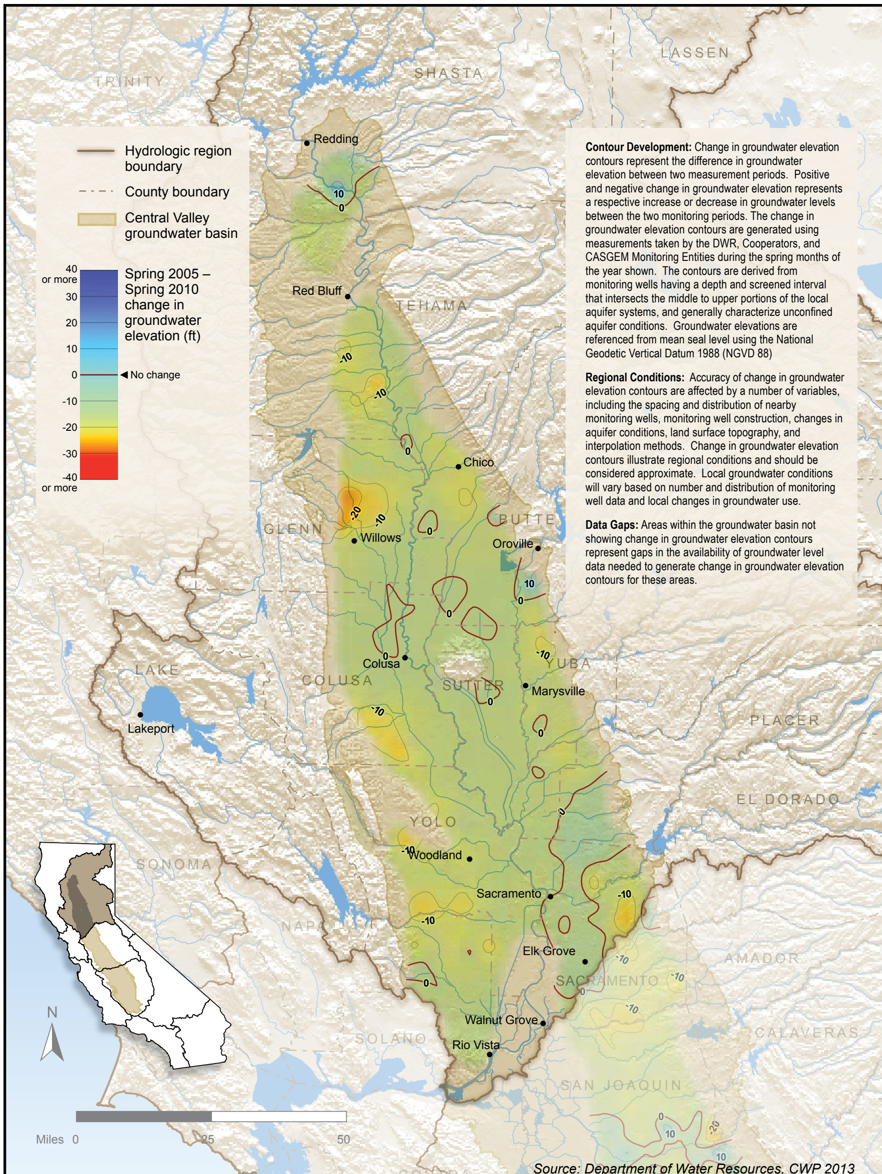


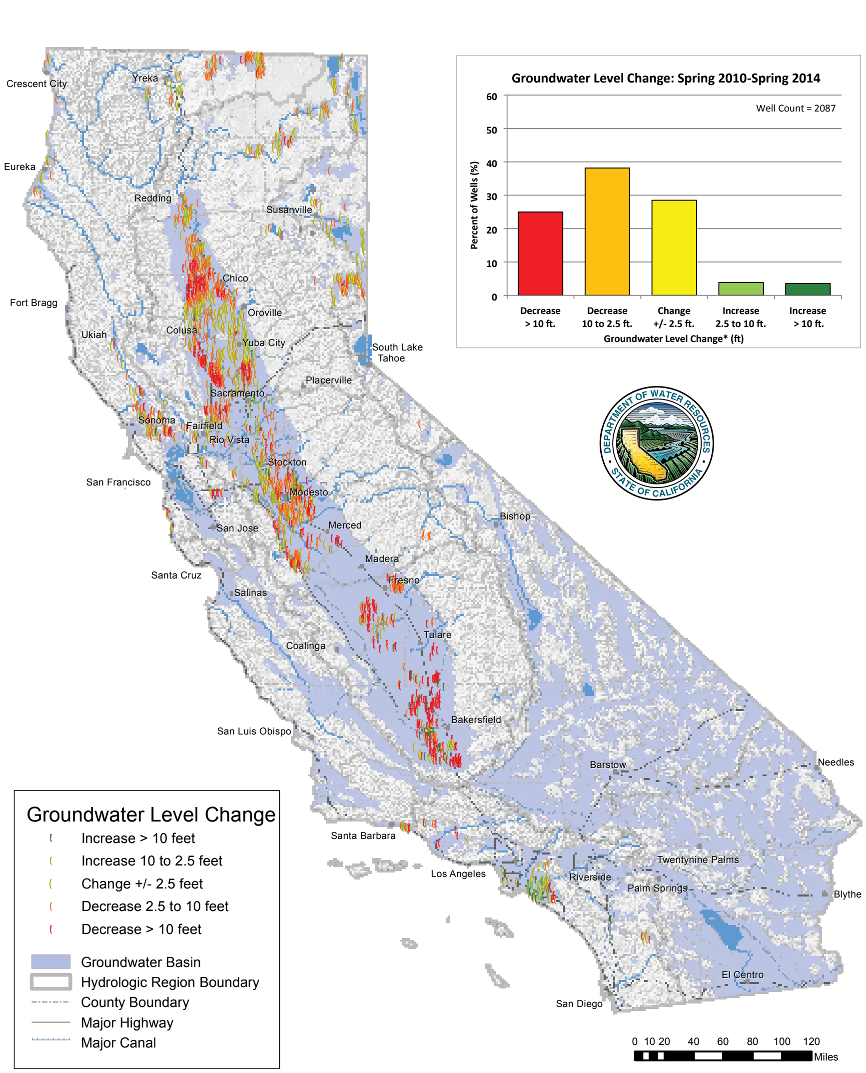
Figure 2-4 Spring 2005 – Spring 2010 Changes in Groundwater Levels, Sacramento Valley

levels declining during this period, although data is unclear how much of this was related to dry conditions and how much associated with long-term increases in groundwater use.

Estimated changes in groundwater storage from the California Central Valley Groundwater-Surface Water Simulation Model Version R374 (C2VSim) are additionally available and can be compared with DWR's "on the ground" estimates from observed groundwater levels. C2VSim is an integrated hydrologic model developed and maintained by DWR (Brush, et. al. 2013, DWR 2014). As with all models of complex natural systems, C2VSim data is subject to a certain degree of uncertainty. Nevertheless, the data provide a consistent and useful means of understanding development trends in the Sacramento Valley (and other regions of the Central Valley). Between 2005 and 2009, the average spring (March to March) change in storage from C2VSim R374 was -311 TAF per year, with estimates based on groundwater level monitoring ranging from -197 TAF to -479 TAF per year. Estimates of change in groundwater storage for individual years vary somewhat between sources, but overall changes in storage for the period of overlap in the data sources as a whole agree well. Some of the differences in estimated change in storage may result in somewhat different areas of coverage between the groundwater basins on the Valley floor and the C2VSim subregions, with the primary difference being the exclusion of southern Sacramento County from the C2VSim subregions.

Since 2010, surface water supplies have been curtailed somewhat in the Sacramento Valley due to generally dry conditions, resulting in greater reliance on groundwater pumping and likely acceleration and expansion of groundwater level declines, although data are not yet available to confirm this. Thus, it is too early to tell whether recent observed groundwater level declines and reductions in storage are persistent or will recover when surface water supplies recover. Figure 2-5 is from the DWR April 2014 report, Report to the Governor's Drought Task Force – Groundwater Basins with Potential Shortages and Gaps in Groundwater Monitoring. This figure shows statewide changes in groundwater levels from Spring 2010 through Spring 2014. While a figure showing only the Sacramento Valley is not available, it is clear from this figure that groundwater levels in many areas of the Sacramento Valley have continued to decline during the ongoing drought.

Municipal/urban uses make up a small fraction of the groundwater pumping in the basin, and this is projected to be the case in the future as agricultural pumping dominates the region's groundwater withdrawals. Table 2-3 summarizes the average groundwater usage for the period from 2005 through 2010 for agricultural, urban



*Groundwater level change determined from water level measurements in wells. Map and chart based on available data from the DWR Water Data Library as of 04/15/2014. Document Name: DOTMAP_S2010_S2014 Updated: 04/21/2014 Data subject to change without notice.

Figure 2-5 Spring 2010 – Spring 2014 Statewide Changes in Groundwater Levels (Ongoing Drought Conditions)

and managed wetland uses in the Sacramento River Hydrologic Region. Agricultural use accounted for approximately 84 percent and urban use accounted for approximately 16 percent of the total groundwater use for the period, with less than one percent used in managed wetlands. This indicates that even small percentage increases in agricultural water demand will overshadow the changes in water demands for urban uses.

The Draft California Water Plan Update 2013 forecasts a reduction in agricultural water demand for all urban growth scenarios, when climate change is not considered (DWR, 2013). This reduction in agricultural water demand is projected mostly based on the reduction in agricultural land area resulting from urban growth and savings from water conservation. More significantly, agricultural demands are forecasted to increase under most urban growth scenarios when climate change is considered (DWR, 2013). According to the Draft California Water Plan Update 2013 regarding the Sacramento River Hydrologic Region:

Agriculture Use Met by Groundwater		**Urban Use Met by Groundwater**		**Managed Wetlands Use Met by Groundwater**		**Total Water Use Met by Groundwater**	
TAF	Percent	TAF	Percent	TAF	Percent	TAF	Percent
2,294.2	30%	428.6	47%	20.1	4%	2,742.9	30%

Notes:

1) TAF = thousand acre-feet

2) Percent use is the percent of the total water supply that is met by groundwater.

3) 2005-2010 precipitation equals 96 percent of the 30-year average for the Sacramento River Hydrologic Region.

4) Total Water Supply = Groundwater + Surface Water + Reuse

Source: Public Review Draft California Water Plan Update 2013

Table 2-3 Sacramento River Hydrologic Region Average Annual Groundwater Supply by Type of Use (2005-2010)

… when considering the potential effects of future climate change many scenarios show an increase in agricultural water demand even when there is a reduction in irrigated crop area as shown in Table SR-25. Under high population scenarios the decrease was about 50 thousand acre-feet, but under the three low and current trend population scenarios, the average increase in water demand was about 110 thousand acre-feet and 200 thousand acre-feet, respectively, when compared with historical average of 7,490 thousand acre-feet.

Other factors, not yet reflected in published agricultural water demand estimates, may also cause agricultural water use to increase in the future. It is commonly known that the Sacramento Valley has experienced a significant expansion in land area planted with perennial crops, such as tree crops and vineyards, in recent years, and this trend is expected to continue. Expansion of permanent crops places additional pressure on the groundwater supply for several reasons. First, by definition, these crops cannot be fallowed during drought conditions when surface water supplies are curtailed or not available; they must be supplied by groundwater pumping. Second, in many cases, perennial crops are being developed on previously dry lands not served by water suppliers with surface water supplies, thus creating new demand for groundwater. Third, perennial crops are often irrigated with drip irrigation systems that require water with low turbidity. Therefore, groundwater is used in these systems due to the substantial cost of filtering surface water supplies. Fourth, for some crops, such as almonds, relatively high water consumption is economically justified by higher crop yield and farm revenue. In recent years, consumptive water use by almond trees in the Central Valley has been found to be similar to alfalfa.

2.2.3 Quality

Groundwater quality is variable across the Sacramento Valley, and this variation has been categorized using six characteristic water types associated with specific geographic areas (Hem, 1984). These areas are the:

1. Tuscan Volcanic Rocks
2. Victor Plain
3. Butte Basin
4. Sutter Basin
5. North Alluvial Fans

Along the eastern side of the basin, groundwater from the Tuscan Formation and the Victor Plain have lower total dissolved solids (TDS) and higher silica concentrations than other areas of the valley. Along the axis of the basin, in the Butte and Sutter Basins, groundwater typically has elevated concentrations of arsenic, iron, manganese and potassium. The South Alluvial Fans are characterized by high TDS and boron concentrations. Selenium and hexavalent chromium are also problematic. Groundwater is typically low in silica beneath the alluvial fans of the basin's west side (North and South Alluvial Fans).

According to Hem (1984), much of the variation in groundwater quality is controlled by two processes: recharge water chemistry and the chemically reducing conditions in fine-grained flood basin deposits along the axis of the valley. Reducing conditions account for the prevalence of arsenic, iron and manganese beneath the flood basins. Reducing conditions support denitrification, and this process may explain the typically low nitrate concentrations beneath the flood basins.

Sediment provenance must be added to the list of factors controlling groundwater quality. Boron is particularly associated with the Clear Lake Volcanics. Sediments derived from the Clear Lake Volcanics carry boron into Valley through the Cache Creek watershed. Selenium originates in sediments derived from marine sedimentary rocks of the Coast Range Great Valley Sequence. Chromium-bearing sediments are derived from oceanic crustal rocks in the Coast Ranges and the Sierra Nevada.

The California Department of Public Health (CDPH) has proposed a 10-micrograms per liter (µg/L) maximum contaminant level (MCL) for hexavalent chromium and anticipates promulgating an enforceable regulation in 2014. The new MCL will significantly impact some municipalities in the Sacramento Valley, particularly the Cities of Woodland and Davis, which both operate municipal wells with elevated hexavalent chromium concentrations. Chromium occurs naturally in rocks bordering the Sacramento Valley, for example, serpentinites and other related oceanic crustal rocks. Valley soils bear insoluble trivalent chromium minerals weathered from these rocks. Under certain conditions, soluble hexavalent chromium is mobilized by oxidation of these minerals and carried to the groundwater system by recharge. Hexavalent chromium is a potential problem anywhere in the Valley that chromium-bearing soils are exposed to oxidizing conditions.

Prior to the advent of extensive irrigated agriculture, groundwater recharge was derived from precipitation and seepage from streams. Recharge from precipitation was mainly limited to recharge areas on the periphery of the valley, because most infiltrated precipitation on the Valley floor was consumed by evapotranspiration.

Since at least the mid-1950s, deep percolation of applied irrigation water has become an increasingly important source of recharge, both volumetrically and in terms of water quality. Deep percolation of applied irrigation water has reversed long-term groundwater level declines in some areas of the valley and stabilizes groundwater levels in many areas of the valley where surface water diversions are used for irrigation, but dissolved constituents acquired during infiltration through the soil have affected groundwater quality with potentially negative consequences for municipal, domestic and other beneficial uses.

Deep percolation of applied irrigation water is volumetrically important because, along with groundwater pumping, it drives groundwater flux rates through the aquifer system that are significantly higher than predevelopment flux rates (Williamson, et.al., 1989). Concentrations of TDS, nitrogen compounds, and nutrients increase in applied water concurrent with its use. This change in recharge water quality and the significantly higher rates of recharge relative to predevelopment conditions has led to progressive declines in groundwater quality with respect to TDS, nitrogen compounds, and nutrients. Pesticides, herbicides and other organic compounds also enter the Valley's groundwater aquifers through recharge of applied water.

These trends are expected to continue in the future and will affect the valley's aquifers to progressively greater depths as recharged water moves downward through the aquifers over time. The full impact of past and current management practices on groundwater quality in the Valley's aquifers may not be apparent for decades or longer, because of the large volume of water in storage and the slow rate of groundwater movement. For this reason, effective management must integrate monitoring programs capable of characterizing historical and ongoing groundwater quality trends, modeling of these trends to assess future conditions and Best Management Practices (BMPs) to minimize groundwater quality impacts.

Chapter 3 of this report provides more detail on existing groundwater quality programs and groundwater models developed for the Valley. Chapter 4 discusses current groundwater management. Chapter 6 provides recommendations for future management.

2.2.4 Land Subsidence

Land subsidence is a settling or sinking of the Earth's surface due to movement of earth materials. In California, it is often caused by three distinctly different water-related processes: 1) compression (compaction or consolidation) of the interbedded layers of clay and silt within the aquifer formation due to groundwater withdrawal; 2) drainage and oxidation of organic soils; and 3) wetting and compaction of previously dry soils above the water table. Land subsidence can damage infrastructure, increase flooding risks due to differential land settlement, and permanently reduce the water storage capacity of the aquifer.

Differential land subsidence and associated earth fissuring resulting from groundwater withdrawal have had and continue to have significant consequences in portions of the San Joaquin Valley, portraying the dangers of overtapping regional water resources. In the Sacramento Valley, land subsidence has been measured in Yolo County, where significant damage occurred to wells during past droughts, such as occurred from 1976 to 1977 and 1986 to 1992.

The risk of future significant 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 impact that would otherwise go unnoticed; and the mineral composition and consolidation history of the aquifer.

DWR operates an extensive network of extensometers and periodically conducts land surface elevation surveys at dedicated land subsidence benchmarks distributed throughout the Sacramento Valley. Based on the available data, the areas within the valley that seem to be the most susceptible to land subsidence are those areas in which groundwater from the Tehama Formation (generally the west side of the Sacramento Valley) is the sole or dominant source of supply.

2.2.5 Fractured-Rock Aquifers

Fractured-rock aquifers adjacent to the Sacramento Valley extend from the edges of the alluvial groundwater basins to the foothills of the Sierra Nevada and Coast Range. Wells in fractured-rock aquifers tend to have less capacity and less reliability than wells drawing from alluvial aquifers. While yields from such wells are typically much less than those in the floor of the Sacramento Valley, they provide essential foothill water supplies for individual domestic wells and small public water systems. The threat to such systems is two-fold. The first is continuing production during long-term droughts. The second is the water supply challenges associated with growth and added competition for the groundwater.

2.3 Entities Managing Groundwater

Section 10755.2 of the California Water Code encourages local agency management of groundwater resources. In addition, DWR's groundwater management web page (www.water.ca.gov/groundwater/gwmanagement/index.cfm) states:

> *There are three basic methods available for managing groundwater resources in California: (1) management by local agencies under authority granted in the California Water Code or other applicable State statutes, (2) local government groundwater ordinances or joint powers agreements, and (3) court adjudications.*

As described in Chapter 4 of this report, the Sacramento Valley has a number of DWR-approved groundwater management plans (GMP). These plans have been developed and are administered by local entities, including individual counties and water districts. In addition, a number of counties in the Sacramento Valley have adopted ordinances that are intended to exert some level of control over discrete groundwater activities. There are no court-adjudicated groundwater basins or subbasins in the Sacramento Valley.

In addition, a number of counties in the region are involved in managing groundwater to some degree through a county ordinance (www.water.ca.gov/groundwater/gwmanagement/local_gw_ordinances.cfm). The degree of active engagement in managing groundwater varies throughout the region, and is associated with a variety of factors including sub-regional groundwater challenges, the nature of county ordinances, and other factors. In general, county ordinances have been put in place to react to new events (for example, short-term water transfers) and may not necessarily call for active year-to-year management activities in the absence of new events.

Chapter 3: Understanding Groundwater Resources

This chapter provides an overview of groundwater monitoring, land use and water supplies, and the importance of stream interactions with groundwater. In addition this chapter describes recent changes in the Sacramento Valley Groundwater Balance.

3.1 Monitoring

There are multiple agencies that routinely collect groundwater level and groundwater quality information in the Sacramento River Hydrologic region. Figure 3-1 shows all of the over 1,300 known monitoring well locations by Agency, Monitoring Cooperator, and CASGEM Monitoring Entity in the Sacramento River Hydrologic Region (DWR, 2013). (Note: Figure 3-1 is labeled "draft" since the final figure from DWR was not available at the time this NCWA report was prepared.)

Figure 3-2 shows that 32 percent of the wells in the region were drilled for observation purposes (DWR, 2013).

The draft Data Assessment and Applicability for the Sacramento Valley Groundwater Assessment Technical Memorandum 1 (TM1) prepared by CH2M Hill in December 2013 provides a thorough summary of the groundwater monitoring efforts conducted in the region. Much of the information on groundwater monitoring from TM1 is summarized below.

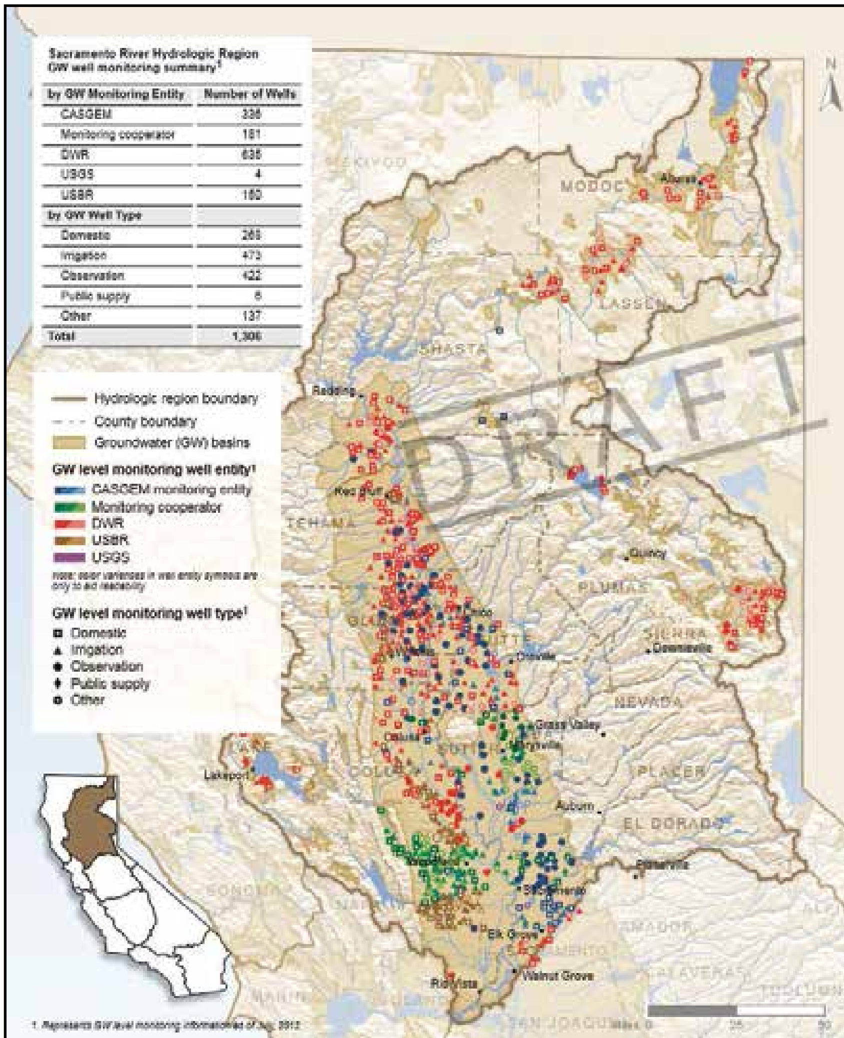


Figure 3-1 Monitoring Well Location by Agency, Monitoring Cooperator, and CASGEM Monitoring Entity in the Sacramento River Hydrologic Region

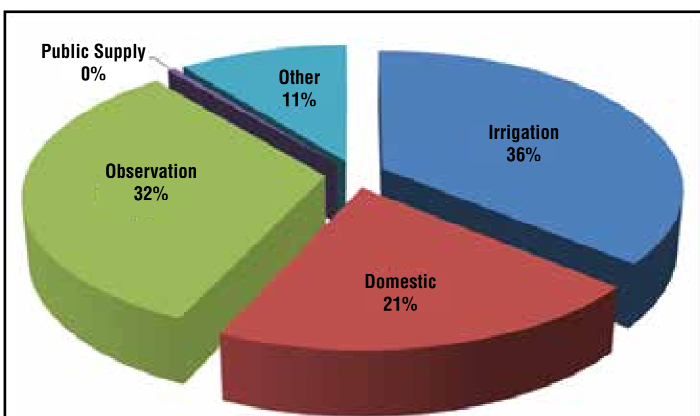


Figure 3-2 Percentage of Monitoring Wells by Use in the Sacramento River Hydrologic Region

Lead Agency	Cooperating Agencies	Monitoring Program	Database Name
California Department of Water Resources (DWR)	DWR Northern and North Central Region Offices	Groundwater Level and Quality Monitoring Program	Water Data Library
	Butte County Department of Water & Resource Conservation, City of Roseville, Colusa County, County of Glenn Department of Agriculture, Feather Water District, Lake County Watershed Protection District, Placer County Water Agency, Reclamation District No. 1500, Sacramento Central Groundwater Authority, Sacramento Groundwater Authority, Shasta County, South Sutter Water District, South Tahoe Public Utility District, Squaw Valley Public Service District, Sutter Extension Water District, Tehama County Flood Control & Water Conservation District, Water Resources Association of Yolo County, Yuba County Water Agency	CASGEM	CASGEM
California Department of Pesticide Regulation (DPR)	California Department of Public Health (CDPH), USGS, DWR	Groundwater Protection Program	Well Inventory Database
State Water Resources Control Board (SWRCB)	SWRCB and Regional Boards, CDPH, DPR, DWR, USGS, and Lawrence Livermore National Laboratory	Groundwater Ambient Monitoring and Assessment Program (GAMA)	GeoTracker GAMA
	CDPH	Drinking Water Program	Electronic Data Transfer (EDT) Library
	DWR	GAMA	GeoTracker GAMA
	USGS	GAMA	GeoTracker GAMA
	N/A	GAMA Program Domestic Wells Project	GeoTracker GAMA
USGS	N/A	National Water Information System (NWIS)	NWIS Database
	SWRCB	GAMA Program Priority Basin Project	GeoTracker GAMA/NWIS
	N/A	National Water Quality Assessment Program (NAWQA)	NAWQA

(a) Source: Table 10 from Sacramento Valley Groundwater Assessment Technical Memorandum 1 prepared by CH2M Hill in December 2013.
(b) Source: Sacramento Valley Groundwater Assessment Technical Memorandum 1 prepared by CH2M Hill in December 2013

Coverage	Types of Data Collected (b)	Data Limitations (b)
Mostly DWR Basins (a)	groundwater levels and quality - specific conductance, nitrate, and TDS	• little coverage outside of the Valley floor
Mostly DWR basins in the Sacramento Valley and mountain valley basins	groundwater levels	• little coverage outside of the Sacramento Valley and mountain valley basins
Good coverage	groundwater quality - pesticides	• precise well location not available • no sample depth information
Overall adequate (a)	groundwater quality - pesticides, drinking water constituents, miscellaneous	
Good study area coverage (a)	groundwater quality in deep wells - regulated drinking water constituents including nitrate	• inexact coordinates, resulting in multiple wells at a single location • many wells with only one sample • wells with multiple samples on the same day with no specific explanation • no well construction information • no sample depth information
Sparse (a)	groundwater quality - nitrate and total dissolved solids (TDS)	• little coverage outside of the Sacramento Valley • many wells with only one sample • wells with multiple samples on the same day with no specific explanation • no specific conductivity measurements • short period of record • not all DWR wells are in Geo Tracker • no well construction information • no sample depth information
Sparse (a)	groundwater quality in deep wells - specific conductivity, some nitrate and TDS	• little coverage outside of the Sacramento Valley in the northern region • many wells with only one sample • wells with multiple samples on the same day with no specific explanation • nitrate and TDS not analyzed for all samples • short period of record • not all USGS wells are included (USGS GAMA and USGS NWIS) • no well construction information • no sample depth information
Tehama, Yuba, and El Dorado Counties (a)	groundwater quality in shallow/intermediate wells - nitrate and specific conductivity, some TDS	• coverage limited to three counties • wells only have one sample • specific conductivity not analyzed for all samples • short period of record • no well construction information • no sample depth information
Good coverage (a)	groundwater quality for wells of varying depth - nitrate, specific conductivity, and TDS	• little coverage outside the Sacramento Valley groundwater basin • not all samples have nitrate, specific conductivity, and TDS concentrations • limited well construction information • limited sample depth information
Only in DWR Basins (a)	groundwater quality for deep wells - broad range of constituents	• coverage limited to DWR basins
Southeast Sacramento Valley (a)	groundwater quality in shallow wells - field measurements, 14 inorganic constituents, 6 nutrient constituents, organic carbon, 86 pesticides, 87 VOCs, tritium (hydrogen-3), radon-222, deuterium (hydrogen-2), and oxygen-18)	• coverage limited to southeast Sacramento Valley • wells only have two samples

Table 3-1 Groundwater Monitoring Programs and Databases in the Sacramento Valley

3.1.1 Groundwater Level Monitoring

The DWR region offices have programs for regularly collecting groundwater level data. In addition, many local water purveyors and water districts have groundwater level collection programs. Specific local agencies with groundwater level monitoring programs include, but are not limited to:

- Anderson Cottonwood Irrigation District
- Butte County Department of Water & Resource Conservation
- City of Roseville
- Colusa County, Feather Water District
- Glenn-Colusa Irrigation District
- Glenn County Department of Agriculture
- Lake County Watershed Protection District
- Placer County Water Agency
- Reclamation District No. 1500
- Sacramento Central Groundwater Authority
- Sacramento Groundwater Authority
- Shasta County
- Shasta County Water Agency
- South Sutter Water District
- South Tahoe Public Utility District
- Squaw Valley Public Service District
- Sutter County
- Sutter Extension Water District
- Tehama County Flood Control & Water Conservation District
- Water Resources Association of Yolo County
- Yolo County Flood Control & Water Conservation District
- Yuba County Water Agency

All of these agencies contribute some or all of their groundwater level collection data to the California Statewide Groundwater Elevation Monitoring (CASGEM) program. TM1 indicates that data from the following two groundwater level monitoring programs will primarily be used in the Groundwater Quality Assessment Report (GAR): DWR's Northern and North Central Region data collection program and the CASGEM program. The information available from both the DWR Region office programs and CASGEM generally do not include groundwater level information for fractured rock areas in the foothills. As available, information from local groundwater monitoring programs will be used to fill data gaps.

3.1.2 Groundwater Quality Monitoring

The public agencies that maintain online-accessible geodatabases of groundwater quality data include:

- State Water Resources Control Board (SWRCB) (GeoTracker GAMA geodatabase)
- USGS (National Water Information System - NWIS Web Portal)
- DWR (Water Data Library)

In general, these water quality datasets have results for nitrate, TDS and/or specific conductance.

The USGS GAMA Priority Basin Project program is unique in that it analyses a very broad range of constituents. In the Northern Sacramento Valley Basin Study Area, the GAMA program analyzed over 275 constituents including volatile organic compounds, pesticides and pesticide degradates, pharmaceutical compounds, constituents of special interest like perchlorate and N-nitrosodimethylamine (NDMA), nutrients, major and minor ions, trace elements, radioactivity, and microbial constituents. The GeoTracker GAMA database includes data from the SWRCB and Regional Water Quality Control Boards (RWQCBs), the California Department of Public Health (DPH), California Department of Pesticide Regulation (DPR), DWR, USGS, and Lawrence Livermore National Laboratory. The DPR Well Inventory Database has served as a central clearinghouse for groundwater pesticide data since the early 1980s. Although there is abundant pesticide data available from DPR, DPR does not include well depths or precise well location in its dataset due to confidentiality concerns and, therefore, the usefulness of this pesticide data is limited.

TM1 identifies the data from the USGS water quality monitoring program as the most useful for a region-wide analysis since USGS provides good well construction information with the "highest-integrity" dataset. In comparison, DWR and GeoTracker GAMA datasets often lack well depths. USGS datasets also typically include QA/QC samples, good documentation of methodology and detection limits, and laboratory analysis. Therefore, the USGS datasets will be used as much as possible in the GAR with other datasets used as-needed to cover the areas where USGS information is sparse. Figure 3-3 shows that the USGS NWIS shallow monitoring wells cover a wide-range of depths between less than 50 and greater than 500 feet below ground surface (CH2MHill, 2013).

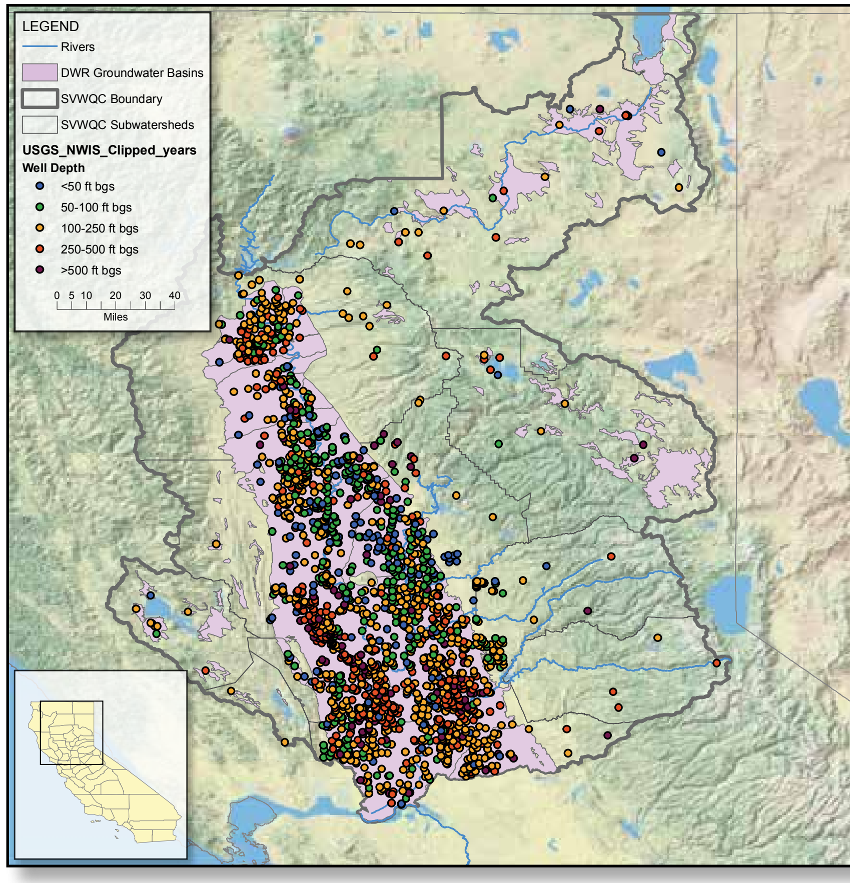


Figure 3-3 USGS NWIS Shallow Wells: Well Depth

Figure 3-4 shows the sample count of USGS NWIS shallow wells by location (CH2MHill, 2013). The large majority of water quality data available from the USGS NWIS is collected in the Sacramento Valley floor. Table 10 in TM1 provides a succinct summary of the available well water quality data sources in the Sacramento Valley (CH2MHill, 2013).

Although there is not one geodatabase containing all of the data sampled by various public agencies, the data that is available, and specifically the data used in the GAR, is sufficient to provide informational trends for the Sacramento River Hydrologic region. The datasets compiled by DWR for groundwater levels and the datasets compiled by the SWRCB, DWR, and USGS for groundwater quality should continue to be reviewed to monitor region-wide changes in groundwater level and quality trends.

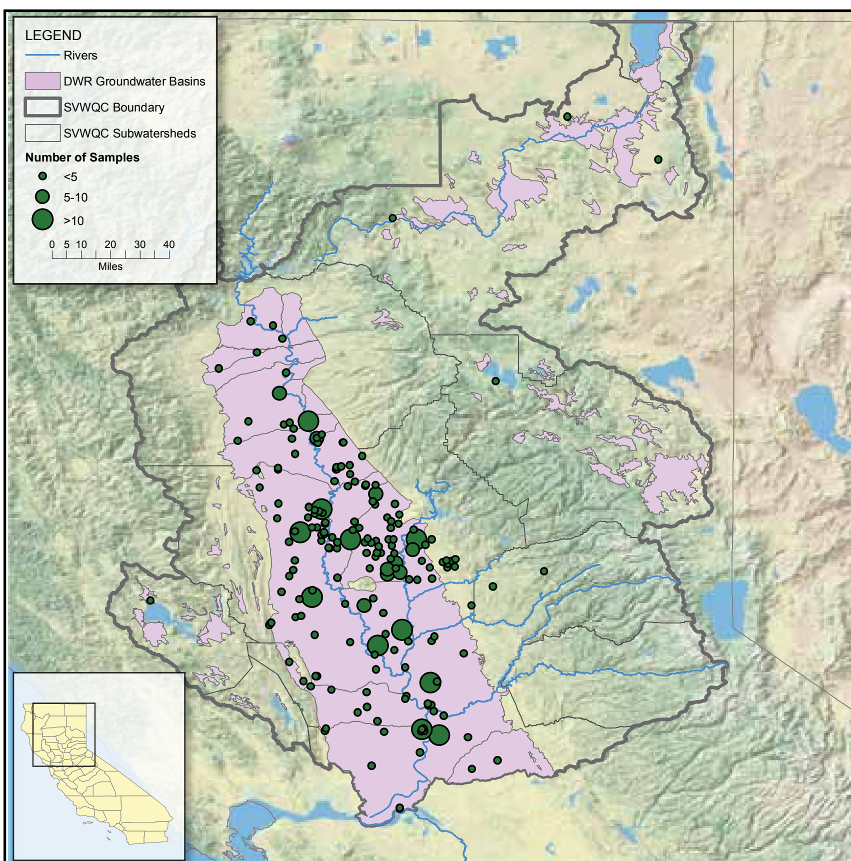


Figure 3-4 USGS NWIS Shallow Wells: Sample Count

3.2 Modeling

Active management of surface water and groundwater resources in the Sacramento Valley requires a significant investment in management support tools. Advanced Geographical Information System (GIS) and geodatabase systems are needed to manage the vast amount of geologic, hydrologic, land use, water use and other information that supports the evaluation of historical and existing conditions. Numerical models capable of simulating the physical processes driving the hydrologic system are the only feasible means of quantifying the relative effects that alternative management scenarios will have over large areas and decades into the future. Suitably calibrated integrated water resources models supported by high quality GIS and geodatabase systems are the only available tools that can be used to forecast the hydrologic effects of alternative management

Model Name	Model	Developer	Coverage	Modeled Processes			
				Groundwater Flow	Stream-flow	Root Zone Flow	Vadose Zone Flow
SacFEM	MicroFEM	CH2MHill	Sacramento Valley	Yes	Yes	No	No
C2VSim	IWFM	DWR	Central Valley	Yes	Yes	Yes	Yes
Central Valley Hydrologic Model	MODFLOW	USGS	Central Valley	Yes	Yes	Yes	Yes
Butte Basin Groundwater Model	FEMFlow3D migrated to IWFM	Hydrologic Consultants Inc./CDM/ Butte County	Butte Basin, Butte County	Yes	Yes	Yes	Yes
Solano County IWFM	IWFM	West Yost	Solano Subbasin, Solano County	Yes	Yes	Yes	Yes
Yolo County IGSM/IWFM	IWFM	WRIME/ DWR/West Yost	Yolo County	Yes	Yes	Yes	Yes
Colusa Area IGSM	IGSM	DWR/WRIME	Colusa County	Yes	Yes	Yes	Yes
Stony Creek IGSM	IGSM	WRIME	Glenn County	Yes	Yes	Yes	Yes
Sacramento County IGSM	IGSM	Montgomery/ WRIME/DWR	Sacramento County	Yes	Yes	Yes	Yes
Western Placer IGSM	IGSM	Montgomery/ WRIME/DWR	Western Placer County	Yes	Yes	Yes	Yes
Sacramento Area Region-al MODFLOW	MODFLOW	Aquveo	Sacramento County, Western Placer County	Yes	Yes	No	No

Table 3-2 Groundwater Models Developed for the Sacramento Valley

scenarios with a quantifiable estimate of the inherent uncertainties in the forecast.

The specific modeling approach and scope chosen depends on the active management objectives and alternatives under consideration. In general, simpler, less rigorous modeling approaches are appropriate for comparison of the relative effects of alternative management approaches, while more complex, integrated water resources models supported by extensive GIS and geodatabase systems and applied with rigorous calibration approaches, uncertainty analysis and sensitivity analysis are required for quantitative forecasting of the effects of alternative management scenarios.

Integrated water resources models have been developed and broadly applied in the Sacramento Valley to assess changes in land use and alternative water management scenarios. Table 3-2 lists models and their applications. Model boundaries are shown on Figure 3-5.

The Sacramento Valley Groundwater Model (SacFEM) is an application of the MicroFEM© model, which is a three-dimensional, finite element modeling platform developed by Dr. C.J. Hemker of the Netherlands (Hemker, 1997). The model is available as part of commercially available graphical user interface software packages. The SacFEM application is a transient groundwater/surface water flow model that operates on a monthly time step over the period of simulation. The finite element mesh has 120,761 nodes, 241,001 elements and seven layers. The mesh covers the entire Sacramento Valley. SacFEM has been used to support the Sacramento Valley Water Management Program and local conjunctive use assessments.

C2VSim is an application of DWR's Integrated Water Flow Model (IWFM) (DWR, 2014). IWFM is a quasi-three-dimensional finite element program that simulates stream flow, soil moisture accounting in the root zone, flow in the vadose zone, groundwater flow, and stream-aquifer interaction. IWFM uses a land use based approach of calculating water demand. Agricultural and urban water demands can be pre-specified, or calculated internally based on different land use types. The model is free and in the public domain, as is the C2VSim application. DWR has developed a graphical user interface and pre- and post-processing tools for the application. Two versions C2VSim exist: a coarse grid version with 1,392 elements, and a fine grid version with over 35,000 elements. Run times for the two versions are approximately six minutes and six hours, respectively. The mesh covers the entire Central Valley. C2VSim is used by DWR to support the groundwater component of CalSim 3, to assess the impact of Sacramento Valley water transfers on Delta outflows and to assess the effects of extended droughts on groundwater levels (DWR, 2013). C2VSim is a complete representation of Central Valley hydrology and hydrogeology. Selected C2VSim results are

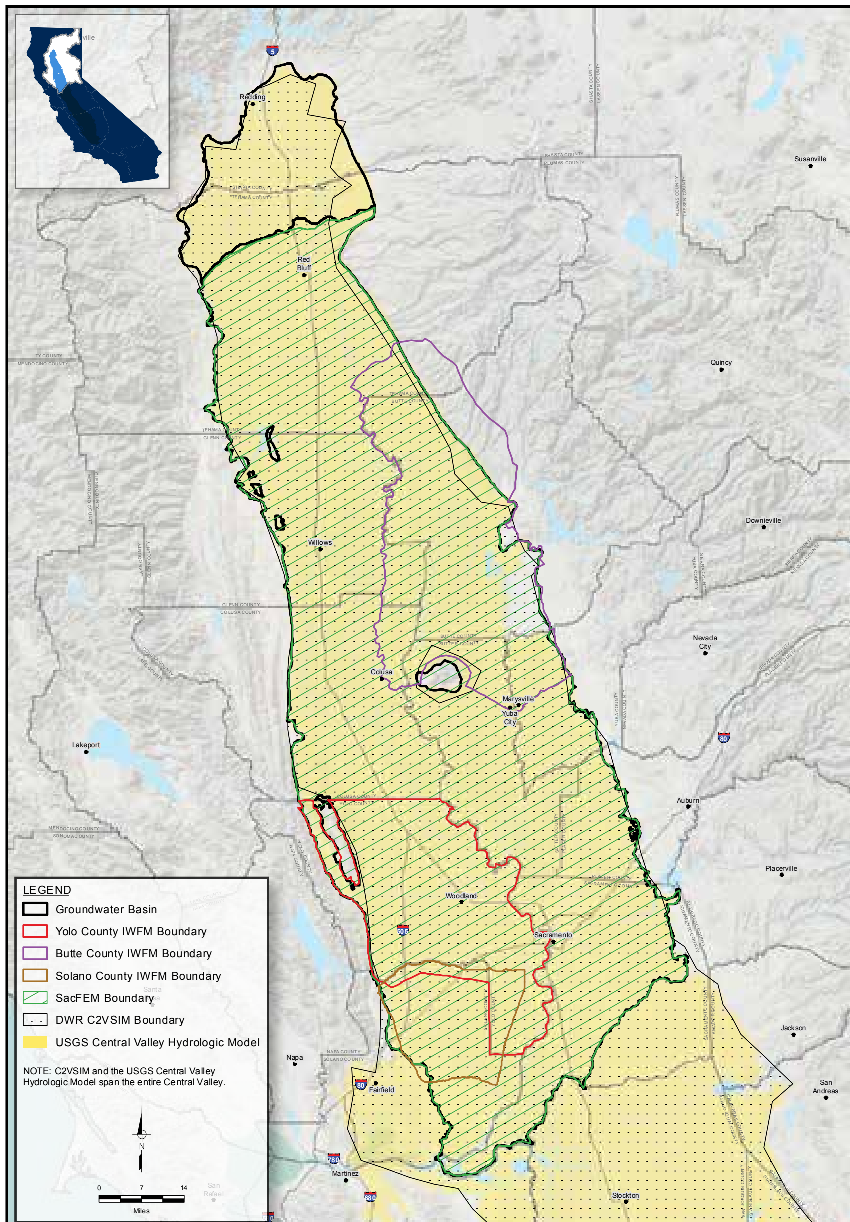


Figure 3-5 Sacramento Valley Groundwater Models

summarized and discussed in Chapter 3 in the context of the Sacramento Valley water balance.

The Central Valley Hydrologic Model (CVHM) is an application of MODFLOW (Faunt, 2009). MODFLOW is a widely used, thoroughly tested and well-documented program developed by the USGS (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996; and Harbaugh, et. al., 2000). MODFLOW implements an approximate quasi-three-dimensional finite difference solution to the groundwater flow equation. Streamflow, land use unsaturated zone processes are simulated in the CVHM application. The model and the CVHM application are free and in the public domain. Graphical user interfaces are available through USGS and commercially. The USGS used CVHM to help complete its study entitled, "Groundwater Availability of the Central Valley Aquifer: U.S. Geological Survey Professional Paper 1766" (USGS, 2009).

The Butte IWFM, Solano IWFM and Yolo County IWFM are local applications of DWR's IWFM model. These applications have been used to assess water management and conjunctive use scenarios in each of the three counties.

The Colusa Area IGSM, Stony Creek IGSM, Sacramento County IGSM, Western Placer IGSM are local applications of the Integrated Groundwater Surface Water Model (IGSM), which is a quasi-three-dimensional finite element program that simulates the same hydrologic processes as IWFM but through different numerical processes. The model code and the applications are not in the public domain but may be available by the sponsoring local agencies. The applications have been used to simulate water management scenarios in Colusa, Glenn Sacramento and Placer Counties.

The Sacramento Area Regional MODFLOW Model was developed by the City of Roseville by converting the Sacramento County IGSM, Western Placer IGSM applications to MODFLOW. The model has been used to assess aquifer storage and recovery scenarios in the City of Roseville. The application is not in the public domain.

3.3 Groundwater Quality Assessment

According to the California Water Plan Update 2013, the following constituents are documented concerns in the Sacramento River Hydrologic region's groundwater:

- Arsenic
- Boron
- Localized contamination by organic compounds and nitrates
- Hexavalent Chromium

Arsenic, boron, and hexavalent chromium are naturally occurring. Arsenic has been found in the center of the Sacramento Valley and emanates from minerals dissolved from the volcanic and granitic rocks of the Sierra Nevada mountains. Boron levels are highest near Cache and Putah Creeks and are likely associated with old marine sediments from the Coast Range. Chromium has been detected throughout the valley floor and is a metal found in natural deposits of ore containing other elements.

Elevated levels of organic compounds and nitrate are due to human activities. Tetrachloroethylene (PCE), which has been detected at levels exceeding the MCL in a number of wells in Butte and Sacramento County, is associated with dry cleaning, textile operations, and degreasing operations. Although nitrate levels do not exceed the MCL in most public water supply wells in the Sacramento Valley, elevated levels have been detected throughout the valley and levels continue to rise. Nitrate is associated with the use of nitrogen-based fertilizers in agricultural operations as well as many other human activities.

The GAR developed by CH2MHill and mentioned earlier in Chapter 1 compiles and analyzes all readily available relevant data, and serves as the basis for an agricultural practice evaluation and for the groundwater monitoring requirements of the CVRWQCB's waste discharge requirements as an element of the Irrigated Lands Program. Specifically, the GAR analyzes available data, evaluates groundwater quality and protection associated with Sacramento Valley irrigated land and farming practices, designates areas as having high or low vulnerability to water quality issues, and includes recommendations on long-term groundwater quality monitoring programs and field-level Best Management Practices (BMP) trials.

The analysis also examines hydrogeology, soil, agronomic, and water quality data, and employs a robust technical approach for the groundwater vulnerability evaluation.

3.4 Land Use & Water Use and Supply Information

Because most of the Sacramento Valley floor is developed for irrigated agriculture, information about land use and cropping patterns is foundational to understanding water use. Although most crops use precipitation stored in the soil to some extent, the large majority of water consumed by crops in the Sacramento Valley comes from applied irrigation water. This is because precipitation occurs mainly in the fall and winter months (November – March) while the growing season of most commercial crops is between April and October, when precipitation is typically negligible or small. In general, the majority of applied irrigation water is consumed by crops through the process of evapotranspiration (ET); this is water volatilized into the atmosphere, causing depletion of water available in the basin. Water applied but not consumed by ET either runs off into surface drains or streams, or percolates beneath the root zone and becomes groundwater recharge, or, most commonly, some combination of the two. In the Sacramento Valley, runoff and deep percolation of applied irrigation water remain available for downstream uses. Land use information is helpful for quantifying depletion by crop ET and, analyzed together with water supply information is essential for developing root water balances that characterize interactions between the land surface (or crop root zone) and underlying groundwater systems.

3.4.1 Land Use Information

DWR for decades has operated a program to survey land use periodically on a county-by-county basis. (See www.water.ca.gov/landwateruse/lusrvymain.cfm for more information.) These surveys are based on visual inspection on a field-by-field basis combined with review of aerial imagery and are therefore very reliable and are typically the best source of land use data. Additionally, for the last 10 to 15 years, most surveys have included irrigation water source and irrigation method on a field-by-field basis, which is critically important for understanding the hydrologic implications of irrigation.

DWR surveys are nominally performed every five years. However, the intervals between surveys have been lengthening and the time between field work and data publication has also been extended. The current status of DWR county surveys is summarized in Table 3-3. The most recent surveys are for Tehama and Butte Counties (2012 and 2011, respectively) and are currently being finalized by DWR for public release. The oldest current surveys are for Placer and Sacramento Counties (1994 and 2000, respectively). The average survey year over all eleven counties for the most recent survey is approximately 2005, meaning that, on average, the data is about nine years old. Information this outdated may be suitable for historical analyses, but is of little value for analyzing land use changes as they occur. Additionally, a significant limitation of the DWR land use data is developing a consistent depiction of Valley-wide land use, due to the different survey dates across counties. For example, the gap between Butte and Sutter Counties, two of the Valley's major agricultural counties, is eight years.

County	DWR Survey Years	Approx. Valley Floor Area (acres)	Percent of Area
Butte	1994, 1999, 2004, 2011*	399,000	9%
Colusa	1993, 1998, 2003, 2009*	437,000	10%
Glenn	1993, 1998, 2003, 2009*	401,000	9%
Placer	1994	135,000	3%
Sacramento	1993, 2000	602,000	14%
Shasta	1995, 2005	225,000	5%
Solano	1994, 2003	283,000	7%
Sutter	1998, 2004	389,000	9%
Tehama	1994, 1999, 2005*, 2012*	731,000	17%
Yolo	1989, 1997, 2008	563,000	13%
Yuba	1995, 2005	158,000	4%
* Survey not yet finalized.			

Table 3-3 Status of DWR Land Use Surveys for Sacramento Valley Counties for the Sacramento Valley

There are other sources of land use data in addition to the DWR land use surveys (Table 3-4). Each County Agricultural Commissioner prepares an annual crop report that provides an aggregate acreage for major crops grown in the county. These reports are compiled from multiple sources, including grower permits with farm maps, surveys and regulatory and inspection data and are considered reliable, but they do not provide spatial information about where crops are grown within the county, posing significant limitations for certain kinds of hydrologic analyses. The level of detail reported varies by county. Minor crops are typically grouped into general categories and reported together to avoid disclosure of confidential information. Additionally, it can be difficult to track crops such as irrigated pasture and winter grains that typically do not use pesticides and to distinguish between irrigated and non-irrigated grain crops. Some counties have developed geographic information systems (GIS) that can be used to estimate cropping through the pesticide use reporting (PUR) process. In the future, these systems might provide spatially discrete, field scale data in a timely manner.

Data Source	Data Features	Limitations
DWR Land Use Surveys	Conducted on a county-by-county basis, approximately every five years. Provides field scale data in GIS format, including crop type and water source (surface water, groundwater, mixed), based on field-by-field visual inspection.	Intervals between surveys are getting longer. Not all counties are surveyed at the same time, so compiling Valley-wide land use means using data from different years. Surveys are typically performed in summer, so winter crops and double cropping may be missed. Otherwise, data is typically very reliable.
County Agricultural Commissioner Crop Reports	Each county agricultural commissioner prepares an annual report of cropping derived from grower surveys, pesticide use reports, and other sources. Reports provide countywide aggregate acres by crop, although some counties are using systems that are capable of providing spatially discrete data in GIS format. Currently, these data are compiled at the state-level by CDFA and NASS.	Crops that do not have fertilizers or pesticides applied to them are not detected. Minor crops are not reported individually. No information describing double cropping. No spatial breakout within counties (until GIS-based data are developed and the data made available).
DPR PUR Databases	Annual databases of agrochemical applications by section with attributes describing grower id, location id, crop, and acreage. By integrating GIS, spatial distribution of cropping can be estimated.	Subject to data entry errors, changes in landowner/lessee, and changes in field boundaries that can lead to double counting of acreages. Challenging to accurately account for double cropping. Crops without agrochemical applications are not reported.
CropScape Cropland Data Layer (U.S. Dept. of Agriculture National Agricultural Statistics Service)	Web-based geospatial data service featuring interactive visualization, geospatial queries and automated data delivery. Provides pixel-scale data in GIS format from 1997 to present, based on remote sensing crop classification algorithms.	Comparisons to ground-based data, such as DWR land use surveys, indicates that the data are fairly reliable for major crops, but may not be reliable for minor crops.
Local Agencies (such as agricultural water suppliers)	Depends on the agency. Often the most reliable and consistent data set at the local level.	Difficult to develop consistent Valley-wide land use because local agencies do not encompass all agricultural areas (e.g., the "groundwater only areas") and data is in different formats.

Table 3-4 Land Use Data Sources

Glenn County is an example of a county that is currently developing such data. According to the California Department of Pesticide Regulation (DPR), as of 2004, 8 of the 11 county agricultural commissioners in the Sacramento Valley had developed or were in the process of developing spatial coverage of field boundaries using GIS.

Data from county agricultural crop reports is compiled annually by the California Department of Food and Agriculture (CDFA) in cooperation with the California field office of the U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS). Currently, reports detailing reported acreages by county are available through 2011 from NASS. In addition to written reports, electronic files are available that can be used to develop a database of cropping over time and evaluate changes in reported cropping. The data are based on the individual county crop reports and thus subject to the same limitations.

Historically, PUR data has been available at the section (1 square mile) scale statewide by year from DPR. These data include the commodity (i.e., crop) and corresponding acreage to which pesticides are applied for each reported application. From 1990 to 2011 (the last year for which data are available), the reports include a unique grower ID and site locator ID that can be used to estimate acreages by crop and field at the section scale. A significant challenge to using the information to estimate crop acreages over time is that any inconsistencies in the grower ID or site ID over time lead to double counting of acreages. These can result from data entry errors, changes in the grower at a given location, or changes in the location identifiers, which are selected by the grower. Double cropping at a given location can be identified in many instances but is also subject to data entry error in the commodity identifier. Additionally, any acreage not receiving pesticides is not reported.

More recently, NASS has been developing the nation-wide Cropland Data Layer (CDL) dataset, which is available through a web-based geospatial data portal called CropScape. The data product is derived through supervised classification of remotely sensed satellite data calibrated using ground truth data. CropScape features an interactive graphical user interface and customizable query and data download features. Informal validations through comparisons to DWR's ground-based land use surveys reveal that the CropScape data are reliable for most major Sacramento Valley crops, but may not be reliable for minor crops or to distinguish between similar crops with respect to spectral characteristics (e.g., orchards and vineyards). Data reliability may improve with time, as crop classification techniques are refined. Currently, CDL datasets are available for California for 2007 through 2012.

Finally, crop information is also available through some local agencies, particularly agricultural water purveyors. While usually very reliable for the agency's service area, spatial breakout within the service area is typically not available. Additionally, the data are of limited value for developing Valley-wide land use coverage because large portions of the Valley's agricultural land do not lie within a local agency, and because different crop groups and data formats are used across different agencies.

3.4.2 Water Use Information

Information on diversions of surface water in the Sacramento Valley (and throughout California) is available from reports submitted pursuant to water rights administered by the State Water Resources Control Board (SWRCB). Since 1965, with certain exceptions, persons and organizations who use water diverted surface are required to file with the SWRCB water right statements of monthly water use for each point of diversion. Historically, the reliability of these reports varies because of differences in the methods used to quantify diversions. In general, diversion reports filed by large irrigation water suppliers were measured and tended to be highly reliable while those filed by smaller suppliers were estimated and therefore tended to be less reliable. However, beginning in 2012, pursuant to changes in the Water Code stemming from the Water Conservation Act of 2009 (Senate Bill SBx7-7), all diversions are required to be measured using best available technology and best available practices, unless those practices can be demonstrated to not be locally cost effective. Thus, the reliability of reported monthly water diversions is expected to improve with time.

In addition to diversion reports filed with the SWRCB, most Sacramento Valley surface water suppliers measure flows within their systems in order to operate efficiently, distribute water equitably and/or to track water deliveries to their customers. Also stemming from SBx7-7, water purveyors serving 25,000 acres or more are required to measure water deliveries to individual customers with certain levels of accuracy depending on whether a device is existing or new, and report on the method used to validate device accuracy. Additionally, these suppliers are required to report aggregated farm deliveries to DWR. While many Sacramento Valley irrigation water suppliers already comply with the customer delivery measurement standards, some of those that do not already comply face costly measurement improvements. It remains to be seen whether and how these districts will achieve compliance with the Water Code.

Water deliveries by the State Water Project (SWP) are reported on a monthly basis for SWP water contractors and water rights settlement contractors in DWR's Bulletin 132: Management of the State Water Project. The bulletin has been published each year since 1963, detailing deliveries made in the prior year (the Bulletin 118 series is usually delayed by 2-3 years in order that final water and cost information can be included in the annual reports). In the most recent edition, monthly deliveries to four SWP agencies and 10 non-SWP agencies in the Feather River Area were reported.

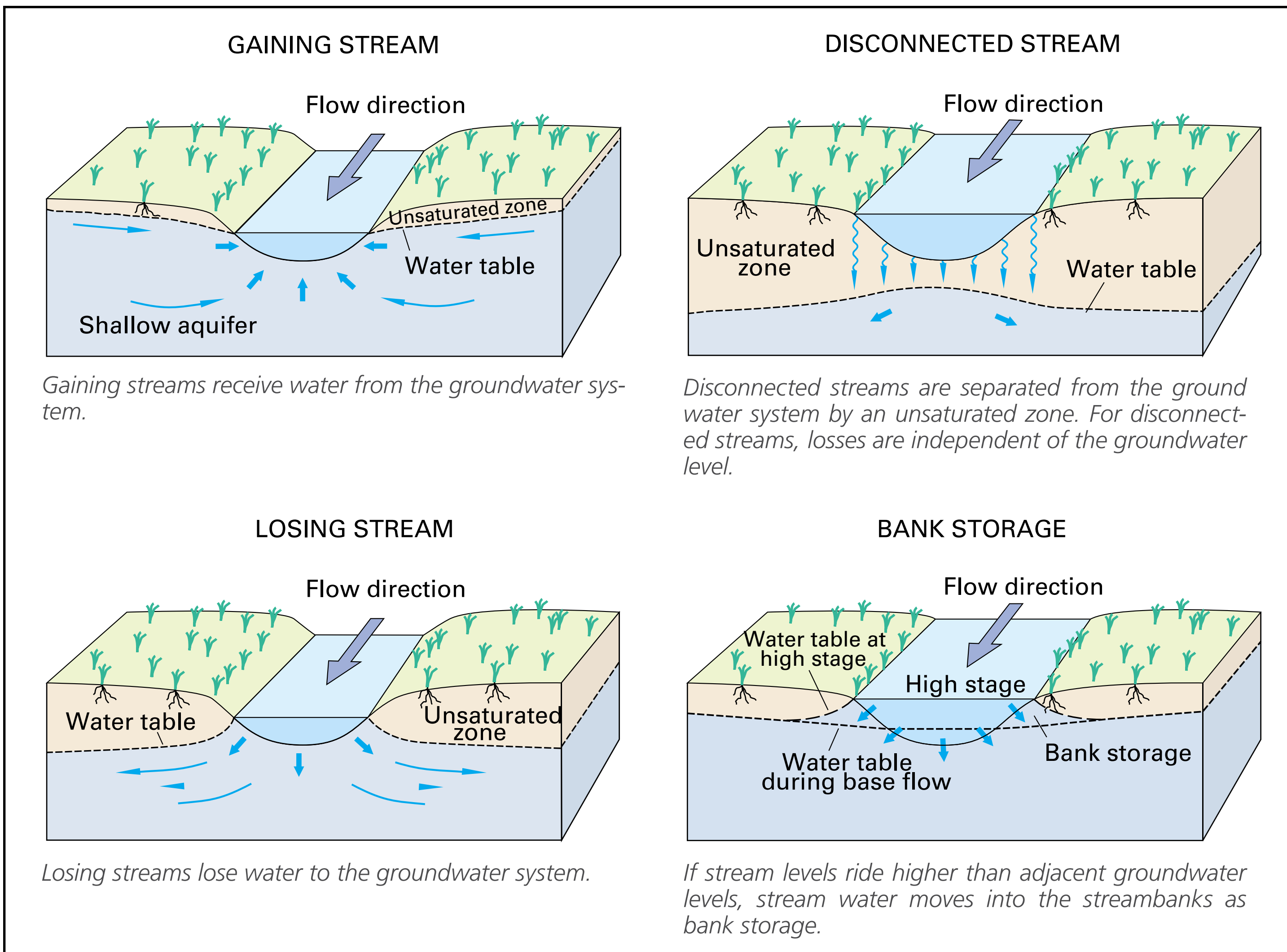
Publicly available diversion data are additionally available for certain locations in the region through DWR and USGS. DWR provides data through the California Data Exchange Center (CDEC, cdec.water.ca.gov) as well as through the Water Data Library (WDL, www.water.ca.gov/waterdatalibrary). USGS provides data through the National Water Information System (NWIS, waterdata.usgs.gov/nwis). Surface water data for each of these sites typically represents natural waterways; however diversion data for a small number of water users are available.

While many groundwater users measure their pumping for water management purposes, there are no requirements that this information be reported because groundwater is not regulated in the Sacramento Valley (or elsewhere in California, except in adjudicated basins). As a result, for purposes of hydrologic analyses, groundwater pumping is generally approximated based on estimates of crop ET and irrigation application efficiency. Models like C2VSim provide the opportunity to estimate spatially distributed pumping to meet applied water demands.

3.5 Concept of Capture and Implications to Groundwater Management

Traditionally, water resource managers have tended to address surface water and groundwater systems as distinct and separate. However, in most cases, as development and use of water resources intensify, it eventually becomes evident that changes in one system affect the other. 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. In the following sections, we examine the general nature of interactions between surface water and groundwater aquifers, providing a technical framework for approaches to groundwater management.

Figure 3-6 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



Gaining streams receive water from the groundwater system.

Disconnected streams are separated from the ground water system by an unsaturated zone. For disconnected streams, losses are independent of the groundwater level.

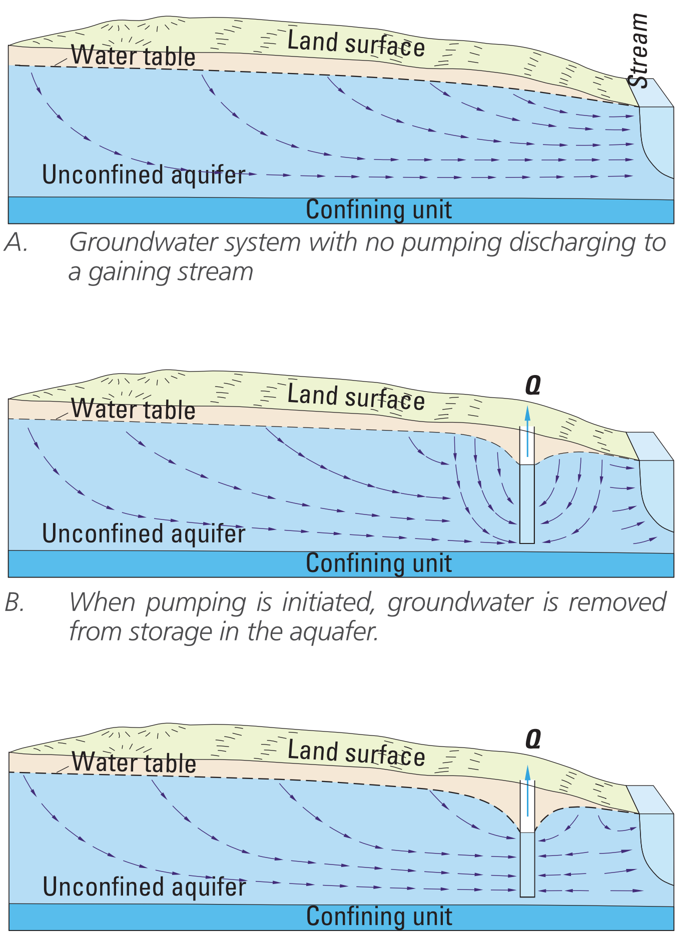
Losing streams lose water to the groundwater system.

If stream levels ride higher than adjacent groundwater levels, stream water moves into the streambanks as bank storage.

Figure 3-6 Conceptual Diagrams of Groundwater/Surface Water Interactions the groundwater system, meaning that it is in 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.

Groundwater pumping can lead to streamflow depletion, potentially reducing supplies for human and ecosystem water uses (USGS 2012). Figure 3-7 illustrates the basic concepts of streamflow depletion caused by groundwater pumping.

On frame A of Figure 3-7, groundwater is shown flowing from an upland area towards a stream to which it discharges. This could be considered representative of the predevelopment Sacramento Valley during a time of year when the Sacramento River was receiving substantial base flow from groundwater. Frame B of Figure 3-7 shows the initial stages of pumping from a well near the stream. When groundwater is pumped, the water table near the well declines, forming what is commonly referred to as a cone of depression. Initially the decline is accounted for by a change in aquifer storage surrounding the well. As pumping continues (frame C of Figure 3-7), 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 (frame D of Figure 3-7). The streamflow depletion is the sum of the captured groundwater discharge that would have otherwise have reached the stream, plus the induced infiltration caused by the groundwater pumping (Barlow and Leake, 2012).



A. Groundwater system with no pumping discharging to a gaining stream

B. When pumping is initiated, groundwater is removed from storage in the aquafer.

C. As pumping continues, some of the water that would have discharged into the stream is captured.

D. Pumping may lower groundwater levels enough to cause induced infiltration and a losing reach in the once gaining stream.

E. After pumping stops, refilling of the cone of depression continues to capture some of the groundwater discharge that would have reached the stream.

F. The system reaches equillibrium when there are no further changes in groundwater storage or streamflow depletion.

Figure 3-7 Streamflow Depletion Caused by Groundwater Pumping

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 (frame E and F of Figure 3-7). The existence of residual drawdown in the aquifer after pumping ceases means that streamflow depletion can continue long after pumping stops..

3.5.1 Considerations Involving Stream-Aquifer Interaction

An adequate understanding of the complex and dynamic interactions between groundwater and surface water is essential for effective water resource management, both to achieve sustainable development of water resources, and to avoid unintended environmental harm.

Whether a given stream is connected to the underlying groundwater system or not can vary with position along the stream because stream bed elevations and groundwater elevations vary with position, and can vary with time because groundwater elevations vary with time.

Connected streams, such as the perennial eastside tributaries of Butte Creek, Deer Creek and Mill Creek have historically been, present a more complex challenge from a water management perspective, because the water manager must consider the interaction between the two systems and how management actions applied to one system will affect the other. This is particularly true for streams that sustain migratory fish species, which depend on sufficient stream flows at certain times for in- and out-migration. However, the complexity of connected systems also represents opportunity because they allow a greater range of management options. In contrast, disconnected systems are simpler to manage because there are no groundwater management options that affect stream flow so long as groundwater levels stay below the threshold that reconnects the system. Upstream reaches of ephemeral, west side tributaries such as Buckeye Creek in northern Yolo County and Salt Creek, Sand Creek and Cortina Creek in Colusa County probably behave as disconnected systems because groundwater levels in these areas are far below the stream bed elevations. Additionally, the historically perennial Big Chico Creek in Butte County may no longer be a connected stream year round, at least in the vicinity of Chico, because groundwater levels there have fallen steadily over recent decades. Further groundwater level declines in the Valley will lead to streams being disconnected over longer reaches and with greater frequency.

Most of the Sacramento Valley stream and aquifer systems are still connected. Management of connected surface and groundwater systems (see section 3.8.3 for additional discussion of river and stream accretions) is challenging for several reasons. First, for a given aquifer, the duration of streamflow depletions caused by pumping depends on the spatial scale: the greater the distance or depth between groundwater pumping and affected stream, the lower the magnitude but the longer the timescale of depletions. 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 an 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, even 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.

This means that adaptive management approaches involving modification of management decisions based on observed effects in the aquifer system do not necessarily ensure that adverse outcomes will be avoided. Instead, it may be necessary to anticipate or forecast management outcomes, using appropriate tools, which may include documented case studies with similar characteristics, mathematical models of the hydrologic system, and economic forecasting models utilizing what-if hydrologic scenarios to conduct cost-benefit analysis of water management scenarios.

3.6 Recent Changes in the Sacramento Valley Groundwater Balance: Background

Hydrologic systems are dynamic, with inflows, outflows and stored water volumes continually changing over both space and time in response to natural and artificial stresses, such as precipitation, surface water diversions and groundwater pumping. The Sacramento Valley typifies such a dynamic system, reflecting seasonal and annual variability in precipitation and related runoff, and extensive human development and management of water for a variety of economic and environmental uses. Understanding such complex and dynamic systems is challenging, but can be made easier through application of water balances, an analytic technique that accounts for inflows, outflows and changes in water storage over time. Correctly done, water balances are helpful because, by definition, they require a reconciled accounting for all water flowing through and stored within a hydrologic system over time, and they typically yield the most plausible depiction of hydrologic conditions and trends possible with available data.

Water balances are based on the principle of conservation of mass, which says that water can neither be created nor destroyed (although it can change states, such as when it is volatilized to the atmosphere by evapotranspiration). Thus, for any defined water balance domain[1] and time period, the sum of inflows minus the sum of outflows plus any change in storage must equal zero:

$$
\begin{array}{rl}
 & \text{Sum of Inflows} \\
- & \text{Sum of Outflows} \\
+ & \text{Change in Storage} \\
\hline
 & = 0
\end{array}
$$

To be most useful, water balances must be carefully designed based on defined analytic objectives and recognition of data limitations. Often, a hydrologic system is broken into parts to reveal how the various components of the system behave and are inter-related. In analytic terms, each component becomes an accounting center, conceptually similar to a bank account, linked to other centers by flow paths that represent the flow of water. Additionally, water balances are prepared for defined periods of time and are usually broken into discrete time steps, which help to reveal the temporal patterns of flow and changes in storage. Depending on analytic objectives, water balances are typically broken into daily or monthly time steps spanning a hydrologic cycle, a full year, or a series of years. The finer the spatial and temporal breakout of a water balance, the more revealing the balance is likely to be, but also the more data required and the more likely that data limitations will be constraining.

1) A water balance domain is a defined 3-dimensional volume that represents an entire hydrologic system or a component of a system. Typical water balance domains include hydrologic basins, the land surface layer within a basin, or the groundwater underlying a basin. Manmade features such as canals and drains can also be designated as water balance domains in order to understand their gain and loss characteristics.

3.7 Sacramento Valley Water Balance

A 3-dimensional view of the Sacramento Valley hydrologic system is shown in Figure 3-8. Water flows into and out of the Valley predominantly via surface water flow paths (i.e., rivers and streams) and to a far lesser extent via subsurface flow paths. However, large changes in storage typically occur in both the surface and groundwater systems, and play a key role in balancing water supplies and demands on a seasonal and year-to-year basis.

Historical water balances for the Sacramento Valley for the surface water and groundwater systems of the seven subregions are represented in C2VSim, DWR's integrated hydrologic model for the Central Valley. For the land surface layer, separate water balances are developed for agricultural, urban, and native and riparian areas. These water balances include valuable information depicting recent trends in land and water use as well as groundwater conditions. The three accounting centers are separate but connected by certain flow paths as illustrated by the schematic diagram illustrated in Figure 3-9. The inflows and outflows associated with each accounting center are defined in Table 3-5.

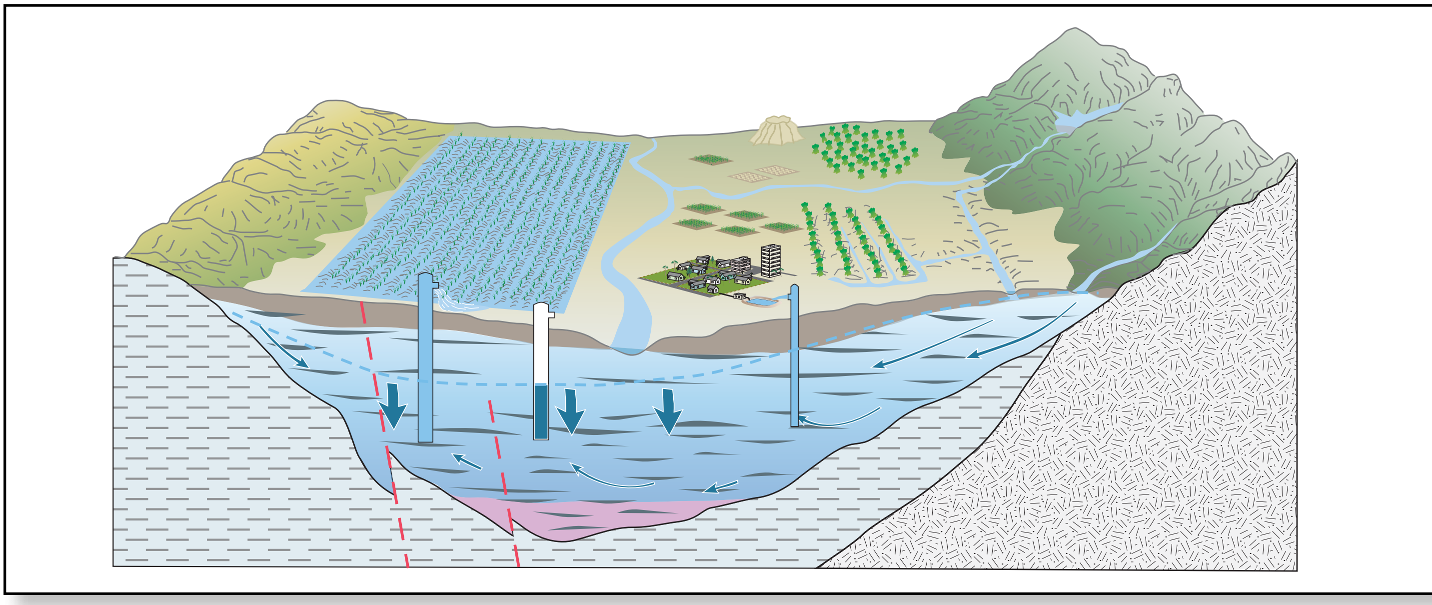


Figure 3-8 3-Dimensional Depiction of the Sacramento Valley Hydrologic System

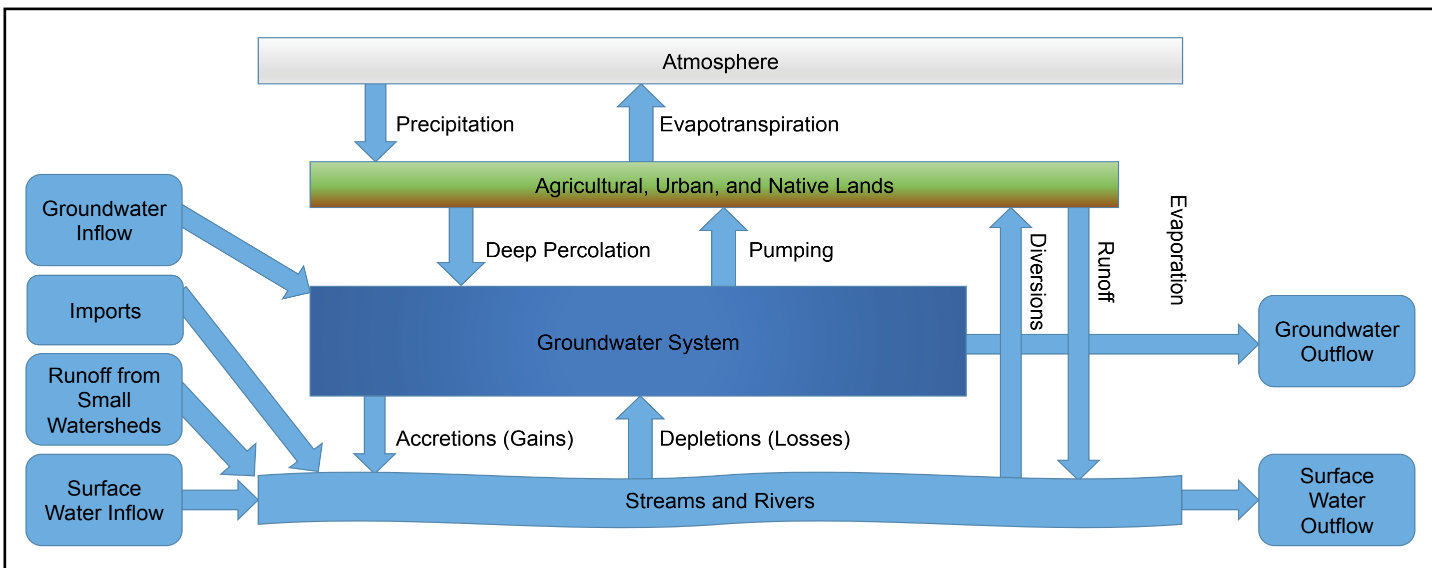


Figure 3-9 Water Balance Schematic of the Sacramento Valley Differentiating the Land Surface from the Underlying Groundwater System and Surface Streams and Rivers

Accounting Center	Flow Path Type	Flow Path	Description
Surface Layer	Inflow	Precipitation	Rainfall and snow on the Valley floor
		Diversions	Withdrawals from surface streams and rivers for agricultural and urban use
		Pumping	Groundwater withdrawals for agricultural and urban use
	Outflow	Evapotranspiration	Combination of evaporation and transpiration from the surface layer, also known as consumptive use
		Runoff	Runoff of surface water resulting from precipitation, irrigation, or wastewater treatment plant discharge
		Deep Percolation	Deep percolation of precipitation and applied irrigation water to the groundwater system
Streams and Rivers	Inflow	Surface Water Inflow	Surface water inflow from major streams and rivers, including releases from upstream reservoirs
		Runoff from Small Watersheds	Surface runoff from ephemeral streams surrounding the valley floor
		Accretions	Gains to streamflow from the groundwater system
		Runoff	Runoff of surface water resulting from precipitation, irrigation, or wastewater treatment plant discharge
	Outflow	Surface Water Outflow	Surface water outflow from the Sacramento River
		Diversions	Withdrawals from surface streams and rivers for agricultural and urban use
		Depletions	Losses of streamflow to the groundwater system
		Evaporation	Evaporation from surface streams and rivers
Ground-water System	Inflow	Boundary Inflow	Horizontal groundwater flows into the region from adjacent lands
		Deep Percolation	Deep percolation of precipitation and applied irrigation water to the groundwater system
		Stream and River Depletions	Losses of streamflow to the groundwater system
	Outflow	Boundary Outflow	Horizontal groundwater flows out of the region to adjacent lands
		Pumping	Groundwater withdrawals for agricultural and urban use
		Stream and River Accretions	Gains to streamflow from the groundwater system

Table 3-5 Inflows and Outflows Associated with the Sacramento Valley Water Balance

In order to understand the surface and groundwater hydrology of the Sacramento Valley and changes in hydrology over time, including drivers of apparent changes in groundwater storage, water balance flow paths have been summarized for three historical decades based on C2VSim R374. The historical decades summarized are the 1920s, the 1960s, and the 2000s. For each decade water balance results are summarized in Tables 3-6, 3-7, and 3-8 for the surface layer, streams and rivers, and groundwater system, respectively. All values are reported in thousands of acre-feet (TAF).

Over time, precipitation has remained relatively steady, at approximately 6.1 to 6.5 million acre-feet (MAF) per year. Diversions and pumping have increased substantially, from approximately 1.8 and 0.5 MAF per year in the 1920s to 4.5 and 2.3 MAF per year in the 2000s, respectively. The increase in diversions and pumping reflect a combination of increases in agricultural and urban demands, enabled in part through increases in surface water supplies from the State and Federal water projects as well as increased groundwater development and pumping.

Agricultural, Urban, and Native Lands							
Decade	Inflows			Outflows			Change in Storage
	Precipitation	Diversions	Pumping	Evapotranspi-ration	Runoff	Deep Percolation[1]	
1920s (1922-1929)	6,051	1,758	451	6,173	1,490	567	31
1960s (1960-1969)	6,143	3,757	1,262	7,925	2,433	800	5
2000s (2000-2009)	6,470	4,487	2,253	8,950	3,510	758	-8

1. Deep percolation from root zone to unsaturated zone. Differs from deep percolation from unsaturated zone to groundwater for any given month or year due to time required from percolation between root zone and groundwater system.

Table 3-6 Summary of Sacramento Valley Historical Water Balance from C2 Sim R374 for Agricultural, Urban, and Native Lands (TAF)

Streams and Rivers							
Decade	Inflows				Outflows		
	Surface Water Inflow[1]	Runoff from Small Watersheds	Net Accretions[2]	Runoff	Surface Water Outflow[3]	Diversions[4]	Evaporation[5]
1920s (1922-1929)	15,399	917	953	1,465	16,001	2,570	163
1960s (1960-1969)	19,601	1,044	402	2,415	18,418	4,837	206
2000s (2000-2009)	19,020	1,079	-358	3,441	18,668	4,312	201

1. Includes rim flows and imports.
2. Accretions from groundwater, net of depletions.
3. Calculated as closure at Sacramento River, upstream of confluence with San Joaquin River.
4. Includes diversions and exports out of region.
5. Estimated as 1% of surface water inflow and runoff from small watersheds.

Table 3-7 Summary of Sacramento Valley Historical Water Balance from C2VSim R374 for Streams and Rivers (TAF)

Groundwater System					
Decade	Inflows			Outflows	Change in Storage
	Boundary Inflow[1]	Deep Percolation[2]	Stream and River Depletions[3]	Pumping	
1920s (1922-1929)	437	779	-953	451	-188
1960s (1960-1969)	334	1,153	-402	1,262	-177
2000s (2000-2009)	418	1,174	358	2,253	-303

1. Net of boundary outflows. Includes gains to storage from subsidence.
2. Deep percolation from unsaturated zone to groundwater system.
3. Depletions from streams, net of accretions.

Table 3-8 Summary of Sacramento Valley Historical Water Balance from C2VSim R374 for the Groundwater System (TAF)

Surface water inflows into the region increased from approximately 15.4 MAF in the 1920s to over 19 MAF, on average, by the 1960s. These increases are due primarily to variability in precipitation in the basin but also in part due to imports of approximately 1.2 MAF annually from the Trinity River since 1964. Surface water outflows have increased similarly. Runoff from small watersheds has remained relatively steady over time, ranging from 0.9 to 1.1 MAF annually, on average, between the 1920s and today. Net accretions to streams have decreased substantially, from approximately 1.0 MAF per year in the 1920s to -0.4 MAF by the 2000s.

Despite increases in deep percolation to the groundwater system from 0.8 MAF in the 1920s to 1.2 MAF in the 1960s and 2000s, accretions to streams have decreased substantially, and annual reductions in groundwater storage have increased from approximately 0.2 MAF annually in the 1920s and 1960s to 0.3 MAF annually in the 2000s. Estimated changes in flow paths for agricultural, urban, and native lands; streams and rivers; and the groundwater system are described in greater detail in the following section.

3.8 Recent Trends in Water Balance Parameters

The negative changes in groundwater storage discussed above suggest that the groundwater basin is under stress and experiencing overdraft in some locations. Review of the Sacramento Valley water balance, as characterized based on C2VSim R374 and summarized in Tables 3-6 through 3-8 reveals substantial changes in water balance parameters over time that affect overall groundwater conditions. For example, evapotranspiration (ET) in the region has increased by approximately 50% over the last 90 years, with additional water demands being met by a combination of increased diversions from surface water supplies (through direct diversions and imports) and groundwater pumping. Actual increases in ET are likely greater due to intensified crop production as described later in this section. Over time, it appears that losses from surface streams have increased as a result of declining groundwater levels. The declining levels result from increased demand for groundwater as a source of supply without corresponding increases in groundwater recharge.

In this section, we examine trends in certain water balance parameters that provide insight into growing stresses on Sacramento Valley water supplies and on the groundwater system in particular. The following parameters are discussed:

- Water consumption and corresponding water demands
- Surface water and groundwater supplies
- River and stream accretions
- Deep percolation

Note that C2VSim is updated and refined on a frequent basis. The results presented herein are based on the most current version (R374) at the time of preparation of this report. As additional refinements are made, the evaluation of trends presented herein could be updated; however the existing C2VSim results have been corroborated based on estimated changes in storage in recent years from groundwater level monitoring and are believed to reflect actual trends in water balance parameters.

3.8.1 Water Consumption and Corresponding Water Demands

There is widespread recognition within the Valley that land use has been changing rapidly over recent years, particularly the increased planting of permanent crops, with almonds, olives and walnuts topping the list. Most of this expansion has occurred on lands previously planted to annual crops and some has occurred on previously undeveloped land (Davids Engineering 2014). The general perception is that water demands have increased as permanent crops have expanded. Unfortunately, as previously noted, ground-based land use surveys are not performed soon enough or frequently enough to fully capture these recent and rapid changes; however, remote sensing data and analyses can be applied to develop a Valley-wide characterization of these changes.

Scientists have relied on the Normalized Difference Vegetation Index (NDVI) for many years as an indicator of vegetation vigor or "greenness" caused by chlorophyll and photosynthetic activity on the Earth's surface. NDVI is a dimensionless parameter that typically ranges from around 0.25 to 0.85 for green vegetation Pinter et al. 2003). Research has shown that plant transpiration is proportional to NDVI, so that changes in NDVI reflect changes in water use. Additionally, NDVI can be used to identify areas that are irrigated (or sub-irrigated) because they are green during the summer growing season, long after precipitation stored in the soil from winter rains has been depleted.

Davids Engineering processed a total of 20 Landsat satellite images for the purpose of this report to compute NDVI in the Sacramento Valley from 1985 through 2013. NDVI was calculated for each pixel in each image, with each pixel representing an area of approximately ¼-acre. As a result, the analysis has high spatial detail, allowing for evaluation of where increases in consumptive use have occurred. Images were selected between late July and mid-August each year based on cumulative growing degree-days, so that each image represents more or less the same point in each year's summer crop growth cycle. Additionally, it can reasonably be concluded that land that is green[1] in late July to mid-August must be irrigated in some manner, either with applied irrigation water, by sub-irrigation or by riparian uptake. The NDVI layer was intersected with other land use information and lands mapped as riparian, wetland, riverine or developed (urban) were excluded, so that the remaining area was regarded as the agricultural water using (or irrigated) area within the Valley[2].

The area identified as irrigated in the manner described above is graphed in Figure 3-10, suggesting that the water using area has increased from about 1.64 million acres in 1985 to 1.98 million acres in 2013. This is an increase of about 340,000 acres, or 21%, over a period of 28 years, or roughly 12,100 acres annually. Spatial analysis shows that most of this increase is associated with fewer summer fallow fields and, to a lesser extent, with development of previously undeveloped areas. Also shown on Figure 3-10 is the Sacramento River Hydrologic Index for each year in the series. One interpretation is that the decline in irrigated area from the late 1980s into the early 1990s was associated with the 1987 to 1992 drought and related water supply shortages that occurred at that time. Additional drivers likely include federal conservation programs and depressed commodity prices. Following this period, the water using area recovered dramatically and remained more or less constant at about 1.8 million acres between 1995 and 2009.

The estimates of the water using area are corroborated by agricultural commissioner crop reports for the 1985 to 2011 period available from NASS. Total producing acres for 11 counties in the Sacramento Valley were compared to the NDVI analysis results[3]. Crops typically not irrigated in the summer such as grain and safflower were excluded. As shown in Figure 3-11, relative changes in the estimated irrigated area appear similar over time, with the water using area from the Landsat NDVI analysis exceeding the reported acreages from the county crop reports. Differences between the analyses may result from inclusion of some non-agricultural lands not classified as riparian, wetland, riverine or developed in the Landsat NDVI analysis, exclusion of non-bearing crop acreages from the county crop reports, or other factors. An advantage of the Landsat-based analysis is that it can be updated each year and can be used to

1) For purposes of the study, lands with NDVI greater than 0.25 during mid-summer were classified as green.

2) Riparian, wetland, or riverine areas were defined based on the California Department of Fish and Wildlife's Central Valley Riparian Mapping Project (CDFW, 2011 www.dfg.ca.gov/biogeodata/gis/clearinghouse.asp). Developed areas were defined based on the California Department of Conservation's Farmland Mapping and Monitoring Program (CDC, 2010).

3) Counties included were Butte, Colusa, Glenn, Placer, Sacramento, Shasta, Solano, Sutter, Tehama, Yolo, and Yuba.

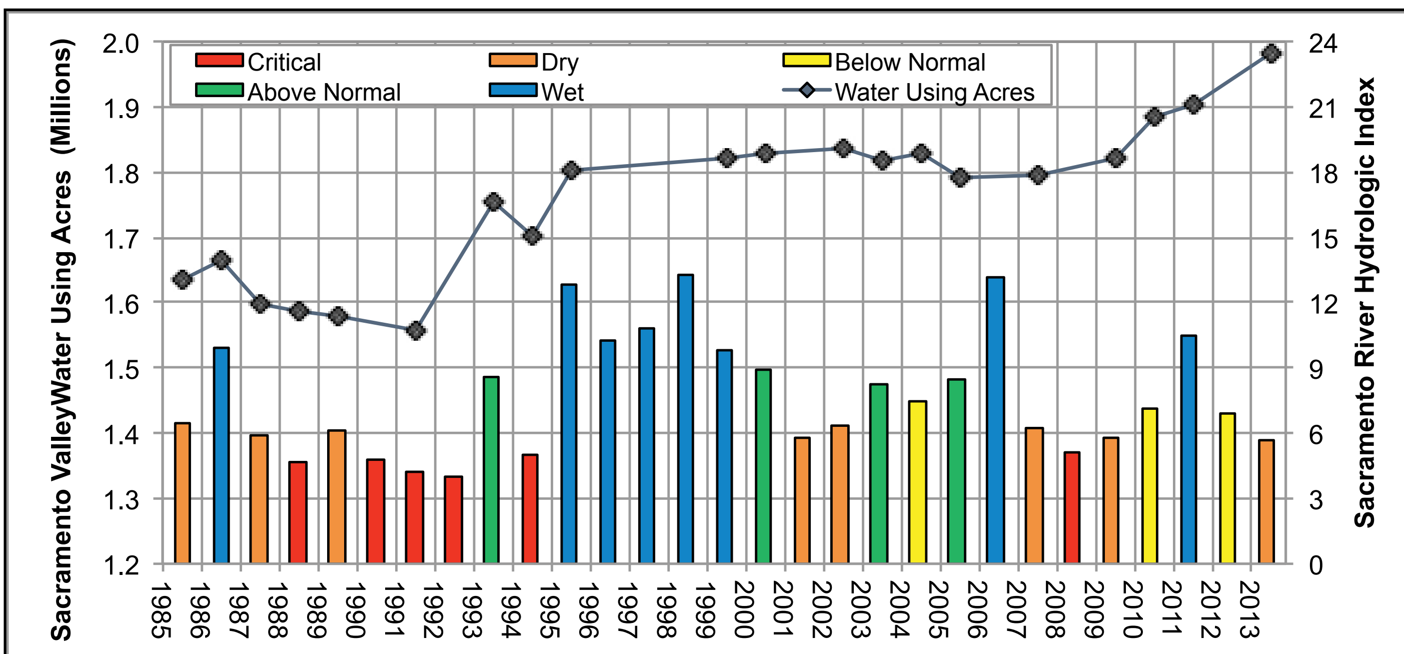


Figure 3-10 Sacramento Valley Irrigated Area as Indicated by NDVI and Hydrologic Year Type

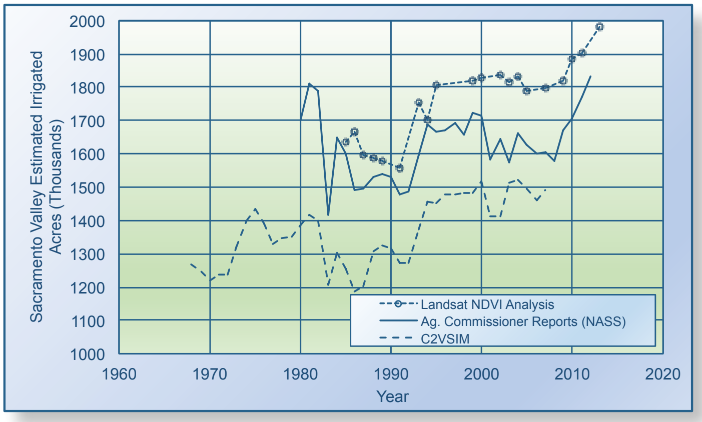


Figure 3-11 Comparison of Estimated Irrigated Acres from Agricultural Commissioner Crop Reports and Landsat NDVI Analysis

evaluate the spatial distribution of changes in the irrigated area. A limitation is that specific crop types are not identified.

Irrigated area was classified by water source as determined by DWR land use surveys (Figure 3-12). Figure 3-13 shows that the irrigated area supplied by surface water increased from 769,000 acres to 949,000 acres between 1985 and 2013, an increase of 167,000 acres, or approximately 52% of the total Valley-wide increase . Over the same period, the area irrigated with groundwater increased from 399,000 acres to 495,000 acres, an increase of 96,000 acres, or approximately 28% of the Valley-wide increase[4]. The area with a mixed water source (surface water and groundwater) grew by 29,000 acres, or about 9% of the Valley-wide increase.

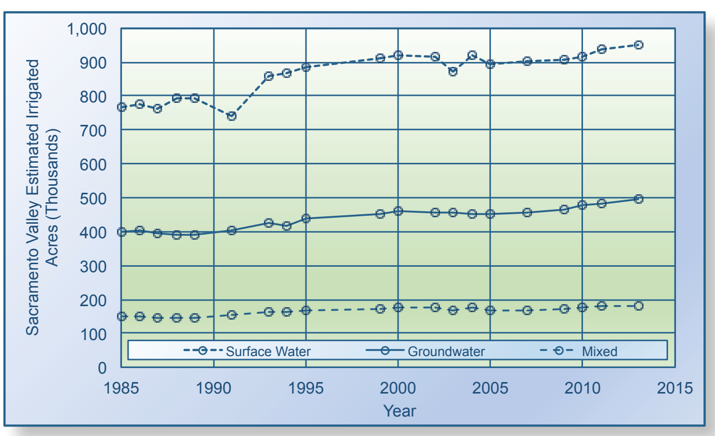


Figure 3-12 Sacramento Valley Irrigated Area by Water Source

4) The Valley-wide estimates of irrigated acres include areas without a DWR-identified water source. As a result the increased acreages described by water source do not exactly equal the Valley-wide estimate.

The relative acreage increase in each water source category is plotted in Figure 3-13, showing that the acreage increase occurred more or less in proportion to the area in each category. This suggests that the increase in irrigated area is not related to water supply source.

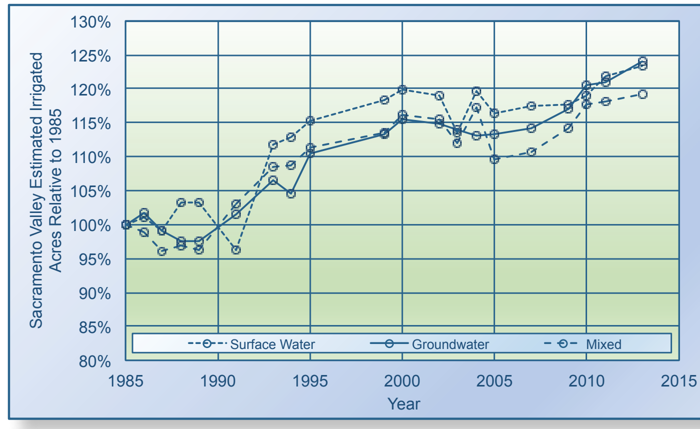


Figure 3-13 Sacramento Valley Irrigated Area by Water Source Relative to 1985

A core (or perennial) irrigated area was defined by pixels that were irrigated (or green) in at least 15 of the 20 images analyzed. The average annual NDVI for the core area is plotted in Figure 3-14, indicating that average NDVI has gradually increased from 0.49 to 0.58 or by approximately 19%. This increase is generally attributed to shifts to crops with greater evapotranspiration, improved farming practices, such as more uniform application of irrigation water, improved fertilization practices, and improved cultural practices, and indicates increased water consumption.

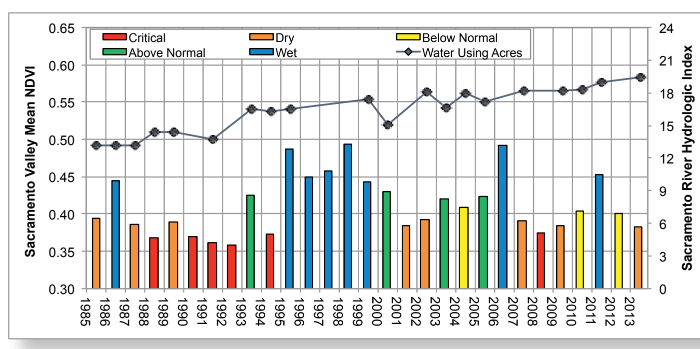


Figure 3-14 Sacramento Valley Vegetation Intensity and Hydrologic Year Type

Increased water use intensity is also supported by the agricultural commissioner crop reports. Substantial increases in yields for major Sacramento Valley crops have occurred. Yields have been positively correlated to transpiration and, as a result, evapotranspiration by

Doorenbos et al. (1986), Steduto et al. (2012), and several other researchers. Average reported yields for selected Valley crops from the county crop reports are shown in Figure 3-15. For rice, average yields have increased from around 3.8 tons per acre to 4.3 tons per acre, or approximately 13 percent. Average yields for tomatoes have increased from around 27 tons per acre to 40 tons per acre, or approximately 56 percent. For walnuts, yields have increased from around 1.4 tons per acre to 2.1 tons per acre, or 50 percent. Corn yields have increased from around 4.1 tons per acre to 6.0 tons per acre or approximately 46 percent.

To evaluate increased cropping intensity in the Valley as a whole, a dimensionless yield index was calculated for major Valley crops[5] between 1985 and 2011. For each year, the crop yield relative to 1985 was calculated. Then the Valley-wide yield index was calculated as the area-weighted average relative yield across crops each for each year. Between 1985 and 2011, the yield index, expressed as a percentage of 1985 yields increased by almost 30 percent, as indicated by Figure 3-16. Based on the correlation of yield to evapotranspiration noted above, this demonstrates a substantial increase in crop consumptive water requirements due to the intensification of crop production.

The increase in average NDVI by water source is illustrated in Figure 3-17. Among the three source categories, NDVI is highest and increases the most for the surface water areas. NDVI increased from 0.52 to 0.64, an increase of about 22 percent. The trend for the mixed water source category displays similar characteristics, but is slightly lower than the surface water category in all years except 1991. In the groundwater source category, NDVI is lower and increases more modestly compared to the other categories. NDVI in these areas was 0.47 in 1986 and increased to 0.54 in 2013, an increase of just 15 percent, or about two thirds of that observed in the surface water areas. The relative change in NDVI for the three water source categories is shown in Figure 3-18, illustrating the more modest increase in NDVI in the areas supplied by groundwater.

While further analysis is needed to support these results based on NDVI and agricultural commissioner data describing cropped acres and yields, it can be

5) Crops included rice, tomatoes, alfalfa, corn, walnuts, prunes, and almonds. These crops represented approximately 70% of cropping in the Valley in 2011 based on the agricultural commissioner data.

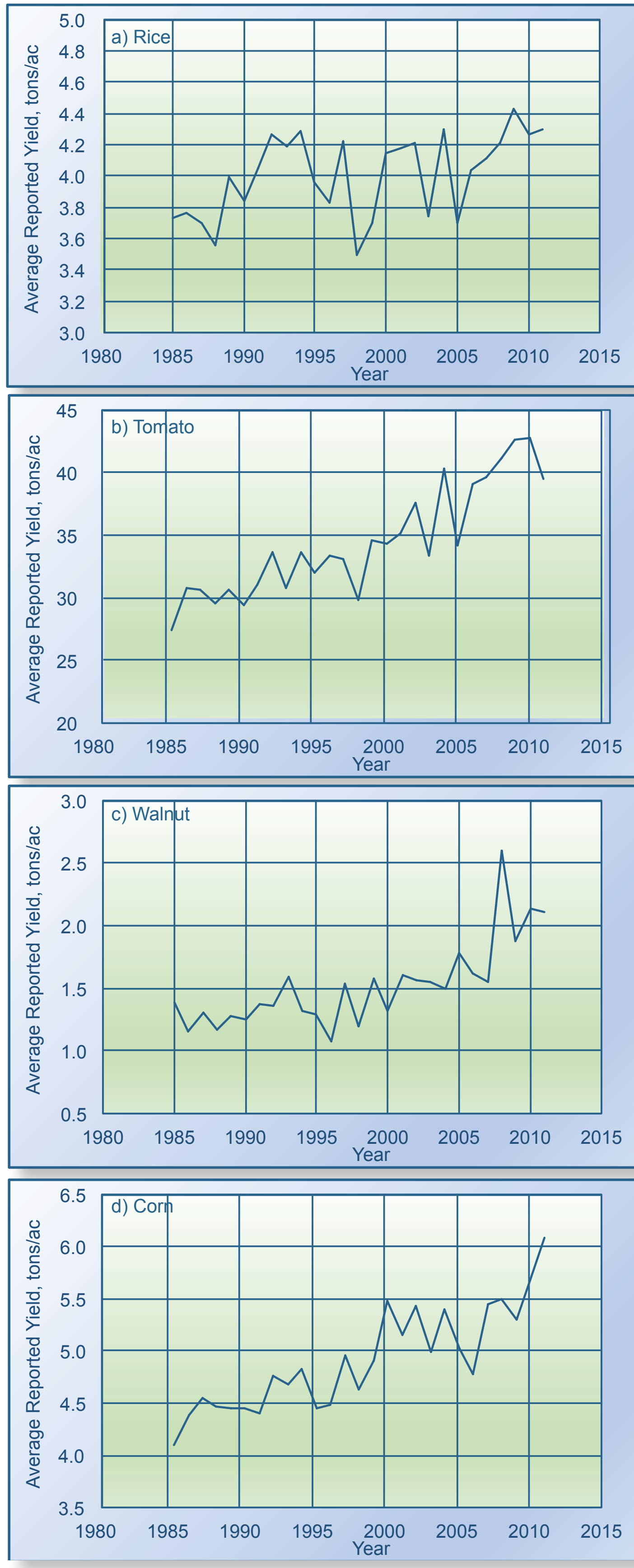


Figure 3-15 Average Reported Yields for Selected Sacramento Valley Crops

reasonably concluded that crop water consumption in the Sacramento Valley has increased appreciably since 1985 due to expanding summer cropped acreage and intensifying crop vegetation density.

As described previously, increased agricultural consumptive water use is captured by the C2VSim R374 results to the extent that the cropped acreage has increased over time; however, there also appears to be an increase in consumptive use on a per-acre basis due to increased cropping intensity that may equal or exceed the increase resulting from the expansion of cropping in the Valley.

Technology exists to quantify actual changes in consumptive use over time. Remote sensing technologies that solve the energy balance at the Earth's surface such as the Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen et al., 2005) or its variant Mapping EvapoTranspiration at High Resolution and Internalized Calibration (METRIC) (Allen et al., 2007) have been shown to provide reliable estimates of actual evapotranspiration within 5 percent of reliable ground-based estimates in agricultural areas. The availability of archived Landsat imagery spanning the period from 1985 to present provides the opportunity to quantify changes in crop consumptive use due to increased cropped area and increased intensification of cropping over time. Application of such technology overcomes the inherent problem of basing crop ET estimates on research results that do not reflect commercial production practices that change with time due to a variety of factors.

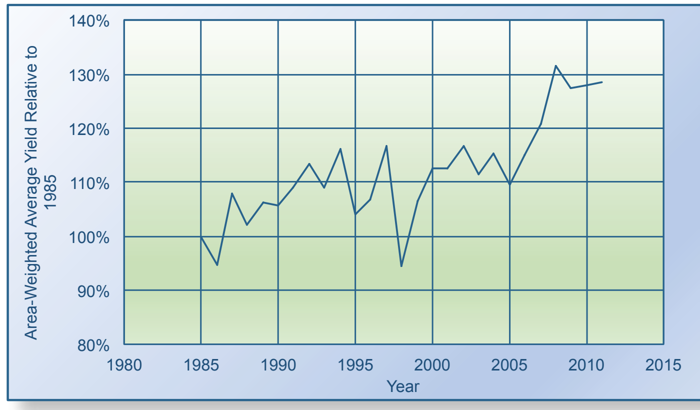


Figure 3-16 Area-Weighted Average Yields Relative to 1985 for Major Sacramento Valley Crops

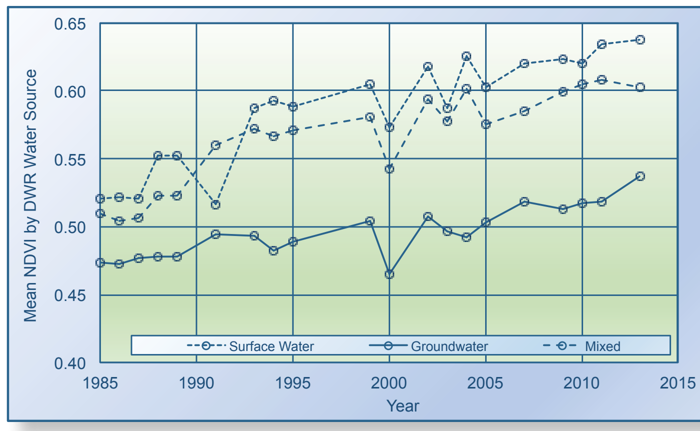


Figure 3-17 Valley-Wide Vegetation Intensity by Water Source

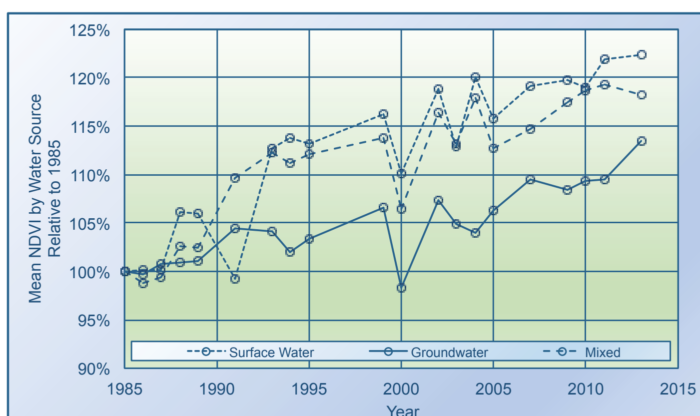


Figure 3-18 Valley-Wide Vegetation Intensity by Water Source Relative to 1985

3.8.2 Surface Water and Groundwater Supplies

Surface water and groundwater supplies have increased substantially over the past 90 years and in recent years in order to meet growing agricultural, urban, and environmental demands. Trends in supplies have been evaluated based on estimated surface water diversions and pumping by C2VSim R374.

Agricultural and urban diversions of surface water have both increased over time. Urban and agricultural diversions have increased substantially over the past 90 years with urban diversions increasing from approximately 41 TAF per year in the 1920s to 286 TAF per year in the 2000s (a seven-fold increase, mostly in the Sacramento metropolitan area) and agricultural diversions increasing from approximately 1,700 TAF to 4,200 TAF (more than a two-fold increase) over the same period. Thus, total diversions increased from approximately 1,760 TAF in the 1920s to 4,500 TAF in the 2000s. Annual estimates of agricultural, urban, and total diversions are provided in Figure 3-19. In the last 40 years, following the development of the CVP and SWP, decreases in diversions are particularly apparent in the dry years of 1977, 1991, and 1992. Estimated average annual diversions by decade are shown in Figure 3-20, reflecting long-term trends in diversions resulting from increased agricultural development and urban growth, made possible through increased surface water storage.

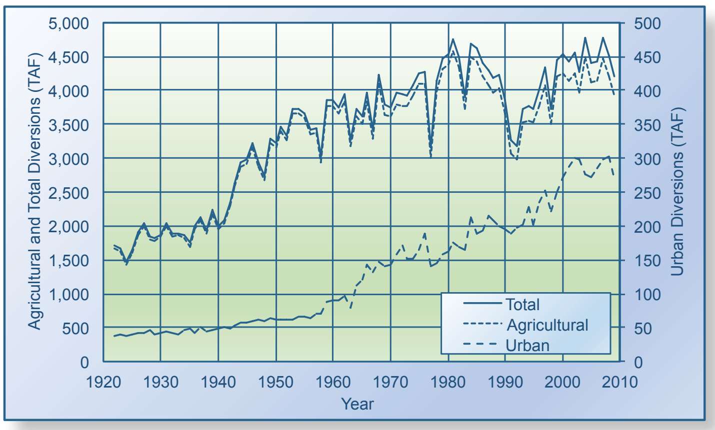


Figure 3-19 Estimated Annual Diversions in the Sacramento Valley

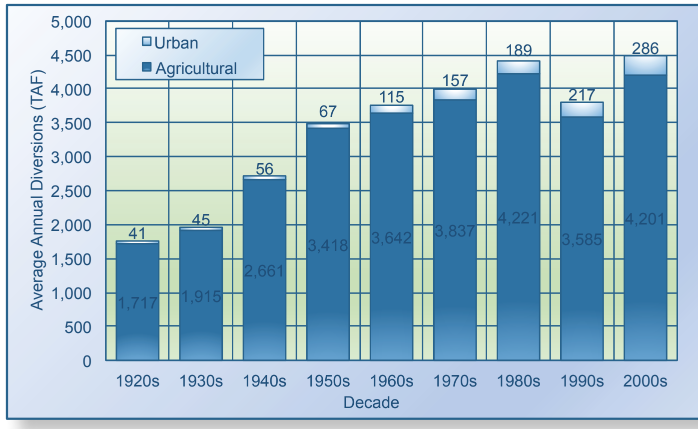


Figure 3-20 Estimated Average Annual Diversions by Decade in the Sacramento Valley

A well log must be filed with DWR when a well is constructed, allowing DWR to track the number and intended uses of wells over time. While the number of wells constructed is not a direct indicator of pumping, it is a general indicator of groundwater development and use. The number of well logs filed with DWR between 1977 and 2010, by well use, is illustrated in Figure 3-21. On average, nearly 3,200 wells have been constructed in the Sacramento Valley Hydrologic Region each year over this period, an average of nearly 8 wells per calendar day and more than 108,000 wells in total. The pattern of well construction is strongly driven by domestic wells, reflecting the "boom and bust" real estate cycles of the late 1980s/early 1990s and the early to mid 2000s. Irrigation well construction is inversely correlated with the availability of surface water supplies, with large numbers of wells being installed during and following

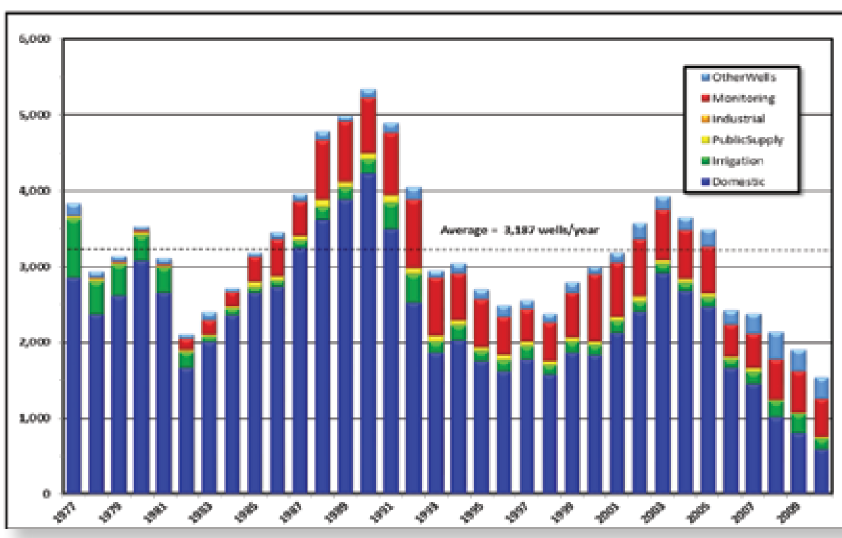


Figure 3-21 Number of Well Logs Filed Per Year by Use for the Sacramento River Hydrologic Region (1977-2010)

the 1976-77 drought and in 1991 and 1992, among the driest years in the 1987 to 1992 drought.

Agricultural and urban pumping of groundwater have both increased over time. Urban and agricultural pumping volumes have increased substantially over the past 90 years with urban pumping increasing from approximately 18 TAF in the 1920s to 314 TAF in the 2000s (a 17-fold increase) and agricultural pumping increasing from approximately 433 TAF to 1,939 TAF (more than a four-fold increase) over the same period. Thus, total pumping increased from approximately 451 TAF in the 1920s to 2,253 TAF in the 2000s. Annual estimates of agricultural, urban, and total pumping are provided in Figure 3-22. Increases in agricultural pumping are particularly apparent in the dry years of 1976, 1977, 1981, 1991, 1994, 2004, 2007, 2008, and 2009. Estimated average annual pumping by decade is shown in Figure 3-23, reflecting long-term trends in pumping resulting from increased agricultural development and urban growth.

3.8.3 River and Stream Accretions

Changes in groundwater levels have a direct effect on accretions of groundwater to rivers and streams in the Sacramento Valley, where groundwater and surface water systems are connected, as discussed previously in Section 3.5.1.

Based on modeling efforts, accretions to Sacramento Valley streams appear to have decreased steadily from the 1940s to the 1990s, with the most dramatic decadal decrease occurring between the 1980s and 1990s. From approximately 1991 to present, the river and stream system as a whole has transitioned from experiencing net accretions to net depletions of an estimated 360 TAF per year. By comparison to the 1920s, which had a net accretion of approximately 950 TAF per year, this is a decrease in streamflow of approximately 1,310 TAF per year or 1,800 cfs when expressed as streamflow. Valley-wide accretions to streams based on the C2VSim groundwater budget are shown from 1922 to 2009 in Figure 3-24. Average annual Valley-wide accretions by decade are shown in Figure 3-25.

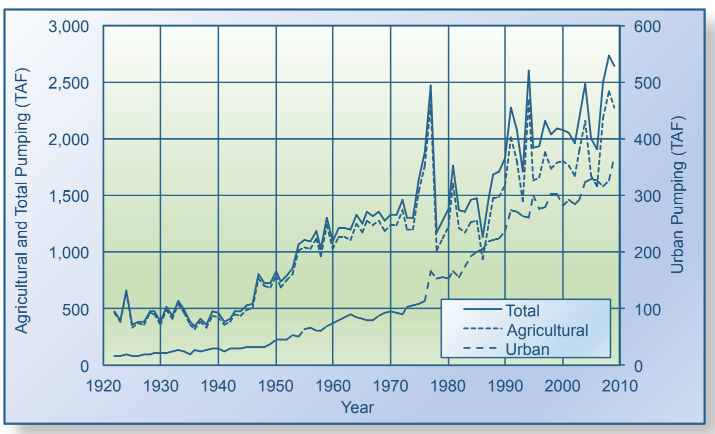


Figure 3-22 Estimated Annual Pumping in the Sacramento Valley

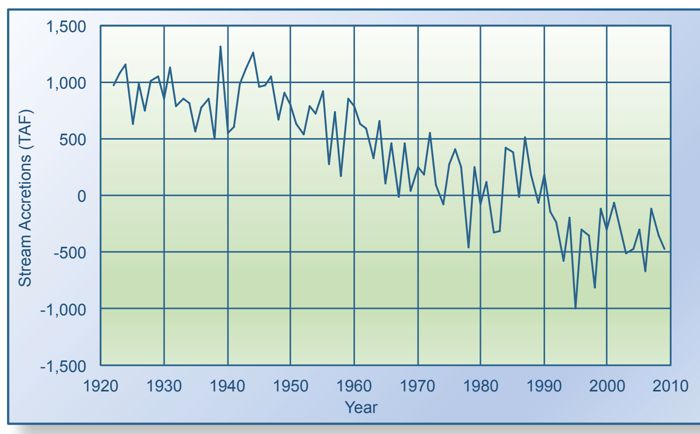


Figure 3-24 Estimated Annual Accretions in the Sacramento Valley

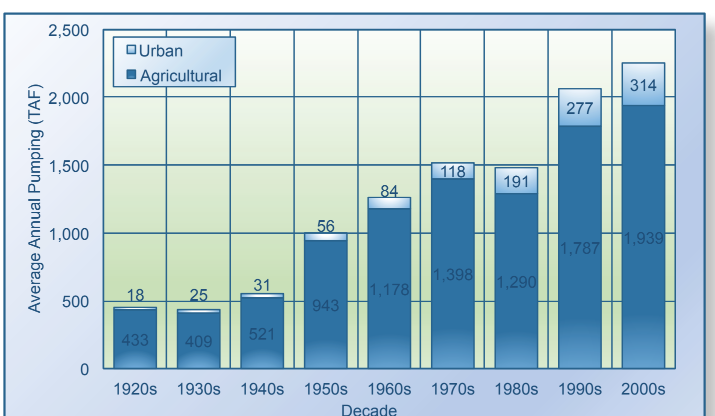


Figure 3-23 Estimated Average Annual Pumping by Decade in the Sacramento Valley

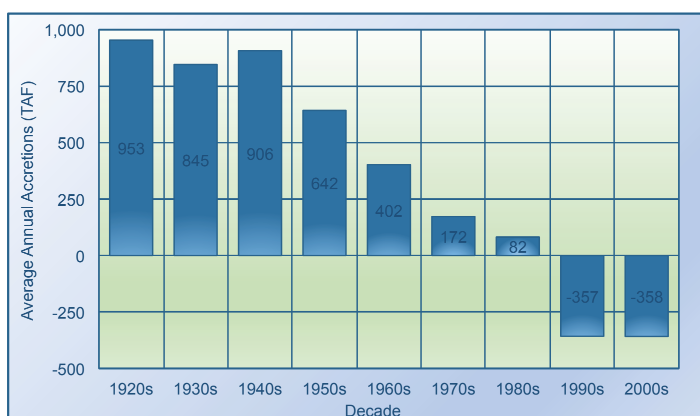


Figure 3-25 Estimated Average Annual Accretions by Decade in the Sacramento Valley

3.8.4 Deep Percolation

A contributing factor to the decrease in accretions to rivers and streams over the last 90 years is that deep percolation of surface water supplies (and other forms of recharge) has not increased in a manner that offsets increased groundwater pumping. Additionally, in recent years there has been an increasing reliance on groundwater both in terms of total pumping and a relative amount of total supply. Groundwater as a relative portion of total supply increased from approximately 20 percent in the 1920s to 25 percent in the 1960s and 33 percent by the 2000s. Groundwater development has continued to occur at a rapid pace in the past few years as indicated based on observations from the field and discussion with water management professionals.

Transition from surface to pressurized irrigation creates a two-fold impact with regards to the groundwater system in some cases, as (1) deep percolation decreases from improved on-farm water management and (2) many fields, when converted to pressurized irrigation, switch from surface water to groundwater as a source of supply as discussed later in this section.

Deep percolation appears to have remained relatively steady from the 1940s to the 2000s, despite expanding agricultural production and development of additional surface water supplies. This likely due to a combination of factors, including soil conditions that limit deep percolation in rice growing areas and improved irrigation systems and management practices in other agricultural areas. Deep percolation averaged approximately 804 TAF per year in the 1920s and 1930s and approximately 1,126 TAF from the 1950s through the 2000s. Valley-wide deep percolation based on the C2VSim groundwater budget is shown from 1922 to 2009 in Figure 3-26. Average annual Valley-wide accretions by decade are shown in Figure 3-27.

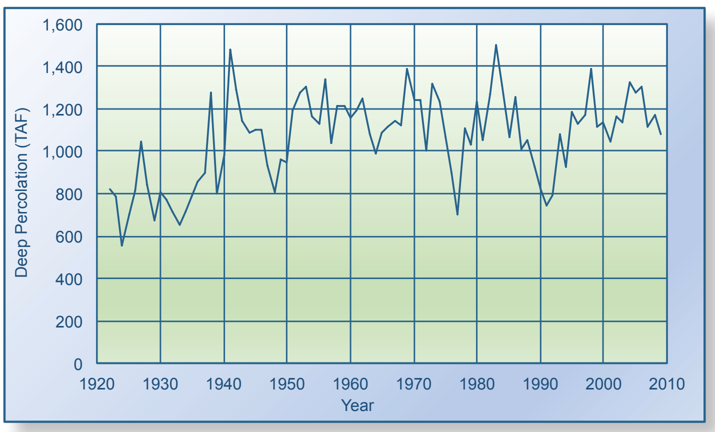


Figure 3-26 Estimated Annual Deep Percolation in the Sacramento Valley

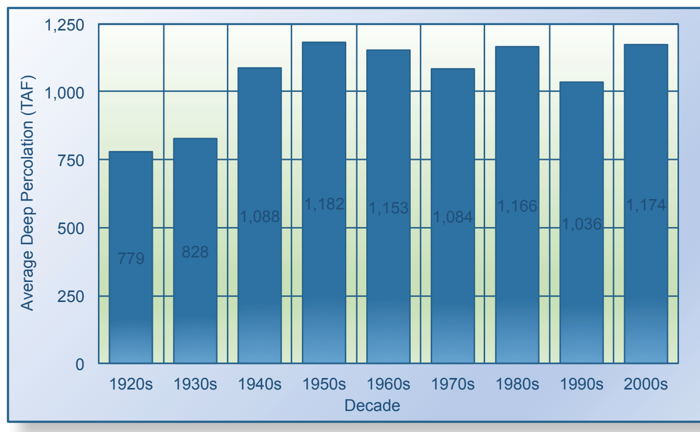


Figure 3-27 Estimated Average Annual Deep Percolation by Decade in the Sacramento Valley

3.8.5 Increasing Adoption of Pressurized On-Farm Irrigation Systems

Sacramento Valley farmers are increasingly using pressurized irrigation systems to grow crops, including subsurface drip systems for row crops such as processing tomatoes, and surface or subsurface drip systems and micro-sprinkler systems for permanent crops such as almonds, olives, and walnuts. The expanding use of pressurized systems is not strongly associated with water conservation, but is driven more by certain production advantages, including:

- More uniform application of water and fertilizers, leading to higher and more uniform yields
- Improved crop quality, leading to higher marketable yields
- Faster maturation of permanent crops, so that orchards reach full production sooner

- Higher irrigation frequency, leading to soil moisture regimes more conducive to crop growth and production

- Reduced irrigation labor and management requirements

- Reduced wet soil area leading to decreased weed growth and improving accessibility for cultural operations and harvest

From the standpoint of maintaining the groundwater balance, adoption of high-efficiency pressurized systems has a desirable effect in areas irrigated with groundwater because less groundwater pumping is needed to meet water demands. However, in surface water areas, the more uniform and efficient application of water achieved with pressurized systems results in reduced deep percolation to the groundwater system.

Furthermore, some growers elect to use groundwater to supply pressurized systems even when surface water is available. This is primarily because surface water distribution systems were originally designed and many are still typically operated to deliver large flows every 2 to 3 weeks as needed for surface irrigation. In contrast, pressurized systems require small flows and are typically operated for a few hours every 2 to 3 days. In cases where surface water deliveries cannot be made sufficiently flexible, growers opt to use groundwater so that pressurized systems can be operated in a manner that achieves the production advantages listed above. Another advantage of groundwater as a source of supply can be improved water quality; surface water that is turbid or contains aquatic weeds, algae, or other material leads to increased filtration requirements and potential clogging of microirrigation systems. Finally, some growers prefer groundwater because it is free of pathogens that are sometimes present in surface water and can infect tree crops. Such conversion to groundwater supplies even when surface water is available can have a dramatic effect on the groundwater balance due to the increase in groundwater pumping and the reduction of deep percolation of applied surface water.

In order to evaluate adoption of pressurized on-farm irrigation systems in recent years, information describing irrigation methods and water source by crop was compared for DWR land use surveys conducted in the Sacramento Valley between the mid 2000s (2003 to 2005, depending on county) and the early 2010s (between 2009 and 2012). Mid 2000 and early 2010 crop surveys that include information describing irrigation method and water source are available for three counties: Butte (2004 and 2011), Glenn (2003 and 2009), and Tehama (2005 and 2012). Figure 3-28 provides a comparison of crop acreages and percent of cropped area by water source for three general irrigation methods: microirrigation (includes both drip and microspray, surface irrigation (furrow, graded border, level basin, etc.), and sprinkler (permanent, hand move, linear move, etc.). Water sources include surface water, groundwater, and mixed (combination of surface water and groundwater).

Based on review of available information describing changes in irrigation methods and water sources, the following can be concluded:

- There was an increase of approximately 50,000 acres of drip/micro irrigation within the 3-county area evaluate between the mid 2000s and the early 2010s (approximately 60%)

- The vast majority of the increase in drip/micro areas is for areas served by groundwater only or a combination of groundwater and surface water.

- The area irrigated by surface and sprinkler methods has decreased; most of this decrease is represented by increases in drip/micro irrigation. There has also been an expansion of the irrigated area of around 4,000 acres, which is primarily irrigated using drip/micro irrigation systems relying on groundwater.

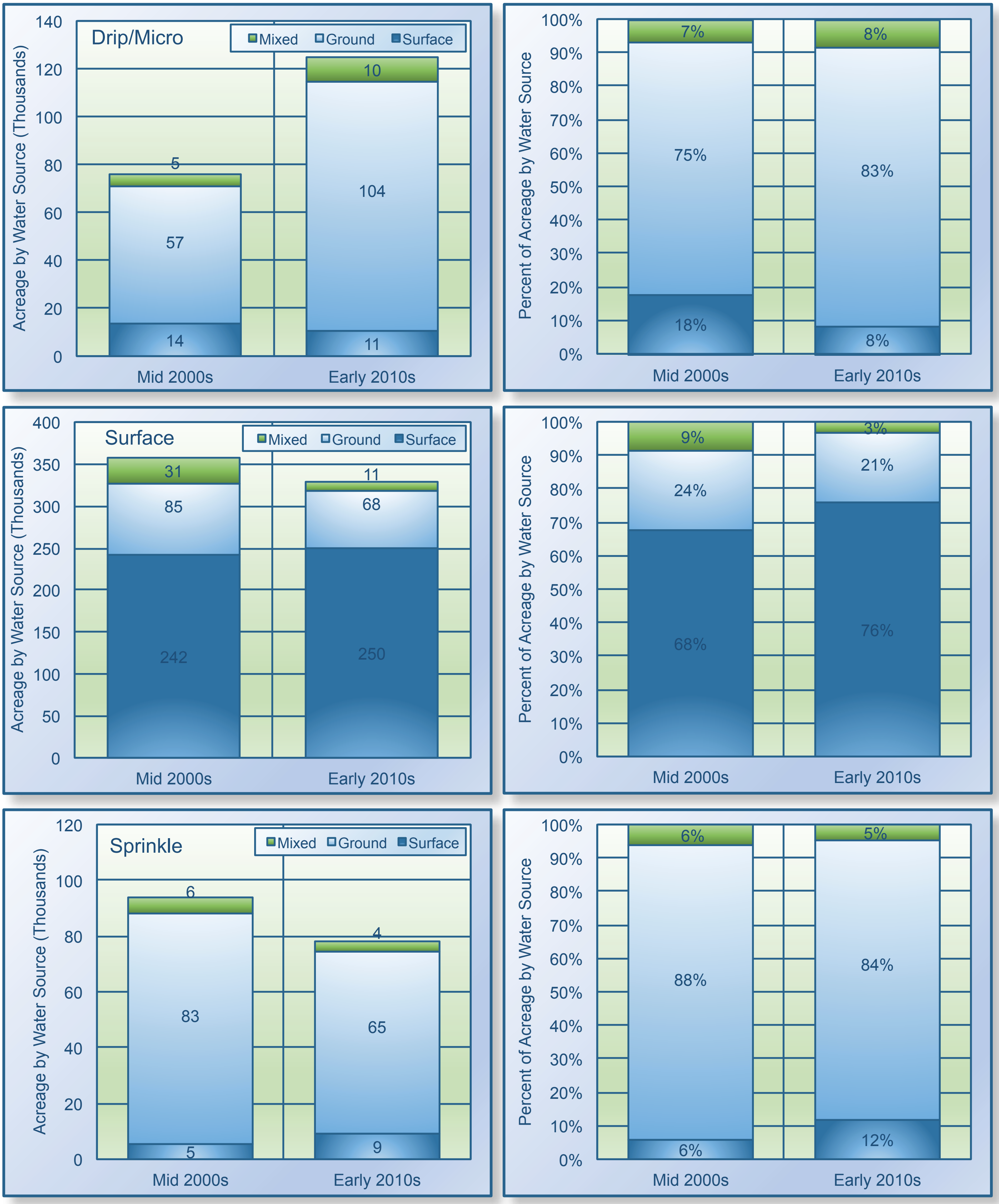


Figure 3-28 Mid 2000s and Early 2010s Crop Acreages and Relative Percentages by Water Source for Drip, Surface, and Sprinkle Irrigation Methods (Butte, Glenn and Tehama Counties)

3.9 Regional Impacts within the Sacramento Valley

Total groundwater usage and groundwater usage as a proportion of total water supply vary widely across the Valley as a result of historical development of surface water supplies. In order to effectively and sustainably manage the Sacramento Valley's groundwater resources as a whole, variability across the region must be understood and used to inform water management decisions. Surface water and groundwater as an absolute and relative source of supply by subregion are shown in Figure 3-29.

As indicated, total developed water supplies have increased for all subregions over time, with increases in surface water and groundwater supplies varying substantially from one subregion to another. Groundwater as a relative portion of total supply has increased for all subregions except subregion 7 (Sacramento River below Verona), which has relied on groundwater for 50 to 60 percent of its supply over the last 90 years, on average. Relative reliance on surface water as a source of supply in recent years has been greatest for subregion 3 (Colusa Trough) that includes the Orland Unit Water Users Association, Sacramento River Settlement Contractors, and Tehama Colusa Canal contractors. In subregion 3, surface water currently represents over 80 percent of the total developed supply. Relative reliance on groundwater as a source of supply in recent years has been greatest in subregion 2 (Red Bluff to Chico Landing), representing approximately 70 percent of the total developed supply.

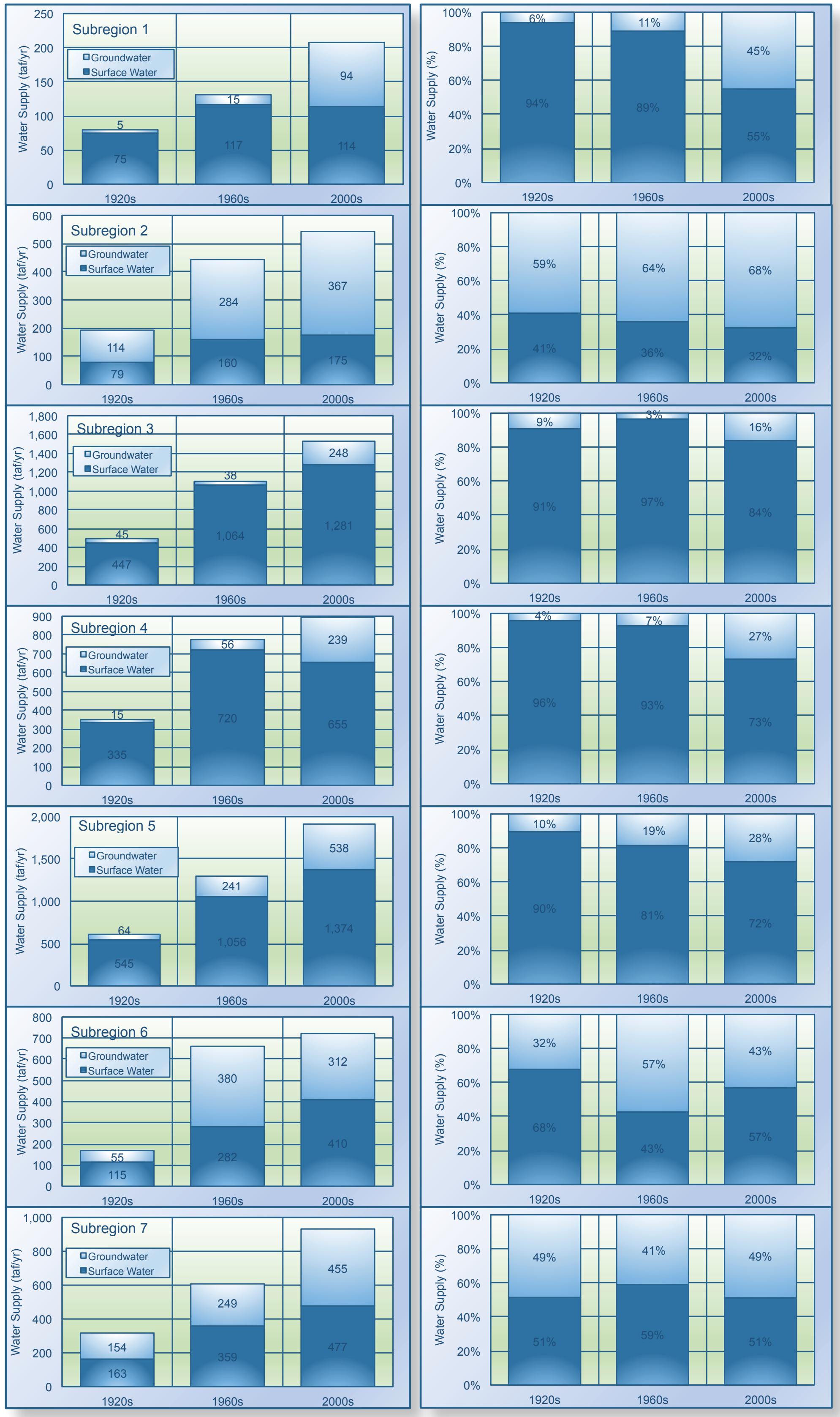


Figure 3-29 Sacramento Valley Absolute and Relative Surface Water and Groundwater Supplies by Subregion and Decade

Chapter 4: Institutional Approaches to Groundwater Management

4.1 Groundwater Management Plans, Including Basin Management Objectives

Groundwater management in the Sacramento Valley has its roots in the 1850 formation of the State, when the legislature adopted English common law as the governing law for state courts. The case of *Katz v. Walkinshaw* (1903) established the rule of correlative rights, under which each landowner is entitled only to a reasonable, proportional share of the common supply. A 1928 constitutional amendment strengthened the concept that overlying landowners can only use the amounts that are reasonable necessary for overlying uses, and available surpluses may be appropriated for non-overlying uses (GRA, 2005).

Formal groundwater management was initiated in 1992 with the adoption of the Groundwater Management Act (California Water Code [CWC] Sections 10750 et. seq.), which is applicable to designated groundwater basins and generally not applicable to groundwater resource areas (for example, fractured rock and volcanic groundwater source areas in the Sierra Nevada foothills). The Groundwater Management Act and subsequent legislation, e.g., SB 1938, which modified the CWC to link groundwater management planning to State funding, encourage local groundwater management with public participation and cooperation between other local management entities. Locally prepared and adopted groundwater management plans are one component of a wide array of management tools applied at the local, state and federal levels to manage groundwater in the Sacramento Valley (GRA, 2005).

Today there are more than 40 adopted groundwater management plans in the Sacramento Valley. Figure 4-1 shows the area covered by adopted groundwater management plans. A list of groundwater management plans is in Appendix D. The original list came from the Draft California Water Plan Update 2013 and was not complete (Appendix D added the RD 2035 and RD 787 GWMPs in Yolo County). Approximately 73 percent of the groundwater basin area in the Sacramento Valley is covered by an adopted groundwater management plan. Although not all of these plans are fully compliant with all provisions of the CWC, they are being used by local agencies to actively manage groundwater. Lack of compliance with the CWC provisions enacted through SB 1938 affects a local agency's eligibility for grants and loans administered by the State but does not demonstrate lack of effective local groundwater management. Virtually all of the areas without adopted groundwater management plans are located in the southwestern Sacramento Valley. These are generally upland areas with limited groundwater yield, areas along the Sacramento River where surface water is abundant or areas within the Sacramento River Delta. Notable exceptions are productive agricultural areas in Yolo and Solano County where groundwater is the primary supply (Figure 4-1). In the northern Sacramento Valley, the City of Chico is not covered by an adopted groundwater management plan, but is covered by Butte County's groundwater ordinance, which is discussed in the following section.

To be fully compliant with the CWC and to be eligible for funding for construction of groundwater projects or groundwater quality projects administered by the DWR, the CWC require local agencies to:

- Make available to the public a written statement describing the manner in which interested parties may participate in development of a groundwater management plan. Prepare and implement a groundwater management plan that includes Basin Management Objectives (BMOs) for the portion of the groundwater basin that is subject to the plan.

- Include components relating to the monitoring and management of groundwater levels within the groundwater basin, groundwater quality degradation, inelastic land subsidence, and changes in surface water flow and quality that directly affect groundwater levels or quality or are caused by groundwater pumping in the basin. Consider additional components listed in CWC Section 10753.8 (a) through (l).

- Prepare a groundwater management plan that involves other agencies and enables the local agency to work cooperatively with other public entities whose service areas or boundaries also overly the groundwater basin.

- Adopt monitoring protocols that are designed to detect changes in groundwater levels, groundwater quality, inelastic subsidence in 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 pumping in the basin. The monitoring protocols should be designed to generate information that promotes efficient and effective groundwater management and supports attainment of the BMOs.

- Prepare a map that details the areas of the groundwater basin, as defined in DWR Bulletin 118, the area that will be subject to the plan, and the boundaries of the local agencies overlying the basin.

- Beginning January 1, 2013, amendments to the CWC brought about by Assembly Bill 359 require the groundwater management plans to include a map identifying the recharge areas for the portion of the groundwater basin underlying the water services area. The map of the recharge areas must be provided to local planning agencies. DWR and interested persons must be notified when the map is submitted to those local planning agencies.

Compliance with these statutes affects the eligibility and award of DWR-administered funding authorized or appropriated after September 1, 2002.

SB 6 (SBx7-6), enacted on November 6, 2009, established a new groundwater-monitoring program known as the California Statewide Groundwater Elevation Monitoring (CASGEM) to more regularly and systematically monitor groundwater in all or parts of groundwater basins throughout the state. Local entities

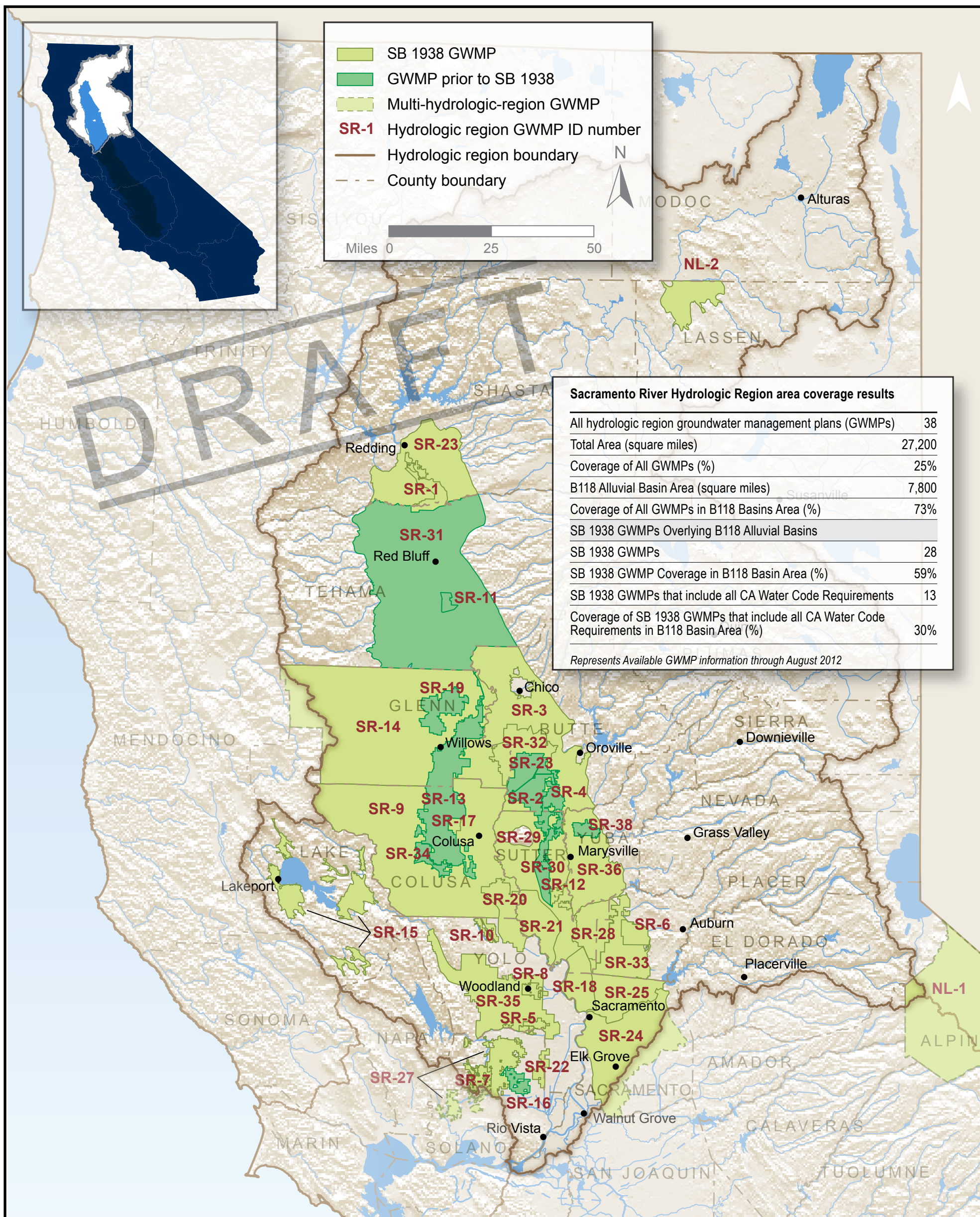


Figure 4-1 Groundwater Management Plans in the Sacramento Valley

were required to register with the state for groundwater monitoring by January 1, 2011, and begin monitoring by January 1, 2012.

Sacramento Valley groundwater management plans have been developed to achieve the overall goal of working cooperatively with basin stakeholders and the public to maintain a sustainable, reliable, high-quality groundwater supply for beneficial use in each local agency's service area and surrounding areas. This goal is supported by BMOs. BMOs are the means of identifying and prioritizing the most important issues in meeting water resources needs. BMOs can range from being entirely qualitative to entirely quantitative. Each BMO should have a criterion or threshold, which can be used to assess progress towards the BMO and trigger management actions. Complying with the groundwater management plan components required under SB 1938 results in the establishment of BMOs that seek to:

- Maintain groundwater elevations that result in a net benefit to basin groundwater users
- Protect and maintain groundwater quality for the benefit of basin groundwater users
- Minimize the risk of future significant impact due to inelastic land subsidence
- Protect against the risk of impacts to surface water flows and quality caused by groundwater pumping
- Protect against the risk of impacts to groundwater levels and groundwater quality caused by changes in surface water flows or surface water quality

These general BMO categories are tailored to each specific plan area by the adopting entities, incorporating input from basin stakeholders and members of the public and are supported by plan components addressing agency coordination, stakeholder involvement and public outreach, monitoring program, groundwater sustainability, adaptive management and mitigation in response to climate change (in more recent plans), groundwater protection, and planning integration.

Overall, most of the Sacramento Valley is covered by functional groundwater management plans adopted by responsible local agencies. Local groundwater management has been an effective tool in the overall groundwater management toolkit. Continued improvement in groundwater management planning, plan integration and plan implementation will ensure that local control of groundwater resources is effective, and local control of groundwater resources is maintained in the future. The preparation and adoption of groundwater management plans covering areas that are currently not addressed by groundwater management plans will help ensure that all beneficial uses in the common pool of groundwater are maintained.

While GWMPs are in place, they emphasize groundwater monitoring rather than comprehensive active management. For example, some plans require that when a water level BMO trigger point is reached, the management action is to send a letter to the elected officials in the area. While this is important, it does not call for specific actions to respond to the trigger point. There is also no overall coordination among Sacramento Valley GWMPs although they overly a common aquifer. There is room for improvement, as set forth in the recommendations at the end of this report.

4.2 County Ordinances

As noted in Chapter 2, county ordinances generally have been put in place to react to new events (for example, short-term water transfers) and may not necessarily call for active year-to-year management activities in the absence of new events. The following counties have adopted ordinances within the Sacramento Valley: Butte, Colusa, Glenn, Lassen, Placer, Sacramento, Shasta, Solano, Sutter, Tehama, Yolo and Yuba. Table 4-1 provides a comparison of the basic elements of each ordinance. The source of this information is the Draft California Water Plan Update 2013 and may not be complete (for example, Yolo County does have a Well Abandonment and Destruction Ordinance). A narrative description of several of the county ordinances is summarized below.

4.2.1 Colusa County Ordinance

Colusa County Code Chapter 43 (Ordinance 615) was developed in reaction to concerns over impacts of water transfers. The Colusa County ordinance addressed the "extraction and export of groundwater", with express concerns regarding the need to protect farm production and the environment within the County and the induced need to develop additional surface water supplies if groundwater supplies were lost or diminished. Ordinance No. 615 established a permit process addressing the extraction of groundwater for use outside the County. Section 43-3 of this ordinance includes this statement:

> *For purposes of this section, the extraction of groundwater to replace a surface water supply which has been, is being, or will be transferred for use outside of the county boundaries shall be considered an extraction or mining of groundwater subject to this ordinance.*

To date, no permitting process has been established. With the adoption of the Colusa County Groundwater Management Plan in November 2008, it is was recommended that the existing ordinance be modified to reflect the implementation of groundwater monitoring programs to be developed and utilize the Colusa County Groundwater Commission (established by Resolution 98-44, and confirmed by Resolution 13-024) and Technical Support Team to review all required groundwater substitution transfer proposal documentation for conditional acceptance, prior to the transfer proceeding.

4.2.2 Butte County Ordinance

In 1996 Butte County expanded (Ordinance 3272) an existing well construction ordinance for the purpose of reducing potential interference problems from new wells with existing wells, and to avoid potential adverse environmental effects caused by new or deepened wells. In the following few years Butte County continued to address and refine its groundwater ordinances, largely to address concerns regarding annual transfers of surface water and an increased reliance on groundwater pumping. Such "groundwater substitution transfers" have seen a great deal of dialogue at Board of Supervisors meetings.

County	Groundwater Management	Guidance Committees	Export Permits	Recharge	Well Abandonment and Destruction	Well Construction Policies
Butte	Y	Y	Y	—	Y	Y
Colusa	—	—	Y	—	—	Y
Glenn	Y	Y	—	—	Y	Y
Lassen	Y	Y	Y	—	Y	—
Placer	—	—	—	—	Y	Y
Sacramento	—	—	Y	—	Y	Y
Shasta	—	—	Y	—	—	—
Solano	—	—	—	—	Y	Y
Sutter	—	—	—	—	Y	Y
Tehama	—	—	Y	—	Y	Y
Yolo	—	—	Y	—	—	—
Yuba	—	—	—	—	Y	Y

(Information taken from preliminary table, Draft California Water Plan Update 2013, Volume 4; California Groundwater)

Table 4-1 Summary of County Groundwater Ordinance Components in the Sacramento Valley

4.2.3 Glenn County Ordinance

Glenn County Ordinance No. 1115 adopted in 2000 modified in 2012 as Ordinance No. 1237. Modifications to the ordinance included implementation of a plan for coordinated water management and guidelines for export. The purpose and intent of the ordinance is to establish an effective policy concerning groundwater and coordinated resource management. This would be accomplished by fostering prudent groundwater practices to avoid significant environmental, social, and economic impacts and assure the overall County is not adversely affected by excessive groundwater use.

4.2.4 Tehama County Ordinance

County Ordinance No. 1552, similar to ordinances in the other counties, was developed in response to serious impacts, or the threat of such impacts, associated with the drought and various drought response actions during the period 1991 through 1994. This ordinance identified the threats associated with overdraft and the mining of groundwater resources during the drought, induced adverse impacts on the environment of local stream systems, and the future threat of transfer of water outside of the County. The ordinance requires a permit for extraction of groundwater for use on other parcels, presumably out of the region.

4.3 Integrated Regional Water Management Plans

The concept of integrated regional water management (IRWM) moved forward in California following passage of the Integrated Regional Water Management Planning Act of 2002 (Act, SB 1672, Costa). Text of the Act can be found at www.leginfo.ca.gov/pub/01-02/bill/sen/sb_1651-1700/sb_1672_bill_20020921_chaptered.html.

DWR more generally describes the concept of integrated regional water management as it has matured since adoption of the Act as:

> *… a collaborative effort to manage all aspects of water resources in a region. IRWM crosses jurisdictional, watershed, and political boundaries; involves multiple agencies, stakeholders, individuals, and groups; and attempts to address the issues and differing perspectives of all the entities involved through mutually beneficial solutions. (www.water.ca.gov/irwm/grants)*

Consequently, IRWM is intended to consider all sources of water in an integrated manner, including groundwater.

In November 2002 California voters approved Proposition 50, which provided $500 million to fund development and implementation of integrated regional water management plans (IRWMP) consistent with provisions of the Act. DWR developed and implemented programs to allocate Proposition 50 funds to both IRWMP development and implementation.

In November 2006 California voters approved an additional $1 billion for IRWMP development and implementation through Proposition 84. At the same time voters also approved Proposition 1E, which provided an additional $300 million specifically for IRWM stormwater flood management (recognizing that IRWMPs may contain a flood management element).

In 2008 State Senate Bill 1, the State "Integrated Regional Water Management Planning Act" was passed (and implemented in 2009) which added additional requirements for IRWMPs including:

- General definition of an IRWMP
- Guidance to DWR regarding development of IRWMP guidelines, including the need to develop standards for accepting a "region" for development of an IRWMP

Since adoption of Proposition 84, Proposition 1E and Senate Bill 1, DWR has developed a series of increasingly specific IRWMP guidelines setting forth more structured and stringent requirements for the content of IRWMPs. Some of this built on experience developed during implementation of the earlier Proposition 50 programs. For example, implementation of Proposition 84 has required pre-approval of regional water management groups through its Regional Acceptance Process (RAP) (www.water.ca.gov/irwm/grants/rap.cfm). One consequence of the new guidelines developed since passage of Proposition 84 is that earlier IRWMPs need to be updated to meet new requirements in order for projects under the older IRWMPs to be eligible for State grant funds. California Water Code Section 10539 defines this newer concept of a regional water management group as:

> *… a group in which three or more local agencies, at least two of which have statutory authority over water supply or water management, as well as those other persons who may be necessary for the development and implementation of a plan that meets the requirements of CWC §10540 and §10541, participate by means of a joint powers agreement, Memorandum of Understanding (MOU), or other written agreement, as appropriate, that is approved by the governing bodies of those local agencies.*

The changing requirements for IRWMPs have resulted in a difference between currently "DWR-accepted" IRWM regions (as approved through the RAP process described above) and historically developed IRWMPs that may not have been updated to be consistent with newer DWR guidelines.

Figure 4-2 shows the boundaries of approved regional water management planning groups that have adopted, or are in the process of adopting, new or updated IRWMPs consistent with current DWR guidelines (DWR, 2013). Figure 4-2 differs from DWR Figure SR-25 in that the boundaries of the geographic boundaries of this report are shown. The consequence is that the following five regional water management planning efforts are included partly or entirely within our study boundary:

- American River Basin (DWR no. 1)
- Cosumnes, American, Bear, Yuba (DWR no. 6)
- North Sacramento Valley Group (DWR no. 22)
- Westside (portions of Yolo, Solano, Napa, Lake and Colusa counties, DWR no. 45)
- Yuba County (DWR no. 46)

A very important distinction needs to be made regarding the Sacramento Valley Integrated Regional Water Management Plan, developed under funding secured by NCWA and approved by its members in 2006. NCWA's Sacramento Valley-wide IRWMP focused on regional sustainability and "…contains a strategic framework to meet the various water supply needs in the region–both now and into the future" and "…to guide the development of water resources policies, programs, and projects" (www.norcalwater.org/regional-planning).

While the Sacramento Valley IRWMP was developed under earlier DWR guidelines, NCWA made the decision to put its efforts into supporting more specific regional planning efforts rather than updating its 2006 plan. These four efforts are listed in Table 4-2 along with web links to each effort and a note regarding current status.

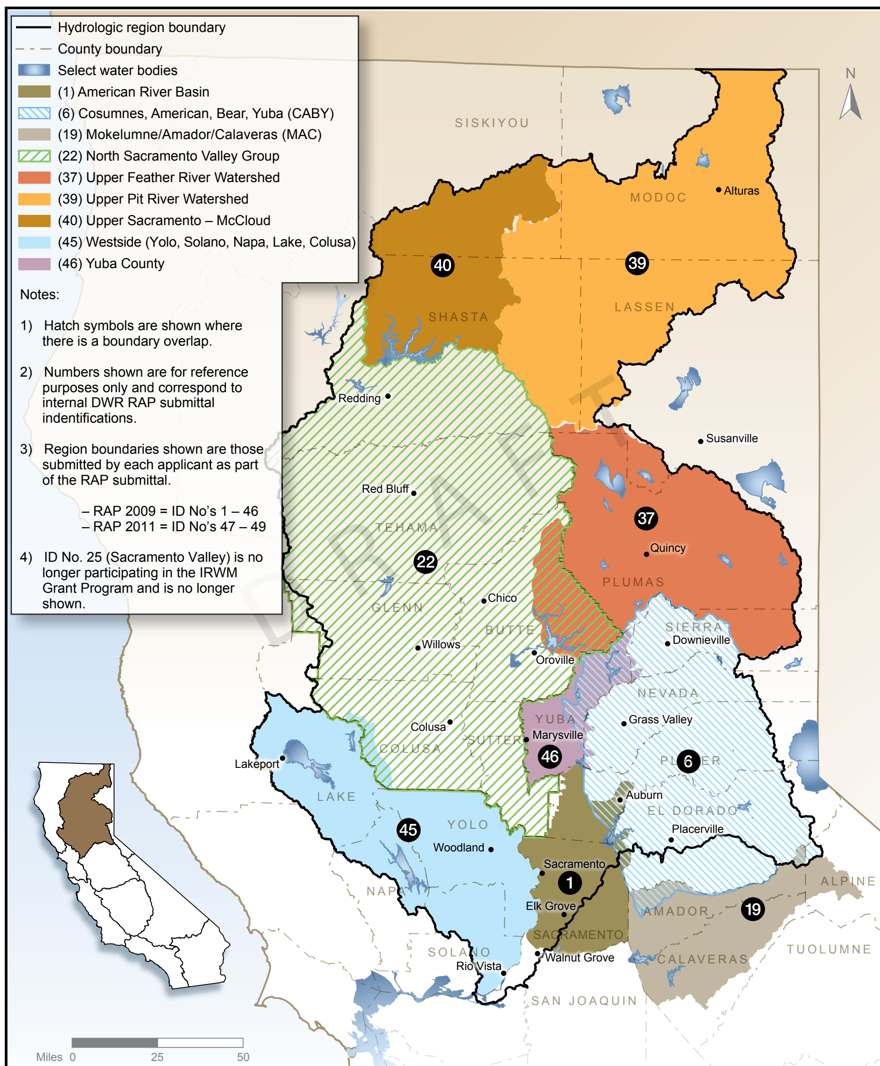


Figure 4-2 Integrated Regional Water Management Planning Efforts in the Sacramento Valley

IRWMP Effort	Web Link	Status
American River Basin IRWMP	www.rwah2o.org/rwa/programs/irwmp/plan	Update adopted in July 2013
Northern Sacramento Valley IRWMP	www.nsvwaterplan.org	Initial IRWMP planned for adoption March 2014
Westside Sacramento IRWMP	www.westsideirwm.com	Initial IRWMP adopted June 2013 (successor effort to Yolo County IRWMP and others)
Yuba County IRWMP	www.ycwa.com/projects/detail/7	Adopted February 2008.

Table 4-2 IRWMP Efforts Related to 2006 Sacramento Valley IRWMP

4.4 Regional Board Waste Discharge Requirements

The Central Valley Regional Water Quality Control Board (CVRWQCB) is developing Waste Discharge Requirements (WDRs) as part of the Irrigated Lands Program. This includes various provisions relating to groundwater, including the previously addressed GAR.

NCWA continues to engage with both the CVRWQVB and the SWRCB on this and other groundwater-related regulatory issues. In December 2013 NCWA provided detailed comments to the SWRCB regarding its "Groundwater Workplan Concept Paper", addressing a full range of interacting State regulatory and monitoring programs. The fundamental themes of NCWA's comments are:

- Local groundwater management should continue to be the preferred approach, consistent with State policy and long-term practice in the Sacramento Valley. This is consistent with Governor Brown's 2013 "State of the State" address that (comments made in context of education, but applicable to water management) stated in part, "…the idea that a central authority should only perform those tasks which cannot be performed at a more immediate or local level."

- Information on groundwater monitoring and management should be centralized by way of a State and local entities partnership, similar to the State's Cooperative Snow Survey program.

- Reliable surface water supplies are essential to sustainable groundwater management, which should be recognized explicitly in various SWRCB programs.

- Groundwater management is linked in several important ways to land use planning.

As noted in Chapters 1 and 3, the GAR has been developed in anticipation of pending requirements of the CVRWQCB Irrigated Lands Program. The GAR will serve as the basis for an agricultural practice evaluation and for the groundwater monitoring requirements of the CVRWQCB's waste discharge requirements (Sacramento Valley Water Quality Coalition, Groundwater Quality Assessment Report Overview).

Chapter 5: Regional Sustainability and Self-Sufficiency for Managing Water Supplies

5.1 Introduction

Groundwater is an essential water supply component contributing to regional sustainability and self-sufficiency of the broad, interconnected diversity of Sacramento Valley water uses. This chapter addresses the linkages among groundwater, regional sustainability and self-sufficiency. The chapter ends with four case studies of water management successes within the Sacramento Valley.

The 2006 Sacramento Valley IRWMP included the following description of the Sacramento Valley in terms of long-term water uses:

> *The Sacramento Valley is a rich mosaic of farmlands, cities and rural communities, refuges and managed wetlands for waterfowl and shorebird habitat, and meandering rivers and streams that support numerous fisheries and wildlife. The natural and working landscape between the foothills of the Sierra Nevada and the Coast Range is dependent on the fertile lands of the Sacramento Valley floor, water supplies from rivers, streams, and the underlying groundwater basins to support and sustain a healthy and vibrant local economy and environment.*

This set forth an initial marker for sustainable water uses in the Sacramento Valley that explicitly addresses both economic and environmental values. Following up on the theme of sustainability, NCWA produced a more specific report in 2011, "Efficient Water Management for Regional Sustainability in the Sacramento Valley" (NCWA, 2011), that addressed the topic of sustainability in more depth. This paralleled the emerging focus over the past decade throughout California on both water supply reliability and the broader theme of "sustainability."

5.2 Sustainability Defined

The modern concept of sustainability had its origin in the outcomes of the United Nations' World Commission on Environment and Development (WCED). WCED was convened in 1983 to address concerns " . . . about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development." (United Nations, Report of the World Commission on Environment and Development: Our Common Future, 1987). The WCED report developed this definition: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In its December 2013 comments to the SWRCB concerning the SWRCB's "Groundwater Workplan Concept Paper", NCWA referred to the "three pillars of sustainability": the economy, environmental stewardship, and social and community well-being. Each of these relies heavily on reliable, long-term water supplies for the Sacramento Valley.

The 2011 NCWA report highlighted a concern that "sustainability" could not be a measure of various factors at one point in time. The report noted that the need to recognize sustainability in the Sacramento Valley is not a static condition, but involves monitoring, feedback, and the capacity to respond. That report went on to list initial indicators of sustainability for the Sacramento Valley:

- Vibrant and growing economy to provide economic opportunity to the valley's growing number of residents
- Reliable, high-quality surface water and groundwater supplies to ensure that water remains adequate and suitable for the valley's beneficial uses

- Stable groundwater levels to ensure that there is no long-term overdraft of the valley's aquifers and that ecologically critical interactions between aquifers and streams are preserved
- Preservation and enhancement of aquatic and terrestrial habitats to ensure species recovery to acceptable numbers and geographic range
- Preservation of agricultural productivity and land fertility so that farming remains the mainstay of the regional economy

5.3 Sustainability, Self-Sufficiency and Groundwater

There is broad recognition of the contributing factors to water sustainability. Those include, but are not limited to :

- Surface water hydrology (variability)
- Interaction between surface water and ground water
- Long-term balance of groundwater resources, including changes in storage and quality
- Water demands, both consumptive and non-consumptive (variability)
- Water infrastructure, for both storage and regulation of raw water supplies, and those facilities needed for treatment and distribution
- Regulatory restrictions
- Economic factors
- Social goals

Chapter 3 describes elements of a classic water balance analysis, reflecting the conceptual relationship among water uses, surface water sources and groundwater resources.

The fifth factor from the list above addressing water sustainability, infrastructure, is one within the control of water users and is often the topic of discussion in the context of local or regional water planning as well as state and federal water resources financing. The six factor, regulatory restrictions, is important in that: (1) regulations affect water use, water supply, competing uses, etc.; and (2) California's water regulatory environment is far from stable since regulatory controls and restrictions continue to evolve. The seventh factor, economic goals, presumes that long-term sustainable water supplies will lead to a sustainable regional economy. The final factor is social goals – at least those that can be attributable to long-term sustainable water supplies.

Some but not all of these factors can be measured objectively in terms of hydrologic risk (recurrence of droughts, floods, etc.), economic output (crop production, jobs), and environmental factors (fish and wildlife population levels, spawning habitat, acres of waterfowl habitat). Addressing social goals and the stability of the regulatory environment are far more difficult. But all are reliant on a stable, long-term source of water. While we know a great deal about surface water hydrology and changes in surface reservoir storage, we know much less about long-term trends in groundwater storage. This is due to a wide variety of factors that are difficult to measure or predict, including but not limited to:

- Land use changes that affect groundwater pumping
- Interaction between surface water and groundwater movement/storage
- Other factors that may change future demands on groundwater

All of the factors contributing to or affecting sustainable water resources (and, indirectly, regional self-sufficiency for water supplies to meet demands within the Sacramento Valley) are very complex, with a great deal of overlap.

So, we know that:

- Regional water supply sustainability is complex, involving a variety of factors
- A long-term evaluation is essential so that we can assure that the needs of "future generations" can be met
- Evaluation of all factors contributing to sustainable water resources requires a comprehensive understanding of each factor.

5.4 Vulnerability: Still Learning

While it is true that certain factors (such as hydrology and groundwater changes) can be measured objectively, it is also true that the Sacramento Valley has a long history of changes to hydrology. Chapter 4 of the Northern Sacramento Valley IRWMP (pages 4-6 and 4-7) addresses water resources vulnerability related to climate change, but observes that for more than 150 years of some form of records in California the Sacramento Valley has seen many records broken with regard to both floods and droughts (see sidebars).

Both wet and dry years are critical factors with regard to sustainability and regional self-sufficiency. Wet years allow water users access to greater surface water, taking pressures off of groundwater use. Wet years also are times when groundwater recharge from streams and rivers is highest. In contrast, dry years put more pressures on groundwater use due to increased pumping, while at the same time providing reduced recharge of groundwater aquifers.

California also appears to be undergoing fundamental changes in hydrology, at least as compared to the relatively water-abundant period from the 1928-1934 record drought up to the 1976-1977 drought. A substantial portion of the Sacramento Valley was developed – both irrigated farming and the expansion of urban areas – during this 40-50 year period. But the 1976-1977 drought, followed by the record-breaking 1987-1994 drought, put more pressures on water users throughout the state. In 1991 Governor Pete Wilson created the Drought Emergency Water Bank, a water-brokering program administered by DWR that purchased water from willing sellers and re-sold it to those water users with critical water needs. 1991 began a new era of market-based water transfers. During the three years of water transfers (1991, 1992 and 1994) during that drought, Sacramento Valley water users demonstrated a willingness to share their water resources under the near-emergency water crisis, while at the same time mindful of the threat of impacts within the Valley if water transfers continued on a long-term basis.

Dry conditions returned over the past decade. Governor Arnold Schwarzenegger declared a drought emergency in 2009 (rescinded by Governor Jerry Brown in 2011 when wet conditions returned). In a third consecutive dry year, Governor Brown declared a drought emergency on January 17, 2014. Indications are that calendar year 2013 may have been the driest year

Sidebar 1: Dry Years

California's largest water projects, including the federal Central Valley Project and State Water Project, were built assuming that water needs would be met during a recurrence of the assumed worst-case drought (similar to the extended 1928-1934 drought), as well as the historic peak floods that existed as of the 1940s, 1950s and 1960s. But we have continued to see new records broken for both drought and flood events. For example, the 1976-1977 drought was short but very severe (1977 is still the driest year in recorded history in the State). The more recent 1987-1994 drought was extreme in its unprecedented duration in modern California history, and saw the development of new water management tools to cope with extended and severe drought. These more recent droughts resulted in more stress on every region of California, including the surface and groundwater resources of the Northern Sacramento Valley.

Sidebar 2: Wet Years

Robert Kelley's book, Battling the Inland Sea, … focuses on historic flood control issues in the Sacramento Valley. The book has a predominant observation that "floods of record" were periodically surpassed to establish new "worst case" conditions. In the 1880s (130 years ago), State Engineer William Hammond Hall said that we would always face larger storms and bigger floods. Record floods in 1907 and 1909 were the basis for design of the Sacramento River Flood Control Project. With construction of reservoirs in the Sacramento River watershed with flood control storage in the second half of the 20th century, the system was able to accommodate flood flows larger than originally envisioned. Even so, record floods in 1983 and 1986 were so extreme that they pushed the total flood system - levees, bypasses and reservoirs - to maximum capacity and required reevaluation of the operations of flood control facilities throughout California. Evaluation of the extraordinary February 1986 series of storms resulted in changes to flood control plans at major reservoirs in northern California. And yet a decade later in January 1997, the largest Sacramento River flows in the State's history again pushed the system beyond capacity and resulted in two major levee breaks in the Sacramento River system.

since detailed recordkeeping began more than 100 years ago. In an announcement also on January 17, 2014, the National Weather Service noted the following:

- All counties within northern interior California have been designated to be primary natural disaster areas by the U.S. Department of Agriculture due to damages and losses caused by dry conditions

- The US Drought Monitor is also indicating an extreme drought (classification D3) for all of interior northern California. This is due in large part to the precipitation deficit, decreasing reservoir levels and increasing local impacts

- Numerous water restrictions are already being implemented by local authorities: Folsom - stage 3 restrictions (no landscape water and 20% cut residential use); Granite Bay and parts of Folsom - stage 5 restrictions (mandatory 50% cut in residential use, no outdoor watering, no water for construction and no new connections); and the City of Sacramento - stage 2 restrictions (mandatory 20% cut to residential use...landscape watering reduce to once per week). If this winter continues to be dry even more significant impacts will occur through the year.

In mid-winter, a number of local water agencies put out press releases noting several water shortages in their service areas. One example is from a January 17, 2014 press release from the Placer County Water Agency (PCWA):

> *Unless we see a dramatic return to significant wet winter weather, we're facing a drought of historic magnitude that may be worse than the drought of 1977," said PCWA General Manager David A. Breninger. The General Manager was referring to the previous record drought year of 1976-77, when water supply deliveries were reduced by 50 percent to PCWA and all agency water customers.*

That press release went on to enumerate the actions PCWA planned to take, including more active coordination with adjacent water districts, greater use of groundwater, and extensive attention to greater water conservation.

On January 22, 2014 the Glenn County Board of Supervisors declared a drought emergency. That declaration noted a serious concern with dropping groundwater levels, serious restrictions to availability of surface water that would result in greater pressures on groundwater use, and a concern that some wells will go dry. "Our aquifers will be stressed to their limits."

In its January 2014 monthly Water Solutions newsletter, the Butte County Department of Water and Resource Conservation stated that water levels in many wells in Butte County were at or near the historic low levels observed at the end of the 1987-1994 drought.

Fortunately, there was moderate rainfall in portions of February and March 2014, but on the whole it is still a critically dry year and California continues to suffer from drought conditions.

In addition, there are many differences between the historically driest year of record in 1977 and current conditions:

- California's population has nearly doubled;

- The Endangered Species Act and other laws have been implemented in the Bay-Delta for various fish, placing restraints on water operations and reducing flexibility in meeting various beneficial purposes;

- California agriculture has evolved, with changes in cropping patterns and significant new plantings (particularly in trees), many of which require water in all years;

- The SWRCB has updated its Bay-Delta Water Quality Control Plan, which has generally led to less water available in storage in dry years;

- Significant water conservation and efficiency in urban and agricultural water use throughout the state has tightened the water system. This is generally positive, but it also means that there is much less flexibility in managing local water supplies in dry years.

So, we have seen many new water demands from 1977 to now, making California – and the Sacramento

Valley – more vulnerable to drought than in the past. Regulatory changes have also greatly increased the vulnerability to drought in meeting all water needs. At the same time we may be facing drought conditions that are potentially more severe than the rainfall, runoff and water storage we have seen in recent droughts. Until we know the severity and length of the current drought, there are questions as to how much water can be shared in the longer term (or even this year) with other regions of California, and how much the Sacramento Valley has in reserve in its groundwater resources to meet current and future needs. This reinforces again the need for a long-term view. Time and time again the Sacramento Valley has learned the lesson that the range and frequency of historic conditions (wet and dry) are not necessarily a predictor of the future.

5.5 Recent Water Management Successes

The Sacramento Valley has a number of dramatic groundwater management successes, several of which are recounted in this chapter. These successes are a credit to local water resource managers, and share the common feature that recovery and maintenance of groundwater systems has been accomplished through conjunctive management with surface water supplies. These examples are largely in the southern parts of the Sacramento Valley, have higher populations and potentially more capacity to generate revenue to invest in active management. Constraints and possibilities might be distinctly different for the more northern rural counties. While representing a relatively small percentage of the land area of the Sacramento Valley overlying groundwater aquifers, they provide important examples of how long-term problems with declining groundwater levels were successfully addressed. It is essential to note that every subregion within the Sacramento Valley is different from a number of standpoints – hydrogeology, access to surface water, water infrastructure, soils suitable for irrigation, urban development and water management institutions – such that successful solutions at the subregional level need to account for local conditions.

5.5.1 South Sutter Water District

The South Sutter Water District (SSWD) is located in southern Sutter and western Placer counties, with the Bear River as the northern boundary and stretching southwest between Highway 65 and Highway 70 to Pleasant Grove and Curry creeks. The District was formed in 1954 to develop, store and distribute surface water supplies. Today SSWD encompasses a gross area of nearly 64,000 acres, including 57,012 acres that are authorized to receive surface water. In recent years, due to urban encroachment and other factors, fewer than 45,000 acres in the district are irrigated using a combination of surface and groundwater supplies. The dominant crop is rice, accounting for more than 80 percent of the irrigated area.

The primary driving factor for forming the district was to develop and distribute supplemental surface water supplies to replenish over-drafted groundwater aquifers. This was accomplished by constructing the enlarged New Camp Far West Dam and Reservoir on the Bear River. These facilities were completed in 1964 creating 104,400 AF of additional storage capacity.

Water is released from New Camp Far West Reservoir into the Bear River and is diverted for irrigation 1.25 miles downstream, about 15 miles above the confluence with the Feather River. The diversion dam and distribution facilities originally had a capacity of 380 cfs, but this was increased to 430 cfs in the 2000s. The enlarged capacity enables more flexible release and diversion operations, so that SSWD can continue to meet a sufficient part of its irrigation demands with surface water while also meeting certain obligations to make reservoir releases for Delta water quality maintenance.

With the delivery of surface water beginning in 1964, groundwater pumping decreased and groundwater levels immediately began recovering. On average, enough surface water has been delivered such that groundwater levels have recovered and appear to have stabilized more or less at pre-development levels. This pattern of steady decline before 1964 and recovery afterward is illustrated by the groundwater well hydrograph shown in Figure 5-1.

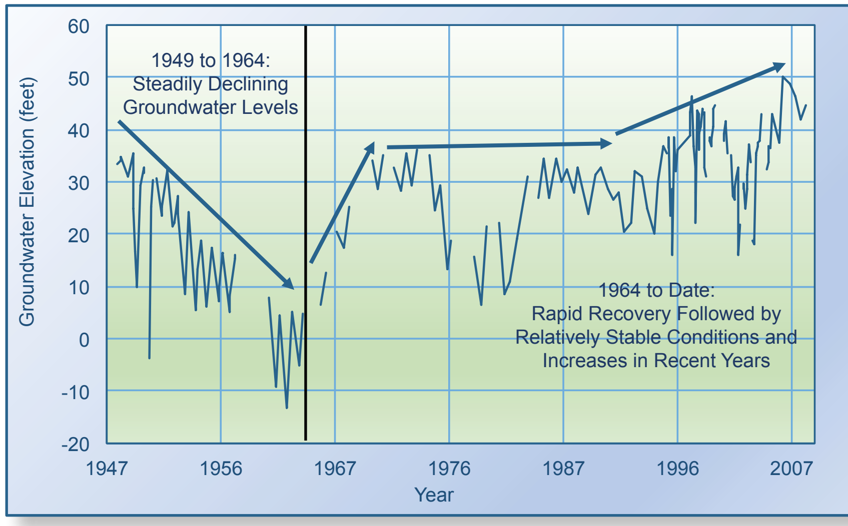


Figure 5-1 Water Levels in a South Sutter Water District Groundwater Well Showing Recovery of Groundwater Levels with Increased Surface Water Deliveries Beginning in 1964

5.5.2 Yuba County Water Agency

Yuba County Water Agency (Agency) was created in 1959 by a special act of the California Legislature for the purpose of developing and promoting the beneficial use and regulation of the water resources of Yuba County. Primary objectives were to improve protection from devastating Yuba River floods and to increase water supply reliability. In particular, groundwater conditions in the South Yuba subbasin, an area that had no surface water supplies, had been declining since the early 1940s with no letup in sight.

The Agency's crowning achievement was construction of New Bullards Bar Dam and Reservoir, completed in 1970, to reduce peak flood flows and store water for beneficial use. Because the County was stretched to the limit to fund the Project, it would be another 13 years before surface water diversion and delivery systems were put in place to deliver water to the southern portion of the County. In 1983 water deliveries to the south began and the immediate recovery of the groundwater basin commenced. Figure 5-2 shows the dramatic recovery of groundwater levels due to surface water deliveries from the Project.

Because of the replenishment of the basin, which today is near pre-pumping levels not seen since the turn of the last century, Agency Member Unit farmers have implemented a conjunctive use program that provides groundwater substitution transfers to water short areas of California, including transfers to south of Delta water users.

With respect to groundwater management, the Agency's authorizing legislation contains two important provisions, one giving the Agency broad authority to ensure sufficient water supplies for a wide range of

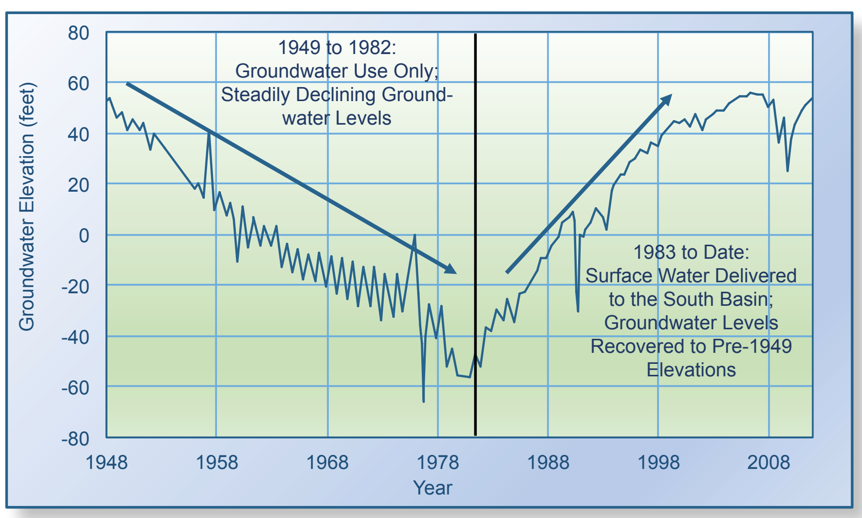


Figure 5-2 Water Levels in a Typical South Yuba Subbasin Groundwater Well Showing Immediate and Full Recovery of Groundwater Levels with Surface Water Deliveries Beginning in 1983

beneficial uses, and another granting the Agency power to store water in surface or underground reservoirs within or outside the Agency, to conserve and reclaim water for present and future use, and to import water into the Agency and to conserve and utilize, within or outside the Agency.

Pursuant to these authorities, the Agency has pursued active conjunctive management of surface water and groundwater as a core element of its commitment to resource management. In recognition of the importance of groundwater management, YCWA has undertaken efforts to formalize its historical groundwater management program by developing a Groundwater Management Plan (GMP) consistent with provisions of California Water Code Section10750 et seq. To achieve the broad goal of maintaining a viable groundwater resource for the beneficial use of the people of Yuba County, the Agency has adopted seven specific basin management objectives (BMO):

- Maintain groundwater elevations that provide for sustainable use of the groundwater basin.

- Protect against potential inelastic land surface subsidence. Land subsidence can cause significant damage to essential infrastructure.

- Maintain and improve groundwater quality in the Yuba basin for the benefit of groundwater users.

- Manage groundwater to protect against adverse impacts to surface water flows in the Yuba River, Feather River, Honcut Creek, and Bear River within Yuba County.

- Improve communication and coordination among Yuba groundwater basin stakeholders.

- Maintain local control of the Yuba groundwater basin.

- Improve understanding of the Yuba groundwater basin and its stressors.

The operative elements of the Agency's GMP are as follows:

- Stakeholder involvement to involve and coordinate groundwater management efforts among the Agency's eight member units, municipal purveyors within the County, other agricultural purveyors, members of the public and the Department of Water Resources.

- Monitoring and measuring water resources under the Agency's authority to "…carry on technical and other necessary investigations, make measurements, collect data, make analyses, studies, and inspections pertaining to water supply…" This includes monitoring programs for groundwater storage and elevation, groundwater quality, inelastic subsidence, and groundwater and surface water interaction.

- Groundwater protection to ensure a sustainable groundwater resource, including both preventing contamination from entering the groundwater basin and remediating existing contamination. Prevention measures include proper well construction and destruction practices, development of wellhead protection measures, and protection of recharge areas. Containment and remediation include measures to prevent contamination from human activities as well as contamination from natural substances such as saline water bodies.

- Sustaining groundwater for the beneficial use of the people of Yuba County, including: assisting the Member Units to make decisions about the volume and distribution of pumping during groundwater substitution transfers; providing technical support to Member Units to determine whether injury claims are related to conjunctive use of groundwater; increasing understanding of groundwater and how it responds to various stresses; improving available tools and models to support groundwater management; analyzing potential effects of climate change on recharge of the Yuba County; developing and implementing a plan to characterize recharge of the groundwater basin from the Yuba Goldfield; and, improving understanding of projected land use changes and their potential impacts to the Yuba groundwater basin.

5.5.3 Yolo County Flood Control and Water Conservation District – Active Groundwater Management in Yolo County

About one million acre-feet per year are used for irrigation in Yolo County, with about half of that met by surface supplies and half by groundwater in an average year. Additionally, while municipal water use is dwarfed by agricultural use, every city and town in Yolo County (with the exception of the City of West Sacramento) currently relies entirely on groundwater. When surface supplies are curtailed in dry years, groundwater provides the majority of the supply, so that municipal needs are fully met, and agricultural production is not dramatically reduced.

Given the critically important role that groundwater plays, local water managers for decades have recognized the need to protect local aquifer from overdraft, subsidence and pollution. In particular, since the 1950s, Yolo County Flood Control and Water Conservation District has been actively engaged in preserving local groundwater resources by recharging aquifers, monitoring groundwater levels and measuring water quality. The District's management programs are founded on the recognition that groundwater and surface water are not distinct, separate resources, but are intimately linked.

One of the ways that the District is committed to maintaining groundwater health is through aquifer recharge of two types: direct recharge and in-lieu recharge. Direct aquifer recharge takes place when surface water from rain, lakes, streams and irrigation seeps back into the aquifer. The District maintains a policy of not concrete lining its irrigation canals and ditches. During the irrigation season, over 160 miles of canals and ditches, and many more miles of sloughs and drainage channels are saturated with water that percolates into the aquifer. In fact, in an average year, more than 25 percent of the surface water diverted from Cache Creek for irrigation goes directly to groundwater recharge. "In lieu" recharge takes place when farmers who otherwise would have used groundwater use District surface water instead. Such groundwater recharge helps to maintain groundwater levels throughout the region.

Because groundwater extraction can cause subsidence, the District participates in a multi-agency Yolo County-wide subsidence monitoring program. Subsidence reduces an aquifer's ability to store water, and can cause major structural damage to foundations, roads, bridges and wells. The monitoring network's goal is to identify areas of subsidence in order to inform appropriate action.

Information about groundwater levels is so important that the District measures almost four hundred measurements in 150 wells per year: once in the spring before the irrigation season, and then again in the fall after the irrigation season is finished. This monitoring program has been in place for over fifty years and serves as a valuable continuous record of groundwater level through multiple cycles of drought and high water years. The District is one of 11 local agencies that participate in the Yolo Water Resources Association (WRA) Groundwater Monitoring Program, which does take measurements in about 400 wells per year (www.yolowra.org/projects_groundwater.html). The WRA is also the official CASGEM Monitoring Entity. All data has all been put into an electronic database that is accessible to the public via the internet. Recently, the District has begun building out a real-time groundwater level monitoring network as part of its SCADA system. This real-time information serves as both a management and an educational tool. Additionally, The District periodically samples selected wells for water quality to detect pollution, track trends, and assess groundwater suitability for irrigation.

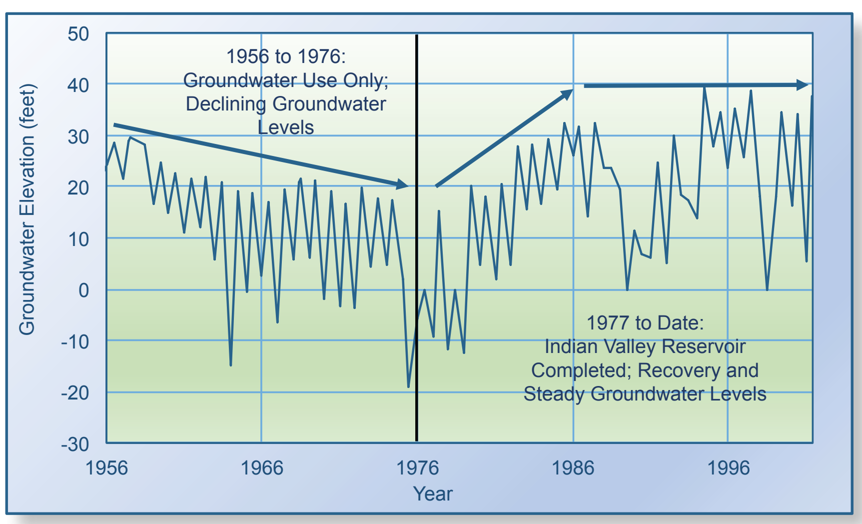


Figure 5-3 Water Levels in a Yolo County Groundwater Well Showing Recovery of Groundwater Levels with Increased Surface Water Deliveries Beginning in 1978

The District has initiated a number of policies, programs and tools to enhance its ability to conjunctively manage groundwater and surface water supplies for the benefit of its customers. In 2007 the District initiated a pump-incentive program, which links the District's water delivery system with the region's privately managed well network in such a way as to maximize the effectiveness of both systems. More recently, the District adopted an inverted, tiered rate structure that encourages surface water use in wet years and groundwater use in dry years, while helping to stabilize the District's surface water sales revenues through wet and dry cycles. Finally, the District commissioned and maintains an integrated hydrologic computer model of its surface and groundwater systems that enables evaluation of possible future changes in water supplies, cropping patterns, irrigation practices and other factors.

Unquestionably, the District's most tangible contribution to sustainable conjunctive management has been the expansion of surface water supplies achieved through construction of Indian Valley reservoir on the North Fork of Cache Creek. Completed in 1977, Indian Valley added an annual average of 80,000 acre-feet to the District's surface supply from Clear Lake. Prior to 1977, groundwater levels had been steading declining throughout most of the District's service area. Since then, groundwater levels have steadily recovered, due to the increased in-lieu recharge made possible by the increased surface water supply as shown in Figure 5-3.

5.5.4 Northern Sacramento County

In April 2000, some 40 stakeholder interests (urban water purveyors, environmental groups and business interests) entered into the Water Forum Agreement (WFA). The WFA is a nationally recognized collaborative process that resulted in a plan to provide a safe and reliable water supply for planned growth in the region to 2030 and preserving the environment of the lower American River. Urban water purveyors were concerned about how they could meet their long-term water needs. Environmental conditions (in particular, flow and temperature) were problematic for a number of fish species including the endangered fall-run Chinook salmon and steelhead. While the WFA required nearly seven years of careful negotiation to complete, it resolved several decades of conflict concerning water supply and the environment.

To implement the WFA, seven primary elements are required. One of those is effective groundwater management. In particular, a sustainable groundwater basin was needed for dry years, so that urban water suppliers could reduce their surface water diversions to provide additional water for the environmental resources on the lower American River.

The water purveyors that eventually signed the WFA agreed in 1998 to form the Sacramento Groundwater Authority (SGA), created "…for the purposes of protecting, preserving, and enhancing, for current and future beneficial uses, the groundwater resources in the North Area Groundwater Basin, in Sacramento County, north of the American River…" (SGA Groundwater Management Plan available at www.sgah2o.org).

The SGA was formed under a joint powers agreement by the cities of Citrus Heights, Folsom and Sacramento and the County of Sacramento using their common police powers to protect the basin. A governing board of directors was created with representatives of the following water purveyors and other water users within their jurisdiction:

- California American Water
- Carmichael Water District
- Citrus Heights Water District
- City of Folsom
- City of Sacramento
- County of Sacramento
- Del Paso Manor Water District
- Fair Oaks Water District
- Golden State Water Company
- Natomas Central Mutual Water Company
- Orange Vale Water Company
- Rio Linda/Elverta Community Water District
- Sacramento Suburban Water District
- San Juan Water District
- Agricultural self-supplied interests within SGA boundaries
- Commercial/Industrial self-supplied water users within SGA boundaries

The SGA developed an initial groundwater management plan (GMP) in 2003, setting forth management objectives for managing the groundwater basin. The SGA agreed that it would conduct a comprehensive review and update of its GMP every five years, with a revised GMP adopted in December 2008. A third GMP revision is currently in progress.

The SGA has made remarkable accomplishments in the 15 years since it was formed. Conjunctive use of surface and ground water has been promoted, as has the banking of water to meet future needs. An early SGA activity was to facilitate an exchange of previously-banked water to the State's Environmental Water Account to aid in environmental protection downstream in the Delta, which proved the viability of such exchanges from the region. In 2010, SGA adopted a Water Accounting Framework, which established policies and procedures to promote greater conjunctive use in the region. Overall, groundwater levels in the basin have reversed a significant downward historical trend (as noted in the long-term hydrograph shown in Figure 5-4) through the actions of SGA members to construct facilities to shift to more surface water supply in wetter years to achieve in-lieu groundwater recharge.

Through its many management actions, SGA has put in place the institutional and technical means to accomplish long-term sustainable management of its groundwater basin.

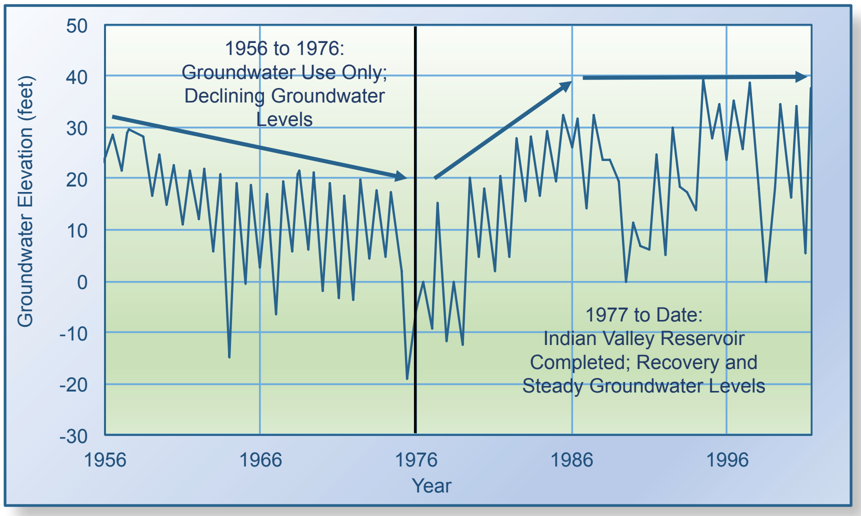


Figure 5-4 Sacramento Area Water Level Responses to Water Management Actions

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

The following conclusions regarding the status of Sacramento Valley groundwater conditions are drawn from the information and analyses presented in this report. These are general, high-level statements that while valid on average do not necessarily hold true in all locations or at all times. This is because groundwater conditions in the Sacramento Valley, as in all places, are both spatially and temporally variable. While understanding this variability is critically important to charting appropriate groundwater strategies, sight should not be lost of the broad perspectives and challenges that are plainly evident with regard to management of the Valley's groundwater resources. Conclusions are organized into five categories:

- Data collection, monitoring and modeling
- Water management
- Water supplies
- Land use
- Other

6.1.1 Data Collection, Monitoring and Modeling

- Groundwater levels have declined in some areas because increases in groundwater discharge, primarily agricultural pumping but including municipal pumping where it occurs, have not been offset by equal increases in groundwater recharge. In short, groundwater use in some areas appears to be exceeding natural and irrigation induced recharge.

- The full impact of past and current management practices on groundwater conditions in the Valley's aquifers may not be apparent for decades or longer, due to the slow rate of groundwater movement and large volume of groundwater in storage.

- Real-time monitoring and evaluation of long term trends is critical. As addressed in Chapter 3, Sacramento Valley supplies and demands are in the midst of change. 2014 is a third consecutive dry year, so serious that on January 17, 2014 Governor Brown proclaimed a Drought State of Emergency (Proclamation of a State of Emergency, Governor Jerry Brown, January 17, 2014). In a news report related to the Drought Proclamation (Sacramento Bee, blogs.sacbee.com/capitolalertlatest/2014/01/jerry-brown-declares-drought-emergency-urges-residents-to-reduce-water-use.html), it was noted that the last drought emergency was made in 2009 by then-Governor Arnold Schwarzenegger and lifted by Governor Brown in 2011. Two of the provisions of the Drought Proclamation addressed concerns related to groundwater:

  1. The Department of Water Resources will evaluate changing groundwater levels, land subsidence, and agricultural land fallowing as the drought persists and will provide a public update by April 30 that identifies groundwater basins with water shortages and details gaps in groundwater monitoring.

  2. The Department of Water Resources will work with counties to help ensure that well drillers submit required groundwater well logs for newly constructed and deepened wells in a timely manner and the Office of Emergency Services will work with local authorities to enable early notice of areas experiencing problems with residential groundwater sources.

  These provisions reflect the concern that additional real-time or near-real-time information is needed to gain a better understanding of groundwater dynamics during drought conditions.

- Groundwater quality needs to be better monitored to maintain the Sacramento Valley's generally high quality groundwater supplies.

6.1.2 Water Management

- Management of connected surface and groundwater systems is challenging for several reasons. One reason is that 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 must account for such impacts, as by the time effects are observed, it may be too late to take action, and the effects may persist for decades. As such it is necessary to anticipate or forecast management outcomes using appropriate tools and analytic techniques.

- Groundwater management plans cover much of the Sacramento Valley and there are a number of successful subregional comprehensive water management programs that have been implemented. This has been possible through leadership instituted within existing institutional structures. However, the Sacramento area has developed new institutional structures over more than a decade to accomplish broad goals within that subregion.

- While a great deal has been written regarding sustainability, there has been no dialogue within the Sacramento Valley directed towards a common definition that would serve as a foundation for future water management actions.

6.1.3 Water Supplies

- In areas with available surface water supplies, typically minor volumes of groundwater are pumped and the net effect of irrigation is recharge to the groundwater system in the form of deep percolation of applied water. By contrast, in areas that rely wholly or predominantly on groundwater, only a portion of the water pumped percolates back to the groundwater system, resulting in net extraction of groundwater.

- The Sacramento Valley's surface water and groundwater systems are coupled, meaning that streams are in physical contact with the groundwater system. Stream gains and losses at any particular location and time depend on the stage of the stream, the groundwater level, and the streambed conductance. Even small changes in groundwater levels can affect stream flow by reducing discharge to streams or by inducing leakage from streams.

- Some areas of the Sacramento Valley have suffered serious water supply shortages, in addition to threats to the sustainability of water supplies. The case studies described in Chapter 5 demonstrate that action has been taken in several subregions to address problems and threats. In all cases, local leadership has been critical to success. Every case study recognized that augmentation of water supplies was necessary, and that an active role in conjunctive management of surface water and groundwater supplies was essential. In all cases this has required the development of new water infrastructure.

6.1.4 Land Use

- The Sacramento Valley has been extensively developed for irrigated agriculture. Surface water is used for irrigation in many areas according to established surface water rights, but high quality groundwater is generally readily available throughout the Valley, and in most areas can be pumped economically. Therefore, land suitability and other economic conditions pose the main constraints to agricultural development, not water supply.

- DWR's land use surveys involving ground-based data collection provide the highest quality land use data (and other information), but the intervals between those surveys are increasing and the time required to assemble and publish the data is also increasing. Other sources of land use information also exist, but each has its limitations. At the present time, there is no institutionalized process that reports land use with sufficient reliability to track land use changes, and related water use changes, in a timely manner.

6.1.5. Other

- Based on hydrologic models prepared by DWR and the USGS, Sacramento Valley streams that historically had a net gain of base flow from the groundwater system now experience a net loss of flow. Accretions to Sacramento Valley streams appear to have decreased steadily from the 1940s to the 1990s, with the most dramatic decadal decrease occurring between the 1980s and 1990s. From approximately 1991 to present, the river and stream system as a whole has transitioned from experiencing net accretions to net depletions. (The potential effects of reduced stream accretion on beneficial uses of surface water were not addressed by this assessment.)

- Declining stream accretions are most likely the result of declining groundwater levels.

- Two Central Valley wide hydrologic models exist, including DWR's C2VSim and the USGS's Central Valley Hydrologic Model. Additionally, the SacFEM model covers the entire Sacramento Valley. While these models have limitations, they are nevertheless useful for characterizing historical groundwater conditions and for evaluating future groundwater management scenarios.

- We are in an era of changing vulnerabilities, in part due to uncertainties over future hydrology and changes in land and water use.

6.2 Recommendations

Recommendations are for the following actions:

- Increase data collection, monitoring and modeling
- Improve water management activities
- Augment water supplies
- Address land use
- Other

6.2.1 Increase Data Collection, Monitoring and Modeling

- Pressures of increasing demand and the current drought (as well as recurring drought conditions) point to the need for a more unified, collaborative approach to modeling. Sacramento Valley water managers should work with DWR, the USGS and others to refine and regularly update and apply the models maintained by those agencies, in a timely manner.

- DWR should increase the frequency of ground-based land use surveys and investigate options for complementing ground-based surveys with remote sensing. This should include evaluation of the NASS CropScape Cropland Data Layer and adoption of energy balance models for quantifying and reporting evapotranspiration.

- Increase real-time or near real-time monitoring. As noted earlier, groundwater responses to change (both pumping and recharge) can occur over prolonged periods of time. A better understanding of groundwater dynamics will require that we have more and better technical information. The Governor's 2014 Drought Proclamation addresses three related concerns: identification of gaps in monitoring information related to water shortages, timely availability of well logs which can provide critical information on technical aquifer characteristics, and timely notice of problems with residential wells (which can provide early warning of more widespread problems, in addition to identifying health and safety problems in rural residential areas). How groundwater areas – both defined aquifers and fractured rock areas and other areas of low water production – respond to drought conditions is an important indicator of the sustainability of water supplies.

- Attention should be given to developing groundwater models to better assess future groundwater quality.

6.2.2 Improve Water Management Activities

- It is important to arrive at a shared understanding of sustainability for the Sacramento Valley. This will require active engagement in these issues from surface and groundwater users as well as local government, and is a region-wide challenge. Comprehensive water management cannot be fully realized until water users in the areas within water districts and the non-district areas work together toward common objectives.

- Groundwater management plans are described earlier in this report, and all plans are required to include basin management objectives (BMOs). It is both prudent and necessary to review the adequacy of all existing BMOs in the Sacramento Valley, both to assess whether they remain appropriate and to evaluate whether collectively all BMOs are effectively integrated.

- Sacramento Valley surface water managers and groundwater managers should cooperate in evaluating the interactions between the Sacramento Valley's coupled surface water and groundwater systems, in order to:

    - Adequately define how the systems interact for purposes of effective management.

    - Validate and assess the causes and implications of the declining streamflow indicated by DWR and USGS models, particularly the implications to the economic, social and environmental sustainability of the Sacramento Valley.

    - Define metrics and tools, including the use of models, for groundwater management that ensure sustainability of the resource and related environments and acknowledge the challenges inherent in managing connected surface water and groundwater systems.

- While groundwater management plans cover much of the Sacramento Valley and there are a number of successful subregional comprehensive water management programs that have been implemented, the current institutional structure does not ensure an overall coordinated approach to water management within the Sacramento Valley. The various IRWMP's and extensive institutional interactions notwithstanding, we recommend that Sacramento Valley water managers hold high-level discussions to see if more can be accomplished within existing institutional structures. Given the increased attention to state groundwater legislation that is described in NCWA's short report to which this serves as the technical supplement (Sacramento Valley Groundwater Assessment, Active Management – Call to Action), we recommend that such discussions address what institutional structures may be useful to support improved local groundwater and overall water management for the future.

6.2.3 Augment Water Supplies

- Based on the increased water supply vulnerability of both the Sacramento Valley and all of the state to the wide variation in water supplies, it is clear that more storage is needed. Additional storage, such as the proposed Sites Reservoir, will serve two purposes. The first is to expand water supplies, particularly to meet critical water needs during drought conditions. This need is reinforced by the stresses to our water systems during all drought conditions beginning in 1976. There is simply not enough water to go around during droughts, particularly with the increase in water allocated for environmental purposes. Second, additional storage is needed to address water system operational needs: water supplies, downstream environmental requirements and flood control. Both the CVP and SWP are operating far differently than originally designed, in part due to increasing regulatory requirements and updated flood management needs. Many local water systems are also operated differently than originally planned. One local example is the operation of Yuba County Water Agency facilities to meet local irrigation and downstream ecosystem needs. Meeting current and future water management challenges requires additional storage coupled with appropriate system operation policies and procedures.

- Additional water infrastructure, particularly that which expands water storage, is needed to increase water supply reliability to meet all needs by providing both additional water and additional water system operational flexibility.

6.2.4 Address Land Use

- Perhaps the most difficult issue is one of land use within the Sacramento Valley. As noted earlier, groundwater use within the Sacramento Valley represents 30 percent on average of total use, although that percentage increases when surface water supplies have been shorted.

- Land use within the Sacramento Valley is undergoing significant, rapid change. Irrigated areas are increasing as is cropping intensity, including the expansion of perennial crops that in turn hardens demand in all years including drought conditions. Many of the areas experiencing conversion to perennial crops are areas where groundwater provides the only source of supply. Urban areas are expanding, potentially increasing water demands for both residential and industrial use (depending in part on previous land use). Residential development continues in rural areas, putting greater pressures on groundwater. Residential development in foothill areas that have no access to surface water – already experiencing low water yields from local wells in normal years – portends a real crisis to the extent development continues and drought conditions prevail. And of course environmental water demands over the past few decades add additional stress on our water management systems. The San Joaquin Valley has seen all of these pressures and more, and has been in a water supply crisis for decades. While not an exact mirror of what our future could be, the lessons of the San Joaquin Valley need to be kept in mind as land use authorities at all levels consider how the Sacramento Valley will change over time.

- The Sacramento Valley can avoid a "tragedy of the commons" if we heed a call to action. Some of this is related to land use, where the decision-making is distributed among cities, counties, local water districts and individual landowners. There are no clear solutions, but the problem is of such great concern to the long-term sustainability of the Valley's economy that regional dialogue is essential. Ignoring this important factor and continuing "business as usual" threatens the Sacramento Valley's essential characteristics of a healthy economy, a vibrant environment and a sustainable water future.

6.2.5 Other

- Gain a better understanding of water supply risk. Given the continuing changes in hydrology evident in recurrence and severity of droughts and floods over the past 150 years, additional technical work is needed to evaluate future risks to meeting long-term water supply demands within the Sacramento Valley. Water supplies originating within the Sacramento River watershed are shared with other areas of California under California's water right priority system. In addition, such supplies are also shared voluntarily during dry times as market-based water transfers. The use of groundwater provides the balance within the Sacramento Valley in meeting regional water needs when surface water supplies are not sufficient. Therefore, it is critical to get a better understanding of risk so that local water managers can operate their systems in a manner to assure long-term regional water self-sufficiency.

- Gain a better understanding of current and future vulnerabilities. In 2014 California is again experiencing extraordinary drought conditions, brought about through record low rainfall throughout calendar year 2013 and continuing through the winter of 2014. Reservoir levels are critically low, and were at near-emergency levels at Folsom Reservoir in January. Folsom Reservoir provides essential water supplies for regional urban water utilities, environmental flows in the lower American River, flows to contribute to meeting water quality standards in the Sacramento-San Joaquin Delta, and overall water supplies for the CVP. Similarly, low levels at Shasta and Oroville reservoirs are also critical to meeting similar broad benefits within the Sacramento Valley and in export areas. Low or critically low surface reservoir storage amounts greatly increase the need for more groundwater pumping throughout the Sacramento Valley, in addition to a wide variety of drought responses including mandatory water conservation and rationing. Even so, many water needs within the Sacramento Valley may not be met. 2014 is likely to identify more vulnerabilities to meeting our region's long-term water needs, and more data collection is essential to understanding both groundwater dynamics and the region's management responses.

Finally, no change – or even a dialogue to discuss whether changes in water management are desirable and possible – can be accomplished without good public outreach. Active engagement in all the issues identified in this report is needed from surface and groundwater users as well as local government. This is a region-wide challenge. Public outreach will be important to tell the story and get fuller engagement. Continued strong local leadership and the Sacramento Valley's extensive water management experience will be essential for the future. As we engage in these issues, it will be important to consider (1) increase data collection, monitoring and modeling, (2) augmenting water supplies, (3) improving water management activities, and (4) addressing land use. Overall management of our water resources require that we look at all factors affecting the water balance – both supply and demand.

Appendix A: Bibliography

2013 Update to California Water Plan. DWR, October 2013 Draft.

Integrated Regional Water Management Planning Act of 2002. Part 2.2 (commencing with Section 10530) of Division 6 of the California Water Code.

Proposition 50: Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002. California Water Code Division 26.5.

Proposition 84: The Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006. Section 1, Division 43 of the California Public Resources Code.

Proposition 1E: Disaster Preparedness and Flood Prevention Bond Act of 2006. Division 43 (commencing with Section 75001) of the California Public Resources Code.

Integrated Regional Water Management Planning Act. California Water Code Sections 10530 et seq (2009).

Sacramento Valley Integrated Regional Water Management Plan. NCWA, 2006.

American River Basin IRWMP, www.rwah2o.org/rwa/programs/irwmp/plan/.

Northern Sacramento Valley IRWMP, www.nsvwaterplan.org/.

Westside Sacramento IRWMP, www.westsideirwm.com/.

Yuba County IRWMP, www.ycwa.com/projects/detail/7.

Irrigated Lands Regulatory Program. State Water Resources Control Board (www.swrcb.ca.gov/water_issues/programs/agriculture/).

NCWA comments, SWRCB Groundwater Workplan Concept Paper. NCWA, December 2013.

2013 "State of the State." Governor Jerry Brown, January 2013.

Efficient Water Management for Regional Sustainability in the Sacramento Valley. NCWA, 2011.

Water Forum Agreement. www.waterforum.org/agreement.cfm

Sacramento Groundwater Authority. Web site, personal communications.

Drought Proclamation. Governor Jerry Brown, January 17, 2014.

Press Release. Placer County Water Agency, January 17, 2014.

Drought Announcement. National Weather Service, January 17, 2014.

Water Solutions Newsletter. Butte County Department of Water and Resource Conservation, January 2014.

Allen, R. G., Tasumi, M. & Trezza, R. (2007) Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC) - Model. Journal of Irrigation and Drainage Engineering, vol. 133, pp. 380-394.

Barlow, P.M., and Leake, S.A., 2012, Streamflow depletion by wells—Understanding and managing the effects of groundwater pumping on streamflow: U.S. Geological Survey Circular 1376, 84 p. Available at pubs.usgs.gov/circ/1376.

Bastiaanssen, W.G.M., Noordman, E.J.M., Pelgrum, H., Davids, G., Thoreson, B.P., and Allen, R.G. 2005. SEBAL Model with Remotely Sensed Data to Improve Water Resources Management under Actual Field Conditions. Journal of Irrigation and Drainage Engineering. 131(1), 85-93.

Bennett, P.A., Bennett, G.L., V, Belitz, Kenneth, 2009, Groundwater quality data for the northern Sacramento Valley, 2007: Results from the California GAMA program: U.S. Geological Survey Data Series 452, 90 p.

Brush C. F., E.C. Dogrul and T.N. Kadir, 2013a, Development and Calibration of the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG, June.

Brush C. F., E.C. Dogrul, 2013b, User Manual for the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG, June.

Bryan, Kirk, 1923, "Geology and Ground-water Resources of the Sacramento Valley, California", U.S. Geological Survey Water-Supply Paper 495, 285 p.

California Data Exchange Center, cdec.water.ca.gov/cgi-progs/iodir/WSIHIST, accessed February 6, 2014.

California Department of Water Resources (DWR). 1963 – 2010. Bulletin 132: Management of the California State Water Project. State Water Project Analysis Office. Available at www.water.ca.gov/swpao/bulletin_home.cfm.

DWR. 1978, Evaluation of Groundwater Resources: Sacramento Valley, Bulletin 118-6, prepared in cooperation with the U.S. Geological Survey, August.

DWR, 2000, Critical Water Shortage Contingency Plan, prepared by the Governor's Advisory Drought Planning Panel with assistance from DWR.

DWR, 2003, Bulletin 118: California's Groundwater, Update 2003.

DWR, 2013, Public Review Draft California Water Plan Update 2013, accessed February 6, 2014.

CDM, 2008a, Butte Basin Groundwater Model Update Phase II Report, prepared for Butte County Department of Water and Resource Conservation, March 2008.

CDM, 2008b, Butte Basin Groundwater Model Update, Base Case and Water Management Scenario Simulations, prepared for Butte County Department of Water and Resource Conservation, April 2008.

CH2MHill, 2009, Documentation of the SACFEM Groundwater Flow Model, Memorandum from Peter Lawson, CH2MHill, to Robert Niblack, California Department of Water Resources, July 2009.

CH2MHill, 2010, Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report, prepared in conjunction with MBK Engineers on behalf of Glenn Colusa Irrigation District and the Natural Heritage Institute, February.

CH2MHill, 2013, Sacramento Valley Groundwater Assessment Technical Memorandum 1, 2013.

Dawson, B.J., Bennett, G.L., V, and Belitz, Kenneth, 2008, Ground-Water Quality Data in the Southern Sacramento Valley, California, 2005—Results from the California GAMA Program: U.S. Geological Survey Data Series 285, 93 p. Available at pubs.usgs.gov/ds285

Doorenbos, J. and A.H. Kassam, A.H. 1979. Crop Yield Response to Water. United Nations Food and Agriculture Organization Irrigation and Drainage Paper No. 33. Rome, Italy.

Faunt, C. C. ed., 2009, Groundwater availability of the Central Valley Aquifer, California: Chapter C. Numerical model of the hydrologic landscape and groundwater flow in California's Central Valley, U. S. Geological Survey Professional paper 1766, pp. 121-212.

Faunt, C. C., Belitz, K., & Hanson, R. T., 2010, Development of a three-dimensional model of sedimentary texture in valley-fill deposits of Central Valley, California, USA, Hydrogeology Journal, v. 18, pp. 625-649.

Groundwater Resources Association of California (GRAC), 2005, California Groundwater Management, second edition.

Harbaugh, A.W., and McDonald, M.G., 1996, User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model. Open File Report 96-485. U.S. Geological Survey.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model — User guide to modularization concepts and the Ground-Water Flow Process, U.S. Geological Survey Open-File Report 00-92.

Harwood, D.S., E.J. Helley and M.P. Doukas, 1981, Geologic Map of the Chico Monocline and Northeastern Part of the Sacramento Valley, California: U. S. Geological Survey Miscellaneous Investigations Map I-1238, scale 1:62,500.

Harwood, D.S., and E.J. Helley, 1987, U.S. Geological Survey Professional Paper 1359, Late Cenozoic Tectonism of the Sacramento Valley, California.

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 Filed Studies Map MF-1790, 24 p., scale 1:62,500, 5 sheets.

Hull, L.C. 1984, U.S. Geological Survey Professional Paper 1401-B, Geochemistry of the Ground Water in the Sacramento Valley, California, Regional Aquifer System Analysis.

Ikehara, M.E., 1994, Global Positioning System Surveying to Monitor Land Subsidence in Sacramento Valley, California, USA: Hydrological Sciences Journal, V. 39, No. 5, pp. 417-429.

Lawrence Livermore National Laboratory (LLNL), 2005, California GAMA Program: Groundwater Ambient Monitoring and Assessment Results for the Sacramento Valley and Volcanic Provinces of Northern California, January.

McDonald M.G. and A.W. Harbaugh, 2003, The History of MODFLOW, Ground Water 41 (2): 280–283.

Olmsted, F.H., and G.H. Davis, 1961, U.S. Geological Survey Water Supply Paper 1497, Geologic Features and Ground Water Storage Capacity of the Sacramento Valley.

Page, R.W., 1986, U.S. Geological Survey Professional Paper 1401-C, Geology of the Fresh Ground-Water Basin of the Central Valley, California with Texture Maps and Sections, Regional Aquifer System Analysis.

Page, R.W., 1998, A Compressible Diatomaceous Clay, Sacramento Valley, California, in Land Subsidence, Case Studies and Current Research, Proceedings of the Dr. Joseph F.

Pinter, P.J., Jr., Hatfield, J.L., Schepers, J.S., Barnes, E.M., Moran, M.S., Daughtry, C.S. T., and Upchurch, D.R. 2003. Remote Sensing for Crop Management. USDA-ARS UNL Faculty. Paper 1372. Available at digitalcommons.unl.edu/usdaarsfacpub/1372.

Poland Symposium on Land Subsidence, J.W. Borchers, ed., Star Publishing Company, 576 p.

Russell, R.D., 1931, The Tehama Formation of Northern California, University of California Ph.D. Thesis, 142 p.

Schmitt, S.J., Fram, M.S., Milby Dawson, B.J., Belitz, K., 2008, Ground-water quality data in the middle Sacramento Valley study unit, 2006—results from the California GAMA program: U.S. Geological Survey Data Series 385, 100 p. Available at pubs.usgs.gov/ds/385.

Steduto, P., Hsiao, T.C., Fereres, E., and D. Raes. 2012. Crop Yield Response to Water. United Nations Food and Agriculture Organization Irrigation and Drainage Paper No. 66. Rome, Italy.

UC Center for Hydrologic Modeling (UCCHM), 2014, Water Storage Changes in California's Sacramento and San Joaquin River Basins From GRACE: Preliminary Updated Results for 2003-2013, February 3.

United Nations World Commission on Environment and Development (WCED), 1987, Report of the World Commission on Environment and Development: Our Common Future.

Williamson, A.K., D.E. Prudic and L.A. Swain, 1989, U.S. Geological Survey Professional Paper 1401-C, Ground-Water Flow in the Central Valley, California, Regional Aquifer System Analysis.

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground water and surface water—A single resource: U.S. Geological Survey Circular 1139, 79 p.

Appendix B: List of Tables

Table 2-1	Groundwater Basins and Subbasins of the Sacramento Valley	11
Table 2-2	Recent Annual Changes in Storage in the Sacramento Valley Groundwater Basin	15
Table 2-3	Sacramento River Hydrologic Region Average Annual Groundwater Supply by Type of Use (2005-2010)	17
Table 3-1	Groundwater Monitoring Programs and Databases in the Sacramento Valley	23
Table 3-2	Groundwater Models Developed for the Sacramento Valley	26
Table 3-3	Status of DWR Land Use Surveys for Sacramento Valley Counties for the Sacramento Valley	29
Table 3-4	Land Use Data Sources	30
Table 3-5	Inflows and Outflows Associated with the Sacramento Valley Water Balance	38
Table 3-6	Summary of Sacramento Valley Historical Water Balance from C2 Sim R374 for Agricultural, Urban, and Native Lands (TAF)	39
Table 3-7	Summary of Sacramento Valley Historical Water Balance from C2VSim R374 for Streams and Rivers (TAF)	39
Table 3-8	Summary of Sacramento Valley Historical Water Balance from C2VSim R374 for the Groundwater System (TAF)	40
Table 4-1	Summary of County Groundwater Ordinance Components in the Sacramento Valley	55
Table 4-2	IRWMP Efforts Related to 2006 Sacramento Valley IRWMP	58

Appendix C: List of Figures

Figure 1-1	Water Management in the Sacramento Valley	8
Figure 1-2	Study Area	9
Figure 2-1	Sacramento Valley Alluvial Groundwater Basins and Subbasins	11
Figure 2-2	Extents of the Tuscan and Tehama Formations	12
Figure 2-3	Spring 2010 Groundwater Elevation Contours in the Sacramento Valley	14
Figure 2-4	Spring 2005 – Spring 2010 Changes in Groundwater Levels, Sacramento Valley	16
Figure 2-5	Spring 2010 – Spring 2014 Statewide Changes in Groundwater Levels (Ongoing Drought Conditions)	17
Figure 3-1	Monitoring Well Location by Agency, Monitoring Cooperator, and CASGEM Monitoring Entity in the Sacramento River Hydrologic Region	21
Figure 3-2	Percentage of Monitoring Wells by Use in the Sacramento River Hydrologic Region	21
Figure 3-3	USGS NWIS Shallow Wells: Well Depth	25
Figure 3-4	USGS NWIS Shallow Wells: Sample Count	25
Figure 3-5	Sacramento Valley Groundwater Models	27
Figure 3-6	Conceptual Diagrams of Groundwater/Surface Water Interactions	33
Figure 3-7	Streamflow Depletion Caused by Groundwater Pumping	34
Figure 3-8	3-Dimensional Depiction of the Sacramento Valley Hydrologic System	37
Figure 3-9	Water Balance Schematic of the Sacramento Valley Differentiating the Land Surface from the Underlying Groundwater System and Surface Streams and Rivers	37
Figure 3-10	Sacramento Valley Irrigated Area as Indicated by NDVI and Hydrologic Year Type	42
Figure 3-11	Comparison of Estimated Irrigated Acres from Agricultural Commissioner Crop Reports and Landsat NDVI Analysis	43
Figure 3-12	Sacramento Valley Irrigated Area by Water Source	43
Figure 3-13	Sacramento Valley Irrigated Areaby Water Source Relative to 1985	43
Figure 3-14	Sacramento Valley Vegetation Intensity and Hydrologic Year Typ	43
Figure 3-15	Average Reported Yields for Selected Sacramento Valley Crops	44
Figure 3-16	Area-Weighted Average Yields Relative to 1985 for Major Sacramento Valley Crops	45
Figure 3-17	Valley-Wide Vegetation Intensity by Water Source	45
Figure 3-18	Valley-Wide Vegetation Intensity by Water Source Relative to 1985	45

Figure 3-19	Estimated Annual Diversions in the Sacramento Valley	46
Figure 3-20	Estimated Average Annual Diversions by Decade in the Sacramento Valley	46
Figure 3-21	Number of Well Logs Filed Per Year by Use for the Sacramento River Hydrologic Region (1977-2010)	46
Figure 3-22	Estimated Annual Pumping in the Sacramento Valley	47
Figure 3-23	Estimated Average Annual Pumping by Decade in the Sacramento Valley	47
Figure 3-24	Estimated Annual Accretions in the Sacramento Valley	47
Figure 3-25	Estimated Average Annual Accretions by Decade in the Sacramento Valley	47
Figure 3-26	Estimated Annual Deep Percolation in the Sacramento Valley	48
Figure 3-27	Estimated Average Annual Deep Percolation by Decade in the Sacramento Valley	48
Figure 3-28	Mid 2000s and Early 2010s Crop Acreages and Relative Percentages by Water Source for Drip, Surface, and Sprinkle Irrigation Methods (Butte, Glenn and Tehama Counties)	50
Figure 3-29	Sacramento Valley Absolute and Relative Surface Water and Groundwater Supplies by Subregion and Decade	51
Figure 4-1	Groundwater Management Plans in the Sacramento Valley	53
Figure 4-2	Integrated Regional Water Management Planning Efforts in the Sacramento Valley	57
Figure 5-1	Water Levels in a South Sutter Water District Groundwater Well Showing Recovery of Groundwater Levels with Increased Surface Water Deliveries Beginning in 1964	64
Figure 5-2	Water Levels in a Typical South Yuba Subbasin Groundwater Well Showing Immediate and Full Recovery of Groundwater Levels with Surface Water Deliveries Beginning in 1983	64
Figure 5-3	Water Levels in a Yolo County Groundwater Well Showing Recovery of Groundwater Levels with Increased Surface Water Deliveries Beginning in 1978	66
Figure 5-4	Sacramento Area Water Level Responses to Water Management Actions	68

Appendix D: Adopted Groundwater Management Plans in the Sacramento Valley

County	Document Name	Lead Agency	Adoption Date	Frequency of Updates
Butte	Butte County GWMP (AB3030)	Butte County Department of Water and Resource Conservation	2004	As-needed
Butte	Thermalito Irrigation District GWMP (i)	Thermalito Irrigation District	1995	
Butte/Glenn	Western Canal Water District GWMP	WCWD	2005 (h)	As funding is available
Butte	Richvale Irrigation District GWMP	Richvale Irrigation District	1995 (e)	
Butte	Biggs-West Gridley Water District GWMP	Biggs-West Gridley Water District	1995	
Butte	Butte Water District GWMP	Butte Water District	1996	
Colusa/Yolo	RD 108 GWMP	RD 108	Amended 2006 (d)	
Colusa	AB3030 Westside WD	Westside Irrigation District	2000	
Colusa	AB3030 RD1004 (i)	RD 1004		
Colusa	Colusa County GWMP	County Water Resources Dep't; Colusa County Groundwater Commission	2008	As funding is available

Plan Jurisdiction	GW Basin/ Subbasin Name	GW Basin/ Subbasin Number	Basin Management Objectives
Butte County	Vina Subbasin, West Butte Subbasin, East Butte Subbasin, North Yuba Subbasin	5-21.57, 5-21.58, 5-21.59, 5-21.60	Minimize longterm drawdown of groundwater levels; protect groundwater quality; protect against inelastic land subsidence; protect against impacts due to interaction with surface water; evaluate and manage groundwater replenishment and recharge
Thermalito Irrigation District			
Western Canal Water District	West Butte Subbasin, East Butte Subbasin	5-21.58, 5-21.59	
Richvale Irrigation District	East Butte Subbasin	5-21.59	
	East Butte Subbasin, Sutter Subbasin	5-21.59, 5-21.62	
	East Butte Subbasin, Sutter Subbasin	5-21.59, 5-21.62	
RD 108	Colusa Subbasin	5.21-52	
Westside Irrigation District	Colusa Subbasin	5.21-52	
Colusa County	Stonyford Town Area Basin, Bear Valley Basin, Little Indian Valley Basin, Funks Creek Basin, Antelope Creek Basin, Blanchard Valley Basin, Colusa Subbasin, West Butte Subbasin, Non-B118 Basin	5-63, 5-64, 5-65, 5-90, 5-91, 5-92, 5-21.52, 5-21.58	Ensure reliable and sustainable groundwater supply, levels, and quality; protect against inelastic land subsidence

County	Document Name	Lead Agency	Adoption Date	Frequency of Updates
Glenn	Glenn County GWMP	Glenn County	2009 (b)	As funding is available
Glenn	AB3030 Orland-Artois Water District	Orland-Artois Water District	2001 (c)	As funding is available
Glenn	Glenn-Colusa Irrigation District GWMP (AB3030)	Glenn-Colusa Irrigation District (GCID)	1993 (a)	As funding is available
Shasta	Coordinated AB 3030 GWMP for the Redding Groundwater Basin	Redding Area Water Council; Shasta County Water Agency	2007 (f)	As funding is available
Shasta	ACID GWMP	Anderson-Cottonwood Irrigation District (ACID)	2006	As funding is available
Sutter	Sutter County GWMP	Sutter County Public Works Department - Water Resources	2012	As needed
Sutter	Sutter Extension Water District GWMP	Sutter Extension WD	1995	As needed

Plan Jurisdiction	GW Basin/ Subbasin Name	GW Basin/ Subbasin Number	Basin Management Objectives
Glenn County	Colusa Subbasin, West Butte Subbasin, Corning Subbasin, Chrome Town Basin, Elk Creek Area Basin, Stonyford Town Area Basin, Stony Gorge Reservoir Basin, Squaw Flat Basin, Funks Creek Basin, Non-B118 Basin	5.21-52, 5-21.58, 5-21.51, 5-61, 5-62, 5-63, 5-88, 5-89, 5-90	Protect groundwater quality; adopt a monitoring program for groundwater levels, quality, and land subsidence; establish a water quality monitoring network
Orland-Artois Water District	Corning Subbasin	5-21.51	
Glenn-Colusa Irrigation District	Colusa Subbasin, Corning Subbasin, Non-B118 Basin	5-21.52, 5-21.51	Protection of natural recharge; protection and maintenance of groundwater quality; monitoring and prevention of basin overdraft
Redding Groundwater Basin	Anderson Subbasin, Enterprise Subbasin, Millville Subbasin	5-6.03, 5-6.04, 5-6.05	Avoid adverse effects to groundwater availability; develop a management program that enables reasonable use of the groundwater resources
	Anderson Subbasin, Enterprise Subbasin, Bowman Subbasin, Rosewood	5-6.03, 5-6.04, 5-6.01, 5-6.02	
Sutter County	East Butte Subbasin, Sutter Subbasin, North American Subbasin, South Yuba Subbasin	5-21.59, 5-21.62, 5-21.64, 5-21.61	
Sutter Extension WD	East Butte Subbasin, Sutter Subbasin	5-21.59, 5-21.62	Avoid ongoing declines in groundwater levels and problematically high levels; maintain or improve the groundwater quality; avoid inelastic land subsidence; protect against impacts due to interaction with surface water.

County	Document Name	Lead Agency	Adoption Date	Frequency of Updates
Sutter	Feather Water District GWMP	Feather Water District	2005	As needed
Sutter	RD 1500 GWMP	RD 1500	2012	As needed
Sutter	RD 787 GWMP (i)	RD 787	2005	As needed
Tehama	Tehama County GWMP	Tehama County Flood Control and Water Conservation District	2013 (g)	Every 5 years
Tehama	El Camino Irrigation District GWMP	El Camino Irrigation District	1995	
Yuba	Yuba County GWMP	Yuba County Water Agency	2010	Every 5 years
Yolo	City of Davis/UC Davis GWMP	City of Davis/UC Davis		
Placer	City of Lincoln GWMP	City of Lincoln	2003	
Solano	City of Vacaville GWMP	City of Vacaville	2011	
Yolo	City of Woodland GWMP	City of Woodland	2011	
Yolo	Dunnigan Water District GWMP	Dunnigan Water District	2007	
Yolo	RD 2035 GWMP	RD 2035	1995	
Yolo	RD 787 GWMP	RD 787	2005	

Plan Jurisdiction	GW Basin/ Subbasin Name	GW Basin/ Subbasin Number	Basin Management Objectives
Feather Water District	Sutter Subbasin	5-21.62	
RD 1500	Sutter Subbasin	5-21.62	
RD 787			
Tehama County	Bowman Subbasin, Rosewood Subbasin, South Battle Creek Subbasin, Red Bluff Subbasin, Corning Subbasin, Colusa Subbasin, Bend Subbasin, Antelope Subbasin, Dye Creek Subbasin, Los Molinos Subbasin, Vina Subbasin	5-6.01, 5-6.02, 5-6.06, 5-21.50, 5-21.51, 5-21.52, 5-21.53, 5-21.54, 5-21.55, 5-21.56, 5-21.57	Sustain groundwater levels above the alert levels over the long term through groundwater level monitoring, flow gradient analysis, quality sampling and analysis, and land subsidence monitoring and analysis
El Camino Irrigation District	Red Bluff Subbasin	5-22.50	
Yuba County	North Yuba Subbasin, South Yuba Subbasin	5-21.60, 5-21.61	Maintain sustainable groundwater basin elevations; protect against inelastic land surface subsidence; maintain and improve groundwater quality; manage groundwater to protect against adverse impacts to surface water flows.
City of Davis/UC Davis	Yolo Subbasin	5-21.67	
City of Lincoln	North American Subbasin	5-21.64	Maintain and protect groundwater quality; manage and protect groundwater supply adequately; protect against adverse impacts from groundwater and surface water interactions.
City of Vacaville	Solano Subbasin	5-21.66	
City of Woodland	Yolo Subbasin, Non-B118 Basin	5-21.67	
Dunnigan Water District	Colusa Subbasin	5-21.52	
RD 2035	Yolo Subbasin	5-21.67	Provide framework for protection and utilization of aquifer system underlying RD 2035
RD 787	Colusa Subbasin	5-21.52	

County	Document Name	Lead Agency	Adoption Date	Frequency of Updates
Lake	Lake County GWMP	Lake County	2006	
Solano	Maine Prairie Water District GWMP	Maine Prairie Water District	1995	
Colusa	Maxwell Irrigation District GWMP	Maxwell Irrigation District	2004	
Sutter/ Sacramento	Natomas Central Mutual Water Company GWMP	Natomas Central Mutual Water Com-pany	2009	
Solano	RD 2068 GWMP	RD 2068	2005	
Sacramento	Sacramento Central County Water Agency GWMP	Sacramento Central County Water Agency	2006	
Sacramento	Sacramento Groundwater Authority GWMP	Sacramento Ground-water Authority	2008	
Solano	Solano Irrigation District GWMP	Solano Irrigation District	2006	
Sutter/Placer	South Sutter Water District GWMP	South Sutter Water District	2009	

Plan Jurisdiction	GW Basin/ Subbasin Name	GW Basin/ Subbasin Number	Basin Management Objectives
Lake County	Upper Lake Valley Basin, Scotts Valley Basin, High Valley Basin, Burns Valley Basin, Coyote Valley Basin, Collayomi Valley Basin, Lower Lake Valley Basin, Long Valley Basin, Clear Lake Cahce Formation Basin, Middle Creek Basin, Gravelley Valley Basin	5-13, 5-14, 5-16, 5-17, 5-18, 5-19, 5-30, 5-31, 5-66, 5-94, 1-48	
Maine Prairie Water District	Solano Subbasin	5-21.66	Basin specific, but all include the following: prevent long-term declines in groundwater levels and maintain sustainable levels; increase monitoring of groundwater levels and quality; prevent inelastic land
Maxwell Irriga-tion District	Colusa Subbasin	5-21.52	
Natomas Central Mutual Water Company	North American Subbasin	5-21.64	
RD 2068	Solano Subbasin	5-21.66	
Sacramento Central County Water Agency	South American Subbasin, Cos-umnes Subbasin	5-21.65, 5-22.16	Maintain a constant groundwater extraction rate; develop specific water quality objectives; protect against any potential inelastic land surface subsidence and negative impacts to surface water.
Sacramento Groundwater Authority	North American Subbasin, Non-B118 Basin	5-21.64	Maintain or improve groundwater quality; maintain groundwater elevations; protect against inelastic land surface subsidence; protect against impacts due to interaction with surface water.
Solano Irrigation District	Solano Subbasin, Suisun-Fairfield Valley Basin, Non-B118 Basin	5-21.66, 2-3	Monitor and manage groundwater levels; maintain reliable groundwater quality; minimize risk of land surface subsidence.
South Sutter Water District	North American Subbasin	5-21.64	

County	Document Name	Lead Agency	Adoption Date	Frequency of Updates
Placer	Western Placer County Group GWMP	Western Placer County Group	2007	
Yolo	Yolo Flood Control & Water Conservation District	Yolo Flood Control & Water Conservation District	2006	
Alpine	Alpine County GWMP	Alpine County	2007	
Lassen	Lassen County GWMP	Lassen County	2007	

(a) Indicates GWMPs that are not on CWP Table SR-17 California Water Plan Update 2013 Table SR-17 shows tha
(b) California Water Plan Update 2013 Table SR-17 shows that this plan was adopted in 2009. The NSV IRWMP ir
(c) California Water Plan Update 2013 Table SR-17 shows that this plan was adopted in 2002. The NSV IRWMP ir
(d) California Water Plan Update 2013 Table SR-17 shows that this plan was adopted in 2008. The NSV IRWMP ir
(e) California Water Plan Update 2013 Table SR-17 shows that this plan was adopted in 1998. The NSV IRWMP ir
(f) California Water Plan Update 2013 Table SR-17 shows that this plan was adopted in 2007. The NSV IRWMP in
(g) California Water Plan Update 2013 Table SR-17 shows that this plan was adopted in 1996. However, Table SR-
(h) California Water Plan Update 2013 Table SR-17 shows that this plan was adopted in 2005. The NSV IRWMP ir

CH table lists only 21 GWMPs (and includes Amador, South Tahoe, and Napa) - they chose to only include the "la

Indicates GWMPs that are not on CWP Table SR-17

Plan Jurisdiction	GW Basin/ Subbasin Name	GW Basin/ Subbasin Number	Basin Management Objectives
Roseville, Lincoln, PCWA	North American Subbasin	5-21.64	Maintain and protect groundwater quality; manage and protect groundwater supply adequately; protect against adverse impacts from groundwater and surface water interactions.
Yolo Flood Control & Water Conservation District	Yolo Subbasin, Capay Valley Subbasin, Colusa Subbasin, Solano Subbasin	5-21.67, 5-21.68, 5-21.52, 5-21.66	Minimize long-term drawdown of groundwater levels and protect groundwater quality; minimize impacts on surface water flows and land surface subsidence.
Alpine County	Carson Valley Basin, Non-B118 Basin	6-6	
Lassen County	Long Valley Basin, Madeline Plains Basin, Willow Creek Valley Basin, Honey Lake Valley Basin, Grasshopper Valley Basin, Dry Valley Basin, Eagle Lake Area Basin, Big Valley Basin	6-104, 6-2, 6-3, 6-4, 6-94, 6-95, 6-96, 5-4	Maintain and protect groundwater uses and minimize long-term groundwater level drawdown; protect groundwater quality; protect inelastic land subsidence due to groundwater pumping; protect against impacts due to interaction with surface water.

t this plan was adopted in 1995. The NSV IRWMP information states 1993 as the date of adoption.

nformation states 2000 as the date of adoption.

nformation states 2001 as the date of adoption.

nformation states 2006 as the date of adoption.

nformation states 2005 as the date of adoption.

nformation states 2006 as the date of adoption. The GAR TM#1 states 2007 as the date of adoption.

-17 is based on information from August 2012. The NSV IRWMP information states 2013 as the date of adoption.

nformation states 1995 as the date of adoption.

arger county-wide GWMPs adopted within the study area").