Chapter 9
Groundwater Resources

9.1 Introduction

This chapter describes the environmental setting for groundwater resources, including the physical characteristics of the four groundwater subbasins (Eastern San Joaquin, Modesto, Turlock, and Extended Merced[1]) that underlie the surface water delivery areas from the three eastside tributaries.[2] It discusses the regulatory background associated with protecting groundwater resources and groundwater management and evaluates the potential environmental impacts on the groundwater basins, as a resource, which could result from the Lower San Joaquin River (LSJR) alternatives, if applicable, it also offers mitigation measures that would reduce significant impacts.

This chapter analyzes increased groundwater pumping, reduced groundwater recharge from surface water percolation, and related effects (e.g., subsidence) that may occur as a result of the effect of the LSJR alternatives on surface water supplies to the irrigation district service areas. This chapter discusses those potential groundwater supply and groundwater recharge effects under current regulatory conditions. Those current regulatory conditions include the Sustainable Groundwater Management Act (SGMA) (Wat. Code, § 10720 et seq.), which took effect January 1, 2015, and requires the formation of local agencies to protect and manage groundwater resources. SGMA is discussed in more detail below. Southern Delta water quality (SDWQ) alternatives are not discussed in this chapter because the SDWQ alternatives would not result in a change in groundwater pumping or groundwater recharge from surface water that currently takes place in the plan area. To comply with specific water quality objectives or the program of implementation under SDWQ Alternatives 2 or 3, construction and operation of different facilities in the southern Delta could occur, which could involve impacts on groundwater resources. These impacts are evaluated in Chapter 16, *Evaluation of Other Indirect and Additional Actions.*

As stated above, this chapter analyzes the groundwater basins in the study area as a resource. For a discussion of potential effects to agricultural lands from the LSJR and SDWQ alternatives, see Chapter 11, *Agricultural Resources*. Irrigation districts in the study area provide some municipal water supplies; this topic is discussed briefly in Section 9.2, *Environmental Setting*. However, multiple communities and water purveyors in the study area either do not have water supply contracts with the irrigation districts or are located outside the irrigation district service areas. Therefore, the potential impacts on municipal water suppliers and domestic wells from LSJR and SDWQ alternatives are addressed in Chapter 13, *Service Providers*.

As described in Chapter 2, *Water Resources,* the plan area overlay seven of the subbasins in the San Joaquin Groundwater Basin (Figure 2-3). The study area for groundwater, as defined in this chapter, includes the four main groundwater subbasins (the Eastern San Joaquin, Modesto, Turlock, and Merced) plus a small area of the Chowchilla Subbasin that is between the Merced Subbasin and the

---

[1] The *Extended Merced Basin* is used to reference the Merced Basin and a portion of the Chowchilla Basin, as defined in the body of the text above.

[2] In this document, the term *three eastside tributaries* refers to the Stanislaus, Tuolumne, and Merced Rivers.

Chowchilla River; this area is part of the surface water delivery area for the Merced River (Figure 9-1). The Merced Subbasin, with this added area, is referenced as the *Extended Merced Subbasin*. The study area represents the primary area that could potentially experience groundwater effects associated with the LSJR alternatives. The remaining portion of the Chowchilla Subbasin south of the Chowchilla River, the Tracy Subbasin, and the Delta-Mendota Subbasin, are not part of the study area because they are not part of the surface water delivery area for the three eastside tributaries.

The extended plan area, also described in Chapter 1, *Introduction*, generally includes the area upstream of the rim dams.[3] Unless otherwise noted, all discussion in this chapter refers to the plan area. Where appropriate, the extended plan area is specifically identified. In addition to the seven subbasins in the plan area, the extended plan area also includes the Yosemite Valley Basin.

In Appendix B, *State Water Board's Environmental Checklist*, the State Water Resources Control Board (State Water Board) determined whether the plan amendments[4] would cause any adverse impact for each environmental category in the checklist and provided a brief explanation for its determination. The Appendix B checklist identified LSJR alternatives as having a "Potentially Significant Impact" on groundwater resources as identified in Section IX(b) and VI(c). Accordingly, this chapter evaluates the potential impacts of the LSJR alternatives on groundwater resources and whether the alternatives would substantially deplete groundwater supplies or interfere substantially with groundwater recharge such that there would be a significant net deficit in aquifer volume or a significant lowering of the local groundwater table level. It also evaluates whether the potential impacts of the LSJR alternatives would result in subsidence. The potential impacts associated with groundwater resources and the LSJR alternatives are summarized in Table 9-1.

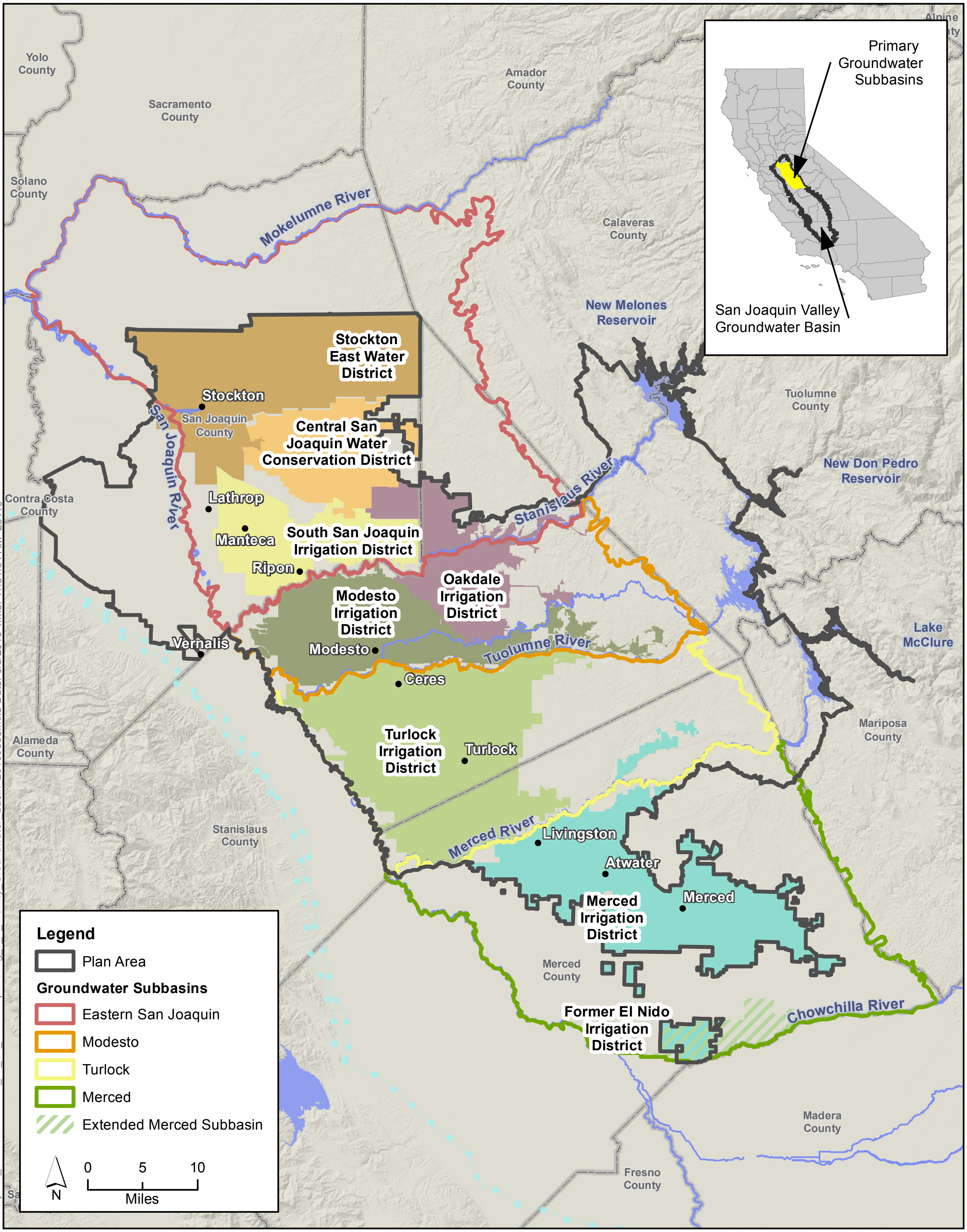
The impacts of the LSJR alternatives on groundwater elevations, aquifer storage, and risk of subsidence cannot be determined with certainty because groundwater conditions vary within each aquifer subbasin and water users would have varied responses to reduced surface water deliveries. In addition, SGMA, mentioned above, will impact groundwater management as it places a mandatory duty upon local agencies in high- and medium-priority groundwater basins to form groundwater sustainability agencies (GSAs) by June 30, 2017, in order to adopt and implement groundwater sustainability plans (GSPs) to sustainably manage groundwater resources.[5] Upon GSP adoption, SGMA grants a local GSA specific authorities to manage and protect its groundwater basin including, but not limited to, the ability to require reporting of groundwater withdrawals and to control groundwater extractions by regulating, limiting, or suspending extractions from wells. (Wat. Code, § 10726.4.) If a local agency is unwilling or unable to manage its groundwater resources to prevent undesirable results including, but not limited to, chronic lowering of groundwater levels, significant and unreasonable reductions in groundwater storage, and significant and unreasonable degraded water quality, then SGMA empowers the State to provide interim management until local agencies are able to assume management. SGMA is discussed in more detail in Section 9.3, *Regulatory Background.*

---

[3] In this document, the term *rim dams* is used when referencing the three major dams and reservoirs on each of the eastside tributaries: New Melones Dam and Reservoir on the Stanislaus River; New Don Pedro Dam and Reservoir on the Tuolumne River; and New Exchequer Dam and Lake McClure on the Merced River.

[4] These plan amendments are the *project* as defined in State CEQA Guidelines, Section 15378.

[5] The Modesto and Turlock Subbasins are listed as high-priority basins and the Eastern San Joaquin, Merced, and Chowchilla Subbasins are listed as high-priority and critically overdrafted basins. For critically overdrafted basins subject to SGMA, plans must be adopted by January 31, 2020. For all other basins subject to SGMA, the deadline is January 31, 2022. See the Sustainable Groundwater Management Act discussion in Section 9.3.2, *State [Regulatory Background].*



K:\Projects_2\SWRCB\00427_11_SJ_River\mapdoc\Fig_9_1_Vicinity_Groundwater_Basin_20160608.mxd Date: 6/8/2016 Time: 11:51:01 AM 25110

Figure 9-1
Vicinity Map of Groundwater Subbasins

However, since the groundwater protections that will be afforded by SGMA cannot be determined at this time with precision, this chapter evaluates the potential impacts on groundwater levels from LSJR alternatives without including SGMA as an ameliorating factor, which means that estimates of impacts are likely more conservative (i.e., worse) than would occur in the groundwater basins over time. Potential impacts from LSJR alternatives were evaluated by estimating increased levels of pumping to replace reduced surface water supplies and estimating reduced deep percolation of surface water in response to decreased conveyance and application of surface water. This analysis assumes that an average annual reduction in the groundwater balance for a subbasin caused by increased groundwater pumping and reduced recharge from surface water equivalent to 1 inch or more of water across the subbasin could be potentially significant: it could result in long-term groundwater resource impacts, including groundwater overdraft (i.e., pumping more than recharge over the long term), and reduced water levels at existing wells.

The impact analysis for this chapter uses results from the State Water Board's Water Supply Effects (WSE) model to determine if the LSJR alternatives would result in impacts on groundwater resources by increasing groundwater pumping and reducing groundwater recharge relative to the baseline water balance for each of the four subbasins in the study area. The WSE model estimates the various levels of demand and surface water diversions for each LSJR alternative. If crop needs are not fully satisfied by minimum groundwater pumping and surface water diversions, additional groundwater pumping is added based on the capacity of the groundwater pumping and distribution infrastructure. Because baseline is representative of 2009 infrastructure, the primary groundwater analysis utilizes estimates of maximum groundwater pumping that were possible in 2009. However, recent drought conditions have resulted in more wells being drilled. Therefore, estimates of maximum groundwater pumping for 2014 were also assessed. A detailed description of the groundwater analysis methods and results is provided in Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives: Methodology and Modeling Results*. A summary of the Appendix G analysis relevant to this chapter is provided in Section 9.4, *Impact Analysis.*

Impacts related to the No Project Alternative (LSJR/SDWQ Alternative 1) are presented in Chapter 15, *No Project Alternative (LSJR Alternative 1 and SDWQ Alternative 1),* and the supporting technical analysis is presented in Appendix D, *Evaluation of the No Project Alternative (LSJR Alternative 1 and SDWQ Alternative 1).* Chapter 16, *Evaluation of Other Indirect and Additional Actions,* includes discussion of impacts related to actions and methods of compliance.

Table 9-1. Summary of Groundwater Resources Impact Determinations

Alternative	Summary of Impact(s)	Impact Determination without Adaptive Implementation	Impact Determination with Adaptive Implementation[a]
Impact GW-1: Substantially deplete groundwater supplies or interfere substantially with groundwater recharge			
No Project Alternative (LSJR/SDWQ Alternative 1)	See note.[b]	Less than significant	NA
LSJR Alternative 2	The average annual groundwater balance is expected to be reduced by less than the equivalent of 1 inch across each of the subbasins. This is not expected to produce a measurable decrease in groundwater elevations. Therefore, there would not be a substantial depletion of groundwater supplies or substantial interference with groundwater recharge. However, if adaptive implementation method 1 were implemented on a long-term basis (an increase in the February–June percent of unimpaired flow from 20% up to 30%), the average annual groundwater balance could potentially be reduced by the equivalent of more than 1 inch across the Extended Merced Subbasin. If this occurred, it would eventually produce a measurable decrease in groundwater elevations. Therefore, there could be a potentially significant and unavoidable depletion of groundwater supplies or interference with groundwater recharge, and resulting potential migration of groundwater contamination in this subbasin under LSJR Alternative 2 with adaptive implementation.	Less than significant	Significant and unavoidable[c]
LSJR Alternative 3	The average annual groundwater balance could potentially be reduced by more than the equivalent of 1 inch in three subbasins (Modesto, Turlock, and Extended Merced). If this occurred, it would eventually produce a measurable decrease in groundwater elevations. The effect would be more severe during dry years and in areas farther from the SJR, the valley low point towards which groundwater slowly moves. Therefore, there could be a potentially significant and unavoidable depletion of groundwater supplies or substantial interference with groundwater recharge, and resulting potential migration of groundwater contamination under this alternative.	Significant and unavoidable	Significant and unavoidable

Alternative	Summary of Impact(s)	Impact Determination without Adaptive Implementation	Impact Determination with Adaptive Implementation[a]
LSJR Alternative 4	The average annual groundwater balance could potentially be reduced by more than the equivalent of 1 inch in all four subbasins. If this occurred, it would eventually produce a measurable decrease in groundwater elevations. The effect would be more severe during dry years and in areas farther from the SJR, the valley low point toward which groundwater slowly moves. Therefore, there could be a potentially significant and unavoidable depletion of groundwater supplies or interference with groundwater recharge, and resulting potential migration of groundwater contamination under this alternative.	Significant and unavoidable	Significant and unavoidable
Impact GW-2: Cause subsidence as a result of groundwater depletion			
No Project Alternative (LSJR/SDWQ Alternative 1)	See note. [b]	Less than significant	NA
LSJR Alternative 2	The average annual groundwater balance is expected to be reduced by less than the equivalent of 1 inch across each of the subbasins. This is not expected to produce a measurable decrease in groundwater elevations or associated subsidence. However, if adaptive implementation method 1 were implemented on a long-term basis (an increase in the February–June percent of unimpaired flow from 20% up to 30%), the average annual groundwater balance could potentially be reduced by the equivalent of more than 1 inch across the Extended Merced Subbasin. If this occurred, it could worsen subsidence that is already occurring in this subbasin. Therefore, subsidence could potentially significantly increase under LSJR Alternative 2 with adaptive implementation.	Less than significant	Significant and unavoidable[c]

Alternative	Summary of Impact(s)	Impact Determination without Adaptive Implementation	Impact Determination with Adaptive Implementation[a]
LSJR Alternatives 3 and 4	The average annual groundwater balance could potentially be reduced by more than the equivalent of 1 inch across three subbasins (Modesto, Turlock, and Extended Merced) under LSJR Alternative 3 and across all four subbasins under LSJR Alternative 4. If this occurred, it could worsen subsidence that is already occurring in the Extended Merced Subbasin. Therefore, there could be a potentially significant and unavoidable increase in subsidence under LSJR Alternatives 3 and 4.	Significant and unavoidable	Significant and unavoidable

[a] Four adaptive implementation methods could occur under the LSJR alternatives, as described in Chapter 3, *Alternatives Description*, and summarized in Section 9.4.2, *Methods and Approach*.

[b] The No Project Alternative (LSJR/SDWQ Alternative 1) would result in the continued implementation of flow objectives and salinity objectives identified in the 2006 *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary* (2006 Bay-Delta Plan). See Chapter 15, *No Project Alternative (LSJR Alternative 1 and SDWQ Alternative 1),* for the No Project Alternative impact discussion and Appendix D, *Evaluation of the No Project Alternative (LSJR Alternative 1 and SDWQ Alternative 1),* for the No Project Alternative technical analysis.

[c] Implementing adaptive implementation method 1 on a more frequent basis could result in a change in the impact determination for LSJR Alternative 2, as summarized in this table, and described in detail in Section 9.4.3*, Impacts and Mitigation Measures*.

9.2 Environmental Setting

This section describes the location, geology, aquifers, recharge and precipitation, groundwater quality, and groundwater use of the seven subbasins in the plan area, with a primary focus on the four subbasins in the study area. The boundaries of the seven subbasins underlying the plan area are described in Table 9-2.

9.2.1 San Joaquin Valley Groundwater Basin and Subbasins

The northern portion of the San Joaquin Valley Groundwater Basin, as defined in the California Department of Water Resources (DWR) Bulletin 118,[6] approximately coincides with the San Joaquin River (SJR) Hydrologic Region.

Although groundwater aquifers are connected between all the subbasins, rivers are generally used as the subbasin boundaries, with the SJR forming the western boundary, and the Mokelumne, Stanislaus, Tuolumne, and Merced Rivers forming the northern and southern boundaries of the four main subbasins underlying the plan area. The Merced-Madera County line and Chowchilla River are used for part of the southern boundary for the Merced Subbasin, but towards the west, the southern boundary is north of the county line and Chowchilla River and follows irrigation district boundaries. The eastern boundary for the four subbasins underlying the study area abuts the Sierra Nevada foothills. There are fewer wells along the eastern edge of the subbasins; the extent of the aquifers is largely unknown in areas without large municipal production wells as domestic wells are generally

[6] DWR's Bulletin 118 series of reports summarize and evaluate California groundwater resources.

unreliable indicators. Aquifer characteristics of these subbasins (Table 9-3) are described in *California's Groundwater*, the 2003 update of the DWR Bulletin 118 (DWR 2003a).

Table 9-2. Groundwater Subbasins Underlying the Plan Area

Subbasin	Subbasin Boundaries	Total Subbasin Surface Area (thousands of acres)	Critically Overdrafted
Eastern San Joaquin	Mokelumne River (north/northwest); San Joaquin River (SJR) (west); Stanislaus River (south); consolidated bedrock (east)	707	X
Tracy[a]	Mokelumne River and SJR (north); Diablo Range (west); San Joaquin-Stanislaus County line (south); SJR (east)	345	
Modesto	Stanislaus River (north); SJR (west); Tuolumne River (south); Sierra Nevada foothills (east)	247	
Turlock	Tuolumne River (north); SJR (west); Merced River (south); crystalline basement rock of the Sierra Nevada foothills (east)	349	
Merced	Merced River (north); SJR (west); Madera-Merced County line (south); Sierra Nevada foothills (east)	491	X
Delta-Mendota[a]	Stanislaus-San Joaquin County line (north); Coast Ranges (west); Fresno Slough (south); SJR and Chowchilla Bypass (east)	747	X
Chowchilla[a]	Triangular region bounded by the southern boundary of the Merced Subbasin (north); SJR and the eastern boundary of the Columbia Canal Company Service Area (west); a border extending south of Dry Creek to the juncture of Merced, Mariposa, and Madera Counties (south and east)	159	X

Sources: DWR 2003a, 2003b, 2003c, 2003d, 2003e, 2003f, 2003g, 2003h, 2016.

[a] The Tracy, Delta-Mendota, and Chowchilla Subbasins comprise very little of the plan area.

Table 9-3. Characteristics of Freshwater Aquifers of the Northern San Joaquin Valley Groundwater Subbasins

Aquifer Characteristic	Subbasin Occurrence							Aquifer Age	Thickness (feet)	Estimated Yield (gpm)	General Description	Comments
	Eastern San Joaquin	Tracy	Modesto	Turlock	Merced	Chowchilla	Delta-Mendota					
Younger Alluvium		X	X	X	X	X		Recent	0–100	Can yield significant water	Dredge tailing and stream channel deposits	Unconsolidated sedimentary deposits.
Older Alluvium (undifferentiated)		X		X	X	X		Pliocene to Pleistocene	150	–[a]	Alluvial fan deposits	One of main water-yielding units of the unconsolidated sedimentary deposits.
Older Alluvium (differentiated)[b]			X					Pliocene to Pleistocene	100–650	–	Alluvial fan deposits	One of main water-yielding units of the unconsolidated sedimentary deposits.
Alluvium and Modesto/ Riverbank Formations	X						X	Recent to Late Pleistocene	0–150	650+	Alluvial and interfan deposits	

Aquifer Characteristic	Subbasin Occurrence							Aquifer Age	Thickness (feet)	Estimated Yield (gpm)	General Description	Comments
	Eastern San Joaquin	Tracy	Modesto	Turlock	Merced	Chowchilla	Delta-Mendota					
Flood basin deposits (undifferentiated)	X	X	X	X	X	X	X	Recent to Pliocene	0–1,400	Low	Flood basin deposits	Unconsolidated sedimentary deposits. Generally poor water quality with occasional areas of fresh water. Basinward (finer-grained) lateral equivalents of the Tulare, Laguna, Riverbank, Modesto, and Recent formations occur within the Delta.
Laguna Formation	X							Pliocene to Pleistocene	400–1,000	Average of 900, but up to 1,500	Fluvial	
Mehrten Formation	X		X	X	X			Miocene to Pliocene	200–1,200	Approximately 1,000	Reworked volcaniclastics (permeable) and dense tuff breccia (confining units)	

Aquifer Characteristic	Subbasin Occurrence							Aquifer Age	Thickness (feet)	Estimated Yield (gpm)	General Description	Comments
	Eastern San Joaquin	Tracy	Modesto	Turlock	Merced	Chowchilla	Delta-Mendota					
Tulare Formation		X					X		1,400	Up to 3,000	Clay, silt, and gravel	Poor water quality above the Corcoran Clay, which occurs near the top of the formation.
Ione Formation			X	X	X			Miocene		Generally low		Consolidated sedimentary deposits. Lies in eastern portion.
Valley Springs			X	X	X			Eocene		Generally low		Consolidated sedimentary deposits. Lies in eastern portion.
Lacustrine and marsh deposits			X		X	X		Pliocene to present	50–200	–		Corcoran or E-clay aquitard. Lies in western portion.
Continental deposits				X	X	X	X	Pliocene to present		Generally low		One of main water-yielding units of the unconsolidated sedimentary deposits.

Aquifer Characteristic	Subbasin Occurrence Eastern San Joaquin	Tracy	Modesto	Turlock	Merced	Chowchilla	Delta-Mendota	Aquifer Age	Thickness (feet)	Estimated Yield (gpm)	General Description	Comments
Turlock Lake				X					150 (unconfined aquifer)	–		Unconsolidated sedimentary deposits. Lies in Western portion. Corcoran Clay aquitard separates into an upper unconfined and lower, confined aquifer.
Terrace deposits							X	Pleistocene		–		

Sources: DWR 2003a, 2003b, 2003c, 2003d, 2003e, 2003f, 2003g, 2003h.

gpm = gallons per minute

[a] California Department of Water Resources (DWR) has not estimated subbasin yield.

[b] Differentiated units are the Modesto, Riverbank, Victor, and Laguna formations.

Geology and Hydrogeology

Each groundwater subbasin may have multiple aquifers. Aquifers are underground layers of water-bearing permeable rock or unconsolidated materials (gravel, sand, or silt) from which groundwater wells can pump water. Each subbasin can be described by its surface area, boundaries (at bedrock or along streams), and geological layers (physical characteristics). This section provides a description of groundwater basin geology and the distribution and movement of groundwater within subbasin aquifers in the plan area.

Two distinct geologic areas are located in the eastern and western portions of the San Joaquin Valley Groundwater Basin. The eastern portion of the basin contains the Ione, Mehrten, Riverbank, and Modesto formations, which are composed primarily of sediments originating from the Sierra Nevada. The western portion of the basin is composed of the Tulare Formation, which is the primary freshwater unit. The Tulare Formation originated as eroded sediments from the Coast Ranges deposited in the San Joaquin Valley as alluvial fan, flood basin, delta or lacustrine, and marsh deposits. The presence of thick, fine-grained lacustrine (originating in lakes) and marsh deposits distinguishes the Tulare Formation from other hydrologic units. These fine-grained units can be up to 3,600 feet (ft) thick in the Tulare Lake Groundwater Basin, but more commonly occur as regional, laterally extensive deposits tens to hundreds of feet thick that create vertically differentiated aquifer systems. The most widespread of these fine-grained units, the Corcoran Clay, divides the groundwater in the Tulare Formation into an upper semi-confined zone and a lower confined zone.

Freshwater-bearing aquifers within the subbasins include younger alluvium, older alluvium, flood basin deposits, lacustrine and marsh deposits, continental deposits, Turlock Lake, terrace deposits, Laguna Formation, Mehrten Formation, Tulare Formation, Alluvium and Modesto/Riverbank Formations, Ione Formation, and Valley Springs. The older alluvium consists of loosely and moderately compacted sand, silt, and gravel, is moderately to locally highly permeable, and is one of the main water-yielding units of the unconsolidated sedimentary deposits (City of Tracy 2011; DWR 2003a, 2003b, 2003c, 2003d, 2003e). The younger alluvium contains actively accumulating deposits, including sediments deposited in the channels of streams, and consists of unconsolidated silt, fine-to-medium grained sand, and gravel that are highly permeable and, where saturated, can yield significant amounts of water (City of Tracy 2011). Because of their fine-grained nature, flood basin deposits generally have low permeability and yield low quantities of water that is typically also of poor quality (City of Tracy 2011; DWR 2003a, 2003b, 2003c, 2003d, 2003e). The Tulare Formation generally yields poor-quality water above the Corcoran Clay layer, but contains freshwater deposits below the Corcoran Clay. The Alluvium and Modesto/Riverbank formations consist primarily of sand and gravel in the fan areas, while clay, silt, and sand are dominant in the interfan areas. Because these units are not very thick, most wells penetrate them to tap deeper aquifers. The Laguna Formation consists of discontinuous layers of stream-laid sand and silt, with lesser amounts of clay and gravel. Table 9-3 summarizes aquifer characteristics in each subbasin from which irrigation districts and water districts draw.

Groundwater Use and Budget

The subbasin water budget is the fundamental description of the groundwater conditions and is the basis for evaluating groundwater impacts. The storage volume for the subbasin may be quite large if the freshwater aquifers extend relatively deep (e.g., 500 ft); however, water surface elevation (or depths to groundwater) is more often used to describe the subbasin storage and to identify whether the subbasin storage is steady (sustainable) or in decline (in overdraft). The inflows to the basin (recharge) may be from adjacent subbasins; from overlying rivers and streams; or from infiltration from rainfall, irrigation canals, reservoirs, and water applied to crops (i.e., applied water). The outflows from the subbasin are predominantly pumping from wells by irrigation districts, municipalities, or individual users for irrigating crops or as potable water sources. However, outflows can also include seepage to springs and rivers when the groundwater elevation is higher than that of the surface water. Figure 9-2 shows a conceptual water budget with various inflows and outflows.

Irrigated agriculture accounts for approximately 95 percent of the total water use in the Modesto, Turlock, and Merced Subbasins, with municipal water use accounting for approximately the remaining 5 percent (USGS 2010). Of that total water use, groundwater accounts for approximately 38 percent of the total supply in the SJR Hydrologic Region (DWR 2013). As discussed in Chapter 13, *Service Providers*, many San Joaquin Valley cities rely on groundwater either wholly or partially to meet municipal needs.

Groundwater pumping in this region has caused a decrease in groundwater levels in recent years (DWR 2015a), which indicates that groundwater pumping is exceeding the amount of water that recharges the basin. When groundwater pumping is greater than recharge over a period of years, the basin or subbasin is considered overdraft. Overdraft is characterized by groundwater levels that decline over a period of years and never fully recover, even in wet years. Overdraft can lead to significant impacts such as increased extraction costs, costs of well deepening or replacement, land subsidence, and degradation of groundwater quality (DWR 2003a).

Groundwater levels in the San Joaquin Valley Groundwater Basin have generally declined as a result of extensive agricultural pumping. Groundwater levels have declined by as much as 100 ft in some areas, primarily in the southern and western-most portions of the basin outside of the plan area (USGS 1999). In 2014, DWR evaluated groundwater elevation levels in California's 515 alluvial groundwater basins and subbasins, prioritizing groundwater basins on multiple factors including reliance on groundwater as a primary source of water for municipal and agricultural use. DWR identified the four subbasins underlying the plan area as high priority (DWR 2014a). Subsequently, DWR was statutorily required to identify groundwater basins and subbasins in a condition of critical overdraft, which was defined as "when a continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts." The resulting list of 21 critically overdrafted basins included the Eastern San Joaquin, Merced and Chowchilla Subbasins (DWR 2016; Table 9-2).

Water Balance Processes within Subbasins

This section describes the movement of water into and out of the groundwater subbasins in the plan area and the resulting known effects on groundwater elevations. This section also describes known subsidence issues in and surrounding the plan area.

Horizontal Groundwater Flow

Patterns of groundwater movement and rates of recharge in the San Joaquin Valley Groundwater Basin have been significantly altered from pre-agricultural and urban development conditions. Prior to development, groundwater generally moved from recharge areas in the higher grounds surrounding the San Joaquin Valley towards the valley trough. Most groundwater discharges (i.e., losses) resulted from evapotranspiration and groundwater discharge to surface waters. In contrast, the majority of groundwater recharge in subbasins today comes from surface water for irrigation. Losses today typically result from groundwater pumped from both the shallow, semi-confined upper aquifer (400–800 ft) and lower confined aquifer(s) (500–4,000 ft) of the San Joaquin Valley Groundwater Basin (Trump 2008). This is generally true unless one aquifer is substantially more permeable or if local groundwater quality issues that affect groundwater pumping exist. Groundwater in the plan area generally moves from high ground down towards the SJR and Delta. However, groundwater may also move into areas of substantial drawdown, such as toward the cone of depression in the eastern half of the Turlock Subbasin or the high groundwater pumping areas west of the SJR (USGS 2015).

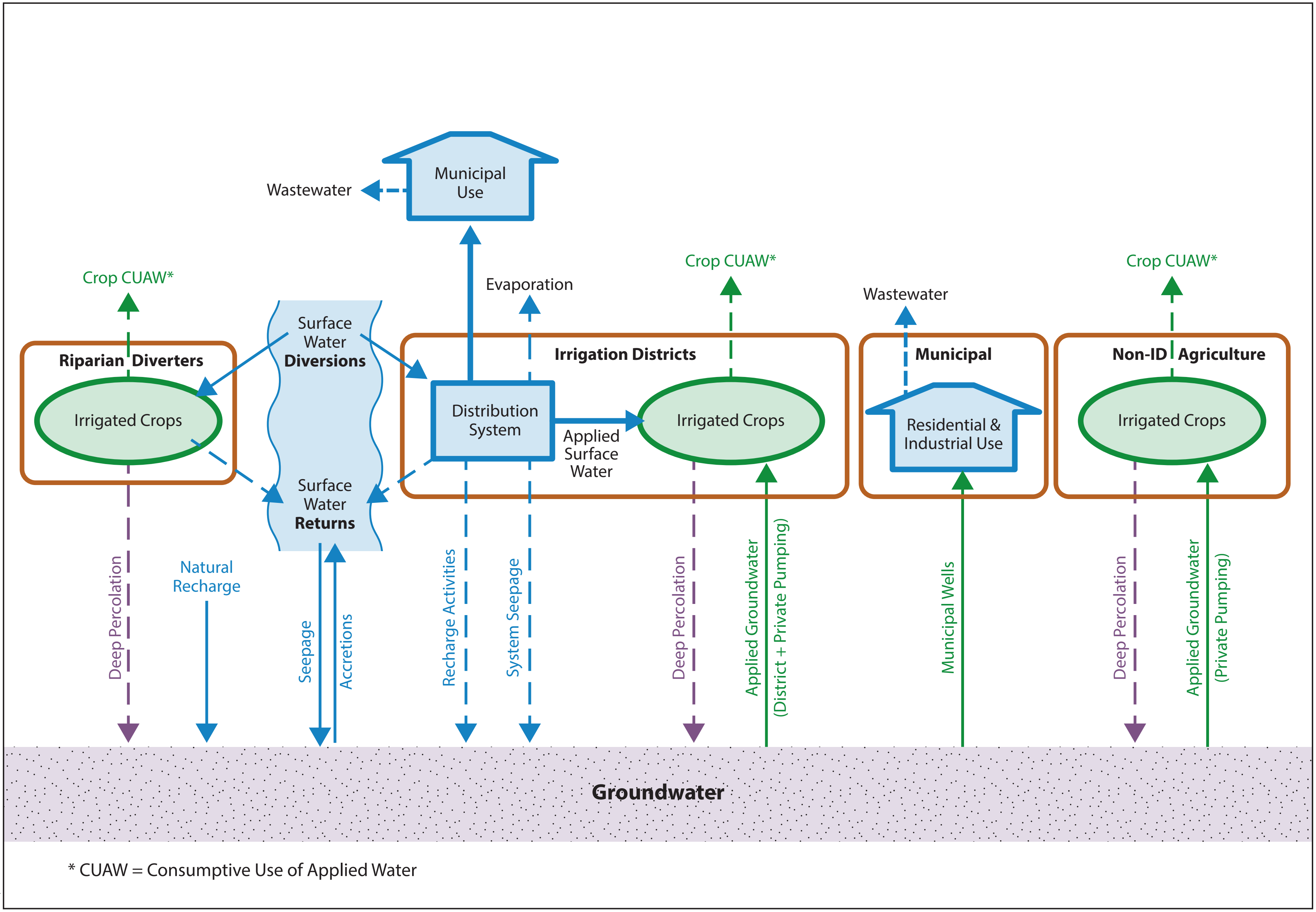
Inflows and Outflows

Each subbasin has a different surface area and different geological features (i.e., aquifer characteristics), and is subject to different pumping volumes. The inflows (i.e., recharge) are more difficult to estimate than outflows (e.g., pumping and other discharges), but the inflows must be similar to the pumping and other discharges in order to maintain groundwater levels in the subbasins. Mean annual rainfall in the plan area is low, ranging from 9 to 15 inches. Natural groundwater recharge from rainfall, streamflow, and lakes in the subbasins provide an important inflow component of the groundwater balance of each subbasin. This inflow is augmented by percolation of applied irrigation water and seepage from the distribution systems that convey this water (MAGPI 2008; TGBA 2008). Seepage originates from reservoirs, unlined water conveyances, and distribution canals. Major outflows occur through well pumping. However, other outflows include groundwater flowing to neighboring basins, seepage to springs, rivers, wetlands, and uptake by plants.

Interaction between Rivers and Groundwater

Stream seepage from the Stanislaus, Tuolumne, and Merced Rivers provides some portion of recharge to the underlying groundwater aquifers. Groundwater can flow to springs or rivers when the river elevation is less than the nearby groundwater elevation. Some sections of rivers are “losing” (i.e., the river recharges the groundwater) and other sections of rivers are “gaining” (i.e., groundwater discharges to the river). The upper reaches of the Stanislaus, Tuolumne, and Merced Rivers (downstream of Goodwin, La Grange, and Crocker-Huffman Dams) are losing rivers, with groundwater recharged by streamflow. The lower reaches of the rivers are gaining rivers, with groundwater discharging to the rivers (TGBA 2008; MAGPI 2008). Between 1997 and 2006, the net groundwater discharge to the lower reaches of the Tuolumne and Merced Rivers and along the entire reach of the SJR was estimated as a combined average of nearly 30 thousand acre-feet per year (TAF/y) (TGBA 2008). Other studies indicate that the SJR downstream of the Merced River is gaining (USGS 2015). Modeling results of groundwater-surface water interactions are not entirely consistent with this upstream versus downstream pattern. For example, based on modeling results performed for San Joaquin County to simulate a 5-year period (1989–1993), the Tuolumne River and upper SJR were gaining rivers, while the Stanislaus River and LSJR (from the Merced River to Vernalis) were losing rivers (NSJCGBA 2004).

In either the losing or gaining scenario, groundwater-surface water interactions are unlikely to have a large impact on total river flow. A recent modeling study of a region east of the SJR extending from north of the Stanislaus River to south of the Merced River indicated that groundwater-surface water interactions have a relatively small effect on river flow, generally changing flow by plus or minus 2 cubic feet per second (cfs) per mile (USGS 2015).



Graphics...00427.11 (10-5-2015)

Figure 9-2
Conceptual Water Budget

The depth to groundwater table (i.e., elevation of standing water in wells) of the near-surface unconfined aquifer is controlled by the surface water elevations of rivers and the amount of water moving in and out of the aquifer. SJR elevation generally increases from approximately 20 ft above mean sea level (MSL) in the north (mouth of Stanislaus River), to approximately 80 ft above MSL in the south (near the Merced–Madera County line), and to approximately 150–200 ft above MSL in the eastern portions of the subbasins along the Sierra Nevada foothills

Groundwater Balance and Elevations

A groundwater balance occurs naturally in an undeveloped aquifer system where inflows and outflows of groundwater are equal. Pumping for urban or agricultural uses changes the balance of the system and may lead to declining groundwater levels and land subsidence (USGS 1999). The general water balance condition (i.e., sustainable pumping or overdraft) of a subbasin can be identified by observing groundwater elevations over a number of years. Declining groundwater levels indicate overdraft, which occurs when average outflow from a subbasin exceeds average inflow to a subbasin. Steady or rising groundwater levels indicate that average pumping is less than or equal to the average net inflow. Increasing pumping in a subbasin is likely to reduce the average groundwater level (i.e., drawdown), with a noticeable effect on groundwater levels over a number of years.

Sustainable (or safe) yield represents a level of groundwater pumping that will not harm other resources. However, it is difficult to determine the sustainable yield of a subbasin because of the large degree of uncertainty associated with all components of the water budget. This includes the difficulty of determining whether a certain level of groundwater pumping will reduce accretions to surface water bodies by an amount that will be detrimental to surface water resources. Furthermore, sustainable yield estimates are highly dependent on recharge from surface water applications for irrigation and seepage from distribution systems. As such, if surface water applications are modified, then the subbasin's sustainable yield changes.

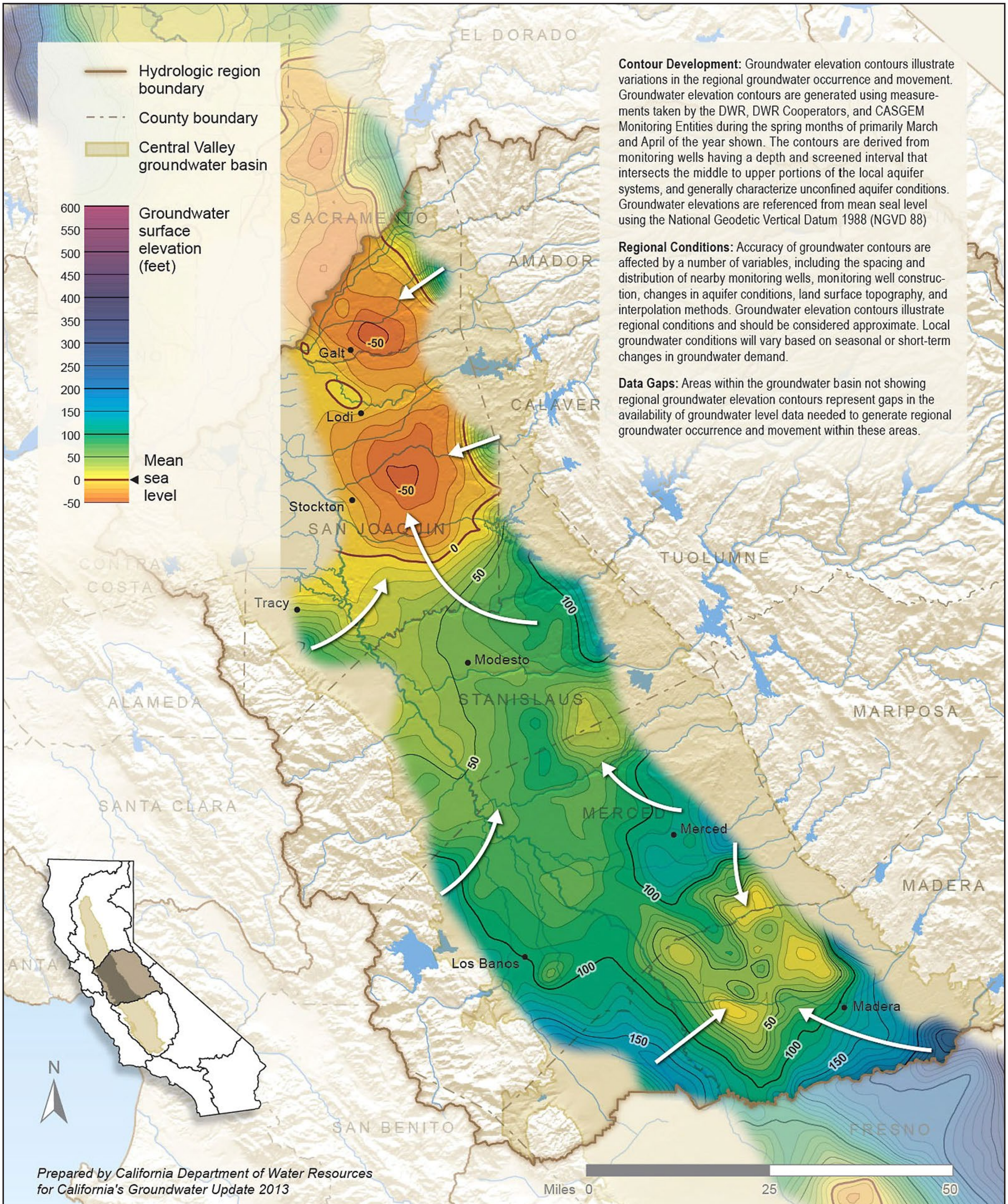
DWR and other agencies monitor groundwater elevations through a network of wells. Each groundwater management plan (GWMP, discussed in Section 9.3.3, *Regional or Local [Regulatory Background]*) prepared for the subbasins includes groundwater elevation contours for each year or every 3–5 years. The depth to groundwater in each well can also be plotted to determine the increases and decreases in the groundwater elevations through time. Groundwater elevations generally decrease during drought periods because the balance between recharge from surface irrigation and pumping for irrigation shifts to more pumping. This shift results in less recharge to the subbasins from surface water diversions and deliveries. Seasonal changes can also affect water table elevations. For example, groundwater elevations may increase slightly during the winter, from higher recharge, and decrease during the summer, from increased groundwater pumping. Seasonal changes in groundwater elevations are less apparent in subbasins with substantial surface water deliveries because the increased pumping coincides with the increased surface water recharge (from canals and applied water).

Figure 9-3 shows recent (2010) groundwater elevations in the San Joaquin Valley portion of the SJR region. The elevation contours show that groundwater elevations are shallowest along the Central Valley floor adjacent to the SJR and its tributaries, and are deepest along the eastern side of the Central Valley, where it abuts the lower foothills of the Sierra Nevada. The elevation contours also show areas of lower elevation (e.g., cones of depression) in some portions of the Turlock and Eastern San Joaquin subbasins (DWR 2015a). Between 2005 and 2010 the subbasins underlying the plan area saw generally small changes in groundwater elevations (Figure 9-4). However, larger decreases occurred along the eastern edges of the irrigation districts and some areas near and east of Stockton experienced increases in groundwater levels (DWR 2015a). More information regarding groundwater elevations related to each subbasin is provided in Section 9.2.2, *Subbasin Groundwater Use*.

Figure 9-5 shows the depth below ground surface to the groundwater level as contours for the San Joaquin Valley portion of the SJR region. The depth to groundwater is generally less than 20 ft along the SJR and western portions of each subbasin underlying the plan area, and increases to more than 100 ft in the eastern portions of the subbasins underlying the plan area. Despite intensive agricultural practices predominant in the valley, depth to groundwater is shallowest along the SJR because the volume of water transferred by SJR tributaries has resulted in a high, near-surface water table as an outcome of recharging shallow aquifers. The deeper depths to groundwater in the eastern portions of the subbasins are due to widespread agricultural development and a lack of surface water. In some locations near the SJR, groundwater is too close to the surface for agriculture, and districts have resorted to pumping groundwater to enhance drainage (DWR 2015a). However, Turlock Irrigation District (TID) and Modesto Irrigation District (MID) have decreased their drainage pumping between 1960 and 2004 (USGS 2015).

Although much of the plan area saw only small changes in groundwater elevations in recent years (Figure 9-4), the San Joaquin Valley has a long history of declining groundwater levels due to overpumping. The most significant decline has occurred south of the study area; however, the four subbasins underlying the study area have all experienced groundwater level declines and overdraft (Table 9-4). The average groundwater level decline is difficult to estimate from scattered wells with incomplete data through time. Overdraft estimates vary because of the use of different data, time periods, and underlying assumptions. Much of the data is incomplete or only represents a certain geography (e.g., county) of a total subbasin. Further, numbers can vary widely depend on what time period reviewed and specific yield[7] values used. Withdrawals and recharge from unconsolidated heterogeneous aquifer systems, like those underlying many locations in the San Joaquin Valley causes measurable elastic (recoverable) land subsidence. Removing water from storage in fine-grained silts and clays that are interbedded in the aquifer system can cause these highly compressible sediments to compact inelastically and permanently. Land subsidence from inelastic (non-recoverable) compaction is a common consequence of the significant groundwater level changes that can result from dependence on groundwater (Borchers et al. 2014).

[7] *Specific yield* is the ratio of the volume of water a saturate soil will yield by gravity drainage to the total volume of the soil.

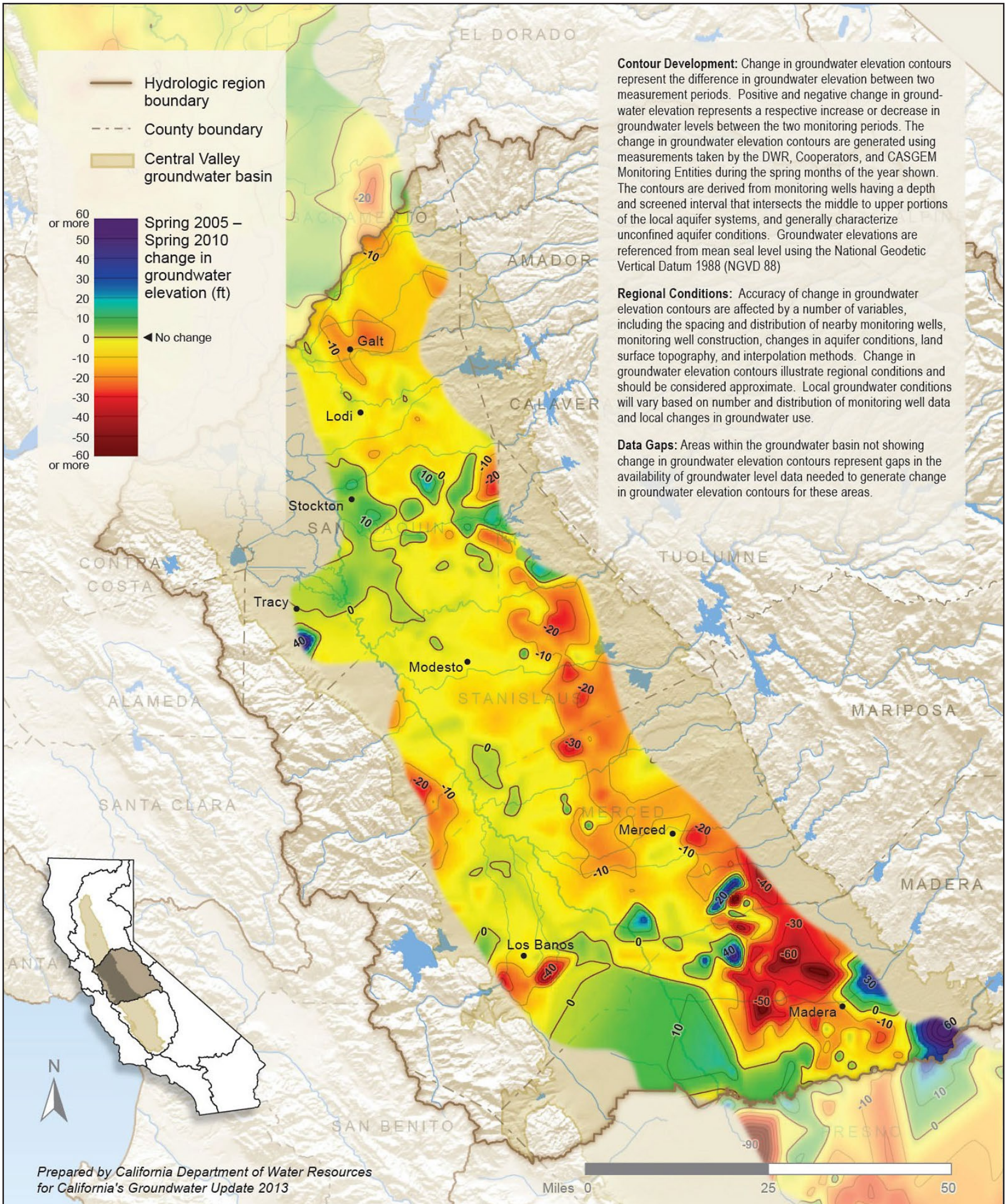


Graphics...00427.11 (10-2-2015)

Source: Figure 8-13 from DWR 2015.

ICF INTERNATIONAL

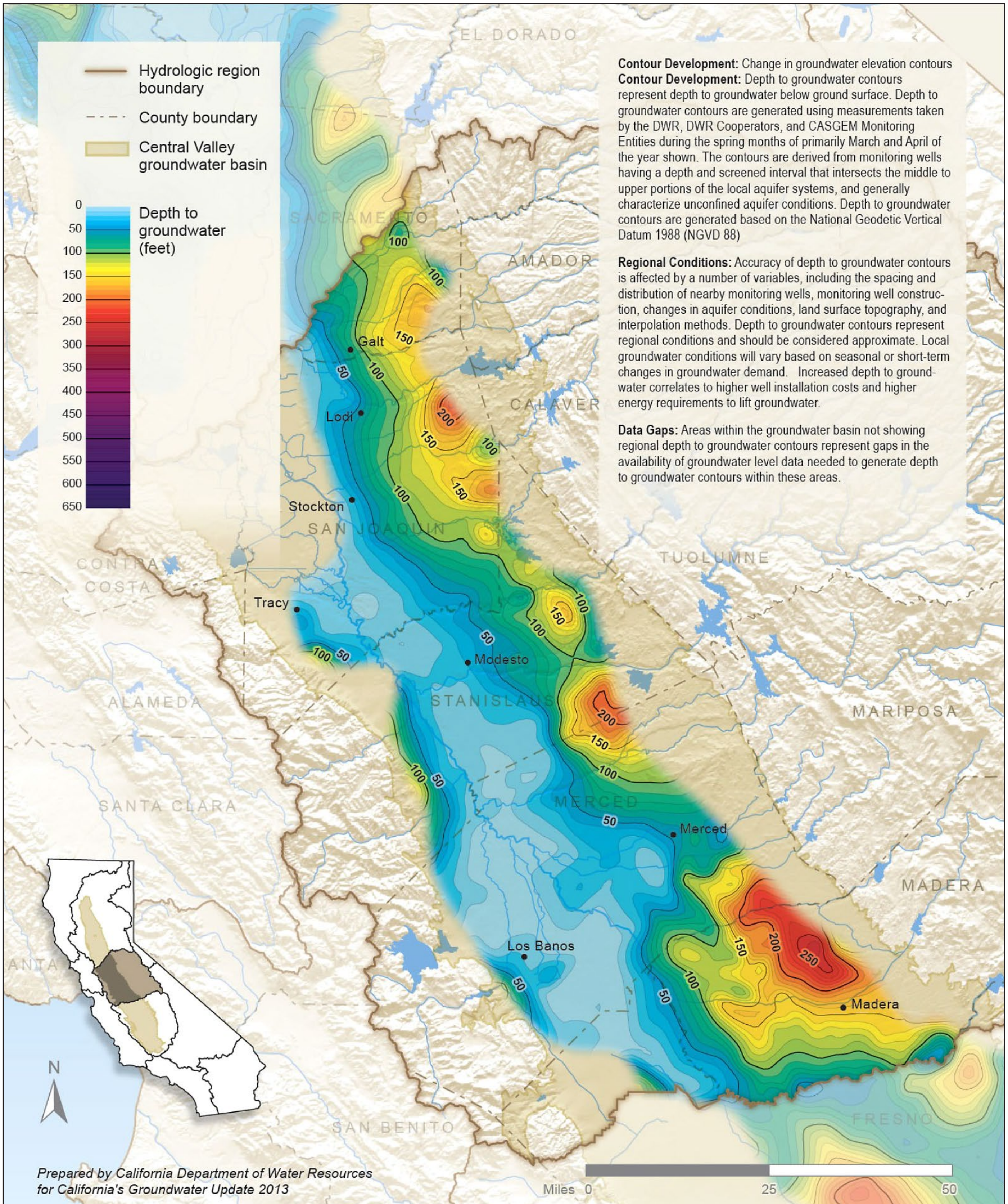
Figure 9-3
Spring 2010 Groundwater Elevation Contours for the San Joaquin Valley Portion of the San Joaquin River Hydrologic Region



Source: Figure 8-15 from DWR 2015.

Graphics...00427.11 (10-2-2015)

Figure 9-4
Change in Groundwater Elevation Contour Map for the San Joaquin Valley Portion of the San Joaquin Hydrologic Region (Spring 2005-Spring 2010)



Source: Figure 8-12 from DWR 2015.

ICF INTERNATIONAL

Figure 9-5
Spring 2010 Depth to Groundwater Contours for the San Joaquin Valley Portion of the San Joaquin River Hydrologic Region

Table 9-4. Estimates of Average Groundwater Level Decline and Overdraft in the Plan Area Subbasins

	Water Level Decline		Overdraft				
Subbasin	DWR Bulletin 118 (in/y)	DWR Groundwater Update 2013 (in/y)	DWR Bulletin 118[a] (TAF/y)	VAMP Supplemental EIR (TAF/y)	Turlock GW Basin Association (2008)[b] (TAF/y)	Turlock GW Basin Association (2003)[b] (TAF/y)	Merced County General Plan Update (2009) (TAF/y)
Eastern San Joaquin	20	5.3	88	–	–	–	–
Modesto	6.0	17	11	15	–	–	–
Turlock	2.8	20	9	85	21.5	30	–
Merced	12	27	44	20	–	–	27
Time Period	1970–2000	2005–2010	1970–2000	1960–1992[c]	1997–2006	1953–2002	1980–2007

Sources: DWR 2015b; DWR 2003b; DWR 2003c; DWR 2003d; DWR 2003e; USBR and SJRGA 2001; TGBA 2008; TGBA 2003; County of Merced 2009.

Note: The average groundwater level decline is difficult to estimate from scattered wells with incomplete data through time. Overdraft estimates vary because of the use of different data, time periods, and underlying assumptions.

DWR = California Department of Water Resources
EIR = Environmental Impact Report
in/y = inches per year
TAF/y = thousand acre-feet per year
GW = groundwater
VAMP = Vernalis Adaptive Management Plan
– = no data

[a] Values based on average water level decline, subbasin acres, and specific yield from DWR Bulletin 118.
[b] The overdraft is primarily located in the eastern part of the Turlock Subbasin.
[c] Exact years vary: Modesto Subbasin 1970–1990; Turlock 1971–1991; Merced Subbasin 1960–1992.

The extensive withdrawal of groundwater from the unconsolidated deposits has causes widespread land subsidence in the San Joaquin Valley (USGS 1986). Long-term groundwater level declines can result in a vast one-time release of "water of compaction" from compacting silt and clay layers in the aquifer system, which causes land subsidence (USGS 1999). Land subsidence in the region due to groundwater pumping began in the mid-1920s (USGS 1975; USGS 1991; USGS 1999). As surface water imports increased during the early 1950s through early 1970s and groundwater pumping decreased, groundwater levels began to recover and reduced the rate of land subsidence in some areas (USGS 1986). During the droughts of 1976–1977 and 1987–1992, reduced surface water availability once again led to increased groundwater pumping and re-initiating subsidence in the San Joaquin Valley. However, following each of these droughts, recovery to pre-drought water levels was rapid and subsidence virtually ceased (Swanson 1998; USGS 1999). During the more recent droughts of 2007–2009 and 2012–present, groundwater pumping and subsidence has increased in some parts of the San Joaquin Valley (Faunt 2015), including in the southern portion of the study area.

In the southern portion of the study area, increased dependence on groundwater during the recent drought resulted in groundwater levels approaching or surpassing historic lows, which caused aquifer-system compaction and land subsidence that most likely is permanent (Sneed and Brandt 2015). Between 2008 and 2010, the southern portion of the study area (Extended Merced Subbasin) experienced some level of subsidence, with the highest subsidence rate occurring around El Nido, which saw a decline of 540 millimeters (mm) (subsidence rate of 270 mm/y). This is among the highest subsidence rates ever measured in the San Joaquin Valley. Assuming the same rate of subsidence occurred during 2007–2014 as occurred during 2008–2010 at the local subsidence maximum near El Nido, approximately 2 meters of subsidence may have occurred during 2007–2014 (Sneed and Brandt 2015; Farr et al. 2015). The periphery of the El Nido subsidence area, both inside and outside the study area, showed seasonally variable subsidence and compaction rates. Groundwater-dependent areas that have not historically depended on surface water supplies experienced fairly consistent rates of groundwater level decline during and between drought periods. Those areas that increased groundwater-dependence while surface water was curtailed experienced subsidence during the drought periods, but very little subsidence between drought periods (Sneed and Brandt 2015).

9.2.2 Subbasin Groundwater Use

This section provides an overview of groundwater use in the four main subbasins underlying the plan area (Eastern San Joaquin, Modesto, Turlock, and Merced) and allows for comparisons between subbasins. The overview is followed by more specific information for each subbasin, including information about irrigation districts, and the groundwater and surface water users of each irrigation district.

In some cases, the numeric values provided in the overview differ from the values in specific subbasin sections; this is due to differences in agencies' analysis. For example, most numbers shown in the tables are from DWR Bulletin 118, while other data and information come from county databases, DWR's 2013 Water Plan Groundwater Update (DWR 2015a), irrigation district agricultural water management plans (AWMPs), GWMPs, integrated regional water management plans (IRWMPs), and urban water management plans (UWMPs). While numbers may be inconsistent throughout this section, in general, the inconsistencies are minor and support scientifically sound conclusions about groundwater trends within the subbasins and the irrigation districts. Irrigation districts manage groundwater resources within their service areas; the groundwater subbasins underlying the plan and study areas are not adjudicated (DWR 2011).

More than half of all land within the study area is irrigated agriculture and the largest use of groundwater is for agricultural purposes. Although agricultural groundwater pumping is not generally measured, total groundwater pumping in each subbasin can be estimated indirectly from the DWR agricultural land surveys. The estimate uses the acres of each crop category within each subbasin or irrigation district boundary. Surface water is assumed to provide the majority of the irrigation districts' water; groundwater pumping is estimated for the irrigated areas that are not supplied with surface water.

Irrigation districts that divert water from the Stanislaus, Tuolumne, or Merced Rivers or the LSJR may also pump groundwater from the subbasins for agricultural or domestic water supplies. These irrigation districts include: South San Joaquin Irrigation District (SSJID), Oakdale Irrigation District (OID), Stockton East Water District (SEWD), Central San Joaquin Water Conservation District (CSJWCD), MID, TID, and Merced Irrigation District (Merced ID). Throughout the rest of this chapter, these districts that regularly receive surface water from the Stanislaus, Tuolumne, and Merced Rivers are collectively referred to as the "irrigation districts."

Other water suppliers in the study area include the Northern San Joaquin Water Conservation District (NSJWCD), Woodbridge Irrigation District (WID), Eastside Water District (EWD), and Ballico-Cortez Water District (BCWD). NSJWCD and WID pump groundwater from the northern portion of the Eastern San Joaquin Subbasin and receive surface water from the Mokelumne River (NSJCGBA 2004). EWD and BCWD are large groundwater users in the Turlock Subbasin; they also receive some surplus surface water from TID and Merced ID during wet weather seasons (TGBA 2008).

Table 9-5 shows the number of irrigated acres that lie within each groundwater subbasin separated by whether the acres are within or outside of the irrigation districts. These acres were estimated using information from the AWMPs prepared by irrigation districts in recent years (2012–2014) and DWR's 2010 agricultural land survey.[8] For more information, see Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives: Methodology and Modeling Results*.

The total irrigated land within each subbasin generally indicates the potential for agricultural pumping effects on the subbasin water balance. The Modesto Subbasin has the fewest acres of irrigated land overall, both by acreage and by percentage (116,000 acres and 47 percent total land, respectively) and the Turlock Subbasin has the greatest percentage of irrigated land (77 percent). However, the best indication of the potential for groundwater impacts that may occur if surface water diversions are reduced in drought years is the percentage of the irrigated area that falls within the irrigation district service areas and usually relies on surface water. Within irrigation district service areas, the Merced Subbasin has the fewest number of irrigated acres, both by acreage and by percentage (86,000 acres and 32 percent, respectively); the Modesto Subbasin has the greatest number of irrigated acres that falls within irrigation district service areas, when determined by percentage (77 percent).

Groundwater Quality

Groundwater quality varies substantially throughout the San Joaquin Valley Groundwater Basin. Poor water quality conditions caused by agricultural and industrial contaminants are more common in the surface aquifer at shallower depths. In addition to agricultural and industrial sources, trace elements (such as arsenic, manganese, vanadium, and uranium) that are naturally occurring in rocks and soils can come in contact with the water and present water quality problems.

Groundwater quality of the subbasins varies depending on the location, substrate material, and land use (e.g., agricultural or urban). The State Water Board's Groundwater Ambient Monitoring and Assessment Program (GAMA), referenced under Section 9.3.2, *State [Regulatory Background]*, provides a comprehensive assessment of the State's groundwater quality. GAMA's Priority Basin Project included the four groundwater basins in the study area. While GAMA demonstrated that groundwater quality in the four subbasins is relatively good (i.e., low salinity and low contaminant levels), organic constituents (i.e. volatile organic compounds [VOCs] and pesticides) and inorganic constituents (i.e., trace elements and nutrients such as nitrite and nitrate) have been detected in some of the primary aquifers in the study area. The GAMA Priority Basin Project is discussed in greater detail in Chapter 13, *Service Providers*.

[8] DWR 2010 agricultural land survey data are available as geographic information systems (GIS) coverages for each of DWR's Detailed Analysis Units (DAU).

Elevated salinity levels, measured as total dissolved solids (TDS) or electrical conductivity (EC),[9] are common in San Joaquin Valley groundwater. Salinity is generally lower along the eastern side of the San Joaquin Valley Groundwater Basin than on the western side, and is generally higher in the shallow aquifer than the deep aquifer. The relatively low groundwater salinity on the eastern side can be attributed to the low salinity of Sierra Nevada runoff and application of surface water as a major irrigation source in the subbasins. However, there are some localized issues. For example, increased levels in groundwater salinity have been detected in the Stockton area due to a lateral saline front to the west (NSJCGBA 2004). In the Merced Groundwater Basin, high TDS concentrations are principally the result of the migration of a deep saline water body which originates in regionally deposited marine sedimentary rocks that underlie the San Joaquin Valley. Under natural pressure, the saline groundwater body is migrating upward. But pumping by deep wells in the western and southern parts of the Merced Subbasin may be causing these saline brines to upwell and mix with fresh water aquifers more rapidly than under natural conditions (MAGPI 2008).

As discussed above, over pumping of groundwater has been depleting the groundwater resources in the Central Valley. A change in groundwater gradient associated with groundwater pumping can indirectly influence groundwater quality in the subbasins. If there is a source of groundwater contamination in an area, groundwater pumping can influence the movement of contaminants toward wells. See Section 13.2.1, *Lower San Joaquin River and Tributaries,* for details of how over-pumping can affect groundwater quality.

For example, while the San Joaquin Valley is not characterized by high concentrations of nitrates at the depth zone used for public supply, application of fertilizers and animal manure to agricultural land has caused downward movement of nitrates into the soil. As groundwater pumping continues and as irrigation water containing elevated concentrations of nitrate moves toward and through deeper parts of the aquifer, high concentrations of nitrates in the public water supply could be a concern in the future (Belitz et al. 2015).The slow movement of water from the surface through the unsaturated zone to deep aquifers means that it may be many years after a persistent chemical has entered the ground before it affects the quality of groundwater supplies (Morris et al. 2003). Although the occurrence of trace elements (e.g., arsenic and uranium) is not anthropogenic, these elements can leach into groundwater and be mobilized by human activities (Smedley and Kinniburgh 2002; Barringer and Reilly 2013). For example, the downward infiltration of irrigation water with elevated bicarbonates caused movement of uranium in an area of the eastern San Joaquin Valley (Belitz et al. 2015).

Over 98 percent of Californians using a public water supply receive safe drinking water that meets all health standards (State Water Board 2013). In general, municipal drinking water wells do not exceed federal and state maximum contaminant levels (MCLs) for water quality. This is because municipal wells are generally deep, and water quality tends to be better in deeper aquifers. Furthermore, water quality is managed such that if the concentration of contaminants in well water exceeds criteria, the well can be brought offline or its water can be blended with higher quality water from other wells. In addition, water quality in community water systems are frequently

[9] In this document, EC is *electrical conductivity*, which is generally expressed in deciSiemens per meter (dS/m). Measurement of EC is a widely accepted indirect method to determine the salinity of water, which is the concentration of dissolved salts (often expressed in parts per thousand or parts per million). EC and salinity are therefore used interchangeably in this document.

monitored by the Division of Drinking Water and the service providers pursuant to various regulatory requirements stated in Section 13.3, *Regulatory Background*.

However, drinking water quality is still a concern in some areas of the four subbasins. Between 2002 and 2010, approximately one-fifth of the state's active community water system wells used by groundwater-reliant communities (i.e., groundwater is the primary source of drinking water) had contaminated groundwater with detections above an MCL two or more times (State Water Board 2013). Of the 510 active wells (serving 148 community water systems) within the four subbasins, 134 wells (serving 54 community water systems) had two or more MCL exceedances between 2002 and 2010. These exceedances reflect raw, untreated groundwater quality; as stated above, water systems that rely on contaminated groundwater typically treat their well water before it is served to the public. For example, the City of Livingston recently improved filtration in order to reduce arsenic concentrations that were above the state's MCL (Giwargis 2014).

Private drinking water wells may have more significant water quality issues than municipal wells because they are often shallower than municipal wells and, therefore, are more susceptible to surface contaminants. However, the state does not regulate the water quality of private drinking water wells, and does not require private drinking water well owners to test for water quality. As such, there is no comprehensive dataset on private drinking water quality, and there is a lack of water quality data for private drinking water wells within the study area.

Although, as stated above, groundwater pumping can influence the movement of contaminants toward wells, specifically determining the changes to groundwater quality is speculative as it is dependent of many factors including, but not limited to, location and depth of the well, the amount and frequency of groundwater pumping, number and proximity of nearby wells, hydrogeological characteristics of the aquifer (e.g., consolidated clays with low permeability or unconsolidated sands with high permeability), distance between the well(s) and the contaminant(s), contaminant characteristics (e.g., highly mobile in water or adhering primarily to soil), and land use near the well. Groundwater quality may also be affected by other factors such as improperly constructed wells that interconnect groundwater strata or introduce surface waters into underground waters (Wat. Code, § 231) or by unused or abandoned wells that, due to the pumping of nearby wells, can draw poor quality water down and into the drinking water aquifer (State Water Board 2015).

Table 9-5. Summary of Irrigated Land in the Plan Area Subbasins

			Total Irrigated Area	
Subbasin	Total Land (1,000 acres)	Total Irrigated Area (1,000 acres and percent of total land)	Outside Irrigation Districts (1,000 acres and percent of total irrigated area)	Within Irrigation Districts (1,000 acres and percent of total irrigated area)
Eastern San Joaquin	707	386 (55%)	192 (50%)	194 (50%)
Modesto	247	116 (47%)	27 (23%)	89 (77%)
Turlock	349	269 (77%)	118 (44%)	151 (56%)
Merced	491	269 (55%)	182 (68%)	86 (32%)
Total	1,794	1,039 (58%)	518 (50%)	521 (50%)

Note: Irrigated acres are based on GIS analysis of DWR 2010 agricultural land survey data, at the detailed analysis unit (DAU) level, and 2012 AWMPs. For more information, see Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives: Methodology and Modeling Results*.

Table 9-6 shows the estimated groundwater pumping in each subbasin. The estimated groundwater pumping for normal years within the subbasins is estimated based on the acres of irrigated lands outside of the irrigation districts, the volume of municipal pumping for cities, and the minimum pumping volume reported within each irrigation district in normal years with full surface water diversions. Groundwater pumping for irrigated lands outside of the irrigation districts is estimated by multiplying estimates of applied water rates for different crop types by the number of acres of each crop type, as described in Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives: Methodology and Modeling Results*.

Groundwater pumping for irrigated lands outside the irrigation districts remains relatively constant during droughts. This is because crop needs are generally met with groundwater regardless of surface water availability (although crops may require more applied water in drought years than in normal years). However, groundwater pumping for irrigated lands within the irrigation districts typically increases in years when the available surface water supply is reduced. When surface water diversions are reduced during dry years, irrigation districts (or individual growers) may increase groundwater pumping to compensate for a portion of, or all of, the reduced surface water diversions. If historical conditions have provided nearly full surface water diversions in most years, an irrigation district may have a limited a capacity in regards to the quantity of groundwater that can be pumped. Minimum and maximum groundwater pumping in the irrigation districts are estimated, as described in Appendix G. Minimum groundwater pumping is expected every year; whereas maximum groundwater pumping is expected only when surface water is in such short supply that irrigation district wells would be fully utilized.

Table 9-6 Estimated Groundwater Pumping in the Plan Area Subbasins

Subbasin	Districts	District Irrigated Lands (1,000 acres)	Minimum Pumping (TAF/y)[a]	Maximum Pumping (TAF/y)[a]	Municipal Pumping (TAF/y)[b]	Irrigated Land Outside Districts (1,000 acres)	Pumping for Irrigated Lands Outside of Districts (TAF/y)[a, c]	Minimum Total Pumping (TAF/y)
Eastern San Joaquin	Total	194	167	353	47	192	446	658
	SSJID	59	26	59				
	OID north	23	8	17				
	SEWD and CSJWCD[d]	99	133	264				
	WID[e]	13	NA	0				
Modesto	Total	89	22	50	81	27	83	187
	OID south	31	10	22				
	MID	59	12	28				
Turlock	Total	151	82	137	65	118	351	498
	Turlock ID	146	81	125				
	Merced ID north	5	2	13				
Merced	Total	86	32	218	54	182	556	642
	Merced ID[f]	86	32	218				

SSJID = South San Joaquin Irrigation District
OID = Oakdale Irrigation District
SEWD = Stockton East Water District
CSJWCD = Central San Joaquin Water Conservation District
TAF/y = thousand acre-feet per year.
NA = Not Applicable (because groundwater pumping for WID land that is not supplied by surface water is included with the pumping for lands outside of the irrigation districts).
TID = Turlock Irrigation District
MID = Modesto Irrigation District
Merced ID = Merced Irrigation District
WID = Woodbridge Irrigation District

[a] Values derived as described in Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives: Methodology and Modeling Results*. These values are for the 2009 base year. Minimum and maximum pumping estimates for 2014 were also assessed as described in Section 9.4.3, *Impacts and Mitigation Measures*, and Appendix G.

[b] Source: Domestic/municipal pumping from DWR Bulletin 118 (DWR 2003a, 2003b, 2003c, 2003d, 2003e).

[c] Values may be slightly high because some surface water may be available to these areas (e.g., some Mokelumne River water for NSJWCD, some Merced ID deliveries to land outside the District, and surface water diversions by riparian users along the rivers).

[d] Minimum pumping estimate assumes that SEWD provides 50 TAF/y for urban use (based on SEWD AWMP) and that SEWD receives 67 TAF/y from Calaveras River (NSJCGBA 2004). Of the 99,000 acres of irrigated land, approximately 48,000 belongs to CSJWCD and 51,000 belongs to SEWD.

[e] Portion of Woodbridge ID with surface water supply from the Mokelumne River. This information is relevant because it means that this land within the subbasin does not depend entirely on groundwater.

[f] Merced ID irrigated land and groundwater pumping estimated for the Turlock and Chowchilla Subbasins not included.

Eastern San Joaquin Subbasin

The Eastern San Joaquin Subbasin has approximately 386,000 acres of irrigated land; 50 percent of these acres are potentially supplied with surface water from SSJID, OID, SEWD, CSJWCD, and WID (Table 9-5). The subbasin underlies the Cities of Manteca, Lathrop, and Stockton, which use groundwater for a large portion of their drinking water supply.

The Eastern San Joaquin Subbasin has been well studied. Unlike the other three subbasins discussed in this chapter (Modesto, Turlock, and Merced), there have been multiple efforts to estimate the water budget components and the subbasin's sustainable yield. Bulletin 118 (DWR 2003b) presents results from two studies. One study estimated a sustainable yield of approximately 740 TAF/y, based on the estimated agricultural pumping (762 TAF/y) plus municipal and industrial pumping (47 TAF/y) minus the overdraft (70 TAF/y) (SJCFCWCD 1985). The other study estimated the sustainable yield of San Joaquin County, which includes more than the Eastern San Joaquin Subbasin, to be 618 TAF/y (USBR 1996). Historically, pumping from agricultural, urban, and rural, wells has been greater than the subbasin's safe yield (SSJID 2012). The subbasin's estimated minimum total agricultural and municipal groundwater pumping is 658 TAF/y (Table 9-6). This pumping estimate represents a minimum amount of pumping; actual average pumping is greater in some years, especially during dry years when surface water supply is reduced.

Declining groundwater levels over a period of time indicate that groundwater use within a subbasin is unsustainable. Groundwater levels have declined over the past 40 years at an average rate of 1.7 feet per year (ft/y) and have dropped as much as 100 ft in some areas (USACE 2001). As of 2010, there was a fairly large cone of depression centered east of Stockton below SEWD and CSJWCD service areas (Figure 9-3). However this cone of depression is not as severe as it once was; between 2005 and 2010, groundwater elevations within some portions of this area showed some signs of improvement (Figure 9-4). During the recent drought, groundwater levels in the San Joaquin County continued to decline; between Spring 2014 and Spring 2015 average groundwater levels declined an average of 3 ft throughout the county, and between Spring 2015 and Spring 2016, average groundwater levels declined an additional 2 ft throughout the county (Breitler 2016). Additionally, reduced groundwater levels below Stockton have caused the migration of saline water from the west to move eastward into the basin. In some areas below Stockton, salinity concentrations in groundwater exceed drinking water standards (SEWD 2014).

In 2014, DWR's California Statewide Groundwater Elevation Monitoring (CASGEM) Program ranked the Eastern San Joaquin Subbasin as a high-priority groundwater basin, partially due to the basin's history of groundwater reliance for agricultural and municipal uses, seawater intrusion along a 16-mile front on the east side of the Delta, large areas of nitrate contamination, and long-term overdraft conditions (DWR 2014b). Additionally, DWR identified the Eastern San Joaquin Subbasin as a critically overdrafted basin (DWR 2016).

South San Joaquin Irrigation District

The SSJID derives its water supply from three sources: (1) surface water diverted from the Stanislaus River at Goodwin Dam, (2) groundwater, and (3) irrigation return flows from OID (SSJID 2011). Although the district receives the majority of its water from the Stanislaus River, groundwater provides important reserves that can supplement surface water during droughts (SSJID 2011). The Cities of Manteca, Ripon, and Escalon comprise approximately 10,000 acres of the SSJID service area (SSJID 2012). In 2005, SSJID began delivering treated surface water to Lathrop, Manteca, and Tracy through the South County Water Supply Program. SSJID also delivers untreated SSJID water to the City of Ripon (SSJID 2015); as of 2011, Ripon used these deliveries exclusively for groundwater recharge (SSJID 2011). The cities use groundwater to meet much of their demands, and some district growers use groundwater as a regular source for irrigation water. SSJID has leased private wells during droughts to augment water supplies to farmers, which can help to minimize cuts to city water supplies (SSJID 2011).

Groundwater recharge within the SSJID service area consists of seepage from SSJID canals and reservoirs and deep percolation of precipitation and applied irrigation water. On average, total recharge for 1994-2008 is estimated to be approximately 97 TAF/y with 52 percent of recharge originating from canal seepage and 48 percent originating from deep percolation of applied water (SSJID 2012). However, even with recharge efforts, groundwater levels continue to decline east of Stockton and north of SSJID's service area where surface water supplies are limited. Groundwater levels in that area have declined to such an extent that groundwater flow under SSJID flows northerly rather than to the west (SSJID 2015). Declining groundwater levels continued during the recent drought; between Spring 2014 and Spring 2015, groundwater levels declined in 23 wells (of 29 wells with adequate groundwater level monitoring data to allow determination of groundwater level trends) in SSJID's service area. Of the remaining 6 wells, 4 wells showed localized increases in groundwater levels and 2 wells had no change in groundwater levels (SJCFCWD 2015).

Groundwater pumped for irrigation use in SSJID is generally of good quality. SSJID monitors 28 production wells for EC using permanently installed sensors. The San Joaquin County Flood Control and Water Conservation District (SJCFCWD) conducts annual groundwater quality monitoring in 26 wells in San Joaquin County, including within the district's service area. Monitored parameters include TDS, turbidity, chloride, and EC (SSJID 2012).

Oakdale Irrigation District

OID overlies two groundwater subbasins; 43 percent (23,000 irrigated acres) overlies the Eastern San Joaquin Subbasin (OID 2012; Table 9-6) and 57 percent of OID's service area (31,000 irrigated acres) overlies the Modesto Subbasin. OID is described in the Modesto Subbasin section below.

Stockton East Water District

SEWD provides surface water for agricultural and urban uses and for groundwater recharge (SEWD 2014). SEWD has a number of surface water supply contracts with various entities; it can receive up to 40 TAF/y from New Hogan Reservoir, with an additional 27 TAF/y of New Hogan Reservoir water that is not used by Calaveras County Water District (NSJCGBA 2004). SEWD also has a contract with the U.S. Bureau of Reclamation (USBR) to receive 75 TAF/y from New Melones Reservoir through the Central Valley Project (CVP) (SEWD 2011a). However, during dry years, water delivery amounts may vary depending upon USBR water allocations. In the past, SEWD contracted with SSJID and OID to receive up to 30 TAF/y from the Stanislaus River. The agreement ended in 2009 but was extended beyond 2010 and may be renewed pending further studies (SEWD 2014). As of 2011, SEWD had two wells that are only used for emergency and dry year supply (SEWD 2011b). In critically dry years, SEWD contracts with farmers along their pipeline to pump groundwater to supply the treatment plant (SEWD 2011b).

SEWD delivers a minimum of 20 TAF/y of treated surface water to the City of Stockton, California Water Service Company, and San Joaquin County. The volume delivered to each retailer is based on the percentage of total groundwater and surface water used in each retailer's area during the previous year, which is updated every year. As of 2010, SEWD has 178 agricultural customers. Based on the 2010 SEWD water inventory, 127,575 AF of water was needed for crop irrigation. Based on actual agricultural water sales, 23,116 AF of surface water was provided by SEWD to agricultural customers, and 117,424 AF of private groundwater[10] was used for agricultural irrigation (SEWD 2014).

Measurements over the past 40 years show a fairly continuous decline in groundwater levels in the eastern San Joaquin County. As a result of groundwater pumping over many decades, a cone of depression exists east of the Stockton urban area (Figure 9-3). Groundwater levels and the extent of the overdraft issues in SEWD's service area have historically fluctuated depending on surface water availability and the district's reliance on groundwater. Water table levels in the southern and eastern areas of Stockton generally rose more than 50 ft during an 8-year period (1977–1985). Groundwater levels in the Stockton urban area and SEWD service area also rose after the 1987–1994 drought as surface water once again became more available and groundwater dependence declined. By 1999, the water table in the Stockton area was higher than the level recorded 20 years prior, reversing a downward trend that had taken place for many years as a result of pumping by various users (SEWD 2011b). SEWD has continued a conjunctive use management approach; between 2011 and 2014, SEWD pumped no groundwater. However, in 2015, as a result of extreme drought conditions and the 100-percent curtailment of water supply from New Melones Reservoir, SEWD resumed pumping groundwater (SEWD 2016). Due to resumed pumping, between Spring 2014 and Spring 2015, groundwater levels declined in 56 wells (of 69 wells with adequate groundwater level monitoring data to allow determination of groundwater level trends) in SEWD's service area. Of the remaining 13 wells, 9 wells showed localized increases in groundwater levels and 4 wells had no change in groundwater levels (SJCFCWD 2015).

Central San Joaquin Water Conservation District

The CSJWCD includes approximately 65,200 acres, of which approximately 48,000 acres are irrigated (Table 9-6); 670 acres of the districts total acreage are within the sphere of influence for the City of Stockton (NSJCGBA 2004). Historically, CSJWCD relied substantially on groundwater pumping for irrigation. CSJWCD is now contracted with USBR to receive up to 80 TAF/y of surface water from the Stanislaus River. However, during dry years, water delivery amounts may vary depending upon USBR water allocations, and the total contracted amount has never been fully delivered. Irrigation facilities have been installed and are operated by individual landowners through a surface water incentive program sponsored by the CSJWCD to mitigate declining groundwater levels in the area. SSJID and OID have occasionally made water available to CSJWCD for irrigation. Surface water deliveries from the New Melones Conveyance System allowed groundwater levels to increase by as much as 15 ft in some localized areas within the CSJWCD service area (NSJCGBA 2004). However, more recently groundwater levels have declined; between Spring 2014 and Spring 2015, groundwater levels declined in 36 wells (of 37 wells with adequate groundwater level monitoring data to allow determination of groundwater level trends) in CSJWCD's service area. The remaining well had no change in groundwater levels (SJCFCWD 2015).

Communities

The Eastern San Joaquin Subbasin has multiple communities and water purveyors that do not have water supply contracts with the irrigation districts discussed above or are located outside the

---

[10] SEWD does not sell groundwater but does quantify its use.

irrigation district service areas. The Cities of Lodi, Stockton, Lathrop, Manteca, and Ripon and Escalon rely solely or partially on groundwater to meet their needs (City of Ripon 2004; NSJCGBA 2004; San Joaquin County 2009). See Chapter 13, *Service Providers*, for additional information about municipal water use in the Eastern San Joaquin Subbasin.

Modesto Subbasin

There are approximately 116,000 acres of irrigated land in the Modesto Subbasin; 77 percent of these acres potentially being supplied with surface water from OID or MID (Table 9-5). The subbasin's estimated minimum total agricultural and municipal groundwater pumping is 187 TAF/y (Table 9-6).

Net groundwater overdraft for a portion of the subbasin has been estimated to be between 11 and 15 TAF/y (Table 9-4). DWR Bulletin 118 indicates groundwater levels in this subbasin decreased approximately 0.5 foot/year between 1970 and 2000 (DWR 2003c). Between 2005 and 2010, the largest decreases in groundwater elevation occurred in the eastern portion of this subbasin in the region not irrigated with surface water (Figure 9-4). Groundwater recharge is primarily from deep percolation of applied irrigation water and canal seepage from MID and OID facilities (STRGSA 1995, MID 2015). Seepage from Modesto Reservoir is also a significant contributor, contributing an estimated 24 TAF/y (MID 2015). Recharge on a lesser basis occurs from the subsurface flows originating from the eastern foothills and mountains, infiltration from minor streams, and percolation of direct precipitation.

In 2014, DWR's CASGEM Program ranked the Modesto Subbasin as a high priority groundwater basin, partially due to the basin's history of groundwater reliance for agricultural and municipal use, and water quality degradation due to industrial and agricultural practices (DWR 2014c).

Oakdale Irrigation District

OID overlies two groundwater subbasins; 57 percent of OID's service area (31,000 irrigated acres) overlies the Modesto Subbasin, with the other 43 percent (23,000 irrigated acres) overlies the Eastern San Joaquin Subbasin (OID 2012; Table 9-6). More than 95 percent of the water served by OID is surface water diverted from the Stanislaus River at Goodwin Dam into the Joint Supply Canal and the South Main Canal (USBR and SJRGA 1999). During dry periods when surface water supplies are limited, surface water is supplemented by groundwater pumping from 25 OID wells, with a combined maximum annual production capacity of approximately 38 TAF/y (OID 2012). Annual well production ranges between 1.5 and 16 TAF/y because wells are not operated continuously (OID 2012). Most private wells in the district are for small farm and domestic use (STRGBA 2005).

Groundwater recharge within OID consists of seepage from OID canals and deep percolation of precipitation and applied irrigation water. Estimates of recharge were derived from the groundwater balance analysis; average estimated recharge for all of OID was 12 TAF/y from drainage canals, 36 TAF/y from irrigation canals, 24 TAF/y from infiltration of applied water (to irrigated land), and 15 TAF/y from infiltration of precipitation. Because OID contributes to surface water recharge of the aquifer, groundwater levels in the portions of the Eastern San Joaquin Subbasin underlying the OID service area have decreased much less than groundwater levels than the rest of the subbasin (OID 2012).

Modesto Irrigation District

MID delivers water to approximately 59,000 acres of land (Table 9-6). MID has approximately 90 groundwater wells that maintain water levels below the root zone (i.e., drainage) in the western portion of the district. MID also supplements irrigation supplies from New Don Pedro Reservoir with groundwater when surface water is limited (MID 2012). Groundwater use in the MID service area varies year-to-year, typically increasing during drought years (STRGBA 2005). As of 2016, MID only pumps and delivers groundwater to supplement water supplies to agricultural customers and does not pump nor deliver groundwater supply to urban suppliers (City of Modesto and MID 2011, City of Modesto and MID 2016). The City of Modesto satisfies approximately half of its demand with MID surface water and half with groundwater from its own wells and recharges approximately 20 TAF/y through its 11,000 dry wells (City of Modesto and MID 2011; MID 2012).

Most of the groundwater recharge within the subbasin is the result of deep percolation of applied surface water to agricultural lands, seepage from canals and reservoirs, and deep percolation of precipitation and urban storm runoff. In recent years, MID has increased recharge activities; in 2009, total groundwater recharge was estimated at approximately 81 TAF, which increased to 152 TAF in 2012 (MID 2012; MID 2015). The majority of recharge comes from MID irrigation water; in 2009, total groundwater recharged by MID irrigation water is estimated to be 58 TAF/y (MID 2012), which increased to 108.5 TAF in 2012 (MID 2015). Additionally, approximately 91 percent of MID canals are concrete-lined, resulting in a relatively small amount of canal seepage (MID 2015).

Communities

The Modesto Subbasin has multiple communities and water purveyors that do not have water supply contracts with the irrigation districts discussed above or are located outside of the irrigation district service areas. The Cities of Oakdale and Riverbank and smaller communities in Stanislaus County generally rely solely on groundwater to meet their needs (City of Oakdale 2009; STRGBA 2005). See Chapter 13, *Service Providers*, for additional information about municipal water use in the Modesto Subbasin.

Turlock Subbasin

There are approximately 269,000 acres of irrigated land in the Turlock Subbasin; 56 percent of these acres potentially being supplied with surface water from TID or a small portion from Merced ID (Tables 9-5 and 9-6). Between 1997 and 2006, total agricultural and municipal groundwater pumping in this subbasin was approximately 457 TAF/y (TGBA 2008). The subbasin's estimated minimum total agricultural and municipal groundwater pumping is 498 TAF/y (Table 9-6).

Groundwater recharge sources include irrigation of crops and landscape vegetation, precipitation, percolation from the Tuolumne and Merced Rivers, seepage from irrigation canals and Turlock Lake, groundwater recharge programs, percolation from Sierra Nevada foothill streams, and upward seepage from deeper aquifers (below the Corcoran Clay) (TID 2008). The upper reaches of the Tuolumne and Merced Rivers provide infiltration recharge (i.e., losing rivers), but the aquifer contributes water (through springs and seeps) to the lower reaches of the Tuolumne and Merced Rivers (i.e., gaining rivers) (TID 2008). Recharge from croplands is estimated to be 375 TAF/y, while recharge from landscaping within urban areas is estimated to be 18 TAF/y (TGBA 2008).

Net groundwater overdraft for the subbasin is estimated to be between 9 and 85 TAF/y (Table 9-4). Between 1970 and 2000, groundwater levels in the Turlock Subbasin declined approximately 7 ft (or 0.25 ft/y), with greater declines in the eastern portion of the subbasin after 1982 (DWR 2003d). There is a fairly large cone of depression in the eastern portion of the Turlock Subbasin below land primarily irrigated with groundwater. In 2010, groundwater elevations were at a high of 100 ft above MSL in the middle portion of the subbasin, but dropped down to 25 ft above MSL in the eastern portion of the subbasin (Figure 9-3). Between 2005 and 2010, groundwater elevations in this eastern portion of the subbasin decreased by up to 30 ft (Figure 9-4).

In 2014, DWR's CASGEM Program ranked the Turlock Subbasin as a high priority groundwater basin, partially due to the basin's history of groundwater reliance for agricultural and municipal use, and overdraft issues (DWR 2014d).

Turlock Irrigation District

TID utilizes a combination of surface water and groundwater to supply water to its agricultural users (TGBA 2008). Agricultural land within the TID service area is primarily irrigated with surface water, which is also a main source of recharge within the Turlock Subbasin (City of Modesto 2008). TID pumps approximately 65 TAF/y for drainage in the western portion of the district, and "rents" wells from growers during drought years (e.g., 1977, 1997–1992) (TGBA 2008). In addition, some growers pump groundwater to supplement their surface water allotments, while others use groundwater to meet their entire irrigation requirement. The minimum pumping within the district for drainage and irrigation is estimated to be 100 TAF/y, while the maximum groundwater pumping within the district is estimated to be 275 TAF/y (TGBA 2008).

Total recharge within the service area is estimated to average 238 TAF/y, with deep percolation of applied water and of precipitation averaging 156 TAF/y and 44 TAF/y (3.5 inches), respectively. Within the district, average groundwater pumping is estimated to be approximately 103 TAF/y (TID 2012).

Merced Irrigation District

Merced ID overlies three groundwater subbasins: 5 percent overlies the Turlock Subbasin, 86 percent overlies the Merced Subbasin, and the remaining 9 percent overlies the portion of the Chowchilla Subbasin that is analyzed with the Merced Subbasin as the "Extended Merced Subbasin" (Table 9-6). Merced ID is described in more detail under the Merced Subbasin section below.

Eastside Water District and Ballico-Cortez Water District

EWD and BCWD depend on groundwater from the Turlock Subbasin for water supply to irrigate approximately 54,000 acres and 67,000 acres, respectively (TID 2008). All irrigation facilities within the EWD and BCWD service areas are privately owned and operated. Growers have installed irrigation supply wells, as needed, to irrigated their crops (TGBA 2008). Growers pumped an estimated 180 TAF/y between 1997 and 2006 (City of Modesto 2008). With the exception of those properties adjacent to the rivers that have riparian water rights and can utilize surface water for irrigation, these districts rely upon groundwater for their entire water supply (City of Modesto 2008). The only other source of water supply is a very limited amount of surface water purchased in wet years from the TID and Merced ID canals adjacent to EWD. EWD does not own or operate water supply infrastructure (TGBA 2008). Groundwater levels in the vicinity have dropped dramatically since the mid-1950s. Groundwater levels within the EWD service area are declining approximately 2 ft/year, creating an average annual deficit of approximately 80 TAF (ESRWMP 2013).

Other Growers

Between 1997 and 2006, growers outside TID, EWD, and BCWD (i.e., located along the river margins and east of the EWD and BCWD service areas) pumped an average of 115 TAF/y (ESRWMP 2013). As agricultural development continues in these areas, dependence upon groundwater will likely increase (City of Modesto 2008).

Communities

The Turlock Subbasin has multiple communities and water purveyors that do not have water supply contracts with the irrigation districts discussed above or are located outside the irrigation district service areas. The Cities of Ceres, Delhi, Denair, Hickman, Hilmar, Hughson, Keyes, and Turlock generally rely solely on groundwater to meet their needs (TGBA 2008). Between 1997 and 2016, average municipal pumping was 44 TAF/y (TID 2008), somewhat less than DWR's estimated 65 TAF/y (DWR 2003d, Table 9-6). See Chapter 13, *Service Providers*, for additional information about municipal water use in the Turlock Subbasin.

Merced Subbasin

There are approximately 269,000 acres of irrigated land in the Merced Subbasin; 32 percent of these acres are potentially supplied with surface water from Merced ID (Table 9-5). The subbasin's natural recharge is 47 TAF/y, and approximately 243 TAF/y of applied water recharge occurs in the subbasin (Merced ID 2013a). Recharge and conservation projects provided an annual in-lieu recharge (i.e., replacing pumping with surface water) of approximately 60 TAF/y (MAGPI 2008). The subbasin's estimated minimum total agricultural and municipal groundwater pumping is 642 TAF/y (Table 9-6).

Long-term well level records show that groundwater elevations have declined with time throughout most of the subbasin; between 1980 and 2008, average levels declined 14 ft (MAGPI 2008). This is approximately half of the decline of 1 ft/y described above for 1970–2000 (DWR 2003e). Overdraft estimates for the subbasin range between 20 and 44 TAF/y (Table 9-4), with more severe water level declines in the eastern portion of the subbasin (DWR 2003e). Well data for 2010 indicate gradually increasing groundwater elevations from the SJR to the mountains and from north to south, which is what would be expected based on the effect of river elevation and topography on groundwater elevations (Figure 9-3). However, the southeast corner of the Merced Subbasin, an area with little surface water supply, has a cone of depression with groundwater elevations close to sea level (Figure 9-3).

In 2014, DWR's CASGEM Program ranked the Merced Subbasin as a high priority groundwater basin, partially due to the basin's history of groundwater reliance for agricultural and municipal use, and known overdraft and water quality degradation issues (DWR 2014e). Additionally, the CASGEM Program ranked the Chowchilla Subbasin (which, combined with the Merced Subbasin, comprises the Extended Merced Subbasin) as a high priority basin, partially due to the basin's history of groundwater reliance for agricultural use, and known overdraft, subsidence, and water quality degradation issues (DWR 2014f). In 2016, DWR identified both the Merced and Chowchilla Subbasins as critically overdrafted basins (DWR 2016).

Merced Irrigation District

As noted above, Merced ID overlies three groundwater subbasins; 5 percent of Merced ID's service area overlies the Turlock Subbasin, 9 percent overlies the Chowchilla Subbasin (or Extended Merced Subbasin), and the remaining 86 percent of Merced ID lands are located in the Merced Subbasin (Table 9-6). The portion of Merced ID that overlies the Chowchilla Subbasin is land that originally comprised the El Nido Irrigation District, which was incorporated into Merced ID in 2005 (Merced ID 2013a). Merced ID primarily uses surface water diversions from the Merced River to supply irrigation water to its service area. Merced ID supplements its surface water supply with groundwater for irrigation. The extent of Merced ID's groundwater supplementation varies year-to-year, depending on the availability of surface water (TGBA 2008). Merced ID owns, operates, and maintains 235 groundwater wells, of which 198 were operational in 2013. Some wells are operated to drain high water levels in the western part of the district's service area. However, the majority of these wells are left on standby to be operated for irrigation during years of surface water shortages. Merced ID's service area contains 1,764 acres of high ground (i.e., land higher than nearby canals) that are served by 8 TAF/y of groundwater pumping, although pumping has been reduced to 4 TAF/y with booster pumps that supply surface water from the canals (Merced ID 2013a). Between 2000 and 2008, Merced ID average groundwater pumping was 31 TAF/y, and active Merced ID customers pumped 32 TAF/y (Merced ID 2013a). During this period, it is estimated that private customers pumped between zero and 153 TAF/y (Merced ID 2013a).

Between 2000 and 2008, groundwater recharge within the Merced ID service area was estimated as deep percolation of applied water (60 TAF/y), canal seepage (98 TAF/y) and in-lieu recharge (32 TAF/y). Therefore, the total annual average estimated recharge from the Merced ID was 190 TAF/y (Merced ID 2013a). Merced ID delivers some water to Madera County, in the Chowchilla Subbasin, and other surrounding areas, such as Stevinson Irrigation District, the Merced Wildlife Refuge, and the City of Merced.

Communities

The Merced Subbasin has multiple communities and water purveyors that do not have water supply contracts with the irrigation district discussed above or are located outside the irrigation districts' service areas. The Cities of Atwater, Livingston, and Merced; the Black Rascal Mutual Water Company; Le Grand and Planada Community Service District; the Meadowbrook Water Company; and the Winton Water and Sanitary District generally rely solely on groundwater to meet their needs (MAGPI 2008). In 2007, total municipal pumping was estimated to be 50 TAF/y (Merced ID 2013a). The City of Merced receives the majority of its water supply from groundwater. However, the city is evaluating long-term and short-term water transfers and other options to obtain surface water and augment its groundwater supply (Merced ID 2013a). See Chapter 13, *Service Providers*, for additional information about municipal water use in the Eastern San Joaquin Subbasin.

9.2.3 Extended Plan Area

The extended plan area has no designated groundwater basins with the exception of the Yosemite Basin in Yosemite National Park in Mariposa County. This lack of designated groundwater basins is primarily due to the generally shallow-to-bedrock geology. Groundwater occurs in fractures in the bedrock and the local and regional rock fracture system characteristics influence water levels and well yields. Consequently, groundwater areas are often small, localized, and isolated from each other (DWR 2003h).

9.2.4 Southern Delta

Agricultural users in the southern Delta apply surface water to irrigate their crops. Some of the agricultural users apply additional surface water to reduce the salts in the root zone of the crops. However, the water sources in the southern Delta are primarily surface water coming from the southern Delta channels and not from groundwater pumping. Therefore, groundwater resources in the southern Delta are not discussed in this chapter.

9.3 Regulatory Background

9.3.1 Federal

Relevant federal programs, policies, plans, or regulations related to groundwater resources are described briefly below but relate principally to preventing the discharge of pollutants into waters of the United States and protecting public health by regulating drinking water. Additional information on both of the federal statutes listed below is found in Chapter 13, *Service Providers*.

Clean Water Act

The federal Clean Water Act (33 U.S.C., §§ 1251–1376) places primary responsibility for developing water quality standards on the states. The CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States and gives USEPA the authority to implement pollution control programs, such as setting wastewater standards for industry. The statute employs a variety of regulatory and non-regulatory tools to reduce pollutant discharges into waters of the United States, finance municipal wastewater treatment facilities, and manage polluted runoff.

Safe Drinking Water Act

The federal Safe Drinking Water Act (42 U.S.C., § 300 et seq.) protects public health by regulating the nation's public drinking water supply. In addition to drinking water itself, the act requires the protection of its sources, such as rivers, lakes, reservoirs, springs, and groundwater wells. The act authorizes the USEPA to set national health-based standards for drinking water, such as MCLs, to protect against contaminants that may adversely affect public health. In California, as of July 1, 2014, the State Water Board's Division of Drinking Water implements the Safe Drinking Water Act.

9.3.2 State

Relevant state programs, policies, plans, or regulations related to groundwater resources are described below. Until SGMA became effective in January 2015, the State regulated groundwater in a relatively minor capacity and considered groundwater management to be a local responsibility.

Sustainable Groundwater Management Act

On January 1, 2015, it became California state policy (Wat. Code, § 113) that "groundwater resources be managed sustainably for long-term reliability and multiple economic, social, and environmental benefits for current and future beneficial uses" and that sustainable groundwater management "is best achieved locally through the development, implementation, and updating of plans and programs based on the best available science." SGMA (Wat. Code, § 10720 et seq.) provides the framework to implement this policy by requiring that local agencies in high- and medium-priority basins[11] (DWR 2014a) form GSAs by June 30, 2017 that will develop and implement GSPs that achieve sustainable groundwater management within 20 years.

SGMA defines sustainable groundwater management as "the management and use of groundwater in a manner that can be maintained during the [50 year] planning and implementation horizon without causing undesirable results." Undesirable results are defined as any of the following effects.

- Chronic lowering of groundwater levels (not including overdraft during a drought if a basin is otherwise managed).
- Significant and unreasonable reduction of groundwater storage.
- Significant and unreasonable seawater intrusion.
- Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.
- Significant and unreasonable land subsidence that substantially interferes with surface land uses.
- Depletions of interconnected surface water that have significant and unreasonable adverse effects on beneficial uses of the surface water.

(Wat. Code, § 10721, subd. (x).) SGMA requires that critically overdrafted high- and medium-priority basins adopt GSPs by January 31, 2020 (DWR 2016). In the study area, that deadline applies to the Eastern San Joaquin, Merced, and Chowchilla Subbasins, which are listed as high-priority and critically overdrafted. All other high- or medium-priority basins must adopt GSPs by January 31, 2022. In the study area, this includes the Modesto and Turlock Subbasins, which are listed as high-priority basins.

If local agencies are unwilling or unable to manage their groundwater resources, SGMA authorizes the State Water Board to step in to protect a groundwater basin in limited circumstances: (1) if no agency has opted by the June 30, 2017 to serve as a GSA for a basin,[12] (2) when a GSA does not complete a GSP by the relevant deadline (2020 or 2022), or (3) when the GSP is inadequate or the GSP is not being implemented in a manner that is likely to achieve the plan's sustainability goal(s), and the basin is either in a condition of long-term overdraft or, after January 31, 2025, the State Water Board determines that the basin is in a condition where groundwater extractions result in significant depletions of interconnected surface waters.

SGMA is intended to promote coordinated management of a groundwater basins through GSA formation. While it is too early to know how GSAs will approach sustainable groundwater management, and GSPs will vary in terms of groundwater management components and implementation methods, sustainably management is a legal obligation. SGMA requires

[11] 127 of California's 515 alluvial groundwater basins, which account for 96 percent of California's annual groundwater pumping, were identified as high- or medium-priority. Prioritization factors include, but are not limited to, the level of population overlying the basin or subbasin, the projected rate of population growth for the basin or subbasin, the number of public supply wells dependent on the basin or subbasin, the irrigated acreage overlying the basin or subbasin, and the degree of reliance on groundwater. (Wat. Code, § 10933, subd. (b).)

[12] In addition, if an agency fails to form a GSA by the deadline, local groundwater users must begin reporting groundwater use to the State Water Board.

consideration of all stakeholder interests within their regions, including beneficial users of water, environmental interests, disadvantaged communities, tribes, and others. SGMA also includes provisions to protect water rights, including stating that nothing in SGMA "determines or alters surface water rights or groundwater rights under common law or any provisions of law that determines or grants surface water rights." However, between SGMA's enactment on January 1, 2015, and until the time that a GSP or its functional equivalent is adopted, SGMA prohibits groundwater extractions from being used as evidence of, or to establish or defend against, any claim of prescription. (Wat. Code, § 10720.5.) As a practical matter this means that pumping more groundwater after enactment of the Act and prior to adoption of the GSP will not later provide the basis for a claim that a groundwater right is larger than the right that existed on December 31, 2014.

Porter-Cologne Water Quality Control Act

As discussed in Chapter 1, *Introduction*, and Chapter 5, *Surface Hydrology and Water Quality*, the Porter-Cologne Water Quality Control Act is California's primary authority for regulating surface and groundwater quality. (Wat. Code, § 13000 et seq.) Under the Porter-Cologne Act, the state is divided into nine regions, and a Regional Water Board has the primary responsibility for protecting water quality within each region. The State Water Board oversees the Regional Water Boards' implementation of the Porter-Cologne Act and, together with the Regional Water Boards, implements the federal Clean Water Act. The Regional Water Boards have primary responsibility for the formulation and adoption of water quality control plans for their respective regions, subject to State Water Board and USEPA approval. The State Water Board may also adopt water quality control plans, which will supersede regional water quality control plans for the same waters to the extent of any conflict.

The SJR Basin falls within the jurisdiction of the Central Valley Regional Water Quality Control Board (Central Valley Water Board). The *Central Valley Board's Water Basin Plan for the Sacramento River and San Joaquin River Basins* (Basin Plan) specifies that all groundwater in the Region are considered as suitable or potentially suitable, at a minimum, for the following beneficial uses (Central Valley Water Board 2016).

- Municipal and domestic water supply (MUN)
- Agricultural supply (AGR)
- Industrial service supply (IND)
- Industrial process supply (PRO)

The Basin Plan provides certain exceptions for when these beneficial uses can be de-designated (e.g., when there is contamination or pollution in the groundwater that cannot reasonably be treated using either best management practices or best economically achievably treatment practices).

Groundwater Quality Protection Strategy for the Central Valley Region

In 2008, the Central Valley Water Board adopted Resolution No. R5-2008-0181 in Support of Developing a Groundwater Strategy for the Central Valley Region. In 2010, the Central Valley Water Board adopted Resolution No. R5-2010-0095 the Groundwater Quality Protection Strategy for the Central Valley Region, "a Roadmap", a long-term strategy that identifies high-priority activities. The roadmap recognizes the Central Valley Water Board's core responsibilities and existing commitments, and builds on existing processes. The roadmap is intended to be an overarching framework for long-range planning and is not a new regulatory program (Central Valley Water Board 2012).

California Statewide Groundwater Elevation Monitoring Program

The CASGEM program (Wat. Code, § 10920 et seq.) established a permanent, locally-managed program of regular and systematic monitoring and reporting in all of California's alluvial groundwater basins. The program relies on the many established local long-term groundwater monitoring and management programs and designates specific monitoring entities to report groundwater elevation data to DWR, which makes it available to the public. There is at least one CASGEM monitoring entity in each of the four subbasins underlying the study area (DWR 2015c). Monitoring entities began submitting CASGEM groundwater elevation data to DWR in January, 2012.

Groundwater Ambient Monitoring and Assessment Program

The GAMA is a comprehensive groundwater quality monitoring program based on interagency collaboration between the State Water Board, Regional Water Boards, DWR, Department of Pesticide Regulations, U.S. Geological Survey, and Lawrence Livermore National Laboratory (LLNL), and cooperation with local water agencies and well owners. GAMA is described in greater detail in Chapter 13, *Service Providers.*

Other State Authorities

State water law includes other more general authorities for the protection of groundwater resources including, but not limited to, the following.

Waste and Unreasonable Use

California Constitution Article X, Section 2 and California Water Code Section 100 prohibit the waste, unreasonable use, unreasonable method of use, and unreasonable method of diversion of water. The constitutional doctrine of reasonable use applies to all water users, regardless of basis of water right, serving as a limitation on every water right and every method of diversion (Peabody v. Vallejo [1935] 2 Cal.2d 351, 367, 372). California Water Code Section 275 directs the State Water Board (and DWR) to take all appropriate proceedings or actions to prevent waste or violations of the reasonable use standard. Thus, the State Water Board may initiate proceedings, either administratively or in court, to prevent the waste and unreasonable use of water.

The State Water Board also has authority to address the waste, unreasonable use, unreasonable method of use, and unreasonable method of diversion of water through quasi-legislative action. Questions of waste, unreasonable use, and unreasonable methods of use or diversion are factual and are determined according to the circumstances of a particular situation, limiting the utility of the regulatory process to only those cases where waste or unreasonableness can be clearly identified and prevented by an appropriately tailored regulatory response. Due to the highly complex nature of findings and proceedings, the State Water Board has only made the findings required to proscribe waste, unreasonable use, and unreasonable method of use or diversion through regulation twice. (Cal Code Regs., tit. 23, §§ 735, 862.)

Groundwater Adjudications

An adjudication is an action filed in Superior Court by one or more groundwater pumpers to comprehensively determine groundwater rights in a specified area. Through adjudication, the courts can assign specific rights to water users and can compel the cooperation of those who might otherwise refuse to limit their pumping of groundwater. The court retains continuing jurisdiction over the adjudicated area and typically appoints a watermaster to ensure pumping conforms to the adjudication's limits. In 2015, the Legislature passed Assembly Bill (AB) 1390 (Alejo), a statute to streamline the methods and procedures for groundwater adjudications (Code of Civil Proc., § 830 et seq.), and Senate Bill (SB) 226 (Pavley), a statute adding a new chapter to SGMA that requires adjudications in groundwater basins subject to SGMA be consistent with SGMA. (Wat. Code, § 10720.1 et seq.)

In addition, the State Water Board has the authority to file an adjudicative action to restrict groundwater pumping, or to impose a physical solution, or both, where necessary to protect groundwater quality. (Wat. Code, §§ 2100-2102.)

Area of Origin Limitations

The State Water Board has permitting authority over subterranean streams flowing in known and definite channels. (Wat. Code, § 1200.) Groundwater not flowing in a subterranean stream, such as water percolating through a groundwater basin, is not subject to the State Water Board's permitting jurisdiction. However, the State Water Board may exercise its authority under the doctrines of reasonable use and the public trust to address diversions of surface water or groundwater that reduce instream flows and adversely affect fish, wildlife, or other instream beneficial uses.

Pumping groundwater for export is prohibited "within the combined Sacramento and Delta-Central Sierra Basins…unless the pumping is in compliance with a groundwater management plan that is adopted by [county] ordinance." (Wat. Code, § 1220.) The statute enables, but does not require, the board of supervisors of any county within any part of the combined Sacramento and Delta-Central Sierra Basin to adopt GWMPs. GWMPs have been adopted in some counties, as described below.

9.3.3 Regional or Local

Relevant regional or local programs, policies, or regulations related to groundwater resources are described below. Although local policies, plans, and regulations are not binding on the State of California, below is a description of relevant ones.

Agricultural Water Management Plans

California Water Code Section 10800 et seq. requires an agricultural water supplier with greater than 25,000 irrigated acres to adopt and implement an AWMP to efficiently manage water resources within its service area. Several irrigation districts have prepared AWMPs that identify methods for dealing with water supply shortages; including reliance on groundwater. 2012 AWMPs that are relevant to the irrigation districts and four subbasins are summarized in Table 9-7. The AWMPs were reviewed for how they allocate water and their policies for water shortages; Table 9-8 compares the methods used in the AWMPs for dealing with surface water shortages.

In April 2015, Executive Order (EO) B-29-15 lowered the irrigated acreage requirement to 10,000 irrigated acres. Those agricultural water suppliers that supply water to 10,000 to

25,000 acres of irrigated lands are required to develop AWMPs and submit the plans to DWR by July 1, 2016 (these plans are called the 2015 AWMPs). EO B-29-15 also requires that 2015 AWMPs include a detailed drought management plan that describes the actions and measures the supplier will take to manage water demand during drought

Table 9-7. Relevant Agricultural Water Management Plans

Relevant Groundwater Subbasin	Entity/Entities	Document Title	AWMP Report Date	Adoption Date	County
Modesto	Modesto ID	Modesto ID AWMP for 2012	12/2012	12/2012	Stanislaus
Eastern San Joaquin, Modesto	Oakdale ID	Oakdale ID 2012 AWMP	12/2012	12/2012	San Joaquin, Stanislaus
Eastern San Joaquin	South San Joaquin ID	South San Joaquin ID 2012 AWMP	12/2012	12/2012	San Joaquin
Turlock	Turlock ID	Turlock ID 2012 AWMP	12/2012	12/2012	Stanislaus, Merced
Merced	Merced ID	Merced ID AWMP	9/2013	9/2013	Merced
Eastern San Joaquin	Stockton East WD	Stockton East WD Water Management Plan	1/2014	1/2014	San Joaquin

Source: Merced ID 2013a; MID 2012; OID 2012; SEWD 2014; SSJID 2012; TID 2012.
AWMP = agricultural water management plan
ID = irrigation district
WD = water district

Table 9-8. Irrigation District Methods for Dealing with Surface Water Shortages

Irrigation District	Conjunctive Use	Reduction in Surface Water Allotments	Allowable Internal Transfers	Groundwater Used for Permanent Crops	Holds Carryover Surface Water for Crops	All Shortages Managed with Groundwater	Fair and Equitable Distribution	USBR Responsible for Shortages
SSJID	X	X	X	NA	NA	NA	X	X
OID	X	X	X	X	NA	NA	X	X
SEWD	X	X	NA	NA	NA	NA	NA	X
TID	X	X	X	X	X	NA	NA	NA
MID	X	X	NA	X	X	NA	NA	NA
Merced ID	X	X	NA	X	C	X	X	NA

Sources: SSJID 2011; SEWD 2014; City of Stockton 2011; TID 2012; OID 2012; MID 2012; EWD 2003; Merced ID 2013a; City of Merced 2001.

Merced ID = Merced Irrigation District
MID = Modesto Irrigation District
NA = Not Applicable
OID = Oakdale Irrigation District
SSJID = South San Joaquin Irrigation District
SEWD = Stockton East Water District
TID = Turlock Irrigation District
USBR = U.S. Bureau of Reclamation

Groundwater Management Plans

Prior to SGMA's passage, groundwater management planning was a voluntary activity by local agencies in accordance with either AB 3030 (Costa), which was passed in 1992, or SB 1938 (Machado), which was passed in 2008 (consequently, those types of plans are commonly referred to as "AB 3030 plans" or "SB 1938 plans"). Both types of plans are discussed in more detail below. Under SGMA, an AB 3030 or SB 1938 plan that existed as of January 1, 2015 (the day SGMA took effect) can be submitted by January 1, 2017, for review by DWR as to whether that existing plan meets SGMA's requirements and therefore is approved as an alternative to a GSP. (Wat. Code, § 10733.6.) However, most AB 3030 and SB 1938 plans to not require sustainable groundwater management such as calculating the annual safe yield of a basin, limiting groundwater pumping to the safe yield, and enforcing the limitation. Unless approved as an alternative, AB 3030 and SB 1938 plans that are in areas subject to SGMA remain in effect until a GSP is adopted and may not be amended. In addition, in areas subject to SGMA, no new AB 3030 or SB 1938 plans may be adopted, only GSPs. (Wat. Code, § 10750.1.)

AB 3030 (Wat. Code, § 10750 et seq.) created a systematic procedure for an existing local agency to voluntarily develop a GWMP. AB 3030 also encouraged local agencies to cooperatively manage groundwater resources within their jurisdictions and to provide a methodology for developing GWMPs for groundwater basins defined in DWR Bulletin 118. The AB 3030 GWMPs introduced 12 technical components that could be, but were not required to be, included in the plans: (1) the control of saline water intrusion; (2) identification and management of wellhead protection areas and recharge areas; (3) regulation of the migration of contaminated groundwater; (4) administration of a well abandonment and well destruction program; (5) mitigation of conditions of overdraft; (6) replenishment of groundwater extracted by water producers; (7) monitoring of groundwater levels and storage; (8) facilitating conjunctive use operations; (9) identification of well construction policies; (10) construction and operation by the local agency of groundwater contamination cleanup, recharge, storage, conservation, water recycling, and extraction projects; (11) development of relationships with state and federal regulatory agencies; and (12) review of land use plans and coordination with land use planning agencies to assess activities (DWR 2014d). SB 1938 modified AB 3030's approach by making the development of GWMPs mandatory for any public agency seeking State funds administered through DWR for the construction of groundwater projects. SB 1938 also established mandatory components that the plans had to include to be deemed adequate: (1) basin management objectives relating to the monitoring and management of groundwater levels within the groundwater basin; (2) groundwater quality degradation, inelastic surface subsidence, and changes in surface flow and surface water quality that directly affect groundwater levels or quality or are caused by groundwater pumping in the basin; (3) agency cooperation such that the development of the plan involved other agencies and that the plan enables the local agency to work cooperatively with other public entities whose service area or boundary overlies the groundwater basin; (4) a map of the local agencies' service area that is subject to the GWMP as well as the boundary of the DWR Bulletin 118 boundary and the boundaries of other local agencies that overlie the basin in with the agency is located; and (5) monitoring protocols designed to detect changes in groundwater levels, groundwater quality, inelastic surface 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 (DWR 2014e). GWMP requirements were again modified by AB 359

(Huffman), which became effective in 2013. AB 359 added additional required technical components and modified several GWMP adoption procedures (DWR 2014f).

GWMPs that are relevant to the irrigation districts and four subbasins are summarized in Table 9-9. The GWMPs do not always include the entire subbasin but describe the general subbasin characteristics. GWMPs vary in terms of groundwater management components and implementation methods included. The plans generally require the protection of existing groundwater resources and identify ways to reduce groundwater pumping or increase the recharge of groundwater basins through surface water diversions.

Table 9-9. Relevant Groundwater Management Plans

Relevant Groundwater Subbasin	Entity/Entities	Document Title	GWMP Report Date	Adoption Date	County
Eastern San Joaquin	South San Joaquin ID	South San Joaquin ID GWMP	12/1994	2/1995	San Joaquin
Eastern San Joaquin	Stockton East WD	Eastern San Joaquin Groundwater Basin GWMP	9/2004	2005	San Joaquin
Eastern San Joaquin, Modesto	Oakdale ID	Integrated Regional GWMP for the Modesto Subbasin	6/2005	6/2005	San Joaquin, Stanislaus
Modesto	Modesto ID	Integrated Regional GWMP for the Modesto Subbasin	6/2005	5/2005	Stanislaus
Turlock	Eastside WD	Turlock Groundwater Basin GWMP	3/2008	1/2008	Merced, Stanislaus
Turlock	Turlock ID	Turlock Groundwater Basin GWMP	3/2008	3/2008	Stanislaus, Merced
Merced	Merced ID	Merced Groundwater Basin GWMP Update	7/2008	7/2012	Merced

Source: MAGPI 2008; NSJCGBA 2004; SSJID 1994; STRGBA 2005; TID 2008.
GWMP = groundwater management plan
ID = irrigation district
WD = water district

Integrated Regional Water Management Plans

Integrated Regional Water Management (IRWM) Planning is a collaborative stakeholder process that promotes sustainable water use. IRWM Planning identifies and implements water management efforts on a regional scale to ensure sustainable water uses, reliable water supplies, better water quality, efficient urban development, protection of agriculture, environmental stewardship, and a strong economy. IRWM plans acknowledge that regions have distinct identities and hydrologic and ecologic conditions, and that water supply reliability should be a primary water management objective to be considered in these integrated plans. IRWMPs that are relevant to the irrigation districts and four subbasins are summarized in Table 9-10.

Table 9-10. Relevant Integrated Regional Water Management Plans

Relevant Groundwater Subbasin	Entity/Entities	Document Title	IRWMP Report Date	Adoption Date	County
Merced	Merced ID	Merced IRWMP	8/2013	11/2013	Merced
Eastern San Joaquin	Central San Joaquin WCD	2014 Eastern San Joaquin IRWMP Update	6/2014	6/2016	San Joaquin
Eastern San Joaquin	South San Joaquin ID	2014 Eastern San Joaquin IRWMP Update	6/2014	6/2014	San Joaquin
Eastern San Joaquin	Stockton East WD	2014 Eastern San Joaquin IRWMP Update	6/2014	6/2014	San Joaquin

Source: ESJCGBA 2014; Merced ID 2013b.
IRWMP = integrated regional water management plan
ID = irrigation district
WCD = water conservation district
WD = water district

Urban Water Management Plans

The California Urban Water Management Planning Act (UWMPA) requires California's urban water suppliers to initiate planning strategies to ensure the appropriate level of reliability in their water service to meet the needs of the various categories of customers during normal, dry, and multiple dry years. To do this, urban water suppliers must prepare a UWMP every 5 years. UWMPs served as a resource for planners and policy makers over a 25-year planning time fame, and include information about groundwater and surface water supplies, historic and projected water use, recycled water, water use efficiency programs in a contracting water district's service area, and contingency planning for the possibility of water shortages.

2015 UWMPs (due to DWR by July 1, 2016) do not reflect new requirements for groundwater management under SGMA. However, DWR recommended that 2015 UWMPs include a discussion of current or planned activities to meet anticipated SGMA requirements (DWR 2016). 2010 UWMPs that are relevant to the irrigation districts and four subbasins are summarized in Table 9-11; 2010 UWMPs that are relevant to the urban water suppliers are summarized in Chapter 13, *Service Providers*. UWMPs vary in terms of water shortage management responses and implementation methods included.

Table 9-11. Relevant Urban Water Management Plans

Relevant Groundwater Subbasin	Entity/Entities	Document Title	UWMP Report Date	Adoption Date	County
Modesto	Modesto ID	City of Modesto and Modesto ID Joint UWMP 2010 Final	5/2011	5/2011	Stanislaus
Eastern San Joaquin	South San Joaquin ID	South San Joaquin ID 2010 UWMP	8/2011	9/2011	San Joaquin

Source: City of Modesto and MID 2011; SSJID 2011.
UWMP = urban water management plan
ID = irrigation district

Groundwater Management Ordinances

Several ordinances applicable to groundwater resources that underlie the Stanislaus, Tuolumne, and Merced Rivers and SJR have been passed. These include ordinances in Merced, San Joaquin, Stanislaus, and Tuolumne Counties. No ordinances exist or have been proposed for groundwater resources in Mariposa County. Ordinances for Merced, San Joaquin, Stanislaus, and Tuolumne Counties are discussed in the following sections.

Merced County

Merced County's groundwater management ordinance was promulgated in 2015. It requires a permit for drilling a new well, mining groundwater, and exporting groundwater outside of the county. The ordinance also requires new well owners to install a metering device to report water usage to the county (Miller 2015).

San Joaquin County

San Joaquin County's groundwater management ordinance was promulgated in 1996. It requires a permit for any groundwater exports from the Eastern San Joaquin Subbasin. Before a permit will be issued, an applicant is required to demonstrate that the proposed export will not exacerbate the existing groundwater overdraft conditions. The ordinance was developed to protect investments supporting groundwater bank development (NSJCGBA 2004).

Stanislaus County

Stanislaus County's first groundwater management ordinance was promulgated in 2013. It restricts out-of-county transfers of groundwater or pumping to replace surface water sold to buyers outside of the county (Carlson 2013). In 2014, San Joaquin County expanded their groundwater management ordinance to align the county's requirements, prohibitions, and exemptions with SGMA. It also required applicants for permits to demonstrate that new wells will not have a detrimental effect on the county's groundwater resources (SCDER 2015).

Tuolumne County

Tuolumne County's groundwater management ordinance requires a permit for exporting groundwater outside of the county (Tuolumne Utilities District 2010).

9.4 Impact Analysis

This section identifies the thresholds or significance criteria used to evaluate the potential impacts on groundwater resources. It further describes the methods of analysis used to determine significance of impacts on groundwater resources. Measures to mitigate (i.e., avoid, minimize, rectify, reduce, eliminate, or compensate for) significant impacts accompany the impact discussion, if any significant impacts are identified.

9.4.1 Thresholds of Significance

The thresholds for determining the significance of impacts for this analysis are based on the State Water Board's Environmental Checklist in Appendix A of the Board's CEQA regulations. (Cal. Code Regs., tit. 23, §§ 3720–3781.) The thresholds derived from the checklist have been modified, as appropriate, to meet the circumstances of the alternatives. (Cal. Code Regs., tit. 23, § 3777, subd. (a)(2).) Impacts on groundwater resources were identified as potentially significant in the State Water Board's Environmental Checklist (see Appendix B, *State Water Board's Environmental Checklist*) and, therefore, are discussed in this analysis as to whether the alternatives could result in the following.

- Substantially deplete groundwater supplies or interfere substantially with groundwater recharge.
- Potentially cause subsidence as a result of groundwater depletion.

9.4.2 Methods and Approach

LSJR Alternatives

This chapter evaluates the potential groundwater impacts associated with the LSJR alternatives. Each LSJR alternative includes a February-June unimpaired flow[13] requirement (i.e., 20, 40, or 60 percent) and different methods for adaptive implementation to reasonably protect fish and wildlife beneficial uses, as described in Chapter 3, *Alternatives Description*. The sections below describe steps for processing the State Water Board's WSE model results for the groundwater analysis, methods of analysis for adaptive implementation in this chapter, and baseline results to which the LSJR alternatives are compared to determine the significance of impacts on groundwater.

Processing of WSE Model Results

Geographical Treatment of Aquifer

The impact analysis uses results from the WSE model to determine if the LSJR alternatives would result in impacts on groundwater resources by increasing groundwater pumping and reducing groundwater recharge relative to the baseline water balance for each of the four subbasins that would potentially be affected (Eastern San Joaquin, Turlock, Modesto, and Extended Merced). Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives:*

[13] *Unimpaired flow* represents the water production of a river basin, unaltered by upstream diversions, storage, or by export or import of water to or from other watersheds. It differs from natural flow because unimpaired flow is the flow that occurs at a specific location under the current configuration of channels, levees, floodplain, wetlands, deforestation and urbanization.

Methodology and Modeling Results, contains a detailed description of the groundwater analysis methods and results; a summary of the analysis is provided here. For analysis purposes, the Merced Subbasin was extended south to the Chowchilla River because the Merced ID land that was formerly the El Nido ID is in the northern part of the Chowchilla Subbasin between the Merced Subbasin and the Chowchilla River (Figure 9-1). This extension added an additional 26,000 acres to the Merced Subbasin, bringing the total area to 517,000 acres. In the analysis, the combination of the Merced Subbasin and the land between the Merced Subbasin and the Chowchilla River is called the Extended Merced Subbasin.

In order to assess the effects of the LSJR alternatives on groundwater, groundwater in the four subbasins was considered to be four separate pools of water, each with no separation between shallow and deep aquifers. In reality, water can move slowly between subbasins, and there may be differences in effects between shallow (semi-confined) and deep (confined) sections of the aquifer. To the extent that water moves between subbasins, some of the groundwater impacts could have slight effects on adjoining subbasins, which would reduce the effects within the subbasins of concern. In some areas, deeper sections of the aquifer may be separated from shallower sections by substrate with low permeability. The evaluation of groundwater effects was not separated by depth because: (1) there is some connectivity between the different depths, and (2) increased groundwater pumping would occur in both shallow and deep wells. Substrate with low permeability (e.g., the Corcoran Clay at the western side of the four subbasins of interest) might slow the interaction between deeper, confined and shallower, unconfined sections of the aquifer, but water pumped from a deeper confined section of the aquifer would eventually be replaced by water from above or from surrounding subbasins. Furthermore, within the four subbasins, there are numerous deep and shallow drinking water and agricultural wells, making it infeasible to assign increases in pumping to separate sections of the aquifer as a whole. These simplifying assumptions of separating the aquifer by subbasin and not by depth are acceptable because the purpose of the analysis is to estimate the general magnitude of the average effect of the LSJR alternatives on the subbasins, not effects at specific well locations.

Apportionment of Diversions Simulated by WSE Model

For each LSJR alternative, the WSE model produced estimates of the amount of diversions that were available from each river. These results were post-processed within the WSE model and in a groundwater analysis spreadsheet to estimate groundwater effects. As part of this post-processing, the diversions for each river were partitioned between different types of deliveries and losses.

In the first step of post-processing, the following volumes, assumed not to be subject to a water shortage, were subtracted from the total diversions for each river to calculate how much water remained.

- Municipal and industrial water supplies – volumes include Stanislaus River water for DeGroot Water Treatment Plant (for the Cities of Lathrop, Manteca, and Tracy through the South County Water Supply Program) and Tuolumne River water for the City of Modesto. These municipal and industrial water suppliers use a relatively small portion of the total surface water diversion from the Stanislaus and Tuolumne Rivers. (The model assumes that municipal water providers would not experience a reduction in surface water supply; this assumption is only used for calculating groundwater impacts and agricultural impacts. Potential impacts on municipal and industrial water users are evaluated in Chapter 13, *Service Providers*.)

- Water for riparian water rights – includes Cowell Agreement[14] diversions on the Merced River.
- Spills – includes water that is present at the downstream ends of the distribution systems. These volumes are assumed to be the same for each LSJR alternative.
- Seepage from off-stream reservoirs – Woodward Reservoir, Turlock Lake, and Modesto Reservoir.

After subtracting the volumes listed above from the total diversions for each river, the remaining water was apportioned to the irrigation districts as applied surface water and conveyance losses (where conveyance losses are a fraction of applied surface water and spills). Applied water for agricultural purposes is a key component of the water balance; it comes from both surface water and groundwater, and includes water that is used consumptively by the crops (evapotranspiration) and water that percolates deep into the ground below the fields. The surface water portion of applied water was estimated as described above based on the WSE model results. The groundwater portion of applied water was estimated as described further below.

As a result of this post-processing method, when diversions were less than what was needed to meet full demands (of all categories of deliveries and losses), generally the only two categories of water that were assumed to be reduced were applied surface water and conveyance losses (which depend on the applied water). The model assumes reductions in applied water available to the irrigation districts. This assumption allows for a simplified approach to calculating groundwater impacts and produces a conservative estimate of agricultural impacts as described in Chapter 11, *Agricultural Resources* (i.e., agricultural impacts may be overestimated rather than underestimated).

In the WSE model, SEWD and CSJWCD diversions from the Stanislaus River were calculated separately from the SSJID and OID diversions. This is because SEWD and CSJWCD are CVP contractors and only receive water after SSJID and OID water rights have been met. As a result, in some years SEWD would not be able to provide Stanislaus River water to its municipal users, but these municipal needs would be met by either Calaveras River water or groundwater. The division of water between CSJWCD and SEWD was based on their contracts for Stanislaus River water. The division of Stanislaus River water between SSJID and OID and Tuolumne River water between MID and TID was calculated as part of post-processing. The division assumes that each district would receive the same percentage of surface water demand for consumptive use, as described in Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives: Methodology and Modeling Results*.

Assessment of Irrigation District Groundwater Pumping

Within the irrigation districts, there is a minimum amount of groundwater pumping that occurs every year. If the amount of minimum groundwater pumping plus the amount of applied surface water is insufficient to meet the irrigation district's total demand for applied water (consumptive use and deep percolation), then additional groundwater pumping would occur up until a maximum amount. Minimum and maximum groundwater pumping estimates were based on an evaluation of irrigation district pumping estimates in CALSIM, 2012 AWMPs, 2010 GWMPs, and information provided by the irrigation districts. The final values primarily came from the AWMPs and the irrigation districts; they are listed in Appendix G. While maximum groundwater pumping can reduce agricultural impacts, it increases the potential for groundwater impacts.

[14] The Cowell Agreement is a 1930's adjudicated agreement between MID and landowners flanking portions of the Merced River riparian areas. Per the Cowell Agreement, MID provides up to 50 cfs in February and up to 100 cfs in March downstream of the Crocker Huffman Diversion Dam.

Because baseline is representative of 2009 infrastructure, the primary groundwater analysis utilizes estimates of maximum groundwater pumping that were possible in 2009. However, recent drought conditions have resulted in more wells being drilled. Therefore, estimates of maximum groundwater pumping for 2014 were also assessed, as discussed below in Section 9.4.3, *Impacts and Mitigation Measures*. All 2014 maximum groundwater pumping estimates are greater than the 2009 maximum groundwater estimates, with the exception of Merced ID, where 2009 and 2014 estimates are the same. This is reasonable because Merced ID's 2009 capacity for increased groundwater pumping was almost sufficient to meet full demand in drought years.

As mentioned above and described in Appendix G, the primary data sources used for estimating the parameters needed for the groundwater assessment were the AWMPs, GWMPs, CALSIM, and information provided by the irrigation districts. Because there are many sources of information available regarding groundwater and because there is a large degree of uncertainty in the values, the values chosen for this analysis and the results of this analysis are not always the same as the water balance terms discussed in Section 9.2, *Environmental Setting*.

Evaluation of Irrigation District Groundwater Balance and Impacts

For the analysis of potential groundwater impacts associated with the LSJR alternatives, the net annual change in the irrigation district groundwater balance was estimated for each groundwater subbasin. The annual net contribution of irrigation district water to the groundwater subbasins was calculated by summing the off-stream reservoir seepage, conveyance losses, and deep percolation and subtracting total groundwater pumping for each irrigation district overlying the subbasin. As discussed in Section 9.2.2, *Subbasin Groundwater Use*, two irrigation districts (OID and Merced ID) affect the results for two subbasins because their service area boundaries are not confined to a single subbasin. The OID service area overlies the Eastern San Joaquin and Modesto Subbasins and the Merced ID service area overlay the Turlock and Extended Merced Subbasins. Hereafter, this chapter refers to the subbasin groundwater balance as the "irrigation district groundwater balance." For SEWD and CSJWCD, only the portion of their water use that could be affected by water supply from the Stanislaus River was included in the analysis.

The effect of the LSJR alternatives on the irrigation district groundwater balance is evaluated by comparing the irrigation district groundwater balance under each of the LSJR alternatives with the irrigation district groundwater balance under baseline conditions. The difference in the irrigation district groundwater balance was then divided by the total surface area of the groundwater subbasin; the result would have units of volume per area, expressed in inches (Table 9-12), which represents the height of the volume of water if it were spread evenly over the subbasin. Normalizing the change in groundwater balance by the subbasin area translates the effect into height and directly shows how average groundwater level could be impacted under the LSJR alternatives. An average decrease in irrigation district groundwater balance equivalent to 1 inch per year or more was considered to be a significant impact.

The estimated average specific yield for the Eastern San Joaquin, Modesto, Turlock, and Extended Merced Subbasins ranges from 7 to 10 percent, based on aquifer information presented in DWR Bulletin 118 (DWR 2003b, 2003c, 2003d, 2003e). The specific yield is the ratio of the volume of water a sample of saturated soil will yield by gravity drainage to the total volume of the soil (i.e., the portion of groundwater that could be available for extraction from the saturated soil). For example, a specific yield of 10 percent means that a reduction in groundwater volume equivalent to 1 inch across the subbasin is comparable to an average decrease in groundwater level of approximately

10 inches in an unconfined aquifer. This 10-inch decline in the groundwater level is similar to the estimated historical groundwater level declines shown the first two columns of Table 9-4. This 10-inch decline in groundwater levels would occur in addition to any decline in groundwater levels that occurred under baseline conditions. As such, a 1-inch decrease in the irrigation district groundwater balance across a subbasin caused by the LSJR alternatives could eventually produce a measurable decline in groundwater levels and a substantial depletion of groundwater resources. Therefore, a threshold of a 1-inch reduction in the irrigation district groundwater balance is used in the impact analysis in Section 9.4.3, *Impacts and Mitigation Measures*.

If a groundwater basin has a large volume of average inflow, outflow from the basin is also high because groundwater would drain to the rivers when groundwater elevations are high. Under these conditions, it is possible to pump groundwater without affecting groundwater elevations, although river flows would likely be affected. As discussed in Section 9.2, *Environmental Setting*, DWR's evaluation of groundwater in the San Joaquin Valley Groundwater Basin shows evidence of decreasing groundwater elevations, existing wide-scale groundwater pumping, and limited accretions to the rivers from groundwater. As such, it appears that the four subbasins are not in a state of excess supply. Therefore, a reduced groundwater supply, resulting from reduced recharge and increased pumping, would have a measurable effect on groundwater elevations in many locations.

Evaluation of Subsidence

Substantial groundwater depletion in an area with soils that are susceptible to inelastic compaction could result in subsidence. For this analysis, subsidence is considered to be significant if substantial groundwater depletion is expected to occur (i.e., if the GW-1 impact is significant and unavoidable) in an area where subsidence has previously occurred. Within the study area the main area of subsidence is in the southern portion of the Extended Merced Subbasin, especially in the area near El Nido. Despite reports of periods of declining groundwater levels, subsidence has not been reported for the other three subbasins of interest.

Adaptive Implementation

This chapter evaluates the potential groundwater impacts associated with the LSJR alternatives. Each LSJR alternative includes a February–June unimpaired flow requirement (i.e., 20, 40, or 60 percent) and methods for adaptive implementation to reasonably protect fish and wildlife beneficial uses, as described in Chapter 3, *Alternatives Description*. In addition, a minimum base flow is required at Vernalis at all times during this period. The base flow may be adaptively implemented as described below and in Chapter 3. State Water Board approval is required before any method can be implemented, as described in Appendix K, *Revised Water Quality Control Plan*. All methods may be implemented individually or in combination with other methods, may be applied differently to each tributary, and could be in effect for varying lengths of time, so long as the flows are coordinated to achieve beneficial results in the LSJR related to the protection of fish and wildlife beneficial uses.

The Stanislaus, Tuolumne, and Merced Working Group (STM Working Group) will assist with implementation, monitoring, and assessment activities for the flow objectives and with developing biological goals to help evaluate the effectiveness of the flow requirements and adaptive implementation actions. The STM Working Group may recommend adjusting the flow requirements through adaptive implementation if scientific information supports such changes to reasonably protect fish and wildlife beneficial uses. Scientific research may also be conducted within the adaptive range to improve scientific understanding of measures needed to protect fish and wildlife and reduce scientific uncertainty through monitoring and evaluation. Further details describing the methods, the STM Working Group, and the approval process are included in Chapter 3 and Appendix K.

Without adaptive implementation, flow must be managed such that it tracks the daily unimpaired flow percentage based on a running average of no more than 7 days. The four methods of adaptive implementation are described briefly below.

1. Based on best available scientific information indicating that more flow is needed or less flow is adequate to reasonably protect fish and wildlife beneficial uses, the specified annual February–June minimum unimpaired flow requirement may be increased or decreased to a percentage within the ranges listed below. For LSJR Alternative 2 (20 percent unimpaired flow), the percent of unimpaired flow may be increased to a maximum of 30 percent. For LSJR Alternative 3 (40 percent unimpaired flow), the percent of unimpaired flow may be decreased to a minimum of 30 percent or increased to a maximum of 50 percent. For LSJR Alternative 4 (60 percent unimpaired flow), the percent of unimpaired flow may be decreased to a minimum of 50 percent.
2. Based on best available scientific information indicating a flow pattern different from that which would occur by tracking the unimpaired flow percentage would better protect fish and wildlife beneficial uses, water may be released at varying rates during February–June. The total volume of water released under this adaptive method must be at least equal to the volume of water that would be released by tracking the unimpaired flow percentage from February–June.
3. Based on best available scientific information, release of a portion of the February-June unimpaired flow may be delayed until after June to prevent adverse effects to fisheries, including temperature, that would otherwise result from implementation of the February-June flow requirements. The ability to delay release of flow until after June is only allowed when the unimpaired flow requirement is greater than 30 percent. If the requirement is greater than 30 percent but less than 40 percent, the amount of flow that may be released after June is limited to the portion of the unimpaired flow requirement over 30 percent. For example, if the flow requirement is 35 percent, 5 percent may be released after June. If the requirement is 40 percent or greater, then 25 percent of the total volume of the flow requirement may be released after June. As an example, if the requirement is 50 percent, at least 37.5 percent unimpaired flow must be released in February–June and up to 12.5 percent unimpaired flow may be released after June. If after June the STM Working Group determines that conditions have changed such that water held for release after June should not be released by the fall of that year, the water may be held until the following year. See Chapter 3 and Appendix K for further details.
4. Based on best available scientific information indicating that more flow is needed or less flow is adequate to reasonably protect fish and wildlife beneficial uses, the February-June Vernalis base flow requirement of 1,000 cfs may be modified to a rate between 800 and 1,200 cfs.

The operational changes made using the adaptive implementation methods above may be approved if the best available scientific information indicates that the changes will be sufficient to support and maintain the natural production of viable native SJR Watershed fish populations migrating through the Delta and meet any biological goals. The changes may take place on either a short-term (for example monthly or annually) or longer-term basis. Adaptive implementation is intended to foster coordinated and adaptive management of flows based on best available scientific information in order to protect fish and wildlife beneficial uses. Adaptive implementation could also optimize flows to achieve the objective, while allowing for consideration of other beneficial uses, provided that these other considerations do not reduce intended benefits to fish and wildlife. While the measures and processes used to decide upon adaptive implementation actions must achieve the narrative objective for the reasonable protection of fish and wildlife beneficial uses, adaptive implementation could result in flows that would benefit or reduce impacts on other beneficial uses that rely on water.

The quantitative results included in the figures, tables, and text of this chapter present WSE modeling of the specified unimpaired flow requirement for each LSJR alternative (i.e., 20, 40, or 60 percent). However, the modeling does allow some inflows to be retained in the reservoirs after June, as could occur under adaptive implementation method 3, to prevent adverse temperature effects and this is included in the results presented in this chapter. If the percent of unimpaired flow is not specified in this chapter, these are the percentages of unimpaired flow evaluated in the impact analysis. However, as part of adaptive implementation method 1, the required percent of unimpaired flow could change by up to 10 percent if the STM Working Group agrees to adjust it. The highest possible percent of unimpaired flow associated with an LSJR alternative is also evaluated in the impact analysis if long-term implementation of method 1 has the potential to affect a determination of significance. For example, if the determination for LSJR Alternative 2 at 20 percent unimpaired flow is less than significant, but the determination for LSJR Alternative 3 at 40 percent unimpaired flow is significant, then LSJR Alternative 2 is also evaluated at the 30 percent unimpaired flow. This use of modeling provides information to support the analysis and evaluation of the effects of the alternatives and adaptive implementation. For more information regarding the modeling methodology and quantitative flow and temperature modeling results, see Appendix F.1, *Hydrologic and Water Quality Modeling*.

Baseline

Results of the baseline groundwater analysis are presented here to illustrate the modeling methods and to show what was used as the basis of comparison for the LSJR alternatives. See Appendix G, *Agricultural Economic Effects of the Lower San Joaquin River Flow Alternatives: Methodology and Modeling Results*, for a more extensive discussion of the model results.

In the first step of the analysis the WSE model diversions were partitioned between different types of deliveries and losses. For example, Figure 9-6 shows this partitioning for baseline conditions for the Stanislaus River. On the Stanislaus River, the largest portion of baseline diversions usually goes to the consumptive use of applied water by agriculture (CUAW). This is also true for the Tuolumne and Merced Rivers (Appendix G). However, during drought conditions the amount of water available for agriculture is greatly reduced. This is particularly apparent in the results for 1934, 1977, and 1992 (Figure 9-6).

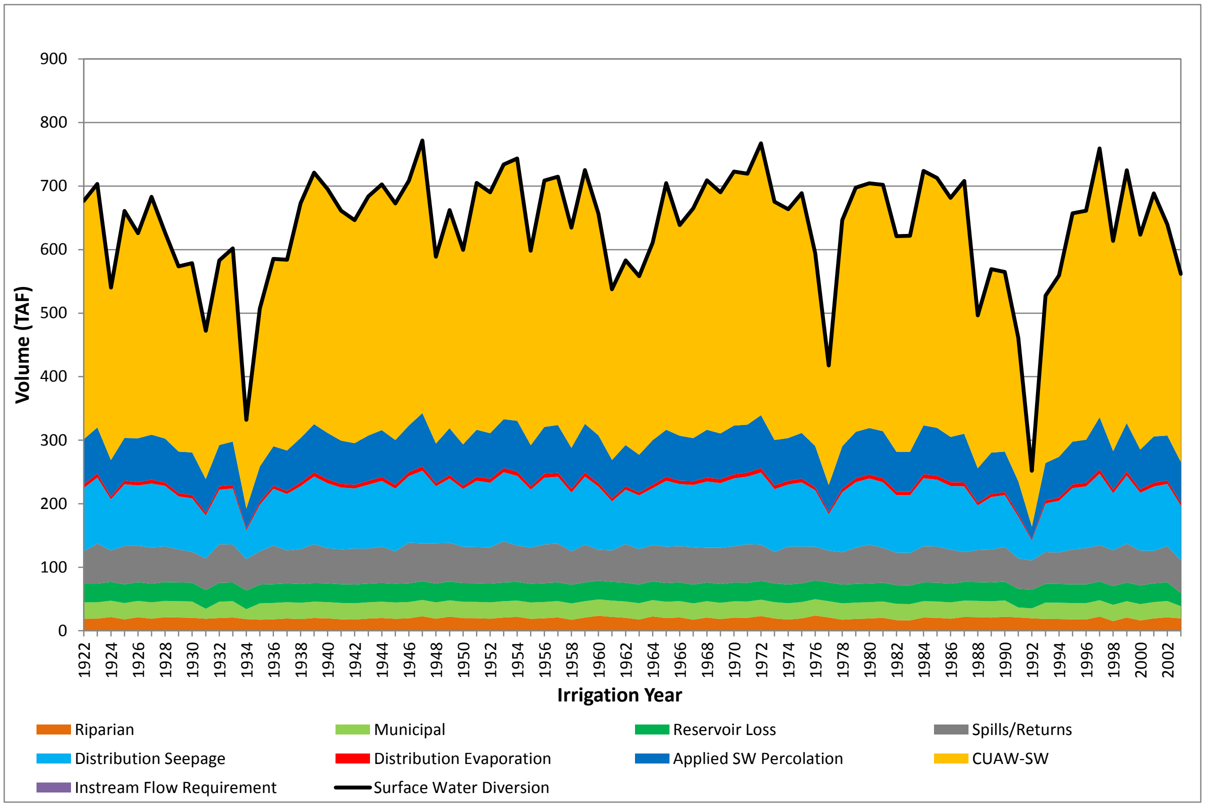


Figure 9-6. Partitioning of Baseline Diversions from the Stanislaus River into End Uses

In years with low water supply, surface water diversions are not sufficient to meet full agricultural demand for applied water (for CUAW and deep percolation). As a result, groundwater pumping increases. Even under baseline conditions, there are years when increases in groundwater pumping are expected to be unable to meet the full agricultural demand of the irrigation districts that obtain surface water from the Stanislaus, Tuolumne, and Merced Rivers (Figures 9-7a, 9-7b, and 9-7c, respectively).

The capacity of each irrigation district to pump groundwater varies and depends on existing infrastructure (Table 9-6 and Appendix G). The capacity for increased groundwater pumping by Merced ID is almost sufficient to meet full demand in drought years. There is moderate capacity to compensate for a reduction in surface water supply on the Stanislaus River, but this comes largely from SEWD and CSJWCD, which can fully compensate for a reduction in their Stanislaus River supply. In contrast, SSJID and OID have only a limited ability to increase groundwater pumping because their surface water supply has historically been reliable, and they have not needed to increase their groundwater pumping capacity. The Tuolumne River irrigation districts, TID and MID, have similarly limited ability to increase groundwater pumping (Table 9-6 and Appendix G).

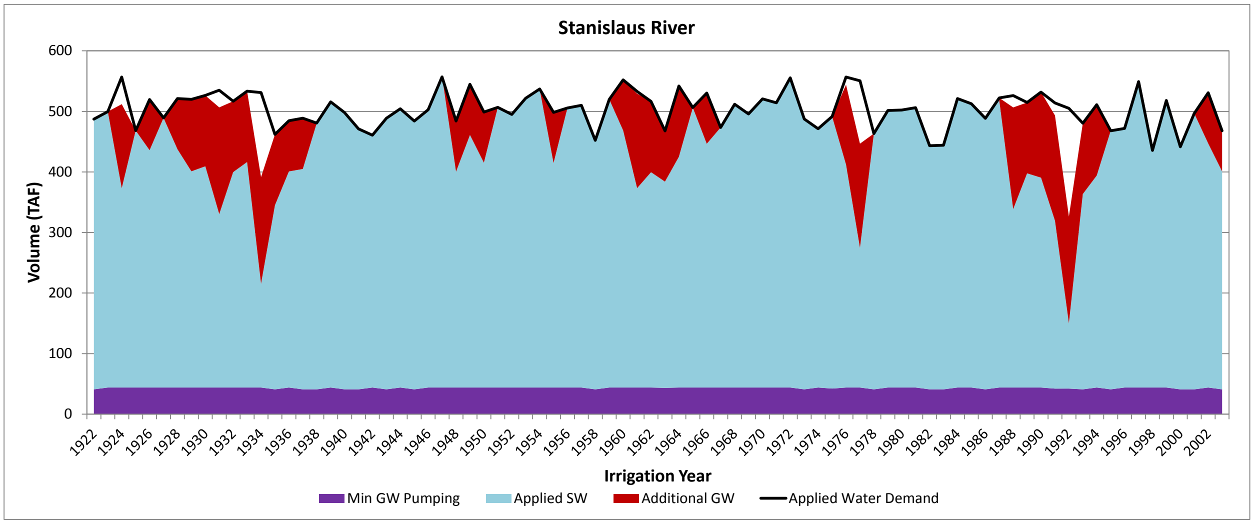


Figure 9-7a. Baseline Groundwater and Surface Water Application to Meet Applied Water Demand for the Stanislaus River

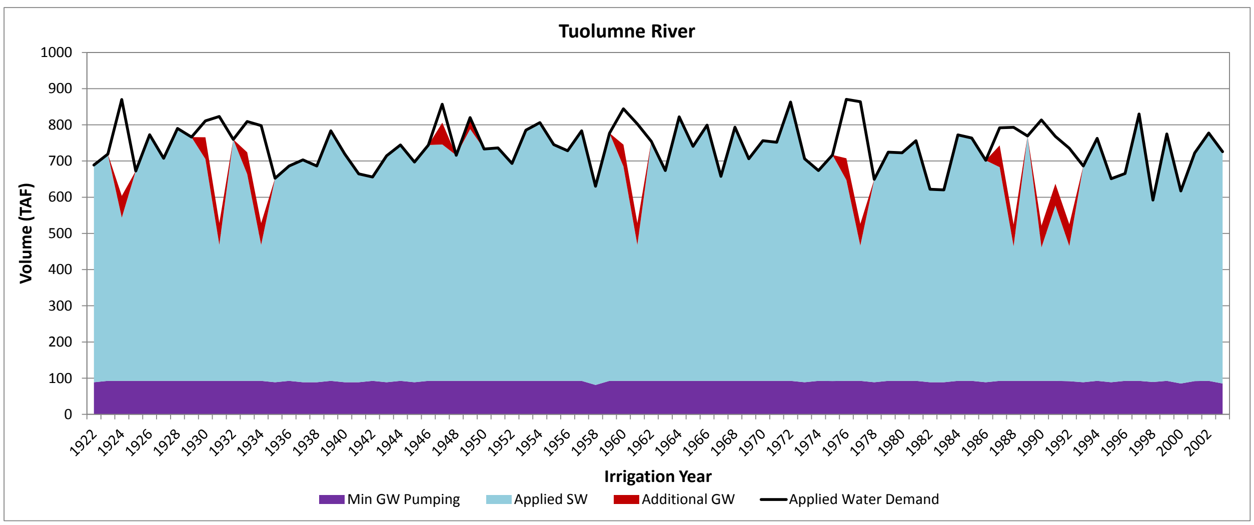


Figure 9-7b. Baseline Groundwater and Surface Water Application to Meet Applied Water Demand for the Tuolumne River

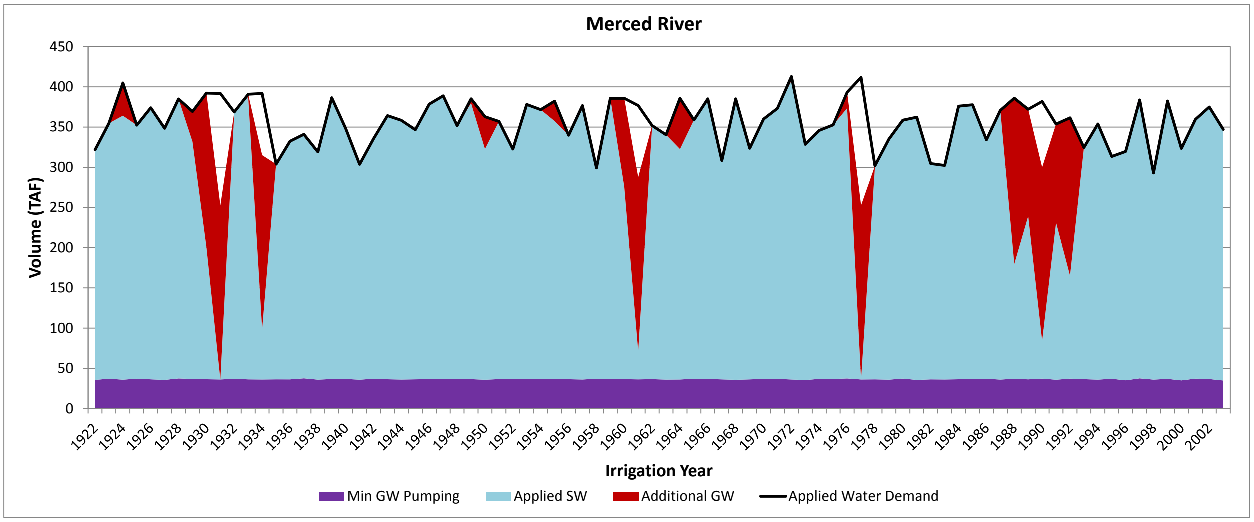


Figure 9-7c. Baseline Groundwater and Surface Water Application to Meet Applied Water Demand for the Merced River

Under baseline conditions, during most years, irrigation districts contribute more surface water to groundwater stores (i.e., recharge) than the irrigation districts remove by groundwater pumping. However, under drought conditions, seepage from the conveyance system and deep percolation from applied surface water is reduced while groundwater pumping increases. For example, in the Stanislaus River drought conditions can cause the irrigation districts to temporarily become net users of groundwater (Figure 9-8). However, in general the irrigation district contributions to groundwater help to offset the groundwater pumping for irrigated land outside of the irrigation districts, which is primarily irrigated with groundwater (Table 9-6).

The baseline contribution of the irrigation districts to the subbasins is typically 100–200 TAF/y if surface water supply meets the irrigation district needs (Figure 9-9). However, during drought, contributions to groundwater are reduced, and in some years, the irrigation districts overlying the Eastern San Joaquin and Extended Merced Subbasins become net users of groundwater under baseline conditions. Drought affects the net irrigation district contribution to groundwater more often in the Eastern San Joaquin Subbasin than for the other subbasins. However, during the worst droughts, drought affects the Extended Merced Subbasin more severely. The severity and frequency of water shortages and the ability of the irrigation districts to increase groundwater pumping directly affects the irrigation district contributions to the subbasins.

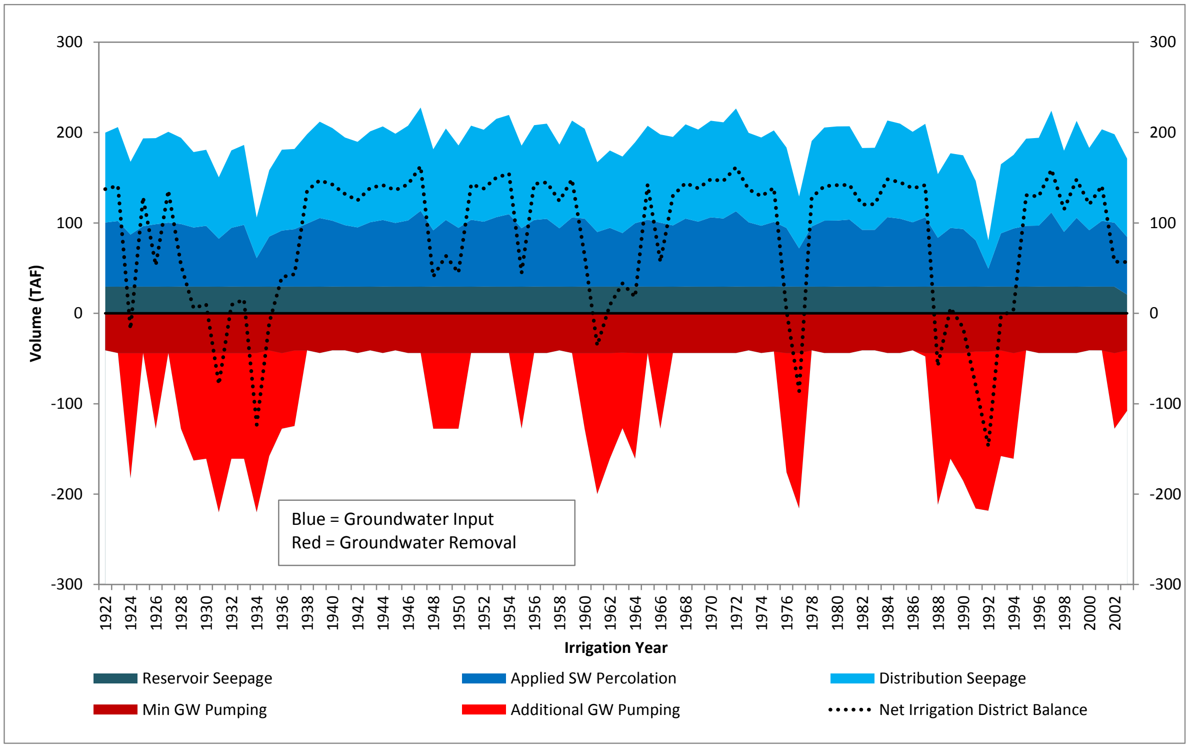


Figure 9-8. Effect of Stanislaus River Irrigation Districts on Baseline Groundwater Balance

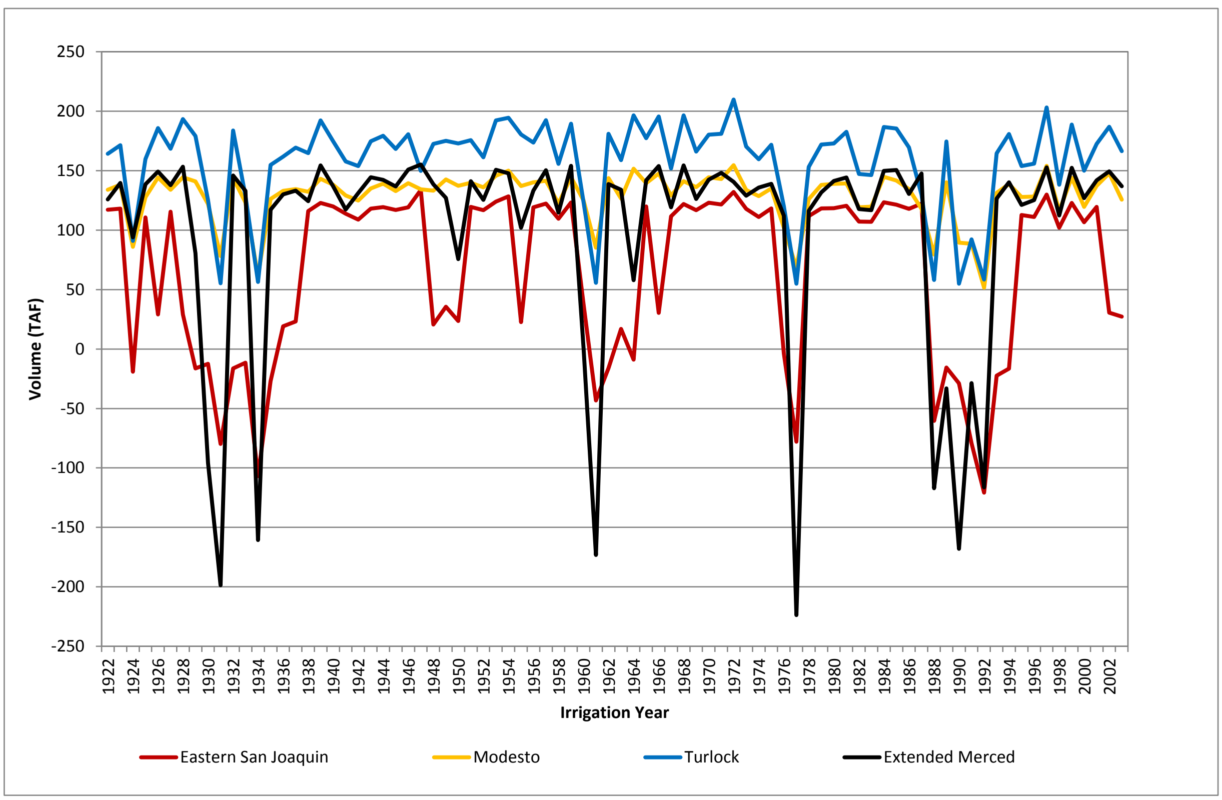


Figure 9-9. Net Annual Contribution to Groundwater Subbasins by the Irrigation Districts under Baseline Conditions

Extended Plan Area

In this chapter, the analysis of the extended plan area generally identifies how the impacts may be similar to or different from the impacts in the plan area (i.e., downstream of the rim dams) depending on the similarity of the impact mechanism (e.g., changes in reservoir levels, reduced water diversions, and additional flow in the rivers) or location of potential impacts in the extended plan area. Where appropriate, the program of implementation is discussed to help contextualize the potential impacts in the extended plan area.

SDWQ Alternatives

The SDWQ alternatives are not considered in this analysis, as described in Section 9.2.4, *Southern Delta*, and Appendix B, *State Water Board's Environmental Checklist*, because increased groundwater pumping or reduced groundwater recharge would not occur as a result of a change to the salinity objective.

9.4.3 Impacts and Mitigation Measures

Impact GW-1: Substantially deplete groundwater supplies or interfere substantially with groundwater recharge

No Project Alternative (LSJR/SDWQ Alternative 1)

The No Project Alternative would result in implementation of flow objectives identified in the 2006 *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary* (2006 Bay-Delta Plan). See Chapter 15, *No Project Alternative (LSJR Alternative 1 and SDWQ Alternative 1),* for the No Project Alternative impact discussion and Appendix D, *Evaluation of the No Project Alternative (LSJR Alternative 1 and SDWQ Alternative 1),* for the technical analysis of the No Project Alternative.

LSJR Alternatives

Baseline groundwater pumping is extensive in the four subbasins. Groundwater pumping is conducted by the irrigation districts and water districts, other water purveyors (e.g., cities and counties), and individual landowners. In dry years, irrigation districts use groundwater to compensate for reduced surface water supplies. However, on average, the irrigation districts (SSJID, OID, MID, TID, Merced ID, and the portions of SEWD and CSJWCD that use Stanislaus River water) provide net recharge to the groundwater aquifer and help compensate for groundwater pumping outside of the irrigation district lands, which is greater than groundwater pumping within the irrigation districts (Table 9-6).

A reduction in surface water supply may affect the groundwater aquifer by simultaneously causing a reduction in recharge volume (by reducing deep percolation from the distribution system and agricultural fields) and an increase in groundwater pumping (to replace lost surface water supplies). If the irrigation districts were able to use groundwater to fully replace any decreases in surface water needed for irrigation of crops, then the effect of the LSJR alternatives on groundwater would be approximately equal to the decrease in river diversions (with a minor difference due to evaporation from the distribution system). If the irrigation districts were not able to use groundwater to compensate for a reduction in surface water supply, then the effect of the LSJR alternatives on groundwater would be equal to the reduction in percolation from the distribution system plus the reduction in percolation from applied water. Because the irrigation districts have some ability to replace reductions in surface water supply with groundwater, the effect of the LSJR alternatives on the change in the groundwater balance is a volume that is between the reduction in diversion volume (maximum groundwater effect) and the reduction in percolation volume from the distribution system and applied water (minimum groundwater effect).

A comparison of the irrigation districts' estimated baseline net groundwater balances to the estimated values for the LSJR alternatives indicates that, as the specified percent of unimpaired flow increases, pumping increases, and groundwater recharge is reduced. Figures 9-10 through 9-13 illustrate this effect and show the percent of the time that net irrigation district contributions to each groundwater basin were equaled or exceeded for each LSJR alternative. Lower values (i.e., less recharge) typically occurs under dry conditions, with more reductions in recharge occurring when higher percentages of unimpaired flow are required. The irrigation districts almost always have a positive effect on the groundwater balance in the Modesto and Turlock Subbasins (Figures 9-11 and 9-12, respectively); however, the Turlock Subbasin balance is occasionally negative under LSJR Alternative 4 (Figure 9-12). The net effect of the irrigation districts on the groundwater balance may be negative, even under baseline conditions, in the Eastern San Joaquin and Extended Merced Subbasins (Figures 9-10 and 9-13, respectively).

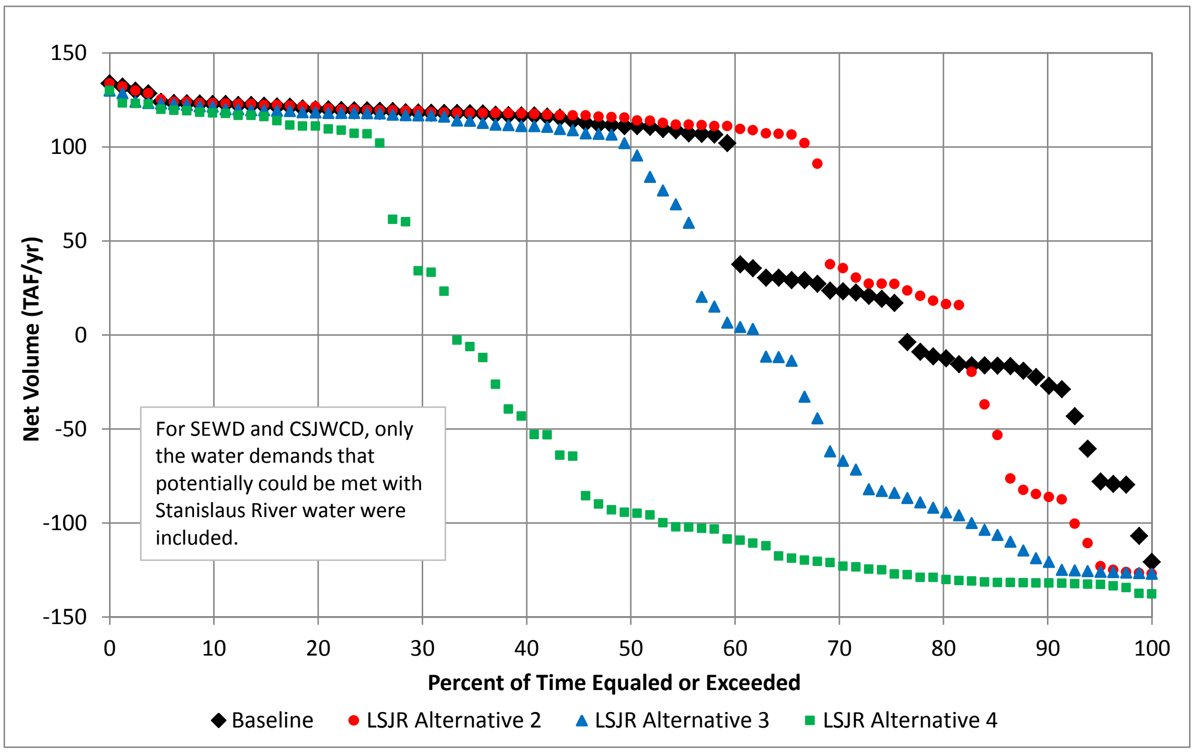


Figure 9-10. Annual Net Contribution to the Eastern San Joaquin Subbasin by SSJID, OID, SEWD, and CSJWCD

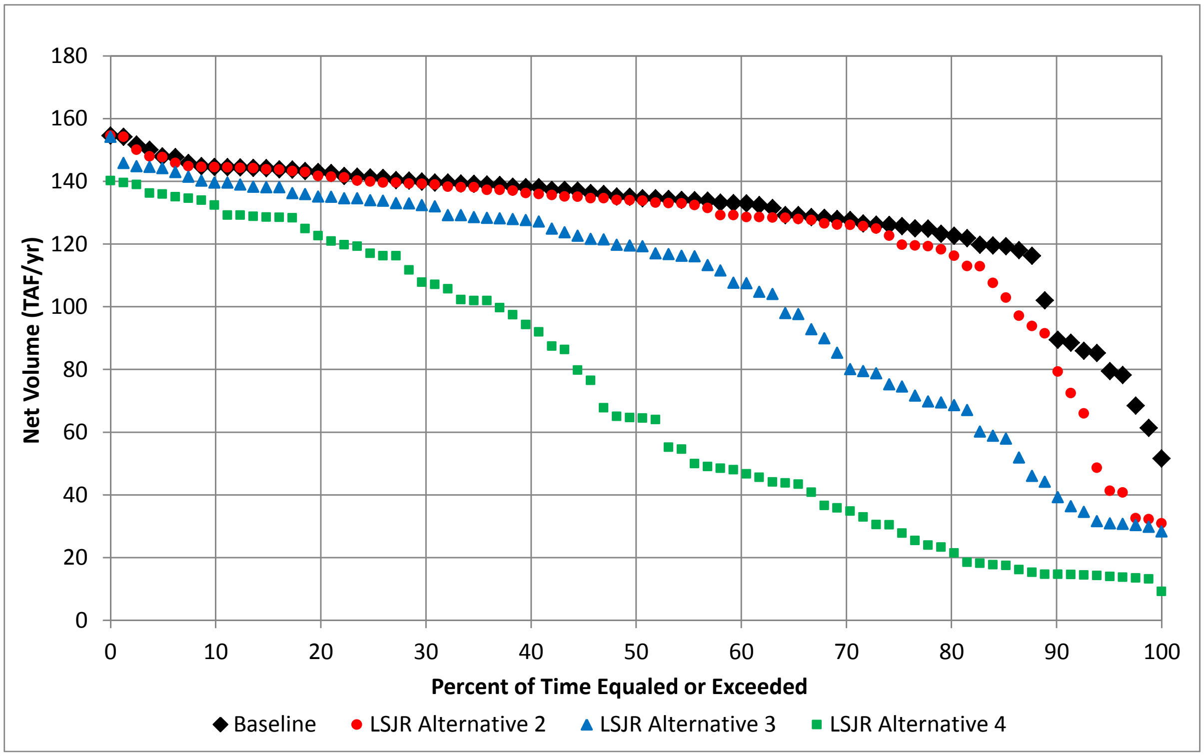


Figure 9-11. Annual Net Contribution to the Modesto Subbasin by MID and OID

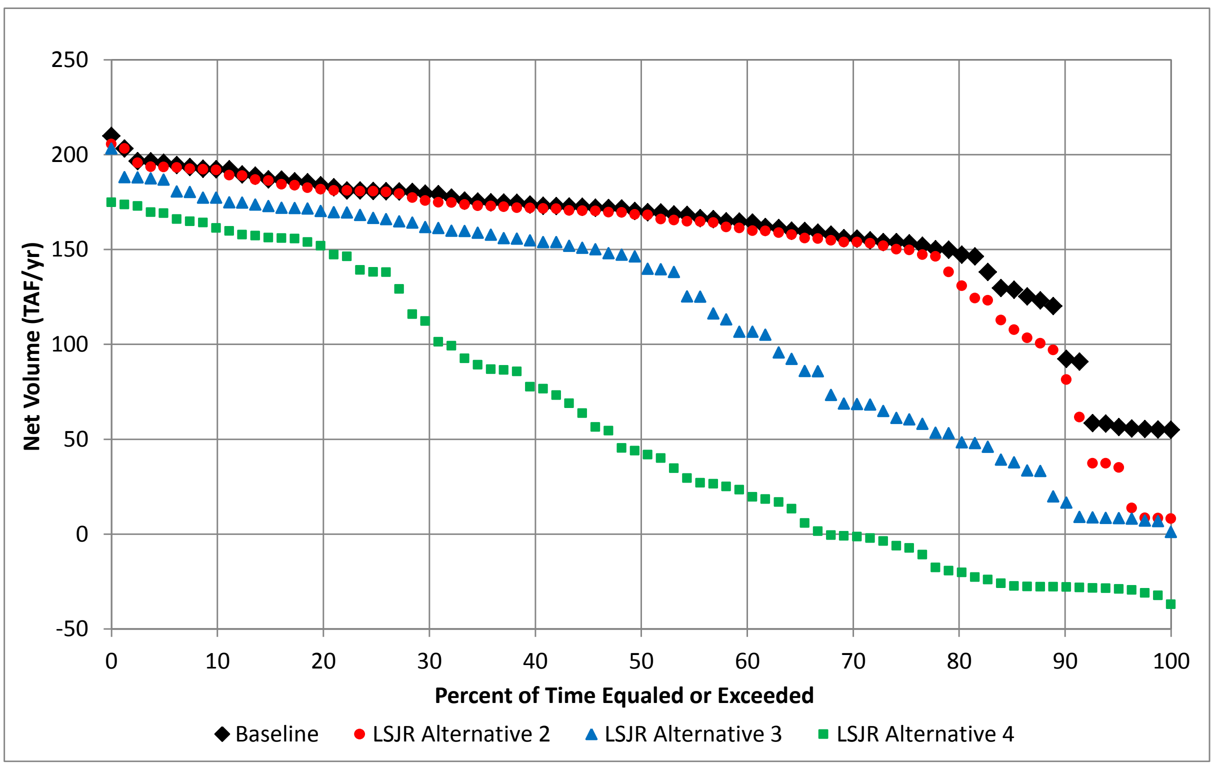


Figure 9-12. Annual Net Contribution to the Turlock Subbasin by TID and MID

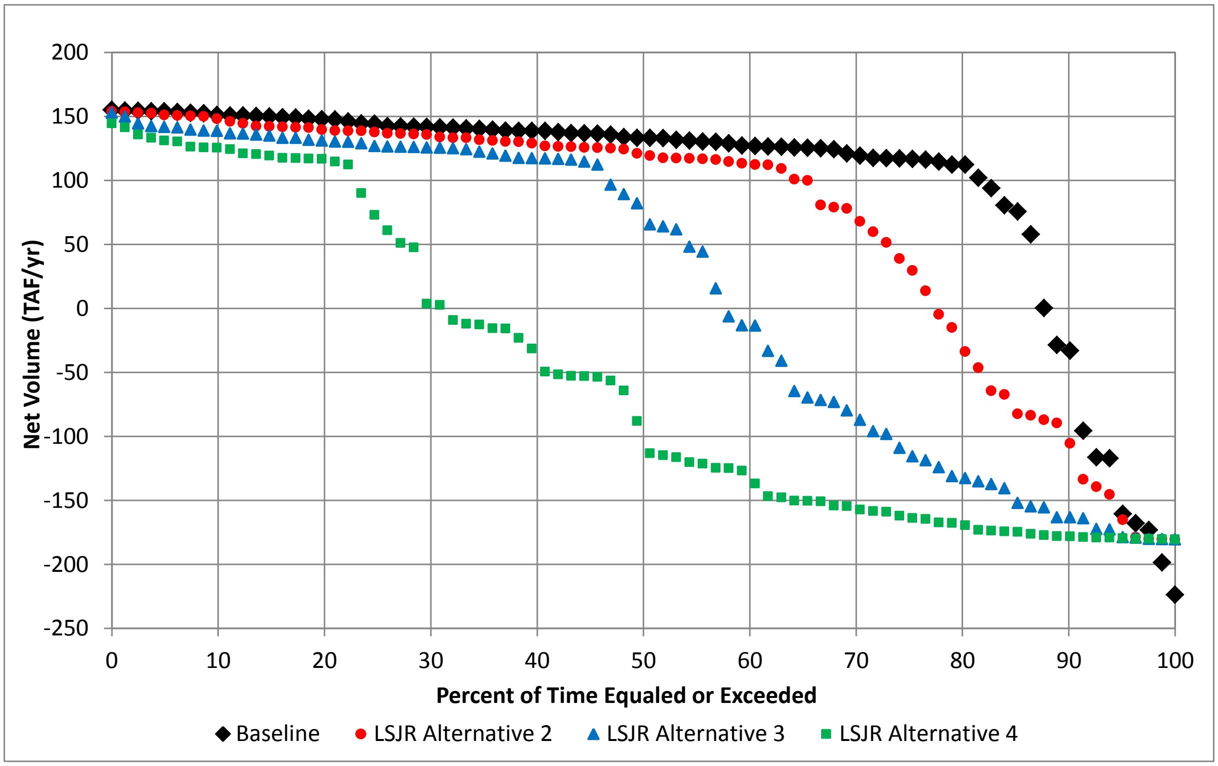


Figure 9-13. Annual Net Contribution to the Extended Merced Subbasin by MID

As described in Section 9.4.2, *Methods and Approach*, this analysis was performed using estimates of maximum groundwater pumping capacity based on 2009 infrastructure. Table 9-12 provides a summary of the average annual net change in the groundwater balance caused by each LSJR alternative, expressed in terms of inches of water spread over the entire subbasin. Table 9-12 also includes results assuming maximum groundwater pumping capacity based on 2014 infrastructure. These results are addressed in more detail in the following sections, which discuss the potential impacts associated with each alternative.

Table 9-12. Average Annual Net Change in Irrigation District Groundwater Balance Associated with the LSJR Alternatives per Subbasin Area

Groundwater Subbasin	Total Area (1,000 acres)	Baseline Irrigation District Groundwater Balance (TAF) (positive indicates recharge)	Baseline Irrigation District Recharge Per Subbasin Area (inches)	Decrease in Groundwater Balance Per Subbasin Area (inches) – LSJR Alternative 2: 20 Percent Unimpaired Flow	Decrease in Groundwater Balance Per Subbasin Area (inches) – LSJR Alternative 2: Adaptive Implementation Method 1: 30 Percent Unimpaired Flow	Decrease in Groundwater Balance Per Subbasin Area (inches) – LSJR Alternative 3	Decrease in Groundwater Balance Per Subbasin Area (inches) – LSJR Alternative 4
Results assuming maximum groundwater pumping based on 2009 infrastructure							
Eastern San Joaquin	707	65	1.1	0.0	0.1	0.6	1.7
Modesto	247	129	6.3	0.3	0.6	1.2	2.8
Turlock	349	158	5.4	0.3	0.7	1.5	3.4
Extended Merced	517	99	2.3	0.7	1.2	1.9	3.5
Results assuming maximum groundwater pumping based on 2014 infrastructure							
Eastern San Joaquin	707	64	1.1	0.0	0.2	0.7	1.9
Modesto	247	120	5.8	0.4	1.1	2.2	5.0
Turlock	349	146	5.0	0.3	1.1	2.2	5.0
Extended Merced	517	99	2.3	0.7	1.2	1.9	3.5

LSJR Alternative 2(Less than significant/Significant and unavoidable with adaptive implementation)

Estimated average net irrigation district groundwater balance under LSJR Alternative 2 is predicted to be either similar to or slightly less than under baseline conditions, with the decrease being most noticeable in the Extended Merced Subbasin (Figures 9-10 through 9-13). The predicted small changes are driven by the small changes to average surface water diversions under LSJR Alternative 2. Under baseline and LSJR Alternative 2, the irrigation districts contribute to groundwater recharge in most years, with the exception that the irrigation district groundwater balance becomes negative in the Eastern San Joaquin and Extended Merced Subbasins during approximately the driest 20 percent and 10 percent of years, respectively (Figures 9-10 through 9-13). The average reduction in annual net groundwater recharge under LSJR Alternative 2 relative to baseline is equivalent to 0.0-0.7 inches of water across each of the four subbasins (with 0.0 inches being for the Eastern San Joaquin Subbasin and 0.7 inches being for the Extended Merced Subbasin [Table 9-12]). These changes are less than the 1 inch threshold for significance.

When the maximum groundwater pumping capacity for 2014 is used in the analysis instead of the estimates for 2009, the results show small increases in baseline pumping in the Eastern San Joaquin, Modesto, and Turlock Subbasins under baseline conditions. However, the only noticeable change in the effect of LSJR Alternative 2 on groundwater recharge would be slightly less recharge for the Modesto Subbasin (reduction in recharge would increase from 0.3 to 0.4 inches across the subbasin [Table 9-12]). The largest effect of switching from the 2009 to 2014 maximum groundwater pumping capacity is in the Modesto Subbasin because MID had a relatively large increase in groundwater pumping capacity between 2009 and 2014 (Table G.2-4) and the smallest acreage (Table 9-12).

As described in Section 9.2.1, *San Joaquin Valley Groundwater Basin and Subbasins*, a change in groundwater flow can indirectly influence groundwater quality. Under LSJR Alternative 2, the direction of groundwater flow would not change such that any existing localized groundwater contamination in the subbasins would be affected. Therefore, there would likely be no degradation of groundwater quality under LSJR Alternative 2. Furthermore, LSJR Alternative 2 would not cause a significant amount of applied surface water, which has relatively low EC, to be replaced with applied groundwater, which has relatively high EC (surface water from the Stanislaus, Tuolumne, and Merced Rivers generally has much lower salinity than groundwater). Consequently, LSJR Alternative 2 would not cause an increase in salinity concentrations in the groundwater subbasins.

Therefore, at the 20 percent unimpaired flow level, the slight reduction in recharge under LSJR Alternative 2, as compared to baseline, would not likely result in groundwater quality impacts or a significant reduction in groundwater levels.

Adaptive Implementation

As discussed above, based on best available scientific information indicating that a change in the percent of unimpaired flow is needed to reasonably protect fish and wildlife, adaptive implementation method 1 would allow an increase of up to 10 percent over the 20 percent February-June unimpaired flow requirement (to a maximum of 30 percent of unimpaired flow). A change to the percent of unimpaired flow would take place based on required evaluation of current scientific information and would need to be approved as described in Appendix K, *Revised Water Quality Control Plan.* Accordingly, the frequency and duration of any use of this adaptive implementation method cannot be determined at this time. However, an increase of up to 30 percent of unimpaired flow would potentially result in different effects, as compared to 20 percent unimpaired flow, depending upon flow conditions and frequency of the adjustment. If this adjustment occurs frequently or for extended durations, impacts under LSJR Alternative 2 could become more like the impacts under LSJR Alternative 3. At the 30 percent unimpaired flow level, impacts on groundwater would increase relative to the 20 percent unimpaired flow level (Table 9-12) and could reach the equivalent of 1.2 inches across the Extended Merced Subbasin (i.e., greater than the threshold of significance). If the 2014 maximum groundwater pumping capacity values are used for the assessment, estimated groundwater impacts become significant for the Modesto and Turlock Subbasins and the Extended Merced Subbasin (Table 9-12).

As described in Section 9.2.1, *San Joaquin Valley Groundwater Basin and Subbasins*, a change in groundwater pumping can indirectly influence groundwater quality. Under LSJR Alternative 2 with adaptive implementation, a reduction in groundwater levels in the Extended Merced Subbasin could cause a degradation of groundwater quality as a result of changes in the direction of groundwater flow. However, specifically determining the changes to groundwater quality is speculative as it is dependent of many factors including, but not limited to, the location of groundwater pumping, the amount of groundwater pumped, the frequency at which pumping would occur, location of contaminants, the type of contaminants (e.g., water soluble or not), proximity of contamination to aquifers, hydrogeological characteristics of the aquifer, individual well construction, well depth, groundwater levels, and localized conditions, such as proximity to unused or abandoned wells. However, while specifically determining the changes to groundwater quality is speculative, it is reasonable to assume that localized groundwater contamination that exists in the subbasins could move in undesirable directions (i.e., toward water supply wells) and reduction in deep percolation of the relatively low EC surface water could also affect groundwater quality by causing a gradual increase in salinity. Consequently, LSJR Alternative 2, with the incorporation of adaptive implementation method 1, could potentially substantially deplete groundwater supplies and interfere with groundwater recharge and affect groundwater quality in these subbasins. Therefore, impacts on groundwater resources would be potentially significant and unavoidable.

Based on best available scientific information indicating that a change in the timing or rate of unimpaired flow is needed to reasonably protect fish and wildlife, adaptive implementation method 2 would allow changing the timing of the release of the volume of water within the February-June time frame. While the total volume of water released February–June would be the same as LSJR Alternative 2 without adaptive implementation, the rate could vary from the actual (7 day running average) unimpaired flow rate. Adaptive implementation method 2 would not authorize a reduction in flows required by other agencies or through other processes, which are incorporated in the modeling of baseline conditions. A change in the timing of the flow releases would not have an effect on groundwater recharge or groundwater quality. Adaptive implementation method 3 would not be authorized under LSJR Alternative 2 since the unimpaired flow percentage would not exceed 30 percent. Adaptive implementation method 4 would allow an adjustment of the Vernalis February–June flow requirement. WSE model results indicate changes due to adaptive implementation method 4 under this alternative would rarely alter the flows in the three eastside tributaries or the LSJR, and thus would not affect groundwater. Accordingly, LSJR Alternative 2, with the incorporation of adaptive implementation methods 2 and 4, would not substantially deplete groundwater supplies and affect groundwater quality.

An SED must identify feasible mitigation measures for each significant environmental impact identified in the SED. (Cal. Code Regs., tit. 23, § 3777, subd. (b)(3).) Mitigation to reduce significant impacts on groundwater resources could include the State Water Board or local agencies exercising their various authorities over groundwater users, including authorities under SGMA.

SGMA is now the state's primary sustainable groundwater management law. Under the SGMA framework, local agencies are tasked with protecting and managing high and medium priority groundwater basins with state intervention to begin by specified dates if local agencies are unwilling or unable to manage. The SGMA deadlines for state intervention are still prospective; therefore, State Water Board mitigation to protect the groundwater basin from the indirect impacts of the LSJR alternatives is infeasible at this time, but mitigation under local authorities is both feasible and required.

Possible mitigation measures to reduce or avoid any potential effects include those listed below.

- Identify the basin's sustainable yield and implement enforceable groundwater management measures (for maximum pumping or minimum water levels) so that reductions in groundwater pumping would result if certain thresholds are met.
- Establish water conservation measures, such as increased efficiency for municipal and industrial uses or conversion of irrigated land to crops that require less water, such that reductions in groundwater pumping would result.
- Establish a conjunctive water management program that would divert surface water during non-irrigation months (e.g., October–April) during wet years into unlined canals and designated fields to recharge the groundwater basin.

Local governments have police powers and groundwater management authority, but that authority was not exercised in most of the state to protect groundwater resources, including in areas that have long been recognized as being critically overdrafted. Although local governments could and should have regulated groundwater pumping to avoid, arrest, or reverse conditions of long-term overdraft, this regulatory authority was not typically used under baseline conditions. However, SGMA now requires that local agencies form GSAs by June 30, 2017. In the critically overdrafted Eastern San Joaquin, Merced, and Chowchilla Subbasins, those GSAs must develop and implement GSPs by January 31, 2020, while GSAs in the Modesto and Turlock Subbasins must adopt GSPs by January 31, 2022. Each GSP must also include measureable objectives as well as milestones in increments of 5 years, to achieve the sustainability goal in the basin within 20 years of the implementation of the GSP. (Wat. Code, § 10727.2.)

Thus, at this time, local agencies are vested with the mandatory duty to achieve sustainable groundwater management, which includes not causing undesirable results such as significant and unreasonable reduction of groundwater storage and degradation of water quality. Therefore, these local agencies with authority over the Extended Merced Subbasin can and should exercise their full authorities to address substantial depletion of groundwater supplies and water quality degradation, both under SGMA and their police powers. Under that authority, they can and should also implement those mitigation measures identified above. Doing so would prevent groundwater depletion and water quality impacts, mitigate those impacts, or both.

The State Water Board has several authorities that are independent of SGMA, including authority to take action to prevent waste, unreasonable use, unreasonable method of use, and unreasonable method of diversion of water. The State Water Board may exercise this authority through quasi-adjudicative or quasi-legislative proceedings. However, it is infeasible for the State Water Board to impose mitigation measures to prevent waste and unreasonable use at this time because it is undertaking a programmatic analysis of the potential groundwater resource impacts and does not have specific facts associated with an individual project to legally and technically apply requirements to prevent waste and unreasonable use in an adjudicative proceeding. In addition, while the State Water Board may impose water conservation or efficiency requirements through the adoption of regulations, the amount of time, high cost, and commitment of staff resources associated with such rule-making proceedings also renders adopting the mitigation measures now infeasible. Adopting regulations right now would require considerable staff time to research, formulate and develop, require extensive stakeholder outreach, and require numerous public meetings before the regulations would take effect. The State Water Board currently has limited resources to pursue adoption of such regulations as most of its budget for the water right program is supported by fees imposed on water right permit and license holders, and is used for program activities related to the diversion and use of water subject to the permit and license system. Only a small amount of funding is available for other regulatory activities and it is speculative to anticipate that additional funding will be made available.

The State Water Board's water quality control planning process relies on periodic reviews of the Bay-Delta Plan. As a result, the planning process continually accounts for changing conditions related to water quality and water planning. As additional information and data are gathered regarding groundwater pumping in the subbasins, SGMA milestones, and SGMA compliance, the State Water Board can and will revisit and analyze the groundwater condition during the periodic review of the water quality control plan. Where and when appropriate, it will also exercise its independent but complementary authorities under SGMA to ensure sustainable management of the groundwater basins in the plan area. Due to the infeasibility of mitigation by the State Water Board at this time and the inherent uncertainty in the degree to which this mitigation may be implemented by local agencies, particularly in the near-term, impacts on groundwater resources under LSJR Alternative 2 with adaptive implementation would remain significant and unavoidable.

LSJR Alternative 3 (Significant and unavoidable/Significant and unavoidable with adaptive implementation)

Estimated net irrigation district groundwater balance under LSJR Alternative 3 is predicted to be lower than under baseline conditions. The effect of LSJR Alternative 3 on groundwater could be largest in years with less than median water availability, but even wet years could experience some small effects in the Modesto, Turlock, and Extended Merced Subbasins (Figures 9-10 through 9-13). Under LSJR Alternative 3, the irrigation districts would still contribute to groundwater recharge in most years, although the irrigation district groundwater balance could become negative in the Eastern San Joaquin and Extended Merced Subbasins during approximately the driest 40 percent of years (i.e., more often than under baseline and LSJR Alternative 2) (Figures 9-10 through 9-13). Even when the net irrigation district groundwater balance is positive, a decrease in the recharge could be detrimental because it could reduce the amount of compensation for groundwater pumping that happens outside of the irrigation district lands.

Under LSJR Alternative 3 there would be more water in the rivers that could recharge the groundwater basins. However, it is unlikely that recharge from the rivers would increase significantly because the amount of recharge from the rivers is not large under existing conditions (USGS 2015) and the average wetted width of the channel would not increase greatly as a result of LSJR Alternative 3. If groundwater level decreases over time, the aquifer may eventually no longer intersect with portions of the rivers. This could also cause an increase in groundwater recharge from the rivers, but is not likely to be substantial enough to compensate for changes in the irrigation district groundwater balances.

Physical changes to the subbasins would occur over time. In wet years, LSJR Alternative 3 could have little effect on groundwater levels, but in dry years, groundwater levels could potentially substantially decrease. The potential calculated reduction in recharge in terms of inches across the subbasins is just an indicator of substantial effect. As described in Section 9.4.2, *Methods and Approach*, 1 inch of water translates to an approximately 10-inch decrease in groundwater level. A decrease in groundwater levels would not be uniform across the subbasins. It would vary depending on the location and amount of recharge, groundwater extraction, and potential movement of groundwater from other locations.

The average reduction in net irrigation district groundwater balance under LSJR Alternative 3 could exceed 1 inch across the Modesto, Turlock, and Extended Merced Subbasins (Table 9-12). When the maximum groundwater pumping capacity for 2014 is used in the analysis instead of the estimates for 2009, the results show small increases in pumping in the Eastern San Joaquin, Modesto, and Turlock Subbasins under baseline conditions. The results also show somewhat greater increases in groundwater pumping under LSJR Alternative 3, which could potentially result in a larger decrease in groundwater elevations (Table 9-12). The largest modeled difference in results between the 2009 and 2014 maximum groundwater pumping capacities are in the Modesto Subbasin because MID had a relatively large increase in groundwater pumping capacity between 2009 and 2014 (Table G.2-4) and had the smallest acreage (Table 9-12). There is no change in the Extended Merced Subbasin because the subbasin saw no change in the estimated maximum groundwater pumping capacity between 2009 and 2014.

As described in Section 9.2.1, *San Joaquin Valley Groundwater Basin and Subbasins*, a change in groundwater pumping can indirectly influence groundwater quality. Under LSJR Alternative 3, reduction in groundwater levels in the Modesto, Turlock, and Extended Merced Subbasins could cause a degradation of groundwater quality as a result of changes in the direction of groundwater flow. Specifically determining the changes to groundwater quality is speculative as it is dependent upon many factors including, but not limited to, the location of groundwater pumping, the amount of groundwater pumped, the frequency at which pumping would occur, location of contaminants, the type of contaminants (e.g., water soluble or not), proximity of contamination to aquifers, hydrogeological characteristics of the aquifer, individual well construction, well depth, groundwater levels, and localized conditions, such as proximity to unused or abandoned wells. However, while specifically determining the changes to groundwater quality is speculative, it is reasonable to assume that localized groundwater contamination that exists in the subbasins could move in undesirable directions (i.e., toward water supply wells) and that reduction in deep percolation of the relatively low EC surface water could also affect groundwater quality by causing a gradual increase in salinity.

Because the average annual reduction in irrigation district groundwater balance under LSJR Alternative 3 would exceed 1 inch across the Modesto, Turlock, and the Extended Merced Subbasins, LSJR Alternative 3 could potentially substantially deplete groundwater supplies and interfere with groundwater recharge and affect groundwater quality in these subbasins. Therefore, impacts on groundwater resources would be potentially significant and unavoidable.

Adaptive Implementation

As discussed under LSJR Alternative 2, adaptive implementation methods 2 and 4 are not expected to result in impacts on groundwater resources. Adaptive implementation method 3 would result in a shift in the volume of February–June water available to other parts of the year and is included in the modeling results presented above for LSJR Alternative 3. Because this method would not affect diversions or the total annual volume of river flow, this method would not affect groundwater, and it would result in impacts similar to those already described. Adaptive implementation method 1 would allow an increase or decrease of up to 10 percent in the February-June 40 percent unimpaired flow requirement (with a minimum of 30 percent and maximum of 50 percent) to optimize implementation measures to meet the narrative objective, while considering other beneficial uses, provided that these other considerations do not reduce intended benefits to fish and wildlife. Adaptive implementation must be approved using the process described in Appendix K, *Revised Water Quality Control Plan*. Accordingly, the frequency and duration of any use of this adaptive implementation method cannot be determined at this time. If the specified percent of unimpaired flow were changed from 40 percent to 30 percent or 40 percent to 50 percent on a long-term basis, the conditions and impacts could become more similar to LSJR Alternatives 2 or 4, respectively. If the adjustment occurs frequently or for extended durations, based on the modeling results for LSJR Alternative 2, with adaptive implementation method 1 incorporated (i.e., 30 percent unimpaired flow), and LSJR Alternative 4, with adaptive implementation method 1 incorporated (i.e., 50 percent unimpaired flow), impacts would remain potentially significant and unavoidable.

An SED must identify feasible mitigation measures for each significant environmental impact identified in the SED. (Cal. Code Regs., tit. 23, § 3777, subd. (b)(3).) Mitigation to reduce significant impacts on groundwater resources could include the State Water Board or local agencies exercising their various authorities over groundwater users, including authorities under SGMA.

As discussed in detail under LSJR Alternative 2 with adaptive implementation, the State Water Board has several authorities that are independent of SGMA but it is local agencies that are vested with the mandatory duty to achieve sustainable groundwater management, which includes not causing undesirable results such as significant and unreasonable reduction of groundwater storage and degradation of water quality. Therefore, these local agencies, with authority over Eastern San Joaquin Basin, Modesto, Turlock, and Extended Merced Subbasins can and should exercise their full authorities to address substantial depletion of groundwater supplies and water quality degradation, both under SGMA and their police powers. Under that authority, they can and should also implement those mitigation measures identified in LSJR Alternative 2 with adaptive implementation above. Doing so would prevent groundwater depletion and water quality impacts, mitigate those impacts, or both. Due to the inherent uncertainty in the degree to which this mitigation may be implemented by local agencies, however, impacts on groundwater resources under LSJR Alternative 3, with or without adaptive implementation, would remain potentially significant and unavoidable.

As further stated under LSJR Alternative 2 with adaptive implementation, the State Water Board can and will revisit and analyze the groundwater condition during the periodic review of the water quality control plan. Where and when appropriate, it will also exercise its independent but complementary authorities under SGMA to ensure sustainable management of the groundwater basins in the plan area.

LSJR Alternative 4 (Significant and unavoidable/Significant and unavoidable with adaptive implementation)

LSJR Alternative 4 could result in the greatest potential increase in groundwater pumping and reduction in recharge from the four subbasins, as compared to baseline levels (Table 9-12). LSJR Alternative 4 could result in physical environmental effects, such as decreases in water quality or a significant reduction in groundwater levels, similar to the impacts described under LSJR Alternative 3. However, LSJR Alternative 4 could result in less groundwater recharge from surface water and require more groundwater to be pumped than would be required under LSJR Alternative 3. As such, the impacts on groundwater levels and quality associated with LSJR Alternative 4 would potentially be greater than the impacts associated with LSJR Alternative 3.

Estimated annual net groundwater contributions from the irrigation districts under LSJR Alternative 4 are predicted to be much lower than under baseline conditions. The effect of LSJR Alternative 4 on groundwater pumping and recharge could be largest in years with less than median water availability, but even wet years could experience some small effects in the Modesto, Turlock, and Extended Merced Subbasins (Figures 9-11 through 9-13). Under LSJR Alternative 4, the irrigation districts would still contribute to groundwater recharge in many years, although the irrigation district groundwater balance could become negative in the Eastern San Joaquin, Turlock, and Extended Merced Subbasins during approximately 65 percent, 30 percent, and 70 percent of years, respectively (i.e., much more often than under baseline conditions) (Figures 9-10, 9-12, and 9-13). Even when the annual irrigation district groundwater balance is positive, a decrease in the recharge could be detrimental because it would reduce the amount of compensation for groundwater pumping that happens outside of the irrigation district lands.

As discussed under LSJR Alternative 3, increased flow in the rivers is expected to have only a small effect on the groundwater balance. The larger effects caused by a reduction in groundwater recharge, and an increase in groundwater pumping could vary year-to-year and location to location.

The average reduction in net irrigation district groundwater balance associated with LSJR Alternative 4 could exceed 1 inch across all four subbasins (Table 9-12). When the maximum groundwater pumping capacity for 2014 is used in the analysis instead of the estimates for 2009, average net contribution from the irrigations districts decreases further, as compared to baseline, by the equivalent of an additional 0.2, 2.2, 1.6, and 0.0 inches for the Eastern San Joaquin, Modesto, Turlock, and Extended Merced Subbasins, respectively (Table 9-12). This is larger than for LSJR Alternatives 2 and 3 because the irrigation districts would need use their expanded pumping capacity more often because of the greater reduction in surface water supply under LSJR Alternative 4.

Under LSJR Alternative 4, reduction in groundwater levels could cause a potential degradation of groundwater quality as described for LSJR Alternative 3. However, under LSJR Alternative 4, degradation of water quality could be worse because all four subbasins would be affected. For example, LSJR Alternative 4 includes groundwater impacts on the Eastern San Joaquin Subbasin, where reduced groundwater levels below Stockton have caused the migration of saline water from the west to move eastward into the basin. In some areas below Stockton, salinity concentrations in groundwater exceed drinking water standards (SEWD 2014). The rate of this intrusion of saline water could increase under LSJR Alternative 4.

The average reduction in net irrigation district groundwater balance under LSJR Alternative 4 could exceed 1 inch across the Eastern San Joaquin, Modesto, Turlock, and the Extended Merced

Subbasins. Thus, LSJR Alternative 4 could potentially substantially deplete groundwater supplies and interfere substantially with groundwater recharge and affect groundwater quality. Therefore, impacts on groundwater resources are potentially significant and unavoidable.

Adaptive Implementation

As discussed under LSJR Alternative 2, adaptive implementation methods 2 and 4 are not expected to result in changes to the impacts on groundwater resources. For reasons discussed under LSJR Alternative 3, adaptive implementation method 3 would not affect impacts associated with LSJR Alternative 4. Adaptive implementation method 1 would allow a decrease of up to 10 percent in the February–June, 60 percent unimpaired flow requirement (to 50 percent) to optimize implementation measures to meet the narrative objective, while considering other beneficial uses, provided that these other considerations do not reduce intended benefits to fish and wildlife. Adaptive implementation must be approved using the process described in Appendix K, *Revised Water Quality Control Plan*. Accordingly, the frequency and duration of any use of this adaptive implementation method cannot be determined at this time. If the specified percent of unimpaired flow were changed from 60 percent to 50 percent on a long-term basis, the conditions and impacts could become more similar to LSJR Alternative 3 (i.e., less severe for groundwater resources, but still significant).

An SED must identify feasible mitigation measures for each significant environmental impact identified in the SED. (Cal. Code Regs., tit. 23, § 3777, subd. (b)(3).) Mitigation to reduce significant impacts on groundwater resources could include the State Water Board or local agencies exercising their various authorities over groundwater users, including authorities under SGMA.

As discussed in detail under LSJR Alternative 2 with adaptive implementation, the State Water Board has several authorities that are independent of SGMA but it is local agencies that are vested with the mandatory duty to achieve sustainable groundwater management, which includes not causing undesirable results such as significant and unreasonable reduction of groundwater storage and degradation of water quality. These local agencies, with authorities over Eastern San Joaquin, Modesto, Turlock, and the Extended Merced Subbasins**,** therefore, can and should exercise their full authorities to address substantial depletion of groundwater supplies and water quality degradation, both under SGMA and their police powers. Under that authority, they can and should also implement those mitigation measures identified in LSJR Alternative 2 with adaptive implementation above. Doing so would prevent groundwater depletion and water quality impacts, mitigate those impacts, or both. Due to the inherent uncertainty in the degree to which this mitigation may be implemented by local agencies, however, impacts on groundwater resources under LSJR Alternative 4, with or without adaptive implementation, would remain potentially significant and unavoidable.

As further stated under LSJR Alternative 2 with adaptive implementation, the State Water Board can and will revisit and analyze the groundwater condition during the periodic review of the water quality control plan. Where and when appropriate, it will also exercise its independent but complementary authorities under SGMA to ensure sustainable management of the groundwater basins in the plan area.

Impact GW-2: Cause subsidence as a result of groundwater depletion

No Project Alternative (LSJR/SDWQ Alternative 1)

The No Project Alternative would result in implementation of flow objectives identified in the 2006 Bay-Delta Plan. See Chapter 15, *No Project Alternative (LSJR Alternative 1 and SDWQ Alternative 1),* for the No Project Alternative impact discussion and Appendix D, *Evaluation of the No Project Alternative (LSJR Alternative 1 and SDWQ Alternative 1),* for the technical analysis of the No Project Alternative.

LSJR Alternative 2 (Less than significant/Significant and unavoidable with adaptive implementation)

As described under Impact GW-1 for LSJR Alternative 2, the estimated average net irrigation district groundwater balance under LSJR Alternative 2 is predicted to be either similar to or slightly less than under baseline conditions, with the decrease being most noticeable in the Extended Merced Subbasin (Figures 9-10 through 9-13). The average reduction in annual net groundwater recharge under LSJR Alternative 2 relative to baseline is equivalent to 0.0-0.7 inches of water across each of the four subbasins (Table 9-12).

These changes are less than the 1 inch threshold for significant reduction in groundwater levels, meaning that the reduction in groundwater levels at the 20 percent unimpaired flow level is less than significant. Therefore, under LSJR Alternative 2, as compared to baseline, the slight reduction in groundwater recharge would not likely result in subsidence.

Adaptive Implementation

As described under Impact GW-1, LSJR Alternative 2 with adaptive implementation methods 2 and 4 would not affect groundwater supplies and therefore would not cause subsidence. Adaptive implementation method 3 would not be authorized under LSJR Alternative 2. However, adaptive implementation method 1 would allow an increase of up to 10 percent over the 20 percent February-June unimpaired flow requirement (to a maximum of 30 percent of unimpaired flow). If this adjustment occurs frequently or for extended durations, impacts under LSJR Alternative 2 could become more like the impacts under LSJR Alternative 3.

At the 30 percent unimpaired flow level, the impacts on groundwater would increase relative to the 20 percent unimpaired flow level (Table 9-12) and could reach the equivalent of 1.2 inches across the Extended Merced Subbasin (i.e., greater than the threshold of significance for Impact GW-1). Because portions of the Extended Merced Subbasin show evidence of subsidence (see Section 9.2.1, *San Joaquin Valley Groundwater Basin and Subbasins*), it is likely that increased groundwater depletion in the Extended Merced Subbasin could lead to increased subsidence. Subsidence in the other subbasins is less likely to occur given that there is little evidence that the soils in these subbasins are subject to inelastic compaction.

Therefore, under LSJR Alternative 2 with adaptive implementation method 1, subsidence due to a reduction in groundwater levels would potentially be significant and unavoidable.

An SED must identify feasible mitigation measures for each significant environmental impact identified in the SED. (Cal. Code Regs., tit. 23, § 3777, subd. (b)(3).) Mitigation to reduce significant impacts on groundwater resources could include the State Water Board or local agencies exercising their various authorities over groundwater users, including authorities under SGMA.

As discussed under Impact GW-1 for LSJR Alternative 2 with adaptive implementation, the State Water Board has several authorities independent of SGMA. However, under SGMA, it is local agencies that are vested with the mandatory duty to achieve sustainable groundwater management, which includes not causing undesirable results such as significant and unreasonable reduction of groundwater storage and significant and unreasonable land subsidence that substantially interferes with surface land uses. Therefore, the local agencies with authority over the Extended Merced Subbasin can and should exercise their full authorities to address substantial depletion of groundwater supplies and subsidence, both under SGMA and their police powers. Doing so would prevent groundwater depletion and subsidence, mitigate those impacts, or both. It is possible that subsidence under LSJR Alternative 2 with adaptive implementation could be limited to areas that would not cause interference with surface land uses. However, it is unlikely that subsidence would have no effect on surface uses. Furthermore, even if subsidence did not invoke actions under SGMA, the associated depletion of the groundwater resources, as described in Impact GW-1, could invoke SGMA triggers for state interaction. Actions taken under SGMA to protect the aquifer would also protect against subsidence. However, given the inherent uncertainty in the degree to which local agencies may implement mitigation actions, the subsidence impact under LSJR Alternative 2, with adaptive implementation, would remain potentially significant and unavoidable.

As discussed under Impact GW-1 for LSJR Alternative 2 with adaptive implementation, the State Water Board can and will revisit and analyze the groundwater condition during the periodic review of the water quality control plan. Where and when appropriate, it will also exercise its independent but complementary authorities under SGMA to ensure sustainable management of the groundwater basins in the plan area.

LSJR Alternative 3 (Significant and unavoidable/Significant and unavoidable with adaptive implementation)

As described under Impact GW-1, the average reduction in net irrigation district groundwater balance under LSJR Alternative 3 could exceed 1 inch across the Modesto, Turlock, and Extended Merced Subbasins (Table 9-12). As a result, LSJR Alternative 3 could potentially substantially deplete groundwater supplies in these subbasins. Because portions of the Extended Merced Subbasin show evidence of subsidence (see Section 9.2.1, *San Joaquin Valley Groundwater Basin and Subbasins*), it is likely that increased groundwater depletion in the Extended Merced Subbasin could lead to increased subsidence. Subsidence in the other subbasins is less likely to occur given that there is little evidence that the soils in these subbasins are subject to inelastic compaction.

Therefore, due to the increased likelihood of subsidence in the Extended Merced Subbasin, under LSJR Alternative 3 subsidence due to a reduction in groundwater levels would potentially be significant and unavoidable.

Adaptive Implementation

As described under Impact GW-1, LSJR Alternative 3 with adaptive implementation methods 2, 3, and 4 would not affect groundwater supplies or, therefore, cause subsidence. Adaptive implementation method 1 could cause a 10 percent increase or decrease in the specified percent of unimpaired flow. If the specified percent of unimpaired flow were changed from 40 percent to

30 percent or 40 percent to 50 percent on a long-term basis, the conditions and impacts could become more similar to LSJR Alternatives 2 or 4, respectively. If the adjustment occurs frequently or for extended durations, based on the modeling results for LSJR Alternative 2, with adaptive implementation method 1 incorporated (i.e., 30 percent unimpaired flow), and LSJR Alternative 4, with adaptive implementation method 1 incorporated (i.e., 50 percent unimpaired flow), impacts would remain potentially significant and unavoidable.

An SED must identify feasible mitigation measures for each significant environmental impact identified in the SED. (Cal. Code Regs., tit. 23, § 3777, subd. (b)(3).) Mitigation to reduce significant impacts on groundwater resources could include the State Water Board or local agencies exercising their various authorities over groundwater users, including authorities under SGMA.

As discussed under LSJR Alternative 2 with adaptive implementation, local agencies vested with the mandatory duty to achieve sustainable groundwater management and authority over the Extended Merced Subbasin, can and should exercise their full authorities to address substantial depletion of groundwater supplies and subsidence, both under SGMA and their police powers. Doing so would prevent groundwater depletion and subsidence, mitigate those impacts, or both. However, given the inherent uncertainty in the degree to which local agencies may implement mitigation actions, the subsidence impacts under LSJR Alternative 3 with adaptive implementation would remain potentially significant and unavoidable.

As further stated under Impact GW-1 for LSJR Alternative 2 with adaptive implementation, the State Water Board can and will revisit and analyze the groundwater condition during the periodic review of the water quality control plan. Where and when appropriate, it will also exercise its independent but complementary authorities under SGMA to ensure sustainable management of the groundwater basins in the plan area.

LSJR Alternative 4 (Significant and unavoidable/Significant and unavoidable with adaptive implementation)

As described under Impact GW-1, under LSJR Alternative 4, the average reduction in net irrigation district groundwater balance could exceed 1 inch across the Eastern San Joaquin, Modesto, Turlock, and the Extended Merced Subbasins (Table 9-12). As a result, LSJR Alternative 4 could potentially substantially deplete groundwater supplies in these subbasins. LSJR Alternative 4 could result in the greatest potential increase in groundwater pumping and reduction in recharge from the four subbasins, as compared to baseline levels (Table 9-12). Because portions of the Extended Merced Subbasin show evidence of subsidence (see Section 9.2.1, *San Joaquin Valley Groundwater Basin and Subbasins*), it is likely that increased groundwater depletion in the Extended Merced Subbasin could lead to increased subsidence. Subsidence in the other subbasins is less likely to occur given that there is little evidence that the soils in these subbasins are subject to inelastic compaction.

Therefore, due to the increased likelihood of subsidence in the Extended Merced Subbasin, under LSJR Alternative 4 subsidence due to a reduction in groundwater levels would potentially be significant and unavoidable.

Adaptive Implementation

As described under Impact GW-1, LSJR Alternative 4 with adaptive implementation methods 2, 3, and 4 would not affect groundwater supplies and therefore would not cause subsidence. Adaptive implementation method 1 could cause a 10 percent decrease in the specified percent of unimpaired flow. If the specified percent of unimpaired flow were changed from 60 percent to 50 percent on a long-term basis, the conditions and impacts could become more similar to LSJR Alternative 3. If the adjustment occurs frequently or for extended durations, based on the modeling results for LSJR Alternative 3, with adaptive implementation method 1 (i.e., 50 percent unimpaired flow), impacts would remain potentially significant and unavoidable.

An SED must identify feasible mitigation measures for each significant environmental impact identified in the SED. (Cal. Code Regs., tit. 23, § 3777, subd. (b)(3).) Mitigation to reduce significant impacts on groundwater resources could include the State Water Board or local agencies exercising their various authorities over groundwater users. including authorities under SGMA.

As discussed under LSJR Alternative 2 with adaptive implementation, local agencies vested with the mandatory duty to achieve sustainable groundwater management and authority over the Extended Merced Subbasin can and should exercise their full authorities to address substantial depletion of groundwater supplies and subsidence, both under SGMA and their police powers. Doing so would prevent groundwater depletion and subsidence, mitigate those impacts, or both. However, given the inherent uncertainty in the degree to which local agencies may implement mitigation actions, the subsidence impacts under LSJR Alternative 3 with adaptive implementation, would remain potentially significant and unavoidable.

As further stated under Impact GW-1 for LSJR Alternative 2 with adaptive implementation, the State Water Board can and will revisit and analyze the groundwater condition during the periodic review of the water quality control plan. Where and when appropriate, it will also exercise its independent but complementary authorities under SGMA to ensure sustainable management of the groundwater basins in the plan area.

9.4.4 Impacts and Mitigation Measures: Extended Plan Area

Bypassing flows, as described in Chapter 5, *Surface Hydrology and Water Quality*, would not impact groundwater resources. The extended plan area primarily has a shallow-to-bedrock geology. There is only one designated groundwater basin, the Yosemite Basin in Yosemite National Park in Mariposa County as the shallow-to-bedrock geology produces relatively small, localized, and isolated groundwater areas. If junior water right holders reduced their reliance on surface water diversions and extracted more groundwater to compensate for the reduction, more groundwater could be extracted over time in the extended plan area, primarily under LSJR Alternatives 3 and 4 with or without adaptive implementation. However, this extraction would be small based on the relatively small amount of consumptive use that occurs in the extended plan area. Thus, impacts would be less than significant in the extended plan area.

9.5 Cumulative Impacts

For the cumulative impact analysis, refer to Chapter 17, *Cumulative Impacts, Growth-Inducing Effects, and Irreversible Commitment of Resources.*

9.6 References Cited

Barringer, J. L., and P. A. Reilly. 2013. Arsenic in groundwater: a summary of sources and the biogeochemical and hydrogeologic factors affecting arsenic occurrence and mobility. Chapter 4 in *Current Perspectives in Contaminant Hydrology and Water Resources Sustainability*. 34 pp.

Belitz, K., M. S. Fram, and T. D. Johnson. 2015. Metrics for assessing the quality of groundwater used for public supply, CA, USA: equivalent-population and area. *Environmental Science & Technology* 49(14):8330–8338.

Borchers, J. W., V. K. Grabert, M. Carpenter, B. Dalgish, and D. Cannon. 2014. *Land subsidence from groundwater use in California*. April. Available: http://aquadoc.typepad.com/files/ca_land_subsidence_gw_use_april2014.pdf. Accessed: May 2, 2016.

Breitler, A. 2016. *Groundwater levels still falling*. June 15. RecordNet. Available: http://www.recordnet.com/news/20160615/groundwater-levels-still-falling. Accessed: June 20.

California Department of Water Resources (DWR). 2003a. *California's Groundwater Bulletin 118, Update 2003*. Last revised: 2006. Sacramento, CA.

———. 2003b. *California's Groundwater Bulletin 118, Update 2003*. *San Joaquin River Hydrologic Region, San Joaquin Valley Groundwater Basin, Eastern San Joaquin Subbasin*. Last revised: 2006. Sacramento, CA.

———. 2003c. *California's Groundwater Bulletin 118, Update 2003. San Joaquin River Hydrologic Region, San Joaquin Valley Groundwater Basin, Modesto Subbasin*. Last revised: 2006. Sacramento, CA.

———. 2003d*. California's Groundwater Bulletin 118, Update 2003. San Joaquin River Hydrologic Region, San Joaquin Valley Groundwater Basin, Turlock Subbasin*. Last revised: 2006. Sacramento, CA.

———. 2003e. *California's Groundwater Bulletin 118, Update 2003. San Joaquin River Hydrologic Region, San Joaquin Valley Groundwater Basin, Merced Subbasin*. Last revised: 2006. Sacramento, CA.

———. 2003f. *California's Groundwater Bulletin 118, Update 2003. San Joaquin River Hydrologic Region, San Joaquin Valley Groundwater Basin, Tracy Subbasin*. Last revised: 2006. Sacramento, CA.

———. 2003g. *California's Groundwater Bulletin 118, Update 2003. San Joaquin River Hydrologic Region, San Joaquin Valley Groundwater Basin, Delta Mendota Subbasin*. Last revised: 2006. Sacramento, CA.

———. 2003h. *California's Groundwater Bulletin 118, Update 2003. San Joaquin River Hydrologic Region, San Joaquin Valley Groundwater Basin, Chowchilla Subbasin*. Last revised: 2006. Sacramento, CA.

———. 2011. *Water Facts 3: Adjudicated Groundwater Basins*. Available: http://www.water.ca.gov/pubs/groundwater/adjudicated_ground_water_basins_in_california__water_facts_3_/water_fact_3_7.11.pdf. Accessed: July 7, 2012.

———. 2013. *California Water Plan. Chapter 9 - Conjunctive Management and Groundwater Storage*. Available: http://www.water.ca.gov/ waterplan/docs/cwpu2013/Final/Vol3_Ch09_ConjMgmt-GW-Storage.pdf. Accessed: July 3, 2016.

———. 2014a. *Final CASGEM Basin Prioritization Results – June 2014*. Available: http://www.water.ca.gov/groundwater/casgem/basin_ prioritization.cfm. Accessed: March 2016.

———. 2014b. *Final CASGEM Basin Summary. San Joaquin Valley Groundwater Basin, Eastern San Joaquin Subbasin*. Available: http://www.water.ca.gov/groundwater/casgem/pdfs/basin_prioritization/NCRO%2071.pdf. Accessed: June 2016.

———. 2014c. *Final CASGEM Basin Summary. San Joaquin Valley Groundwater Basin, Modesto Subbasin*. Available: http://www.water.ca.gov/ groundwater/casgem/pdfs/basin_prioritization/SCRO%2036.pdf. Accessed: June 2016.

———. 2014d. *1992 Assembly Bill 3030 (AB3030).* Available: http://www.water.ca.gov/groundwater/docs/1992_AB3030_Summary_ 02202014.pdf. Accessed: June 2016.

———. 2014e. *1992 Senate Bill 1938 (SB1938).* Available: http://www.water.ca.gov/groundwater/docs/2002_SB1938_Summary_ 02202014.pdf. Accessed: June 2016.

———. 2014f. 1992 *Assembly Bill 359 (AB359).* Available: http://www.water.ca.gov/groundwater/docs/2011_AB359_Summary_ 02192014.pdf. Accessed: June 2016.

———. 2015a. *California's Groundwater Update 2013. Chapter 8: A compilation of enhanced content for California water plan update 2013. San Joaquin River Hydrologic Region Groundwater Update*. April.

———. 2015b. *California's Groundwater Update 2013. Appendix E. California's Groundwater Update 2013 Technical Memorandum: Calculating Annual Change in Groundwater in Storage by Using Groundwater-Level Data*.

———. 2015c*. CASGEM Online System*. Available: https://www.casgem.water.ca.gov/. Accessed: May.

———. 2016. *Critically Overdrafted Basins. Final List of Critically Overdrafted Basins*. January. Available: http://www.water.ca.gov/groundwater/sgm/cod.cfm. Accessed: March.

Carlson, K. 2013. *Stanislaus County supervisors approve the county's first groundwater ordinance.* The Modesto Bee. Available: http://www.modbee.com/news/special-reports/groundwater-crisis/article3155799.html. Accessed: April 6, 2016.

Central Valley Regional Water Quality Control Board (Central Valley Water Board). 2012. *Developing Groundwater Quality Protection Strategy for the Central Valley Region*. Available: http://www.waterboards.ca.gov/rwqcb5/water_issues/groundwater_quality/index.shtml. Accessed: July 6j, 2012.

———. 2016. *The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region*. Fourth Edition. The Sacramento River Basin and the San Joaquin River Basin. Available: http://www.waterboards.ca.gov/centralvalley/water_issues/basin_plans/sacsjr.pdf. Accessed: June 21, 2016.

City of Merced. 2001. *Merced Water Supply Plan Update*. Final Report. September. Prepared by CH2Mhill, Sacramento, CA.

City of Modesto. 2008. *Turlock Groundwater Basin*. Draft Groundwater Management Plan. January 17. Prepared by Turlock Groundwater Basin Association. Available: http://www.modestogov.com/uppd/reports/water/masterplans/Turlock_Groundwater_Basin_Groundwater_Management_Plan.pdf. Accessed: January 12, 2012.

City of Modesto and Modesto Irrigation District (MID). 2011. *Joint 2010 Urban Water Management Plan*. May. Prepared by West Yost Associates.

City of Oakdale. 2009. *City of Oakdale 2010 Urban Water Management Plan*. Prepared by HDR, Folsom, CA. January 2009. Available: ftp://ftp.water.ca.gov/uwmp/completed-plans/Oakdale/2009%20Final%20Urban%20Water%20Management%20Plan%20Oakdale.pdf. Accessed: March 2, 2012.

City of Ripon. 2004. *City of Ripon Urban Water Management Plan*. January. Available: http://www.water.ca.gov/urbanwatermanagement/2005uwmps/Ripon%20%20City%20of/Ripon%202005%20Urban%20Plan-1-6-04.pdf. Accessed: October 6, 2015.

City of Stockton. 2011. *2010 City of Stockton Urban Water Management Plan*. May 26.

City of Tracy. 2011. *City of Tracy 2010 Urban Water Management Plan.* May. Prepared by Erler & Kalinowski, Inc.

County of Merced. 2009. *Draft General Plan Update: Qualitative Comparison of Water Supply and Demand in Merced County*. Available: http://www.co.merced.ca.us/pdfs/gpu/documents_maps/Supply_and_Demand_TM_drft_1109.pdf. Accessed: November 2012.

East Stanislaus Regional Water Management Partnership (ESRWMP). 2013. *East Stanislaus Integrated Regional Water Management Plan*. Available: http://www.water.ca.gov/irwm/grants/docs/PlanReviewProcess/East_Stanislaus_IRWMP/Final%20ESIRWMP%2020Dec13.pdf. Accessed: June 2014.

Eastern San Joaquin County Groundwater Basin Authority (ESJCGBA). 2014. *Eastern San Joaquin Integrated Regional Water Management Plan Update*. June. Prepared by GEI Consultants.

Eastside Water District (EWD). 2003. *Eastside Water District Agricultural Water Management Plan*. Agricultural Water Management Council. Sacramento, CA.

Farr, T. G., C. Jones, and Z. Liu. 2015. *Progress Report: Subsidence in the Central Valley, California*. September, 10. Available: http://www.water.ca.gov/groundwater/docs/ NASA_REPORT.pdf. Accessed: March 28, 2016.

Faunt, C. C., M. Sneed, J. Traum, and J. T. Brandt. 2015. Water Availability and Subsidence in California's Central Valley. *Hydrogeology Journal* 24(3):675–684.

Giwargis, Ramona. 2014. Nonprofit sues Livingston over drinking water. *Merced Sun-Star*. May 15. Available: <http://www.mercedsunstar.com/news/local/article3290072.html>. Accessed: December 1, 2015.

Merced Area Groundwater Pool Interests (MAGPI). 2008. *Merced Groundwater Basin Groundwater Management Plan Update*. July 29. Prepared by AMEC Geomatrix, Inc.

Merced Irrigation District (Merced ID). 2011. *About MID.* Available: http://www.mercedid.org/aboutmid. Accessed: December.

———. 2013a. *Agricultural Water Management Plan*. September 3. Available: http://www.mercedid.com/index.cfm/water/ag-water-management-plan/. Accessed: July 20, 2015.

———. 2013b. *Merced Integrated Regional Water Management Plans*. August. Prepared by RMC Water and Environment.

Miller, T. 2015. *Merced County adopts groundwater ordinance to regulate new wells.* Merced Sun-Star. March 17. Available: http://www.mercedsunstar.com/news/local/article15065393.html. Accessed: April 6, 2016.

Modesto Irrigation District (MID). 2012. *Agriculture Water Management Plan for 2012 for the Modesto Irrigation District.* December. Modesto, CA.

———. 2015. *Agriculture Water Management Plan 2015 Update for the Modesto Irrigation District*. December. Prepared by Provost & Pritchard Consulting Group, Modesto, CA.

Morris, B. L., A. R. L. Lawrence, P. J. C. Chilton, B. Adams, R. C. Calow, and B. A. Klinck,. 2003. *Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management. Early Warning and Assessment Report Series, RS*. 03-3. United Nations Environment Programme, Nairobi, Kenya.

Northeastern San Joaquin County Groundwater Banking Authority (NSJCGBA). 2004. *Eastern San Joaquin Groundwater Basin Groundwater Management Plan*. September. Prepared for Northeastern San Joaquin County Groundwater Banking Authority.

Oakdale Irrigation District (OID). 2012. *Oakdale Irrigation District Agricultural Water Management*. December. Prepared by Davids Engineering, Inc. Available: http://www.oakdale irrigation.com/files/OID%202012%20AWMP%20-%20OID%20Web%20Version.pdf. Accessed: July 20, 2015.

San Joaquin County. 2009*. San Joaquin County general plan update. Chapter 9: public utilities and services*. Public review draft background report. July 2. Available: http://www.sjcgpu.com/pdf/backgroundreport/prd_br_09s.pdf. Accessed: October 2015.

San Joaquin County Flood Control and Water Conservation District (SJCFCWCD). 1985. *Eastern San Joaquin County Groundwater Study*. Final Report. Prepared by Brown and Caldwell Consulting Engineers.

———. 2015. *Spring 2015 Eastern San Joaquin County Groundwater Report*. Available: http://www.sjwater.org/ Documents/Groundwater%20Reports/Groundwater%20Report-Spring%202015.pdf. Accessed: June 2016.

Smedley, P. L., and D. G. Kinniburgh. 2002. A review of the source, behavior and distribution of arsenic in natural waters. *Applied Geochemistry* 17(5):517–568.

Sneed, M., and J. T. Brandt. 2015. *Land Subsidence in the San Joaquin Valley, California, USA, 2007-2014.*

South San Joaquin Irrigation District (SSJID). 1994. *South San Joaquin Irrigation District Groundwater Management Plan*. December. Prepared by Grant A. Kreinberg Water Resource Consultands. Available: http://www.water.ca.gov/groundwater/docs/GWMP/SJ-15_South SanJoaquinID_GWMP_1994.pdf. Accessed: May 2016.

———. 2011. *Urban Water Management Plan*. Prepared by Provost & Prichard Consulting Group and South San Joaquin Irrigation District.

———. 2012. *2012 Agricultural Water Management Plan, South San Joaquin Irrigation District*. December. Prepared by Davids Engineering, Inc.

———. 2015. *2015 Agricultural Water Management Plan, South San Joaquin Irrigation District*. December. Prepared by Davids Engineering, Inc.

Stanislaus County Department of Environmental Resources (SCDER). 2015. *SGWP Grant Application: Programmatic EIR for Implementation of the Stanislaus Count Groundwater Ordinance*. December 8. Prepared by Jacobson, James and Associates. Available: https://www.stancounty.com/er/pdf/ groundwater/complete-sgwp-grant-proposal.pdf. Accessed: April 6, 2016.

Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA). 2005. *Integrated Regional Groundwater Management Plan for the Modesto Subbasin*. June. Prepared by Bookman-Edmonston.

Stanislaus and Tuolumne Rivers' Groundwater Subbasin Association (STRGSA). 1995. *Development of a Groundwater Management Plan Phase I, Technical Memorandum*. Prepared by Black & Veatch, Provost & Prichard, and Kenneth D. Schmidt & Associates Consulting Firms.

State Water Resources Control Board (State Water Board). 2013. *Communities that Rely on a Contaminated Groundwater Source for Drinking Water, Report to the Legislature*. January.

———. 2015. Groundwater Ambient Monitoring and Assessment Program (GAMA). *A Guide for Private Domestic Well Owners*. Available: http://www.swrcb.ca.gov/gama/docs/wellowner_guide.pdf. Accessed: July 5, 2016.

Stockton East Water District (SEWD). 2011a. *History*. Available: http://www.sewd.net/history.htm. Accessed: February 1, 2012.

———. 2011b. *2010 Stockton East Water District Urban Water Management Plan Update*. June. Prepared by Kennedy-Jenks Consultants. Available: http://www.water.ca.gov/urbanwatermanagement/2010uwmps/Stockton%20East%20 Water%20District/SEWD_2010_UWMP%20June%202011.pdf. Accessed: March 1.

———. 2014. *Final Stockton East Water District Water Management Plan*. January 20. Available: http://www.water.ca.gov/wateruseefficiency/sb7/docs/2014/plans/Stockton-Eeast_WD_WMP-Final_012014.pdf.

———. 2016. *Draft 2015 Urban Water Management Plan.* May 2. Available: http://sewd.net/wp-content/uploads/2016/05/SEWD-2015-UWMP_DRAFT_050216.pdf. Accessed: June.

Swanson, A. A. 1998. Land Subsidence in the San Joaquin Valley, Updated to 1995. In J. W. Borchers (editor) Land Subsidence Case Studies and Current Research: Proceedings of the Dr. Joseph F. Poland Symposium on Land Subsidence. Special Publication *Association of Engineering Geologists* No. 8. 75–79 pp.

Trump, S. 2008. *The Aquifer of the San Joaquin Valley*. University of Kansas – Geohydrology. Available: http://academic.emporia.edu/schulmem/hydro/TERM%20PROJECTS/2008/Trump/mineral%20resources%20of%20Kansas.html. Accessed: February 23, 2012.

Tuolumne Utilities District. 2010. *Tuolumne County Coordination Plan. Exhibit A*. Available: http://www.tudwater.com/pdf/2011_pdf/Board/PublicOut_Det_03072011.pdf. Accessed: March 1, 2012.

Turlock Groundwater Basin Association (TGBA). 2003*. Turlock Groundwater Basin Water Budget, 1952-2002*. December. Prepared by Timothy J. Durbin, Inc., Carmichael, CA.

———. 2008. *Assessment of Future Groundwater Impacts Due to Assumed Water-use Changes, Turlock Groundwater Basin, California*. September 11. Prepared by Timothy J. Durbin, Inc., Carmichael, CA.

Turlock Irrigation District (TID). 2008. *Turlock Groundwater Basin Groundwater Management Plan*. March 18. Prepared by Turlock Groundwater Basin Association. Available: http://www.tid.com/sites/default/files/documents/tidweb_content/Groundwater%20Management%20Plan.pdf. Accessed: July 25, 2015.

———. 2012. *Turlock Irrigation District Agricultural Water Management Plan*. December. Turlock, CA.

U.S. Army Corps of Engineers, Sacramento District (USACE). 2001. *Farmington Groundwater Recharge/Seasonal Habitat Study*. Final Report. Prepared by M. W. Harza.

U.S. Geological Survey (USGS). 1975. *Land Subsidence in the San Joaquin Valley, California, as of 1972*. Professional Paper 437-H. Edited by J. F. Poland, B. E. Lofgren, R. L. Ireland, and A. G. Pugh.

———. 1986. *Land Subsidence in the San Joaquin Valley, California, as of 1983*. Water-Resources Investigations Report 85-4196. Edited by R. L. Ireland.

———. 1991. *Ground Water in the Central Valley, California – A Summary Report*. Professional Paper 1401-A. Edited by G. L. Bertoldi, R. H. Johnston, and K. D. Evenson.

———. 1999. *Land Subsidence in the United States*. Circular 1182. Edited by D. Galloway, D. R. Jones, and S. E. Ingebritsen.

———. 2009*. Groundwater Availability of the Central Valley Aquifer, California*. Professional Paper 1766. Groundwater Resources Program. Edited by C. C. Fount.

———. 2010. *Groundwater Quality in the Central Eastside San Joaquin Valley, California. Fact Sheet 2010-3001*. Available: http://pubs.usgs.gov/fs/2010/3001/. Accessed: July 3, 2016.

———. 2015. *Hydrologic model of the Modesto Region, California, 1960 – 2004*. USGS Scientific Investigations Report 2015-5045. Available: http://pubs.usgs.gov/sir/2015/5045/pdf/sir2015-5045.pdf.

U.S. Bureau of Reclamation (USBR). 1996. *American River Water Resources Investigation Planning Report and Draft Environmental Impact Report/Environmental Impact Statement.*

U.S. Bureau of Reclamation (USBR) and the San Joaquin River Group Authority (SJRGA). 1999. *Meeting Flow Objectives for the San Joaquin River Agreement 1999–2010 Final Environmental Impact Statement and Environmental Impact Report*. Prepared by EA Engineering, Science, and Technology, Lafayette and Sacramento, CA. Available: *http://www.sjrg.org/EIR/contents.htm*. Accessed: January 28, 2011.

———. 2001. *VAMP Supplemental EIR*. March. Prepared by URS. Available: http://www.sjrg.org/EIR/supplemental/sup_cover.htm. Accessed: November 2012.