Chapter 6
Groundwater Resources

This chapter presents the existing conditions of groundwater resources within the area of analysis and discusses potential effects of the proposed alternatives on groundwater levels, land subsidence, and groundwater quality.

6.1 Affected Environment

This section presents the area of analysis, describes the regulatory setting pertaining to groundwater resources in the area of analysis, and describes the existing hydrologic and groundwater characteristics in the area of analysis.

6.1.1 Area of Analysis

The area of analysis consists of the following groundwater basins/subbasins which are subdivided by hydrologic regions as defined by the California Department of Water Resources (DWR):

- Sacramento River Hydrologic Region: Redding Area Groundwater Basin; Sacramento Valley Groundwater Basin (in the north of the Sacramento-San Joaquin River Delta [Delta] geographic region)
- San Joaquin River Hydrologic Region: San Joaquin Valley Groundwater Basin (Northern Potion) (generally in the south of Delta geographic region)
- Tulare Lake Hydrologic Region: San Joaquin Valley Groundwater Basin (Southern Portion); Panoche Valley Groundwater Basin (in the south of the Delta geographic region)
- San Francisco Bay/Central Coast Hydrologic Region: Santa Clara Valley Groundwater Basin; Bitter Water Valley Groundwater Basin; Gilroy-Hollister Valley Groundwater Basin; San Benito Valley Groundwater Basin, Pajaro Valley Groundwater Basin (generally in the south of the Delta geographic region)

Figure 6-1 shows the area of analysis and the groundwater basins subdivided by the hydrologic region.

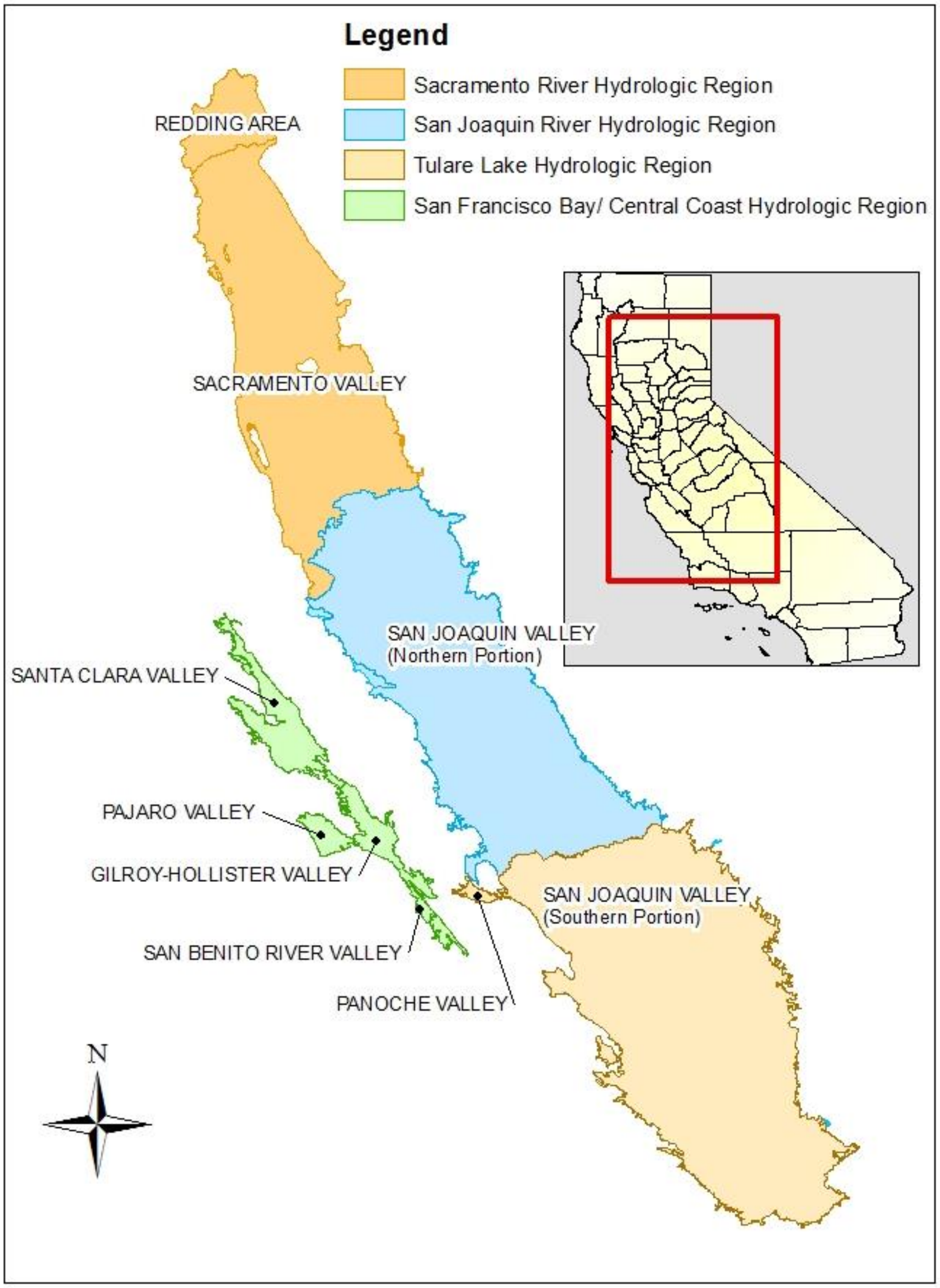


Figure 6-1. Groundwater Basins within the Area of Analysis

6.1.2 Regulatory Setting

This section describes the applicable laws, rules, regulations and policies relating to groundwater resources.

6.1.2.1 Federal Regulations

There are no federal regulations applicable to groundwater resources in the area of analysis.

The Bureau of Reclamation (Reclamation) approves water transfers consistent with provisions of the Central Valley Project Improvement Act (CVPIA) and State of California (State) law that protect against injury to third parties. According to the CVPIA Section 3405, the following principles must be satisfied for any transfer:

- Transfer may not violate the provisions of Federal or State law;
- Transfer may not cause significant adverse effects on Reclamation's ability to deliver Central Valley Project (CVP) water to its contractors or other legal user;
- With the exception of transfers within counties, watersheds, or other areas of origin as referenced in CVPIA 3405(a)(1)(M), Ttransfer will be limited to water that would be consumptively used or irretrievably lost to beneficial use;
- Transfers cannot exceed the average annual quantity of water under contract actually delivered; and
- Transfer will not adversely affect water supplies for fish and wildlife purposes.

Reclamation will not approve a water transfer if these basic principles are not satisfied and will issue its decision regarding potential CVP transfers in coordination with the United States (U.S.) Fish and Wildlife Service, contingent upon the evaluation of impacts on fish and wildlife.

6.1.2.2 State Regulations

All water use in California is subject to constitutional provisions that prohibit waste and unreasonable use of water (State Water Resources Control Board [SWRCB] n.d.). In general, groundwater is subject to a number of provisions in the California Water Code (Water Code). Some of these provisions are listed below:

Water Code (Section 10750) or Assembly Bill 3030 Assembly Bill 3030 (AB 3030), commonly referred to as the Groundwater Management Act, permits local agencies to develop Groundwater Management Plans (GMPs) that cover certain aspects of management. Subsequent legislation has amended this chapter to make the adoption of a management program mandatory if an agency is to receive public funding for groundwater projects, creating an incentive for the development and implementation of plans.

Water Code (Section 10753.7) or Senate Bill 1938 Senate Bill 1938 (SB 1938), requires local agencies seeking State funds for groundwater well construction or groundwater quality projects to have the following: 1) a developed and implemented GMP that includes basin management objectives[1] (BMOs) and addresses the monitoring and management of groundwater levels, groundwater quality degradation, inelastic land

[1] BMOs are management objectives that define the acceptable range of groundwater levels, groundwater quality, and inelastic land subsidence that can occur in a local area without causing significant adverse impacts.

subsidence, and surface water/ groundwater interaction; 2) a plan addressing cooperation and working relationships with other public entities; 3) a map showing the groundwater subbasin the project is in, neighboring local agencies, and the area subject to the GMP; 4) protocols for the monitoring of groundwater levels, groundwater quality, inelastic land subsidence, and groundwater/surface water interaction; and 5) GMPs with the components listed above for local agencies outside the groundwater subbasins delineated by DWR Groundwater Bulletin 118, published in 2003 (DWR 2003).

Water Code (Section 10920-10936 and 12924) or SB X7 6 SB X7 6 established a voluntary statewide groundwater monitoring program and requires that groundwater data collected be made readily available to the public. The bill requires DWR to: 1) develop a statewide groundwater level monitoring program to track seasonal and long-term trends in groundwater elevation; 2) conduct an investigation of the State's groundwater basins delineated by DWR Bulletin 118 and report its findings to the Governor and Legislature no later than January 1, 2012 and thereafter in years ending in five or zero; and 3) work cooperatively with local Monitoring Entities to regularly and systematically monitor groundwater elevation to demonstrate seasonal and long-term trends. AB 1152 (Amendment to Water Code Section 10927, 10932, and 10933), allows local Monitoring Entities to propose alternate monitoring techniques for basins meeting certain conditions and requires submittal of a monitoring plan to DWR for evaluation.

Water Code (Section 10927, 10933, 12924, 10750.1 and 10720) or SB 1168 SB 1168 requires the establishment of Groundwater Sustainability Agencies (GSA) and adoption of Groundwater Sustainability Plans (GSP). GSAs must be formed by June 30, 2017. GSAs are new entities that consist of local agency(ies) and include new authority to: 1) investigate and determine the sustainable yield of a groundwater basin; 2) regulate groundwater extractions; 3) impose fees for groundwater management; 4) require registration of groundwater extraction facilities; 5) require groundwater extraction facilities to use flow measurement devices; and 6) enforce the terms of a GSP.

GSPs for groundwater basins designated by DWR as high- and medium-priority with critical overdraft conditions (per SB X7 6) are required to be developed by January 31, 2020. GSPs for the remaining high- and medium-priority groundwater basins are to be developed by January 31, 2022. GSPs are encouraged to be developed for groundwater basins prioritized as low- or very low-priority (Pavley 2014a). All high- and medium-priority basins must achieve sustainability within 20 years of adopting a GSP.

Water Code (Section 10729, 10730, 10732, 10733 and 10735) or AB 1739 AB 1739 establishes the following: 1) provides the specific authorities to a GSA (as defined by SB 1168); 2) requires DWR to publish best management practices for the sustainable management of groundwater by January 1, 2017; and 3) requires DWR to estimate and report the amount of water available for groundwater replenishment by December 31, 2016. The bill authorizes DWR to approve and periodically review all GSPs (Dickinson 2014).

The bill authorizes the SWRCB to: 1) conduct inspections and obtain an inspection warrant; 2) designate a groundwater basin as a probationary groundwater basin; 3) develop interim plans for probationary groundwater basins in consultation with DWR if the local agency fails to remedy a deficiency resulting in the designation of probationary; and 4) issue cease and desist orders or violations of restrictions, limitations, orders, or regulations issued under AB 1739 (Dickinson 2014).

Water Code (Section 10735.2 and 10735.8) or SB 1319 SB 1319 would authorize the SWRCB to designate high- and medium-priority basins (defined by SB 1168) as a probationary basin after January 31, 2025. This bill allows the SWRCB to develop interim management plans that may override a local agency. However, if the appointed GSA can demonstrate compliance with sustainability goals for the basin, then the SWRCB has to exclude the groundwater basin or a portion of the groundwater basin from probationary status (Pavley 2014b).

Other Groundwater Regulations Groundwater quality issues are monitored through a number of different legislative acts and are the responsibility of several different State agencies including:

- SWRCB and nine Regional Water Quality Control Boards – responsible for protecting water quality for present and future beneficial use;
- SWRCB Division of Drinking Water (DDW, formerly California Department of Public Health) - responsible for drinking water supplies and standards;
- California Department of Toxic Substances Control - responsible for protecting public health from improper handling, storage, transport, and disposal of hazardous materials;
- California Department of Pesticide Regulation - responsible for preventing pesticide pollution of groundwater;
- California Integrated Waste Management Board - oversees non-hazardous solid waste disposal, and
- California Department of Conservation - responsible for preventing groundwater contamination due to oil, gas, and geothermal drilling and related activities.

6.1.2.3 Regional/Local

Local groundwater management plans and county ordinances vary by authority/agency and region, but typically involve provisions to limit or prevent groundwater overdraft, regulate transfers, and protect groundwater quality.

AB 3030, the Groundwater Management Act, encourages local water agencies to establish local GMPs. The Groundwater Management Act lists 12 elements that should be included within the plans to ensure efficient groundwater use, good groundwater quality, and safe production of water. Table 6-1 lists the current GMPs that apply to CVP contractors subject to the Municipal and Industrial Water Shortage Policy (M&I WSP).

Table 6-1. Local Groundwater Management Plans and Ordinances

Hydrologic Region	Groundwater Basins	Groundwater Management Plans, (GMPs or GWMPs), Agreements and County Ordinances
Sacramento River Hydrologic Region	Redding Area	• Coordinated GMP for the Redding Groundwater Basin
	Sacramento Valley	• Coordinated AB 3030 GMP (Tehama County Flood Control & Water Conservation District) • Glenn County GMP • Colusa County GMP • Dunnigan Water District GMP • Sacramento Groundwater Authority GMP • Sacramento County WA GMP • Central Sacramento County GMP • GWMP of Feather Water District • Martis Valley GWMP • Western Placer County GWMP
San Joaquin River/Tulare Lake Hydrologic Region	San Joaquin Valley	• Tracy Regional GMP • GMP for the Northern Agencies in the Delta-Mendota Canal Service Area and a Portion of San Joaquin County • Amended GMP for James Irrigation District • Westlands Water District GMP • GMP for Orange Cove Irrigation District, Tri Valley Water District, Hills Valley Irrigation
San Francisco Bay/Central Coast Hydrologic Region	Santa Clara Valley	• South East Bay Plain Basin GMP • Santa Clara Valley Water District (SCVWD) GMP
	Gilroy-Hollister Valley Groundwater	• Final Program-Environmental Impact Report-GMP Update for the San Benito County Portion of the Gilroy-Hollister Valley Groundwater Basin • Revised Basin Management Plan

Source: DWR 2008b

6.1.3 Existing Conditions

6.1.3.1 Sacramento River Hydrologic Region

Redding Area Groundwater Basin The Redding Area Groundwater Basin is in the northernmost part of the Central Valley. Underlying Tehama and Shasta Counties, it is bordered by the Klamath Mountains to the north, the Coast Range to the west, and the Cascade Mountains to the east. Red Bluff Arch separates the Redding Area Groundwater Basin from the Sacramento Valley Groundwater Basin to the south. DWR Bulletin 118 subdivides the Redding Area Groundwater Basin into six subbasins (DWR 2003). Figure 6-2 shows the Redding Area Groundwater Basin and subbasins. The following section provides information on geology, hydrogeology, hydrology, groundwater production, groundwater levels and storage, land subsidence, and groundwater quality.

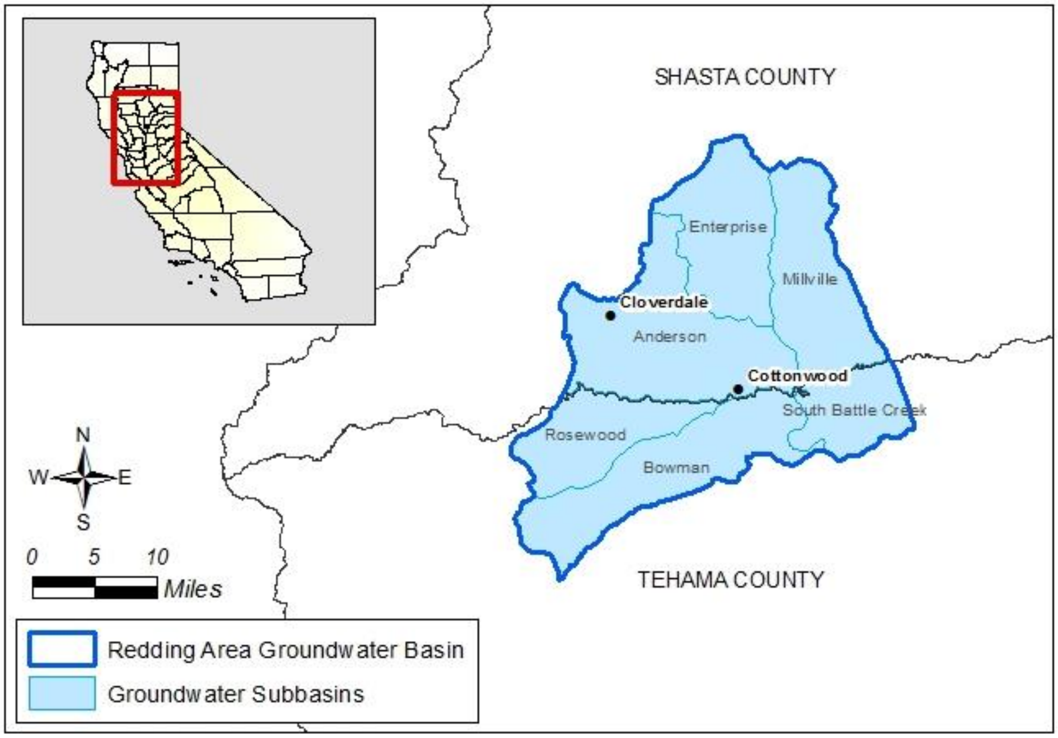


Figure 6-2. Redding Area Groundwater Basin and Subbasins

Geology, Hydrogeology, and Hydrology The Redding Area Groundwater Basin consists of a sediment-filled, southward plunging symmetrical trough (Shasta County Water Agency 2007). Concurrent deposition of material from the Coast Range and the Cascade Range resulted in two different formations, which are the principal freshwater-bearing formations in the basin. Geology of the Redding Area Groundwater Basin is similar to the geology in the northern portion of the Sacramento Valley Groundwater Basin (shown in Figure 6-6). The Tuscan Formation in the east is derived from the Cascade Range volcanic sediments, and the Tehama Formation in the western and northwest portion of the basin is derived from Coast Range sediments. These formations are up to 2,000 feet thick near the confluence of the Sacramento River and Cottonwood Creek. The Tuscan Formation is generally more permeable and productive than the Tehama Formation (Shasta County Water Agency 2007).

As illustrated in Figure 6-3, groundwater in the Redding Area Groundwater Basin generally flows southeasterly on the west side of the basin and southwesterly on the east side, toward the Sacramento River. The Sacramento River is the main drain for the basin (DWR Northern District 2002). The Shasta County Water Resources Master Plan Phase 1 Report estimated the total annual groundwater discharge to rivers and streams at about 266 thousand acre-feet (TAF), and seepage from streams and canals into groundwater at 59 and 44 TAF, respectively (CH2MHill 1997). Groundwater is typically unconfined to semi-confined in the shallow aquifer system and confined where deeper aquifers are present. Surface water and groundwater interact in many areas in the Redding Area

Groundwater Basin. The principal surface water features in the Redding Area Groundwater Basin are the Sacramento River and its tributaries: Battle Creek, Cow Creek, Little Cow Creek, Clear Creek, Dry Creek, and Cottonwood Creek.

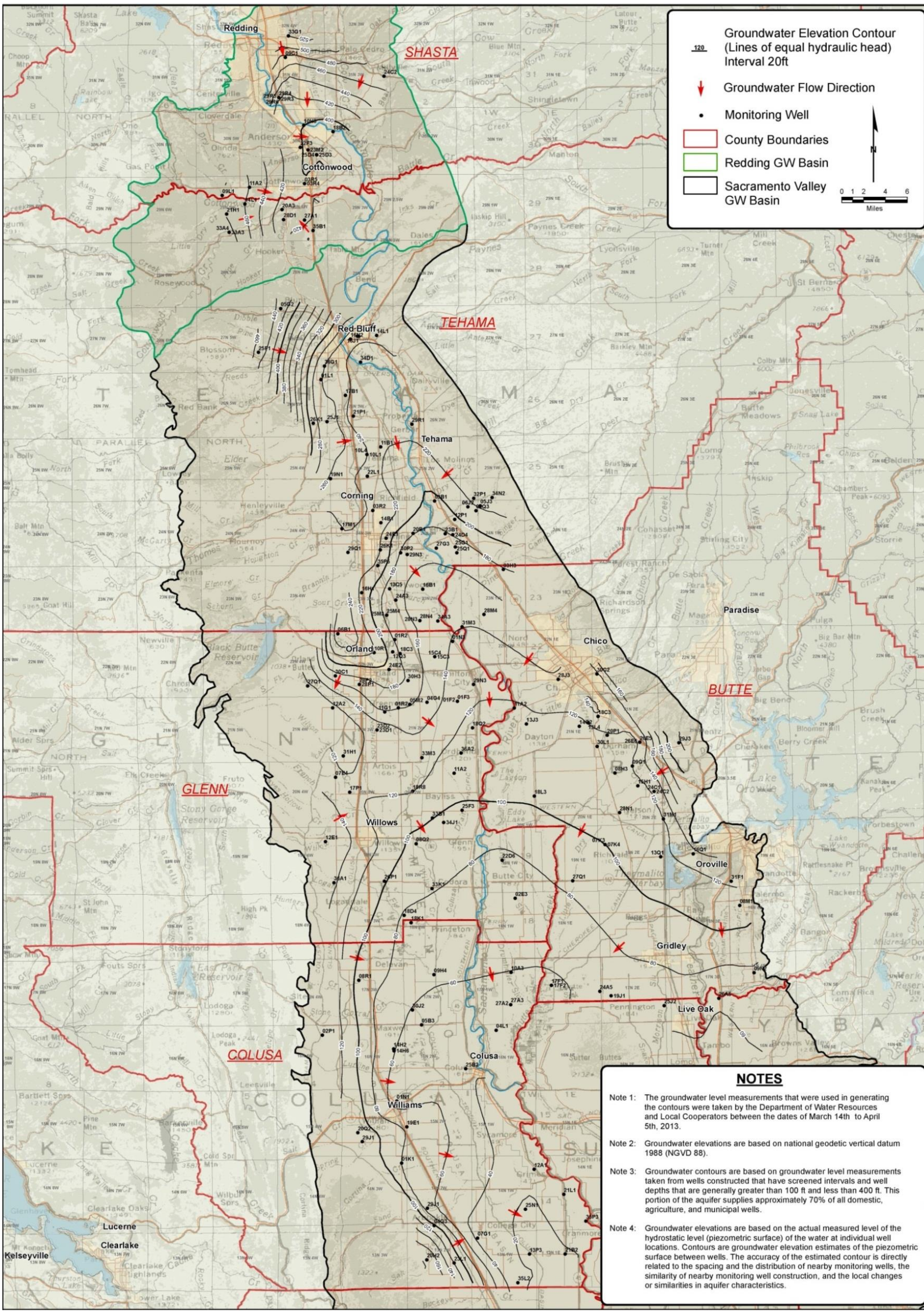
Groundwater Production, Levels and Storage The Redding Area Groundwater Basin water resources management plan estimates the watersheds overlying the Redding Basin yield an average of 850 TAF of annual runoff (CH2M HILL 2003). Applied irrigation water (from all sources) totals approximately 270 TAF annually in the Redding Area Groundwater Basin (CH2M HILL 1997). It has been estimated that approximately 55 TAF per year of water is pumped from M&I and agricultural production wells (CH2M HILL 2003). This magnitude of pumping represents approximately six percent of the average annual runoff.

Figure 6-3 shows spring 2013 groundwater elevation contours within the Redding Area Groundwater Basin. The storage capacity for the entire Redding Area Groundwater Basin is estimated to be 5.5 million acre-feet (AF) for 200 feet of saturated thickness over an area of approximately 510 square miles (Pierce 1983 as cited in DWR 2003).

Groundwater-Related Land Subsidence Land subsidence has not been monitored in the Redding Area Groundwater Basin. However, there would be potential for subsidence in some areas of the basin if groundwater levels decline below historic low levels. The groundwater basin west of the Sacramento River is composed of the Tehama Formation; this formation has exhibited subsidence in Yolo County and because of the similar hydrogeologic characteristics, the Redding Area Groundwater Basin could be susceptible to land subsidence.

Groundwater Quality Groundwater in the Redding Area Groundwater Basin is typically of good quality, as evidenced by its low total dissolved solids (TDS) concentrations, which range from 70 to 360 milligrams per liter (mg/L). Areas of high salinity (poor water quality), are generally found on the western basin margins, where the groundwater is derived from marine sedimentary rock. Elevated levels of iron, manganese, nitrate, and high TDS have been detected in some areas. Localized high concentrations of boron have been detected in the southern portion of the basin (DWR Northern District 2002).

Sacramento Valley Groundwater Basin The Sacramento Valley Groundwater Basin includes portions of Butte, Colusa, Glenn, Placer, Sacramento, Sutter, Solano, Tehama, Yuba, and Yolo counties. The Sacramento Valley Groundwater Basin is bordered by the Red Bluff Arch to the north, the Coast Range to the west, the Sierra Nevada to the east, and the San Joaquin Valley to the south. Bulletin 118 further divides the Sacramento Valley Groundwater Basin into subbasins (DWR 2003). Figure 6-4 shows the Sacramento Valley Groundwater Basin and subbasins. The following section provides information on geology, hydrogeology, hydrology, groundwater production, groundwater levels and storage, land subsidence, and groundwater quality.



Source: DWR 2013

Figure 6-3. Redding Area and Northern Sacramento Valley Spring 2013 Groundwater Elevation Contours

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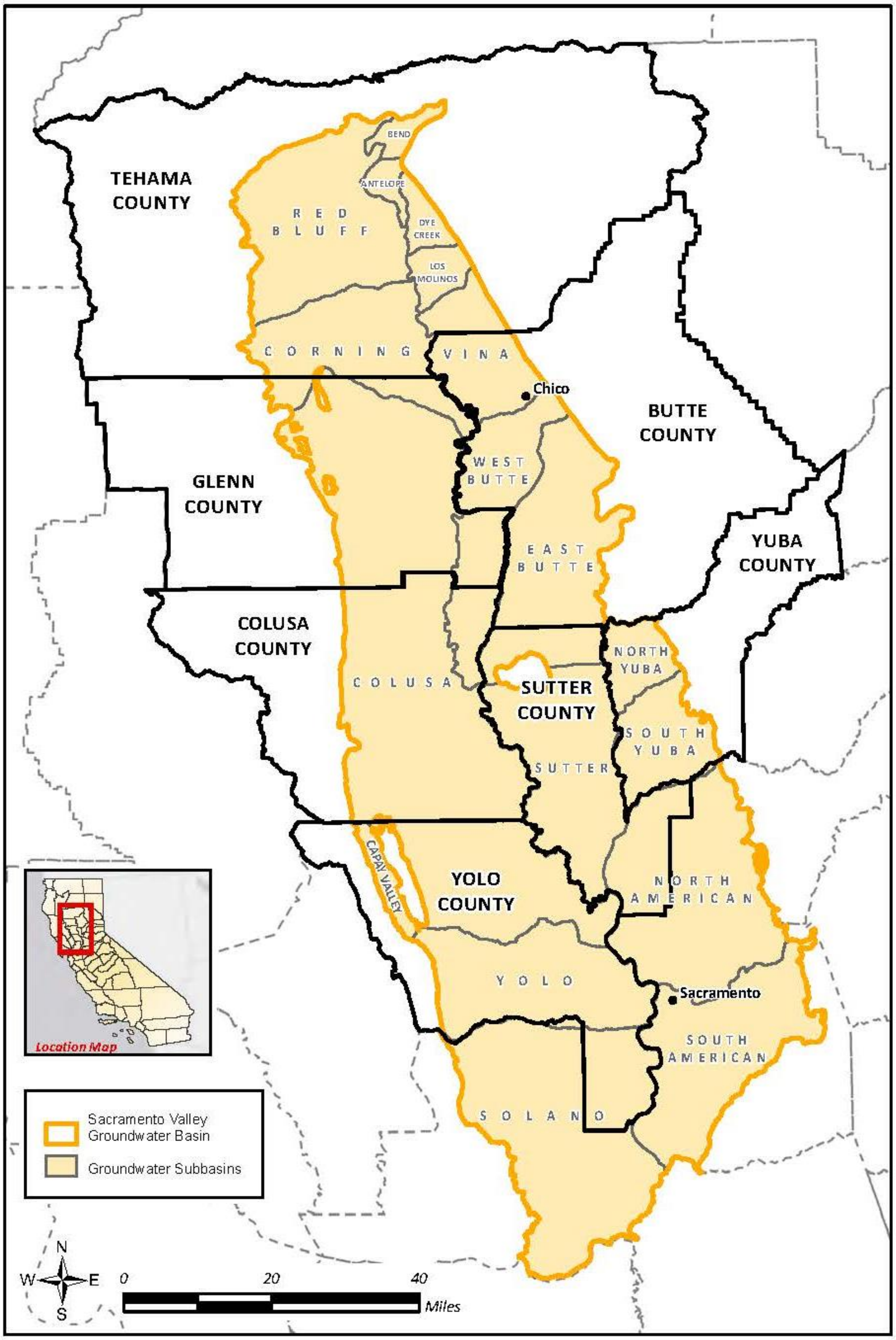


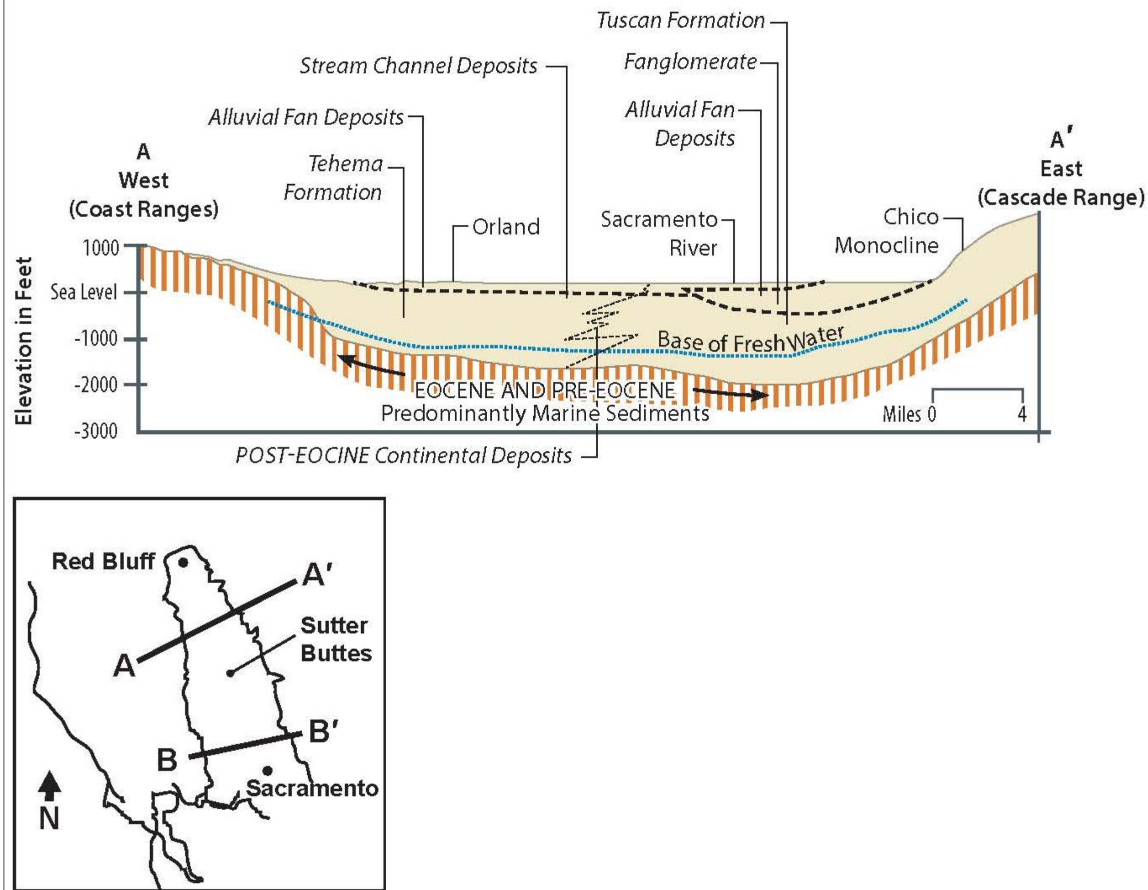
Figure 6-4. Sacramento Valley Groundwater Basin

Geology, Hydrogeology, and Hydrology The Sacramento Valley Groundwater Basin is a north-northwest trending asymmetrical trough filled with both marine and continental rocks and sediment. On the eastern side, the basin overlies basement rock that rises relatively gently to the Sierra Nevada, while on the western side the underlying basement rock rises more steeply to form the Coast Range. Overlying the basement rock are marine sandstone, shale, and conglomerate rocks, which generally contain brackish or saline water (DWR 1978). The freshwater-bearing formation in the valley is comprised of sedimentary and volcanic rocks that have the ability to absorb, transmit and yield fresh water. The depth below ground surface (bgs) to the base of freshwater is approximately 1,150 feet in the northern portion of the Sacramento Valley and approximately 1,600 feet in the southern portion of the Sacramento valley (DWR 1978).

Along the eastern and northeastern portion of the basin are the Tuscan and Mehrten formations, derived from the Cascade and Sierra Nevada ranges. The Tehama Formation in the western portion of the basin is derived from Coast Range sediments. In most of the Sacramento Valley Groundwater Basin, the Tuscan, Mehrten, and Tehama formations are overlain by relatively thin alluvial deposits.

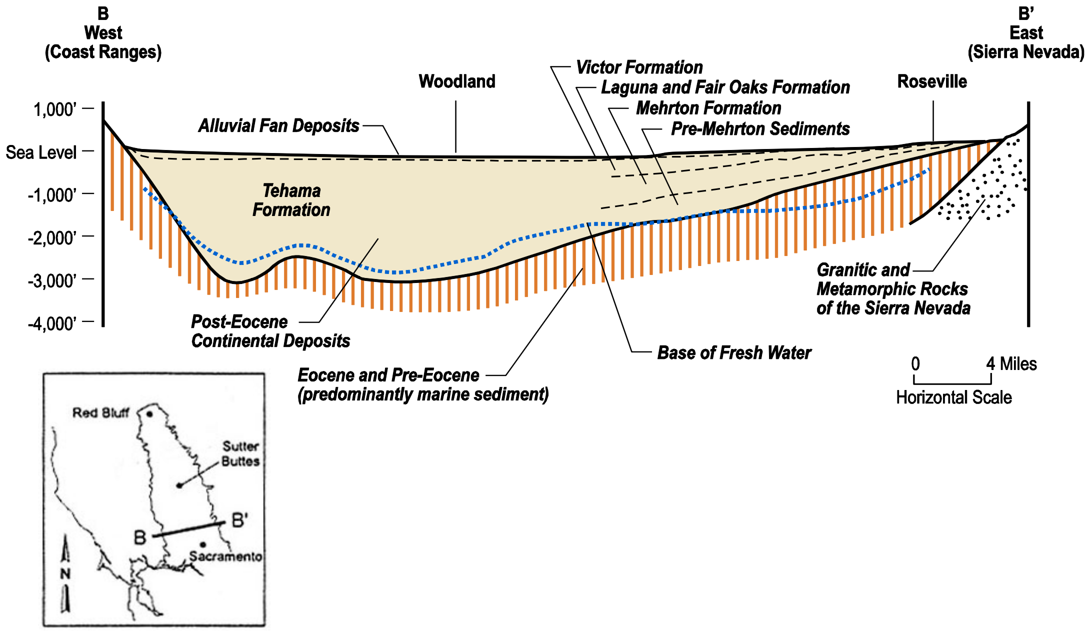
Freshwater is present primarily in the Laguna, Mehrten, Tehama, and Tuscan formations and in alluvial deposits that overly the deeper Eocene and Pre-Eocene marine deposits. Figure 6-5 and Figure 6-6 are generalized cross sections for the northern and southern portions of the Sacramento Valley Groundwater Basin, respectively. Groundwater users in the basin pump primarily from aquifers above the marine deposits.

Groundwater is recharged by deep percolation from rainfall infiltration, leakage from streambeds, lateral inflow along the basin boundaries, and landscape processes, including irrigation. A significant source of recharge has become deep percolation of irrigation water below crop roots, sometimes referred to as recharge from excess applied irrigation water. Of the average 13.3 million AF of groundwater recharged annually from 1962 to 2003, approximately 19 percent was from streamflow leakage and 79 percent was from the landscape processes, including recharge from excess applied irrigation water and from precipitation (Faunt 2009). Net recharge from landscape processes within the Sacramento Valley has been estimated to be 2.9 million AF (Faunt 2009).



Source: DWR Northern District 2002

Figure 6-5. North Geologic Cross Section of the Sacramento Valley Groundwater Basin



Source: DWR Northern District 2002

Figure 6-6. South Geologic Cross Section of the Sacramento Valley Groundwater Basin

Average annual precipitation in the Sacramento Valley Groundwater Basin ranges from 13 to 26 inches, with the higher precipitation of 46 inches occurring along the eastern and northern edges of the basin. Typically, 85 percent of the basin's precipitation occurs from November to April, half of it during December through February in average years (Faunt 2009).

The main surface water feature in the Sacramento Valley Groundwater Basin is the Sacramento River which flows from north to south through the basin. The Sacramento River has several major tributaries draining the Sierra Nevada, including the Feather, Yuba, and American Rivers. Stony, Cache, and Putah Creeks drain the Coast Range and are the main west side tributaries of the Sacramento River. Surface water and groundwater interact on a regional basis, and gains and losses to groundwater vary spatially and temporally.

Groundwater Production, Levels, and Storage Groundwater pumping can be generally grouped into agricultural and urban, which includes M&I sources. Agricultural groundwater pumping supplies water for the crops grown in the basin. Truck, field, orchard, and rice crops are grown on approximately 2.1 million acres. Rice represents about 23 percent of the total acreage (DWR 2003 as cited in Faunt 2009). The water supply for growing rice relies on a combination of surface water and groundwater. Groundwater accounts for less than 30 percent of the annual supply used for agricultural and urban purposes in the Sacramento Valley (Faunt 2009). Urban pumping in the Sacramento Valley increased from approximately 250 TAF annually in 1961 to more than 800 TAF annually in 2003 (Faunt 2009).

DWR and other monitoring entities, as defined by SB X7 6 extensively monitor groundwater levels in the basin. The total depth of monitoring wells range from 18 to 1,380 feet bgs within the Sacramento Valley Groundwater Basin.

Figure 6-7 and Figure 6-8 show the location and groundwater elevation of select monitoring wells that portray the local groundwater elevations within the Sacramento Valley Groundwater Basin. Water levels at well 21N03W33A004M generally declined during the 1970s and prior to import of surface water conveyed by the Tehama-Colusa Canal. During the 1980s, groundwater levels recovered due to import and use of surface water supply and because of the 1982 to 1984 wet water years (DWR 2014). Groundwater levels in well 15N03W01N001M (which is surrounded by agricultural lands) declined until 1977 and then recovered during the wet years from 1982 to 1984. After the 2008 to 2009 drought, water levels declined to historical lows. Water levels recovered quickly during 2010 and 2011 (DWR 2014). Even though groundwater levels at wells 21N03W33A004M and 15N03W01N001M are generally showing a declining trend, groundwater levels in other wells in the basin have remained steady, declining moderately during extended droughts and recovering to pre-drought levels after subsequent wet periods (See Figure 6-7 and Figure 6-8 for Groundwater Elevations within the Sacramento Valley Groundwater Basin).

Figure 6-3 shows spring 2013 groundwater elevation contours within the northern Sacramento Valley Groundwater Basin. In general, groundwater flows inward from the edges of the basin and south, parallel to the Sacramento River. In some areas there are groundwater depressions associated with pumping that influence local groundwater gradients and flow direction. Prior to the completion of CVP facilities in the area (1964-1971), pumping along the west side of the basin caused groundwater levels to decline. Following construction of the CVP, the delivery of surface water and reduction in groundwater extraction resulted in a recovery to historic groundwater levels by the mid to late-1970s. Throughout the basin, individuals, counties, cities, and special legislative agencies manage and/or develop groundwater resources. Many agencies use groundwater to supplement surface water; therefore, groundwater production is closely linked to surface water availability. Climatic variations and the resulting surface water supply directly affect the demand and the amount of groundwater required to meet agricultural and urban water demands (Faunt 2009).

Figure 6-9 shows the simulated cumulative change in groundwater storage in the Sacramento Valley Groundwater Basin since 1962, along with the other major groundwater basins in the Central Valley of California. As shown in this figure, groundwater storage in the Sacramento Valley Groundwater Basin has been relatively constant over the long term. Storage tends to decrease during dry years and increase during wetter periods.

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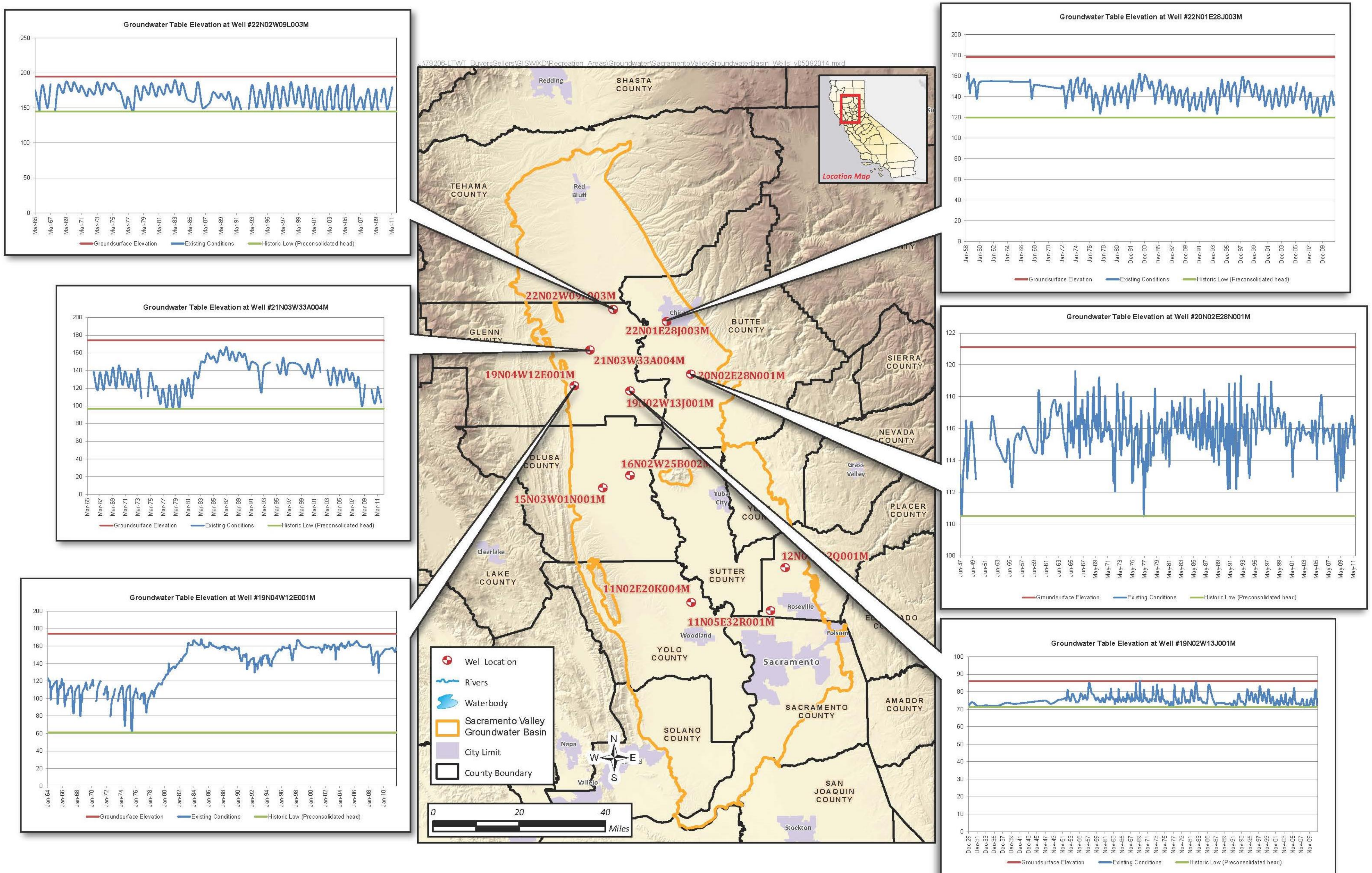

Figure 6-7. Sacramento Valley Groundwater Basin Historic Groundwater Elevations

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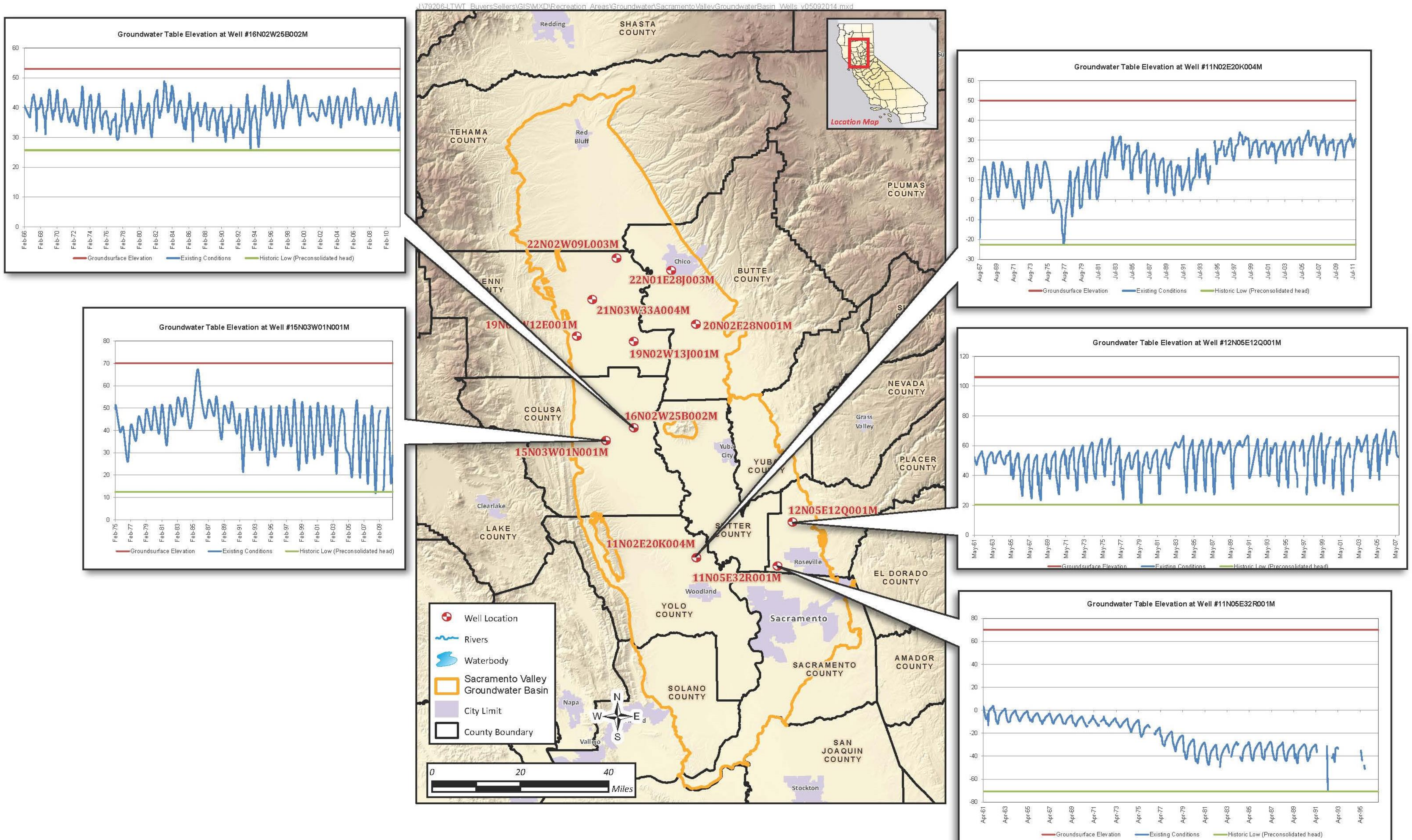

Figure 6-8. Sacramento Valley Groundwater Basin Historic Groundwater Elevations

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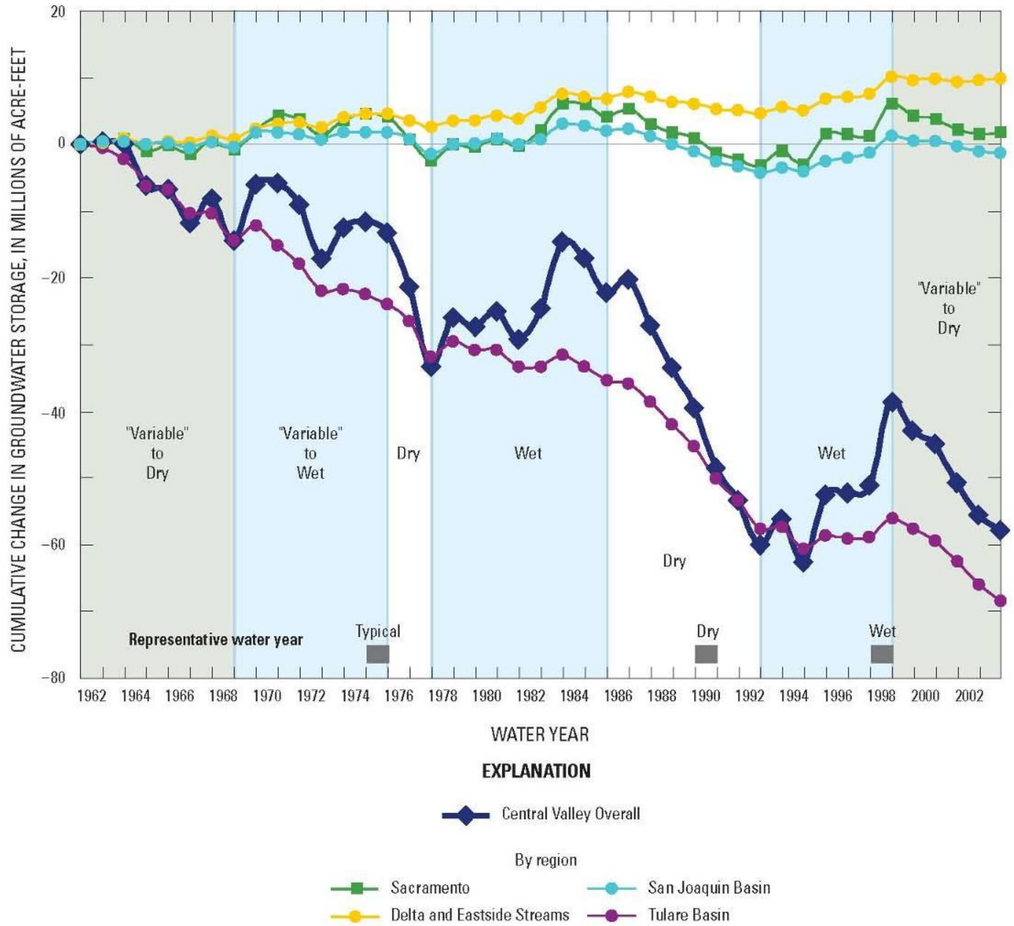

Source: Faunt 2009

Figure 6-9. Cumulative Annual Change in Storage, as simulated by the USGS's Central Valley Hydrologic Model

Groundwater-Related Land Subsidence This section discusses land subsidence due to changes in groundwater levels. Groundwater-related land subsidence is a process that causes the elevation of the ground surface to lower in response to groundwater pumping. Non-reversible (i.e., inelastic) land subsidence occurs where groundwater extraction lowers groundwater levels causing loss of pore pressure and subsequent consolidation of clay beds within a groundwater system. Subsidence is typically a slow process that occurs over a large area. Subsidence generally occurs in small increments during dry years when groundwater pumping lowers groundwater levels below historical lows.

Because of the slow rate of subsidence, the general appearance of the landscape may not change; however, subsidence can lead to problems with flood control and water distribution systems due to substantial changes in ground surface elevation. Subsidence can reduce the freeboard of levees, allowing water to over top them more easily. It also can change the slope, and even the direction of flow, in conveyance and drainage systems, including canals, sewers, and storm drains. Subsidence can also damage infrastructure, including building foundations and collapsed well casings.

There are several methods used to measure land subsidence. Global Positioning System (GPS) surveying is a method used for monitoring subsidence on a regional scale. DWR uses this method to monitor subsidence in the Tule Lake Basin, Glenn and Yolo counties, and the Sacramento-San Joaquin River Delta (Delta). The GPS network consists of 339 survey monuments spaced about seven kilometers apart and covers all or part of 10 counties within the Sacramento Valley Groundwater Basin (DWR 2008a). It extends from northern Sacramento County eastward to Reclamation's Folsom Lake network, southwest to DWR's Delta/Suisun Marsh network, and north to Reclamation's Shasta Lake network. The land surface elevations will be re-surveyed every few years to track changes in elevation.

Vertical extensometers are a more site-specific method of measuring land subsidence. DWR's subsidence monitoring program within the Sacramento Valley Groundwater Basin includes 11 extensometer stations that are located in Yolo (2), Sutter (1), Colusa (2), Butte (3), and Glenn (3) counties. Figure 6-10 shows the areas within the Sacramento Valley Groundwater Basin that have experienced subsidence due to significant declines in groundwater levels as a result of increased groundwater pumping (DWR 2008a).

Figure 6-10 also shows the locations of DWR's extensometers and extent of subsidence at the locations. Data from the GPS subsidence monitoring network and complementary groundwater levels in monitoring wells revealed a correlation between land subsidence and groundwater declines during the growing season (DWR 2008a). DWR found that the land surface partially rebounds as aquifers recharge in winter (DWR 2008a). Out of the 11 extensometers five show potential subsidence over time:

- 09N03E08C004M, in Yolo County within Conaway Ranch: DWR observed higher rates of inelastic land subsidence estimated at approximately 0.2 feet from 2013 to 2014 (DWR 2014b). In comparison, slightly less than 0.1 feet of subsidence occurred over the previous 22 years (1991-2012);

- 11N01E24Q008M, in Yolo County near the Yolo-Zamora area: 0.5 to 0.6 foot decline from 1992 to present;

- 11N04E04N005M, in Sutter County: approximately 0.01 foot decline from 1994 to present;

- 21N02W33M001M, in Glenn County: 0.05 foot decline from 2005 to present; this extensometer is located in areas in which the Tehama Formation is mapped in the subsurface and indicates the potential for inelastic subsidence (West Yost Associates 2012); and
- 16N02W05B001M, in Colusa County: 0.04 foot decline from 2006 to present.

Historically, land subsidence occurred in the eastern portion of Yolo County and the southern portion of Colusa County due to extensive groundwater extraction and geology. The earliest studies on land subsidence in the Sacramento Valley occurred in the early 1970s when the U.S. Geological Survey (USGS), in cooperation with DWR, measured elevation changes along survey lines containing first and second order benchmarks. As much as four feet of land subsidence due to groundwater withdrawal occurred east of Zamora over the last several decades. The area between Zamora, Knights Landing, and Woodland has been most affected (Yolo County 2009). Subsidence in this region is generally related to groundwater pumping and subsequent consolidation of compressible clay sediments.

Groundwater Quality Groundwater quality in the Sacramento Valley Groundwater Basin is generally good and adequate for municipal, agricultural, domestic, and industrial uses. However, there are some localized groundwater quality issues in the basin. In general, groundwater quality is influenced by stream flow and recharge from the surrounding Coast Range and Sierra Nevada. Runoff from the Sierra Nevada is generally of higher quality than runoff from the Coast Range because of the presence of marine sediments in the Coast Range. Specific groundwater quality issues are discussed below.

Within the Sacramento Valley, water quality issues may include occurrences of high TDS or elevated levels of nitrates, naturally occurring boron, and other introduced chemicals. The SWRCB's Groundwater Ambient Monitoring and Assessment (GAMA) Program's Priority Basin Project evaluated statewide groundwater quality and sampled 108 wells within the Central Sacramento Valley region and 96 wells in the Southern Sacramento Valley region in 2005 and 2006. Water quality data was analyzed for inorganic constituents (e.g., nutrients, radioactive constituents, TDS and iron/manganese); special interest constituents (e.g., perchlorate); and organic constituents (e.g., solvents, gasoline additives, and pesticides).

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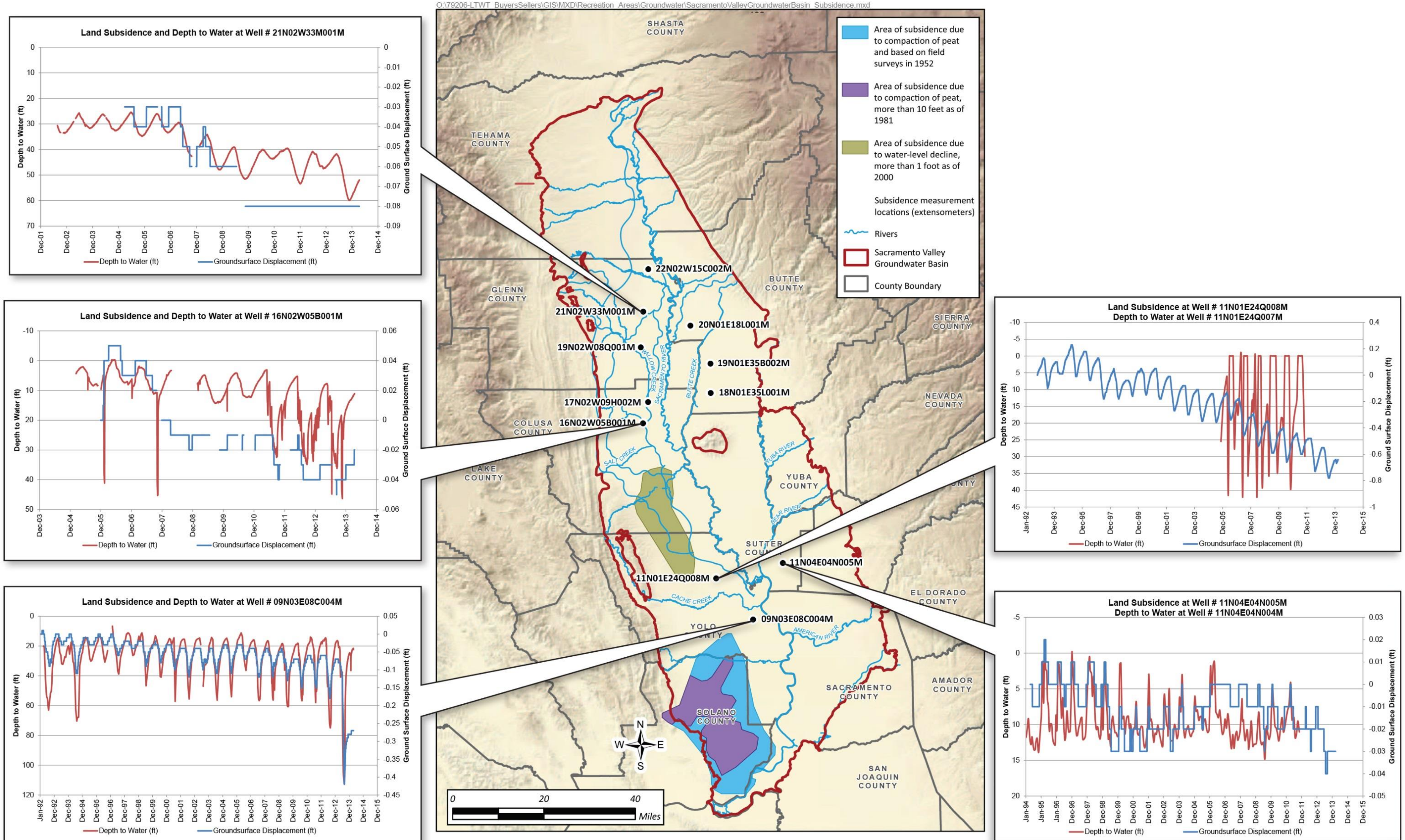

Source: DWR 2014c

Figure 6-10. Sacramento Valley Groundwater Basin Land Subsidence

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Inorganic Constituents Arsenic and boron were the two trace elements that were most frequently detected at concentrations greater than the maximum contaminant level (MCL) within the basin. Arsenic was detected above the MCL of 10 micro grams per liter (µg/L) in approximately 22 percent of the wells sampled. Boron was another trace element that was detected above the MCL of 1 mg/L in seven percent of the wells sampled. Aluminum, chromium, lead, and fluoride were also detected in concentrations above the MCLs (1 mg/L for Aluminum, 50 µg/L for Chromium; 15 µg/L for Lead and 2 mg/L for Fluoride) in less than one percent of the wells sampled. Concentrations of radioactive constituents were above the MCLs in less than one percent of the wells sampled within the Central Sacramento Valley region. Most of the radioactivity in groundwater comes from decay of naturally occurring isotopes of uranium and thorium in minerals in the sediments of the aquifer (Bennett 2011a, 2011b).

Nutrient concentrations within the Central Sacramento Valley region were above the MCLs in about three percent of the wells sampled. In the southern portion of the basin, nutrients were detected above the MCLs in about one percent of the sampled wells (Bennett 2011a, 2011b).

The DDW and United States Environmental Protection Agency's (USEPA) secondary drinking water standard for TDS is 500 mg/L, and the agricultural water quality goal for TDS is 450 mg/L. TDS concentrations were above these standards in about four percent of the sampled wells in the central portion of the valley. TDS levels in the Sacramento Valley Groundwater Basin are generally between 200 and 500 mg/L. TDS levels in the southern part of the basin are higher because of the local geology (DWR 2003). Along the eastern boundary of the basin, TDS concentrations tend to be less than 200 mg/L, indicative of the low concentrations of TDS in Sierra Nevada runoff. Several areas in the basin have naturally occurring high TDS, with concentrations that exceed 500 mg/L. TDS concentrations as high as 1,500 mg/L have been recorded (Bertoldi 1991). One of these high TDS areas is west of the Sacramento River, between Putah Creek and the confluence of the Sacramento and San Joaquin rivers; another is in the south-central part of the Sacramento Basin, south of Sutter Buttes, in the area between the confluence of the Sacramento and Feather rivers.

Organic Constituents Volatile organic compounds (VOCs) are present in many household, commercial, industrial, and agricultural products, and are characterized by their tendency to volatilize into the air. Solvents have been used for a number of purposes, including manufacturing and cleaning. Solvents were detected at concentrations greater than the MCLs in less than one percent of the sampled wells throughout the basin. The solvent present at higher concentrations than the MCL was perchloroethene (PCE). The MCL for PCE is set at 5 µg/L by DDW. Gasoline additives were detected at higher concentrations in less than one percent of the sampled wells throughout the basin. The gasoline additives detected at higher concentrations were benzene and tert-butyl alcohol (Bennett 2011a, 2011b). DDW has set the MCL for benzene at 1µg/L and tert-butyl alcohol at 12µg/L. Additionally, groundwater wells around Chico have exceeded standards for VOCs (trichloroethylene and perchloroethylene) (City of Chico 2006).

6.1.3.2 San Joaquin River Hydrologic Region

San Joaquin Valley Groundwater Basin, Northern Portion The San Joaquin Valley Groundwater Basin extends over the southern two-thirds of the Central Valley regional aquifer system. The Northern Portion of the San Joaquin Valley Groundwater Basin, shown on Figure 6-11, extends from just north of Stockton in San Joaquin County to north of Fresno in Fresno County, covering approximately 5,800 square miles.

Geology, Hydrogeology, and Hydrology The Northern Portion of the San Joaquin Valley Groundwater Basin is similar in shape to the Sacramento Valley Groundwater Basin and was formed by the deposition of several miles of sediment in a north-northwestern trending trough. The Sierra Nevada lies on the eastern side of the basin, and the Coast Range is to the west.

The aquifer system in the Northern Portion of the San Joaquin Valley Groundwater Basin is comprised of continental and marine deposits up to six miles thick, of which the upper 2,000 feet generally contain freshwater (Page 1986). A significant hydrogeologic feature in the basin is the Corcoran Clay. This clay layer divides the aquifer system into two distinct zones, an upper unconfined to semi-confined aquifer and a lower confined aquifer. Both aquifers are composed of formations derived from the deposition of Sierra Nevada sediment in the eastern portions of the basin, and from deposition of Coast Range sediments in the western portions of the basin. Overlying these formations are flood-plain deposits. The formations in the eastern portions of the basin are derived from the granitic Sierra Nevada and are generally more permeable than the sediments derived from the western marine formations.

Sediments derived from marine rocks generally contain more silt and clay and also contain higher concentrations of salts. The lower confined aquifer system contains sediments of mixed origin.

Historically, these aquifers were two separate systems; however, wells in the western side of the basin have penetrated both aquifers and are commonly perforated directly above and below the Corcoran Clay. This has allowed “almost free flow [of groundwater] through the well casings and gravel packs” (Williamson 1989) and has resulted in groundwater interaction between the upper and lower aquifer in some localized areas (Reclamation 1990).

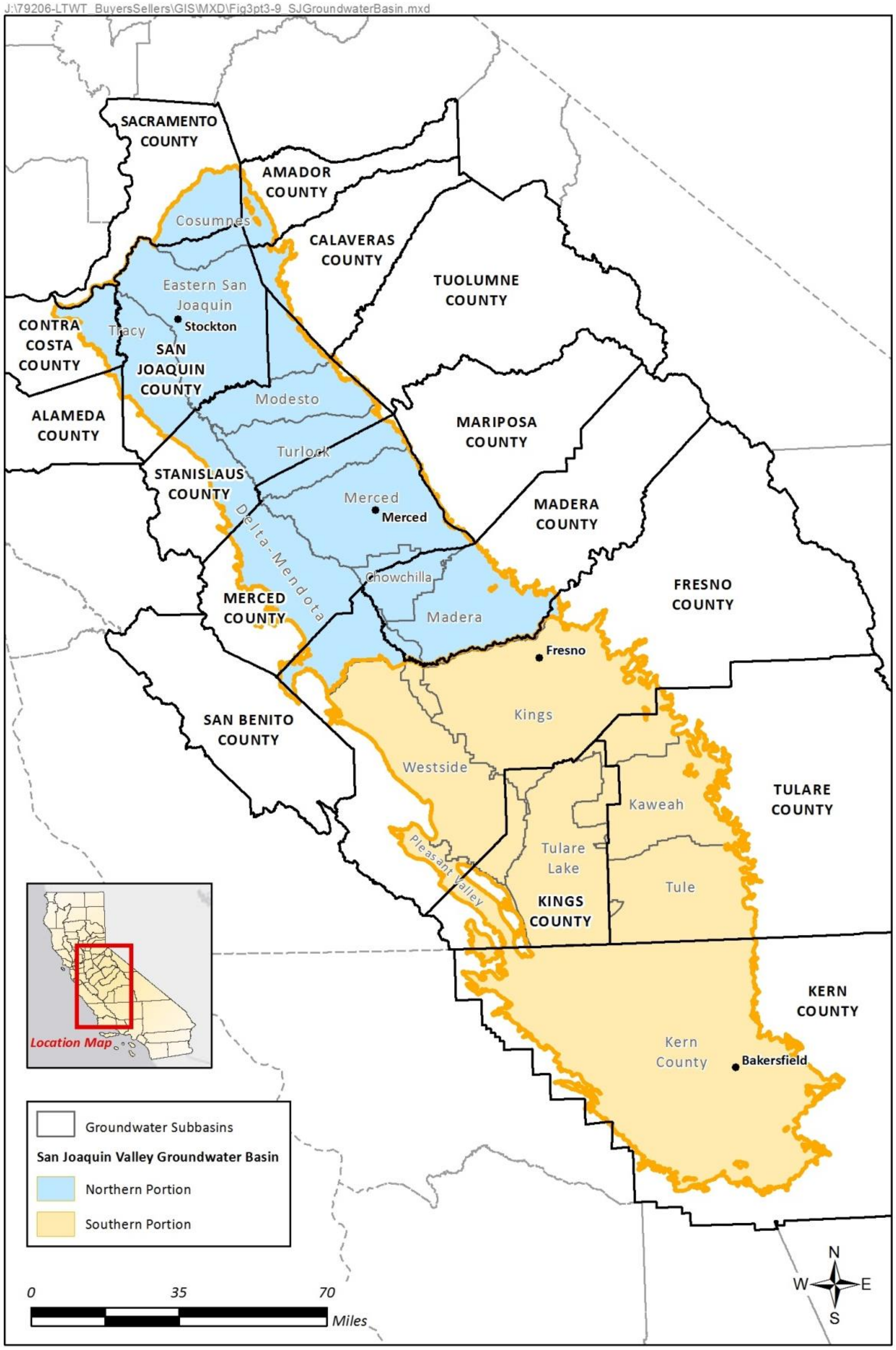
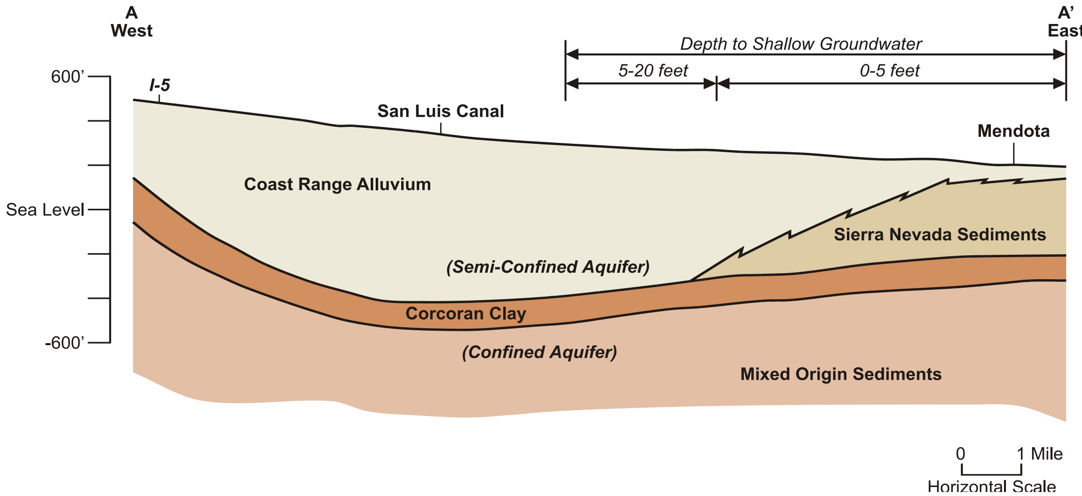


Figure 6-11. San Joaquin Valley Groundwater Basin

Figure 6-12 shows a generalized geologic cross section of the Northern Portion of the San Joaquin Valley Groundwater Basin.



Source: Reclamation 1997

Figure 6-12. Geologic Cross Section of the Northern Portion of the San Joaquin Valley Groundwater Basin

The Corcoran Clay, the most extensive of several clay layers, was formed by the periodic filling and draining of ancient lakes in the San Joaquin Valley. Six laterally extensive clays, designated Clays A through F, have been mapped (Page 1986). The Modified E-Clay includes the Corcoran Clay, which is between 0 and 160 feet thick at depths between 100 and 400 feet bgs. Figure 6-13 shows the lateral extent of the Corcoran Clay layer in the Northern and Southern Portions of the San Joaquin Valley Groundwater Basin along with the locations of the cross section.

Historically, groundwater in the unconfined to semi-confined upper aquifer system was recharged by streambed infiltration, rainfall infiltration, and lateral inflow along the basin boundaries. Average annual precipitation in the area is significantly less than in the Sacramento Valley Groundwater Basin and ranges from 5 to 18 inches (Faunt 2009). The percolation of applied agricultural surface water supplements natural groundwater replenishment. The lower confined aquifer is recharged primarily from lateral inflow from the eastern portions of the basin, beyond the eastern extent of the Corcoran Clay. Precipitation in the Sierra Nevada to the east of the basin can be as high as 65 to 75 inches, although much of it is in the form of snow. Peak runoff in the basin generally lags precipitation by five to six months (Bertoldi 1991).

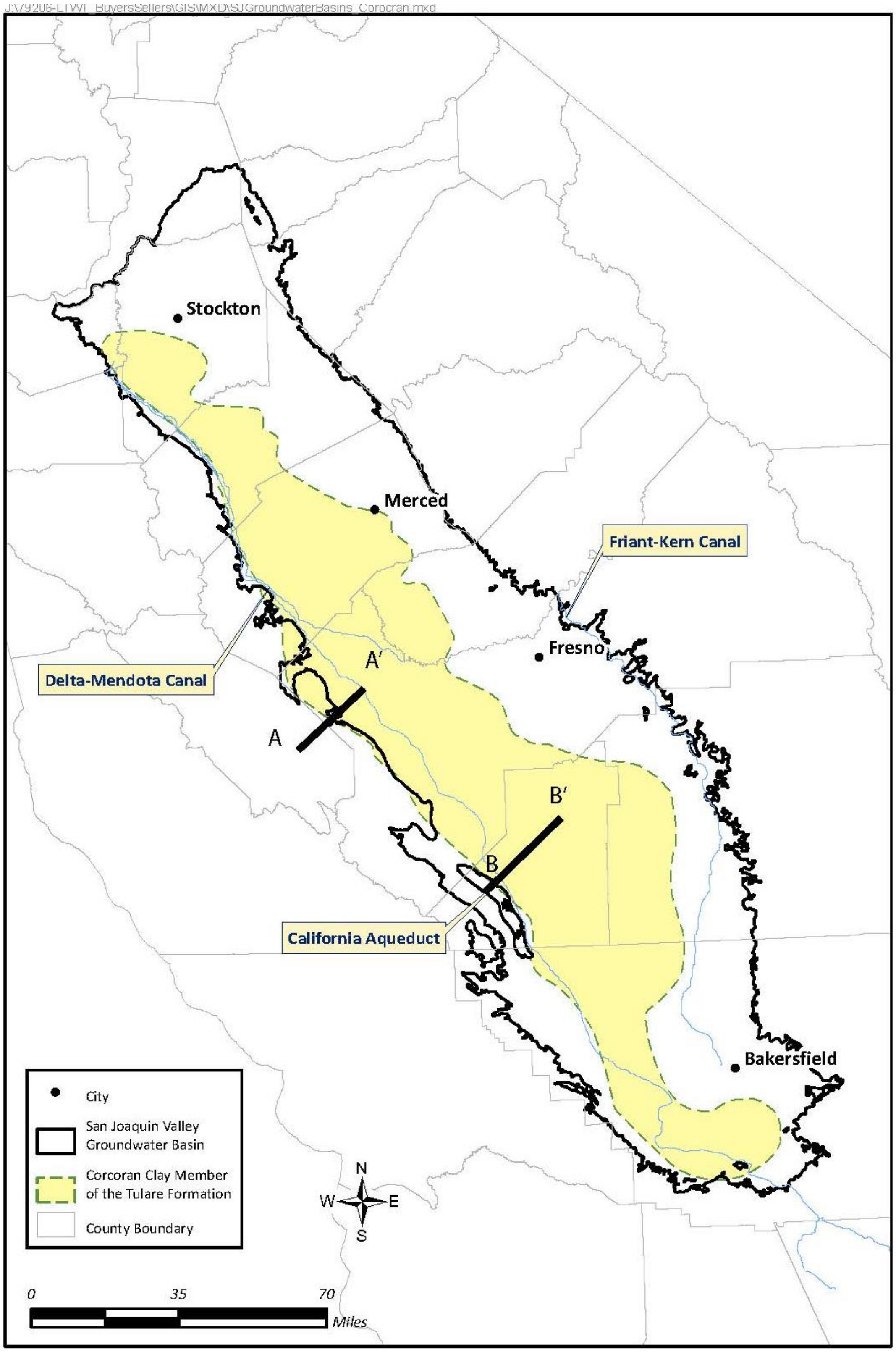


Figure 6-13. Lateral Extent of the Corcoran Clay in the San Joaquin Valley Groundwater Basin

The main surface water feature in the northern portion of the San Joaquin Valley Groundwater Basin is the San Joaquin River, which has several major tributaries draining the Sierra Nevada, including the Fresno, Chowchilla, Merced, Tuolumne, and Stanislaus rivers. Historically, these streams were "gaining" streams (i.e., they had a net gain of water from groundwater discharge into the river). With the decline of groundwater levels in the basin, areas of substantial pumping have reversed the local groundwater flow, and reaches of streams now lose water to the aquifer system (losing streams).

Groundwater Production, Levels, and Storage Prior to the large-scale development of irrigated agriculture, groundwater in the basin generally flowed from areas of higher elevation (i.e., the edges of the basin) toward the San Joaquin River and ultimately to the Delta. Most of the water in the San Joaquin Valley moved laterally, but a small amount leaked upward through the intervening confining unit (Planert and Williams 1995). Upward vertical flow to discharge areas from the deep confined part of the aquifer system was impeded partially by the confining clay beds, particularly the Corcoran Clay. Extensive groundwater pumping and irrigation (with imported surface water) have modified local groundwater flow patterns and in some areas, groundwater depressions are evident. Annual average groundwater production in the basin was estimated to be 0.9 million AF in the Central Valley Hydrologic Model (CVHM) model (Faunt 2009). Groundwater flow in the basin has become more rapid and complex. Groundwater pumping and percolation of excess irrigation water has resulted in steeper hydraulic gradients as well as shortened flow paths between sources and sinks (Faunt 2009).

Irrigated agriculture in the Northern Portion of the San Joaquin Valley Groundwater Basin increased from about 1 million acres in the 1920s to more than 2.2 million acres by the early 1980s (Reclamation 1997). The USGS's CVHM shows the average groundwater pumping to be 799,000 AF per year (AFY) from 1962 through 2003 in the southern portion of the Northern San Joaquin Groundwater Basin (includes the Turlock, Merced, Chowchilla and Madera subbasins) (Faunt 2009).

Figure 6-14 shows spring 2010 groundwater elevation contours and groundwater elevation hydrographs for select monitoring well location for the San Joaquin Valley Groundwater Basin. The two hydrograph locations shown in Figure 6-14 best portray the local groundwater elevations within the San Joaquin Valley Groundwater Basin. Hydrograph 05S12E11G001M is for an irrigation well from a region that lacks surface water and is solely dependent on groundwater within the San Joaquin Valley Groundwater Basin. Groundwater levels have generally declined over time at this location. Groundwater levels briefly stabilized between 1990 and 2002 which could potentially be attributed to the utilization of efficient irrigation techniques. A decline in the water level is observed beginning in 2011 through the end of the period of data shown in Figure 6-14. Monitoring well 11S10E24N001M is an industrial well in the Delta-Mendota subbasin (San Joaquin Valley Groundwater Basin). At this location groundwater levels increased from 1960 to 1987; however, there has been a decline of approximately 30 feet since 1987.

The cumulative change in groundwater storage for the entire San Joaquin Valley Groundwater Basin was relatively constant from 1962 through 2003 according to the CVHM (Figure 6-9). Similar to the Sacramento Valley Groundwater Basin, storage tends to drop during dry periods and increase during wetter years.

Groundwater-Related Land Subsidence From the 1920s through the mid-1960s, the use of groundwater for irrigation of crops in the San Joaquin Valley increased rapidly, causing land subsidence throughout the west and southern portions of the Valley. From 1920 to 1970, approximately 5,200 square miles of irrigated land in the San Joaquin River Watershed showed at least one foot to as much as 28 feet of land subsidence. Land subsidence is concentrated in areas underlain by the Corcoran Clay.

Interferometric Synthetic Aperture Radar (InSAR) analyses conducted over the San Joaquin Valley in 2013 indicate substantial subsidence at: 1) approximately 7,000 square kilometers west of Tulare and east of Kettleman City; and 2) 3,100 square kilometers near El Nido (south of Merced and west of Madera). Land Elevation benchmark surveys conducted by Caltrans along Highway 198 corroborate the InSAR analyses and indicate 9.37 feet of subsidence occurring in this area between 1960 and 2004. Figure 6-15 shows the contours of subsidence in both the subsiding areas from preliminary InSAR analysis (California Water Foundation 2014).

Land subsidence measurements have shown that an increase in groundwater pumping during 1984 to 1996 resulted in land subsidence of up to two feet along the Delta-Mendota Canal (CALFED 2000). Similarly, increased pumping caused Westlands Water District to experience up to two feet of subsidence between 1983 and 2001, with most of the subsidence occurring after 1989 (Westlands Water District 2000).

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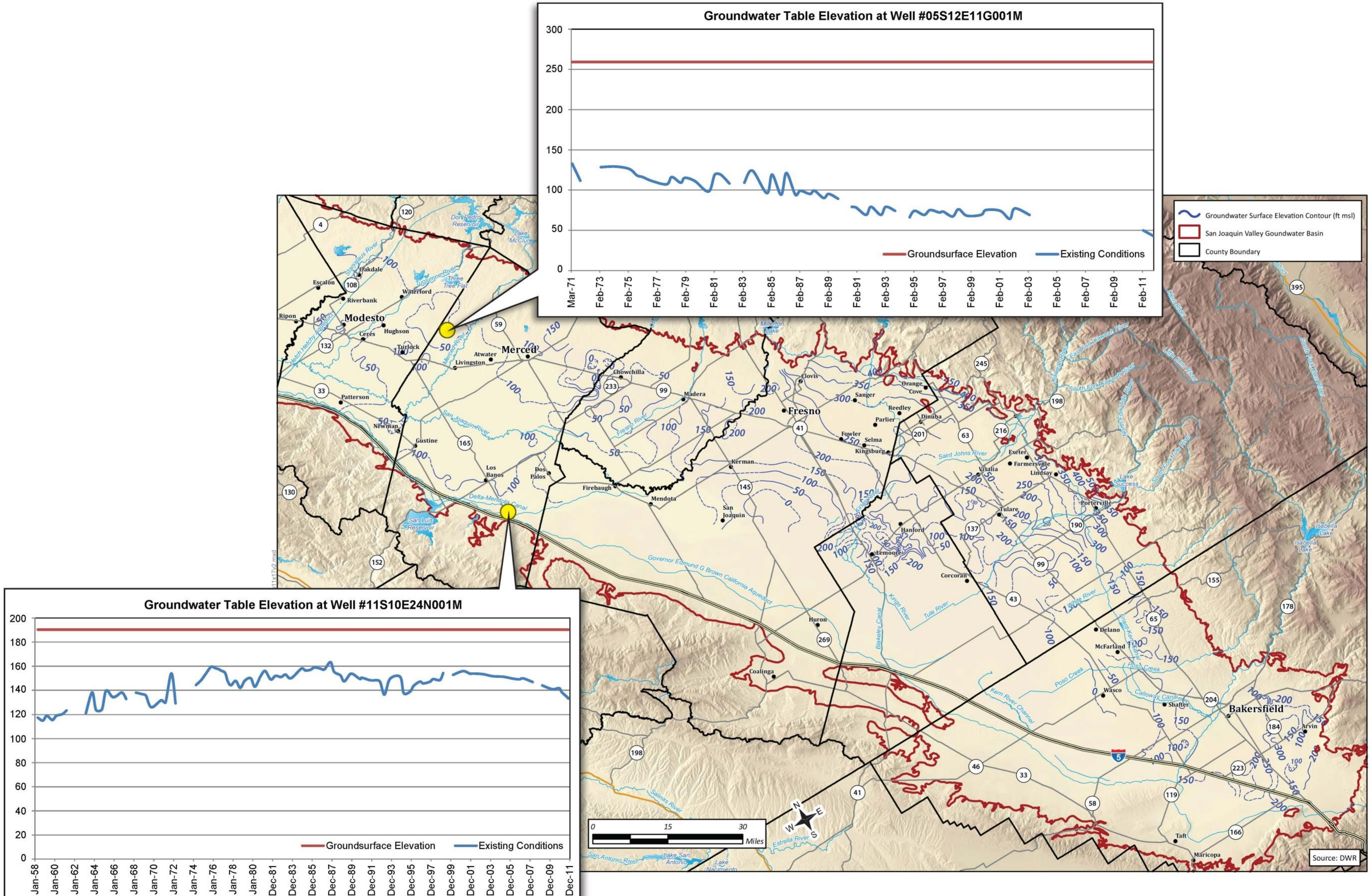

Source: DWR 2011

Figure 6-14. San Joaquin Valley Spring 2010 Groundwater Elevation Contours

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