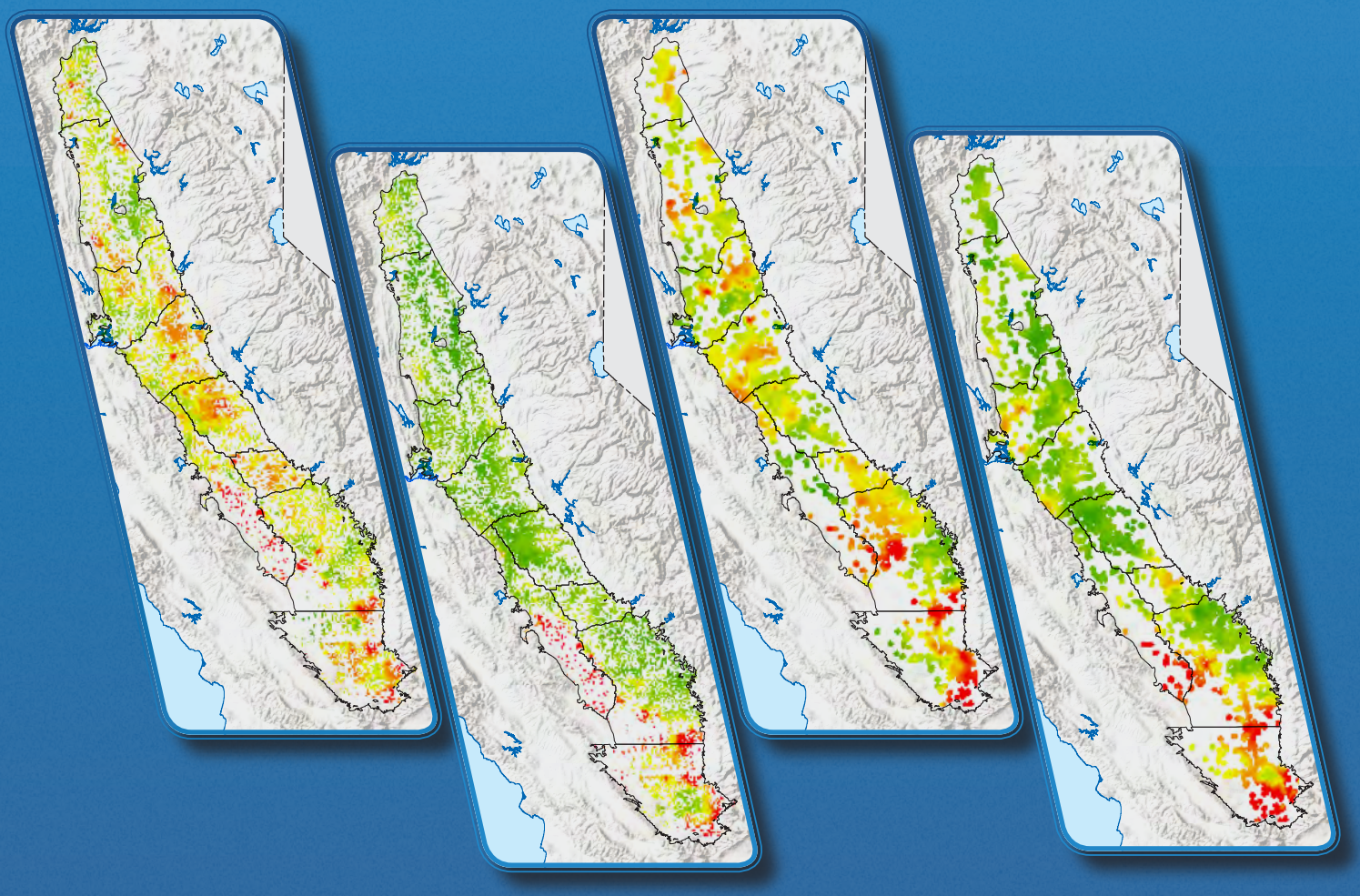
USGS
science for a changing world

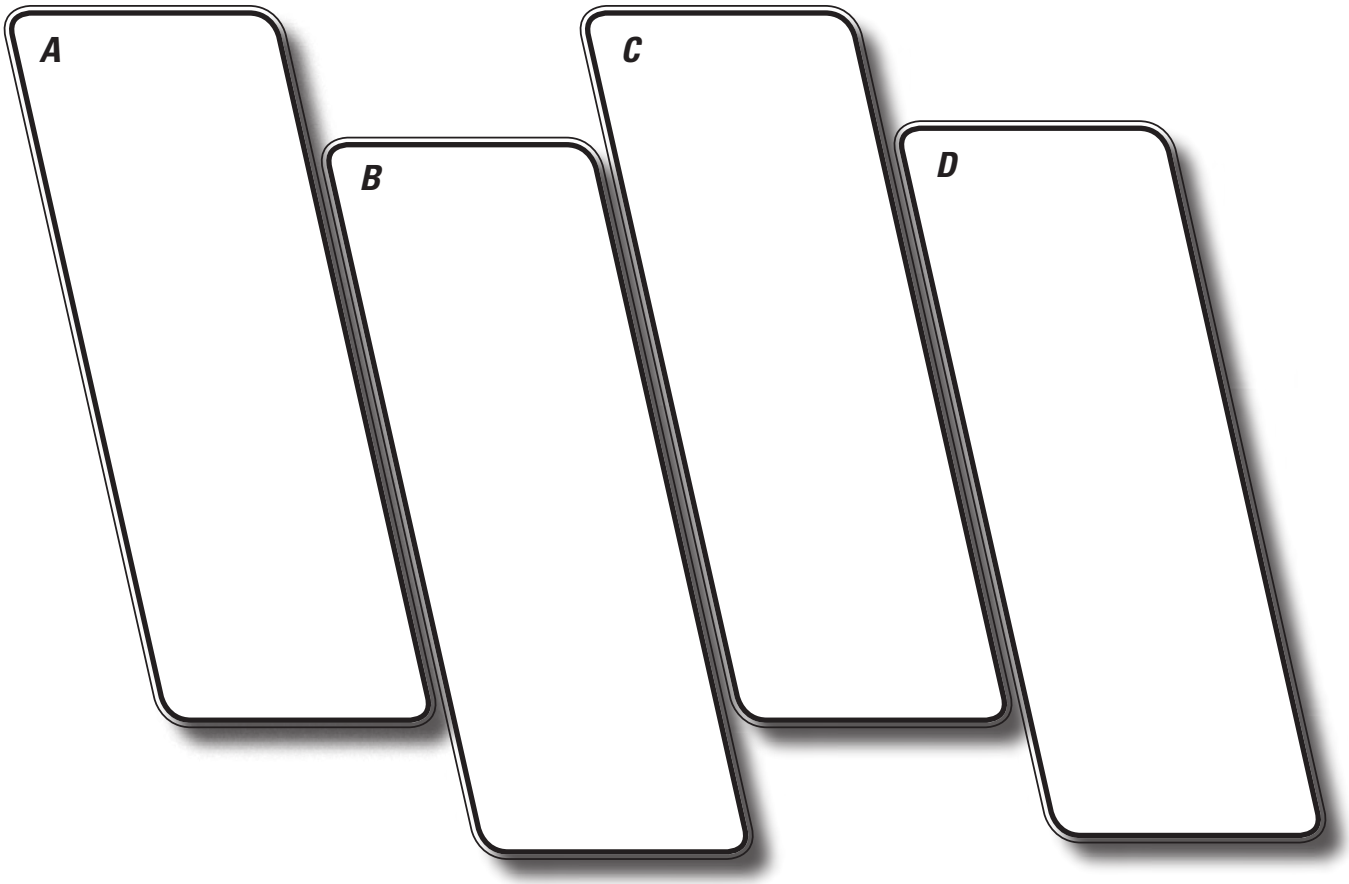
Prepared in cooperation with the California State Water Resources Control Board

Delineation of Spatial Extent, Depth, Thickness, and Potential Volume of Aquifers Used for Domestic and Public Water-Supply in the Central Valley, California



Scientific Investigations Report 2019–5076

U.S. Department of the Interior
U.S. Geological Survey



Cover. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen for domestic supply wells in the Central Valley, California. See figures 10*A* and 10*B* for more details.

Interpolated surfaces of *C*, the 10th percentile (Q10) of depth to top of screen and *D*, 90th percentile (Q90) of depth to bottom of screen for public supply wells in the Central Valley, California. See figures 11*A* and 11*B* for more details.

Delineation of Spatial Extent, Depth, Thickness, and Potential Volume of Aquifers Used for Domestic and Public Water-Supply in the Central Valley, California

By Stefan A. Voss, Bryant C. Jurgens, Miranda S. Fram, and George L. Bennett V

Prepared in cooperation with the California State Water Resources Control Board

Scientific Investigations Report 2019–5076

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2019

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit https://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:
Voss, S.A., Jurgens, B.C., Fram, M.S., and Bennett, G.L., V, 2019, Delineation of spatial extent, depth, thickness, and potential volume of aquifers used for domestic and public water-supply in the Central Valley, California: U.S. Geological Survey Scientific Investigations Report 2019–5076, 34 p., https://doi.org/10.3133/sir20195076.

ISSN 2328-0328 (online)

Acknowledgments

Funding for this work was provided by the California State Water Resources Control Board Groundwater Ambient Monitoring and Assessment Program, U.S. Geological Survey Cooperative Matching Funds, and the U.S. Geological Survey National Water Quality Assessment Program.

Contents

Abstract 1
Introduction 1
Study Area Description 2
Methods 4
Data Compilation 4
Estimated Potential Extent of the Area Used for Domestic and Public Supply 7
Interpolation Method 10
Statistical Methods 10
Results 11
Temporal Well-Depth Construction Patterns 16
Interpolated Maps of Depth to Top and Bottom of Domestic- and Public-Supply Well Screens 18
Thickness and Volume of Drinking-Water Production Zone Used for Domestic and Public Supply 27
Summary and Conclusions 31
References Cited 32

Figures

1. Map of California showing the Central Valley, San Joaquin Valley, Sacramento Valley, California Groundwater Ambient Monitoring and Assessment Program Priority Basin Project study units, and bordering mountain ranges in the Central Valley, California 3
2. Maps showing location of domestic-supply and public-supply well sites in the Central Valley, California 5
3. Maps showing domestic-supply wells overlaid on 1-kilometer buffer and public-supply wells overlaid on 3-kilometer buffer in the Central Valley, California 8
4. Graph showing an example of 10th percentile (Q10) and 90th percentile (Q90) encompassing a broad range of depths to top and bottom of well screens compared to the arithmetic mean of depths to top and bottom of well screens 11
5. Box plots of selected construction data of depths to top and bottom of screen for domestic-supply wells by study unit in the Central Valley, California 13
6. Map showing depth to water from the Central Valley Hydrogeologic Model, Central Valley, California 14
7. Box plots of selected construction data for public-supply wells by study unit in the Central Valley, California 15
8. Box plots of domestic-supply well depths binned by a multidecadal period of well construction in the Central Valley, California 17
9. Box plots of public-supply well depths binned by a multidecadal period of well construction, Central Valley, California 18

10. Map showing interpolated surfaces of the 10th percentile (Q10) of depth to top of screen and 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of the Q10 of depth to top of screen and the Q90 of depth to bottom of screen for domestic-supply wells in the Central Valley, California....19
11. Maps showing interpolated surfaces of the 10th percentile (Q10) of depth to top of screen and 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of the Q10 of depth to top of screen and the Q90 of depth to bottom of screen for public-supply wells in the Central Valley, California....23
12. Maps showing calculated interpolated surfaces representing thickness of the drinking-water production zone accessible for domestic-supply and public-supply wells in the Central Valley, California....28
13. Boxplots by well type of estimated aquifer thickness accessible for domestic and public supply for study units in the Central Valley, California....30

Tables

1. Summary of well compilation....4
2. Summary of selected well-construction characteristics of domestic-supply and public-supply wells in meters....12
3. The estimated area at land surface and potential volume of aquifer accessible for domestic and public supply in the Central Valley, California....30

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Flow rate	
liter per second (L/s)	15.85	gallon per minute (gal/min)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

CDWR	California Department of Water Resources
CESJV	central eastside San Joaquin Valley
DDW	Division of Drinking Water
DS	domestic supply
EBK	Empirical Bayesian Kriging
GAMA	Groundwater Ambient Monitoring and Assessment
ID	identification
MIDSJV	middle San Joaquin Valley
MSACV	middle Sacramento Valley
NAWQA	National Water Quality Assessment
NSACV	northern Sacramento Valley
NOSJV	northern San Joaquin Valley
NWIS	National Water Information System
PBP	Priority Basin Project
PS	public supply
Q10	10th percentile
Q90	90th percentile
SAC	Sacramento Valley
SESJV	southeast San Joaquin Valley
SJV	San Joaquin Valley
SOSJV	southern San Joaquin Valley
SSACV	southern Sacramento Valley
SWRCB	California State Water Resources Control Board
TRS	township-range-section
USGS	U.S. Geological Survey
WCR	well-completion report
WSJV	western San Joaquin Valley

Delineation of Spatial Extent, Depth, Thickness, and Potential Volume of Aquifers Used for Domestic and Public Water-Supply in the Central Valley, California

By Stefan A. Voss, Bryant C. Jurgens, Miranda S. Fram, and George L. Bennett V

Abstract

Identification of the groundwater resources used for drinking-water supplies is essential for the design of strategies to manage those resources. In this study, the spatial extent, depths, thicknesses, and volumes of groundwater aquifers used for domestic and public drinking-water supply were estimated from locations and well-construction data from 11,725 domestic-supply wells and 2,376 public-supply wells in the Central Valley, California. The data were compiled as part of the U.S. Geological Survey National Water Quality Assessment Project and California State Water Resources Control Board Groundwater Ambient Monitoring and Assessment Program Priority Basin Project. The spatial distributions of the depth to top and bottom of well screens were interpolated using Empirical Bayesian Kriging across buffer areas surrounding domestic- and public-supply wells. These surfaces provide a measure of the likely maximum horizontal and vertical extent of the aquifer volume accessed for drinking water in the Central Valley during the past century. Well depth generally increased from north to south, and over time from 1905 to 2010. Well-construction depths were generally more consistent in the Sacramento Valley than in the San Joaquin Valley. The total potential aquifer volume accessed for public supply was calculated to be greater than domestic-supply access, even though the estimated spatial extent of domestic-supply wells was 1.5 times larger than the spatial extent of public-supply wells. Public-supply wells commonly have screen lengths greater than 51 meters, whereas domestic-supply wells typically have shorter screen lengths (overall median of 6 meters). Consequently, the accessed thickness and volume of the aquifer is on average 1.8 and 1.4 times greater for public-supply wells than domestic-supply wells, respectively. Results are presented as maps of areal extent, depth, and thickness of zones in the Central Valley aquifer system used for domestic and public drinking-water supplies.

Introduction

Groundwater is the major source of drinking water in the Central Valley (Brandt and others, 2014). In 2010, groundwater constituted 51 percent of the water used for public supply (PS) and 89 percent of the water used for domestic supply (DS) in the 20 counties that compose the Central Valley (Brandt and others, 2014). Although the primary use of groundwater in the Central Valley is for irrigation (Brandt and others, 2014), reliance on groundwater as a source of drinking water is expected to increase in response to periods of drought (where surface water is less available), increased urbanization of agricultural land, and population increase. The population in the Central Valley is predicted to increase from 4.2 million in 2016 to 6.4 million in 2060 (California Department of Finance, 2018).

Effective management of groundwater resources in the Central Valley is necessary to respond wisely to competing demands for groundwater and to maintain the long-term availability of groundwater for drinking-water supply. To address these needs, the U.S. Geological Survey (USGS) in cooperation with the California State Water Resources Control Board (SWRCB) began this study to define the areas, depth zones, and volumes of the Central Valley aquifer system used for DS and PS of drinking water to facilitate more informed resource management decisions.

The groundwater resources used for DS and PS in the Central Valley may not always overlap even though both supply drinking water. Consequently, it is necessary to compile well-construction characteristics separately for DS and PS wells. This information can be used to identify areas where construction patterns are similar, which may be geologically or hydrologically related, and where construction patterns are significantly different, which can be used to identify hydrologic and water-quality relationships between the two resources. One construction pattern already known to generally differ is that DS wells commonly are shallower than PS wells because of the high cost of construction of deep wells and because the relatively low yields in many shallow wells may be sufficient for domestic use.

The distinction between DS and PS wells is primarily based on the number of people served. The California State Water Resources Control Board Division of Drinking Water (SWRCB-DDW) defines PS wells as wells operated by entities that either provide 25 (or more) people drinking water daily for at least 60 days a year or have 15 or more service connections (California State Water Resources Control Board, 2018). Drinking-water quality from wells operated by entities that serve fewer people and have fewer than five service connections is unregulated; these are DS wells that generally serve individual households. Well-completion reports (WCRs) submitted to the California Department of Water Resources (CDWR) have designation for water use; wells intermediate between PS wells and unregulated DS wells generally are designated as DS wells in these WCRs.

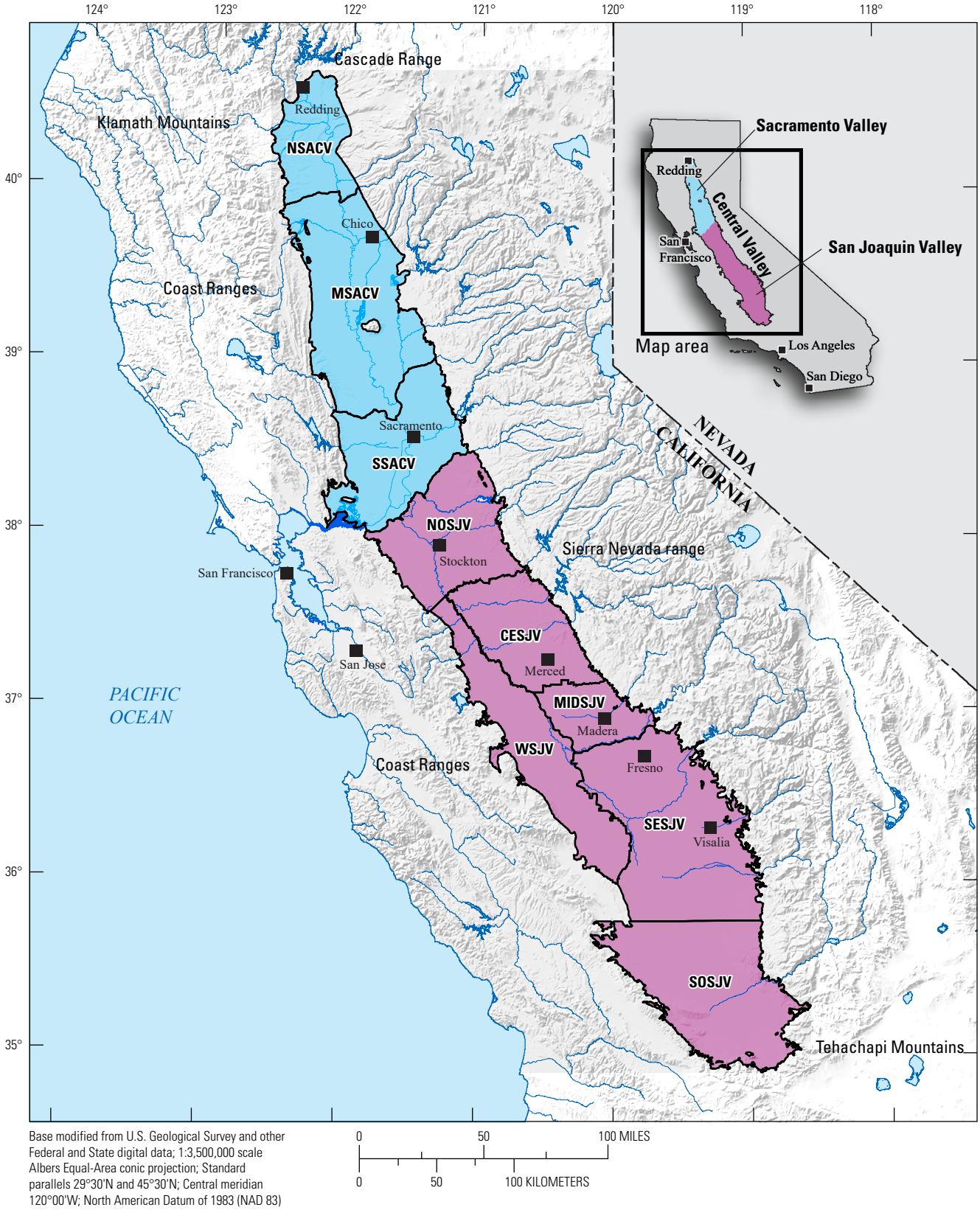
The purpose of this report is to define and summarize the spatial extent, depth zones, and volume of aquifers used for DS and PS of drinking water across the Central Valley. This report compiles well-construction data from multiple sources for 11,725 DS and 2,376 PS wells to delineate the spatial distribution and extent of areas used for DS and PS drinking water from wells constructed between the early 1900s and into the first decade of the 2000s. We use kriging to define surfaces representing the top (10th percentile), median, and bottom (90th percentile) depths of the parts of the Central Valley aquifer system used for DS and PS. We compare aquifer-depth characteristics between nine regions within the Central Valley, three in the Sacramento Valley (SAC) and six in the San Joaquin Valley and Tulare Basins (SJV). These nine regions correspond to study units sampled by the California Groundwater Ambient Monitoring and Assessment Program Priority Basin Project (GAMA-PBP) and divide the SAC and SJV in a north to south orientation that organizes the results along regional groundwater flow patterns or groundwater divides. The spatial extent, depth zones, and volumes used for DS and PS defined in this report can provide useful water-management information, for example, for making predictions of likely future water use, understanding the potential available volume of water, and summarizing well-construction patterns through time, which could assist future well-drilling operations. The results are viewed as quantifying the potential maximum volume of the aquifer production zone, which has been made accessible by drinking-water well drilling during the past century.

This work to define the groundwater resources used for DS and PS of drinking water is part of two USGS projects: the GAMA-PBP and the National Water Quality Assessment Project (NAWQA). The GAMA-PBP is a cooperative project between the USGS and the SWRCB. NAWQA was established by Congress in 1986 to assess and monitor water quality and the effects of human activities on drinking-water resources throughout the United States.

Study Area Description

The Central Valley is an asymmetrical structural trough filled with marine and continental sediments up to 15-kilometers (km) thick covering an area of more than 50,000 square kilometers (km^2), bounded by the Cascade Range to the north, the Sierra Nevada ranges to the east, the Klamath Mountains and Coast Ranges to the west, and the Tehachapi Mountains to the south (fig. 1). The aquifer system in the Central Valley comprises unconfined, semi-confined, and confined aquifers, which are primarily contained within the upper 300 meters (m; though some wells exceed that depth) of alluvial sediments deposited by streams draining the surrounding Sierra Nevada and Coast Ranges (Page, 1986; California Department of Water Resources, 2003; Faunt, 2009). The SAC occupies the northern third of the Central Valley and the SJV occupies the southern two-thirds of the Central Valley (fig. 1). The SJV is often further divided into the San Joaquin River Basin, which occupies the northern half of the SJV, and the Tulare Basin, which occupies the southern half of SJV. The Tulare Basin is, hydrologically, a closed basin, but it receives imported water from the San Joaquin and Sacramento Rivers. These will collectively be referred to as the SJV. In much of the western side of the SJV, the aquifer system is divided into an upper and lower zone by the Corcoran Clay Member of the Tulare Formation, a regionally extensive clay layer that limits vertical movement of groundwater (Page, 1986; Williamson and others, 1989; Belitz and Heimes, 1990; Burow and others, 2004). Both zones of the aquifer in the area of the Corcoran Clay generally are tapped for groundwater withdrawals (Shelton and others, 2013; Fram, 2017)

The CDWR defined 23 groundwater subbasins in the Central Valley (California Department of Water Resources, 2003). Not all 23 subbasins had a sufficient number of wells to support statistically meaningful comparisons between subbasins, therefore the 23 subbasins were grouped into 9 study units (fig. 1). These study units correspond to the study units used by the GAMA-PBP. The nine GAMA-PBP study units are the northern (NSACV), middle (MSACV), and southern (SSACV) parts of the Sacramento Valley (Bennett and others, 2011); northern San Joaquin Valley (NOSJV; Bennett and others, 2010); central eastside of the San Joaquin Valley (CESJV; Landon and others, 2010); Madera and Chowchilla subbasins of the San Joaquin Valley (MIDSJV; Shelton and others, 2013); southeast San Joaquin Valley (SESJV; Burton and others, 2012); western San Joaquin Valley (WSJV; Fram, 2017); and the southernmost part of the San Joaquin Valley (SOSJV; Burton and others, 2012; fig. 1).



Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 1. Central Valley, San Joaquin Valley, Sacramento Valley, California Groundwater Ambient Monitoring and Assessment Program Priority Basin Project study units, and bordering mountain ranges in the Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]

Methods

The methods employed in this study consisted of data compilation, estimation of area affected by DS and PS withdrawal, data interpolation, and visualization. Data compilation was intended to capture the largest possible number of wells that met the requirements for inclusion in the study in the Central Valley. For each data point, a spatial buffer was applied to restrict the interpolation to areas of effect of withdrawal. Interpolation was done with Empirical Bayesian Kriging (EBK) and prediction and residual surfaces were produced. The interpolation surfaces were then used to calculate potential aquifer volumes across the Central Valley.

Data Compilation

Well-construction and location data were compiled for DS and PS wells in the Central Valley from three sources: the USGS National Water Information System (NWIS), the SWRCB, and the CDWR. The NWIS database contains information about wells visited and inventoried by the USGS (U.S. Geological Survey, 2016), including wells sampled by the GAMA-PBP. Wells coded as withdrawal wells with water used for DS or PS drinking-water were included in this study. The SWRCB provided the USGS with a database containing partial construction information for many PS wells (John Borkovich, California State Water Resources Control Board, written commun., September 2015). The CDWR WCRs were scanned and transcribed to USGS databases as part of several projects (Burow and others, 2004; Faunt, 2009; Johnson and Belitz, 2015a, b). Only wells designated on the WCR as DS or PS (municipal) were included in this study. Well identification descriptors including CDWR-WCR number, PS-code, State well number, USGS station ID (identification), and well name were used to identify wells that are in more than one dataset. The entry with the most complete construction and location information was retained in the combined dataset. The USGS NWIS and the SWRCB-DDW databases provided location information as latitude and longitude of the well site; most DWR WCRs were cataloged with their location as the centroid of the Public Land Survey System defined meridian-township-range-section in which the well was located.

There were an estimated 93,000 and 4,500 active (for example, not reported as destroyed) DS and PS wells, respectively, as of March 2016 in the Central Valley (table 1; Johnson and Belitz, 2015b; California Department of Water Resources, 2018), of which 11,725 DS and 2,376 PS wells had location information that placed them inside or within 500 m of the Central Valley boundary as defined by Faunt (2009; fig. 2; table 1), and sufficient well-construction information to include in the study. The compilation includes wells constructed between 1911 and 2008.

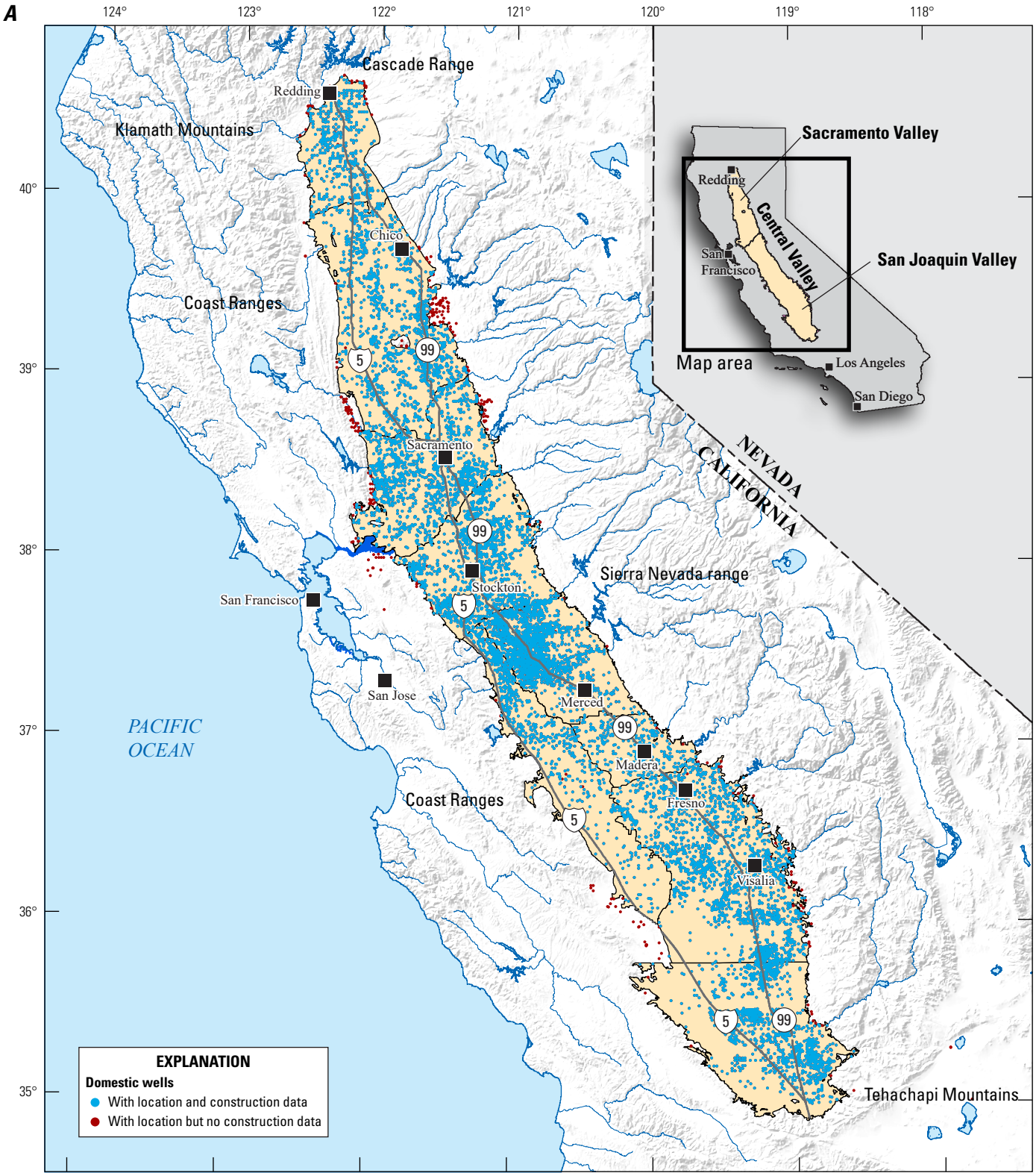
Table 1. Summary of well compilation.

[km², square kilometer; DS, domestic supply; PS, public supply; NSACV, northern Sacramento Valley; MSACV, middle Sacramento Valley; SSACV, southern Sacramento Valley; NOSJV, northern San Joaquin Valley; CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; WSJV, western San Joaquin Valley; SWRCB-DDW, California State Water Resources Control Board-Division of Drinking Water]

Study area	Area (km²)	Estimated number of DS wells[1]	DS data compilation				Estimated number of PS wells[2]	PS data compilation			
			Number with location and construction	Number with well depth	Number with top of screen	Number with bottom of screen		Number with location and construction	Number with well depth	Number with top of screen	Number with bottom of screen
NSACV	3,065	9,000	506	304	334	497	222	56	40	33	56
MSACV	8,651	14,000	1,612	1,343	799	1,545	387	178	144	136	173
SSACV	5,555	12,000	1,312	1,066	711	1,281	866	499	423	395	483
NOSJV	5,393	13,000	1,489	1,202	767	1,435	710	283	242	230	274
CESJV	4,389	12,000	2,535	2,412	2,216	2,497	506	372	333	267	347
MIDJSV	2,235	4,000	301	230	148	287	158	41	38	28	40
SESJV	9,770	25,000	1,956	1,391	614	1,677	1,131	574	495	356	554
SOSJV	7,872	1,600	1,319	909	290	977	444	307	250	190	279
WSJV	5,612	2,300	695	597	397	637	119	66	57	46	63
total	**52,542**	**92,900**	**11,725**	**9,454**	**6,276**	**10,833**	**4,543**	**2,376**	**2,022**	**1,681**	**2,269**

[1]Number of DS wells estimated (Johnson and Belitz, 2015a; California Department of Water Resources, 2018).

[2]Number of PS wells estimated from the SWRCB-DDW database, includes active, standby, and idle wells.

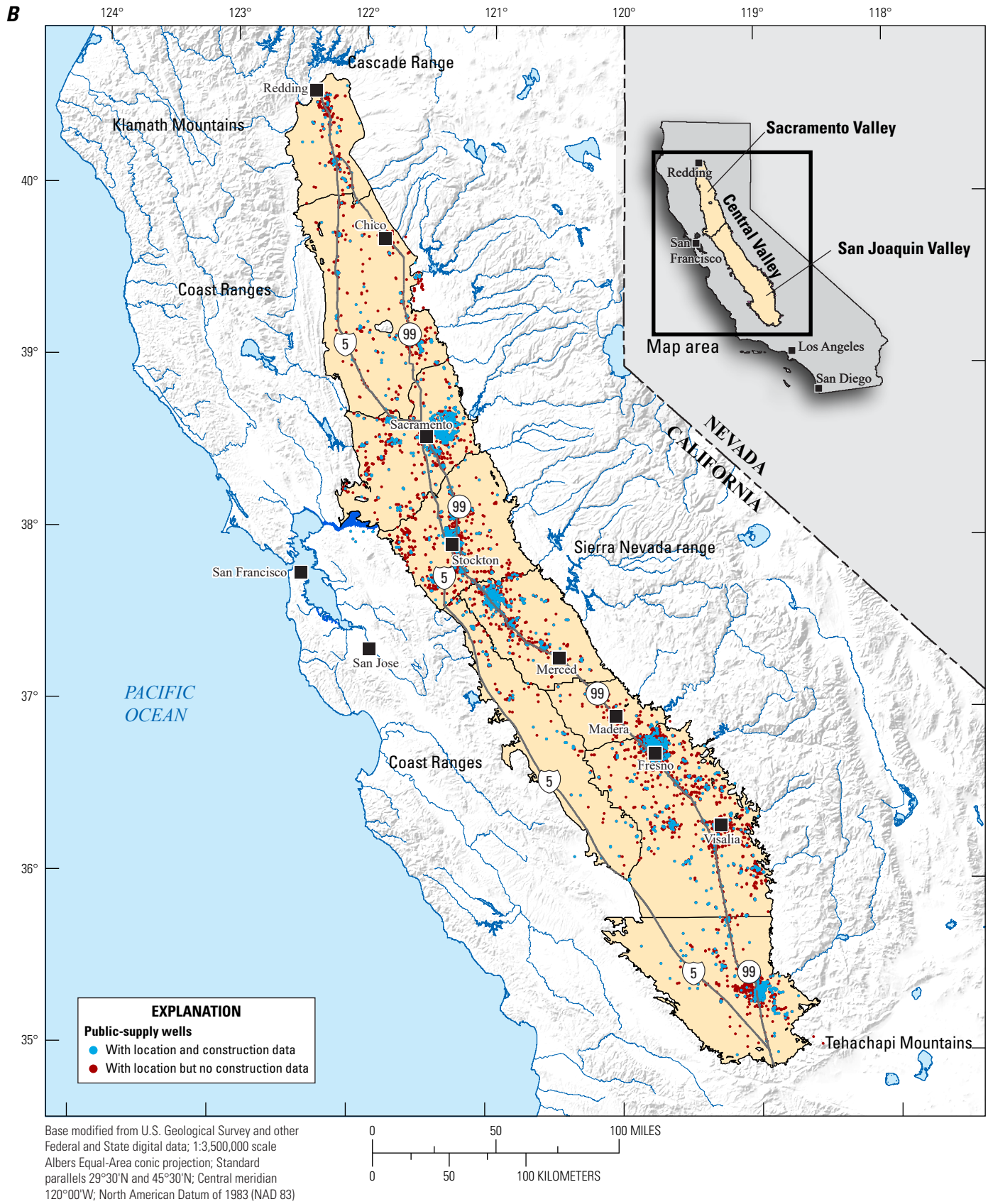


Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

0 50 100 MILES

0 50 100 KILOMETERS

Figure 2. Location of *A*, domestic-supply and *B*, public-supply well sites in the Central Valley, California.



Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 2. Location of *A*, domestic-supply and *B*, public-supply well sites in the Central Valley, California.—Continued

The PS wells with well location and construction information constitute more than 52 percent of the estimated total number of PS wells and tend to be clustered in urban areas or along major transportation corridors (fig. 2). About 20 percent of PS wells with construction data were sampled by the GAMA-PBP, which uses a stratified random-sampling design to ensure a spatially distributed, representative selection of wells (Belitz and others, 2003); the GAMA-PBP PS sampling occurred in the entire Central Valley. The DS wells with well-location and construction information constitute about 13 percent of the total estimated number of DS wells and are spatially distributed throughout the Central Valley (fig. 2). Most DS wells are in more rural parts of the Central Valley, but also can be in or near urban centers when urbanizing areas expand into surrounding rural and agricultural areas. The source data for DS wells in large part comes from studies designed to capture statistically unbiased assessments of water use or sediment-texture information from drillers logs throughout the Central Valley. About 30 percent of the DS wells with data are from Johnson and Belitz (2015b) and Faunt (2009). Johnson and Belitz (2015a) subsampled CDWR WCRs from a collection of more than 740,000 WCR images for the purpose of getting a representative sampling of the distribution of DS wells statewide. Faunt (2009) also systematically subsampled CDWR WCRs in order to compile lithologic information to extract sediment-texture distributions representative of the entire Central Valley.

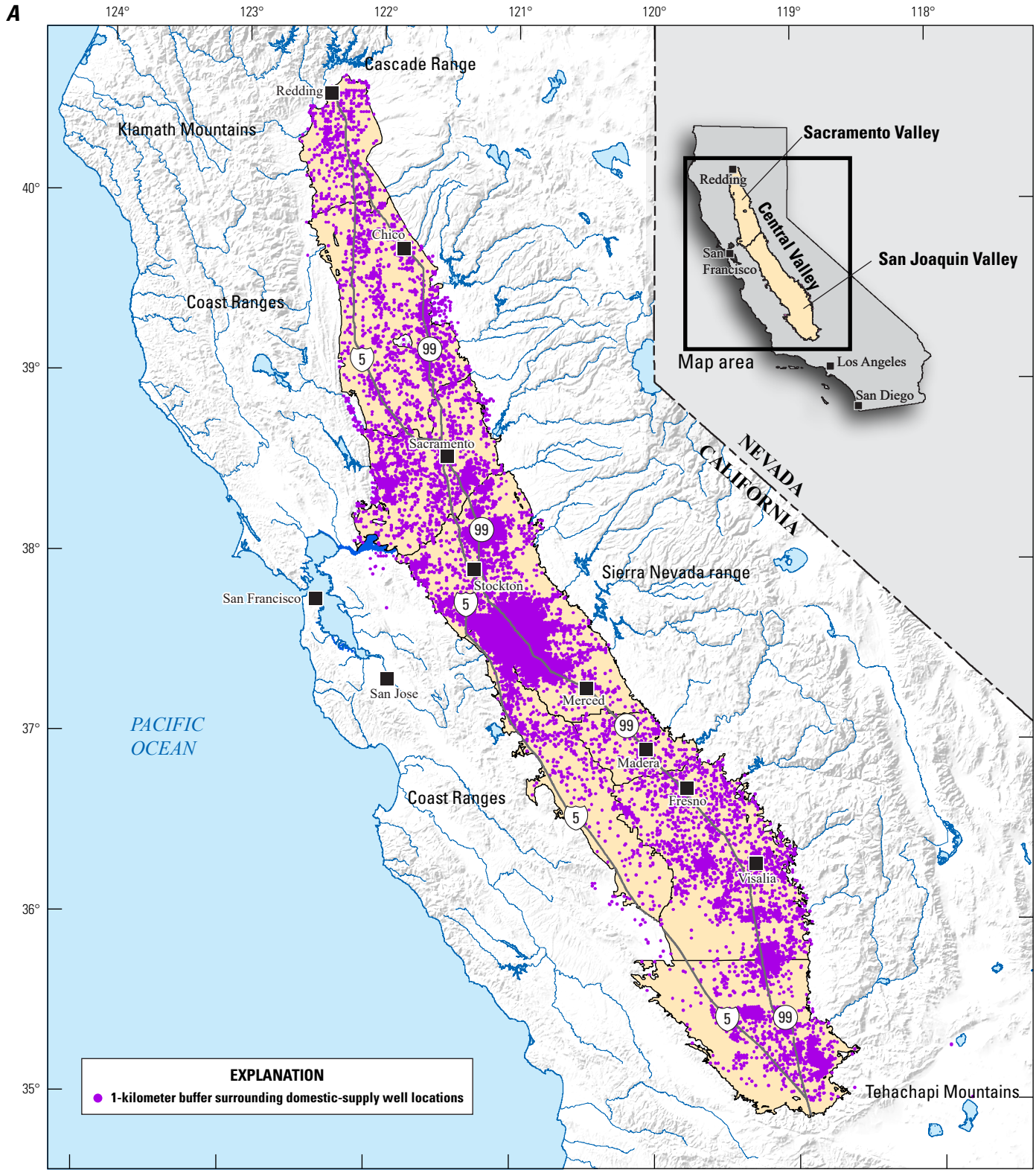
Well-construction data for depth to top of screen, depth to bottom of screen, well depth, and hole-completion depth were reported in feet and converted to meters (m) below land surface. In cases where depth to bottom of screen was missing, well depth was used for bottom of screen, and hole-completion depth was used in cases where well depth was unavailable. The well depth and hole-completion depth are often close approximations to the bottom of the well screen, so these substitutions are reasonable, but could overestimate the thickness and volume of the aquifer accessed for DS and PS. Some DS and PS wells are constructed with open bottoms and those wells may not be well-represented by this compilation because it is often unclear whether water is contributed to the well at depths greater than the bottom of the well screen or casing. In these cases, the depth to bottom of well screen could underestimate the thickness and volume of the aquifer accessed for DS and PS. The SWRCB-DDW had data for top of screened/perforated interval and length of screened/perforated interval; the depth to bottom of screen was calculated from these data. All of the compiled well data are available in Voss and Jurgens (2018).

Estimated Potential Extent of the Area Used for Domestic and Public Supply

To compute the volume of aquifer used for DS and PS, the spatial extent of the groundwater resource used for DS and PS was estimated by using a 1-km and 3-km buffer around DS and PS wells in the Central Valley, respectively (fig. 3). All wells with location data were used to define the spatial extent of DS and PS aquifer use.

A 1-km-buffer size was used for DS wells because the main method for identifying the spatial extent of DS wells in the Central Valley was from random sampling of well driller's logs that were assigned locations based on the centroid of the nearest township-range-section (TRS). The area of each TRS is equal to 2.59 km^2 or about the area within a 1-km buffer (3.14 km^2). Johnson and Belitz (2015a) reported that the average DS well density in the Central Valley was 1.74 wells per km^2, which indicates that most TRSs had more than one DS well. The 1-km buffer also is consistent with the GAMA-PBP DS-aquifer assessments' area selection method, where wells may be broadly distributed (Bennett, 2018; Burton and Wright, 2018). Although DS wells typically have low pumping rates (less than 20 gallons per minute, gal/min) and small areas contributing recharge (less than 500 m), the 1-km buffer provides an estimate of the potential extent of areas likely to have one or more DS wells in the Central Valley (Johnson and Belitz, 2015a).

A 3-km buffer size was used for PS wells because these wells typically have high pumping rates (greater than 200 gal/min) and withdraw water from greater depths and therefore, could access water that originated several kilometers away from the well (Franke and others, 1998; Phillips and others, 2007). A 3-km buffer also is consistent with the buffer size used by the GAMA-PBP to define the areal extent of study areas in parts of the state where wells are not distributed across entire groundwater basins (Bennett and others, 2011; Wright and Belitz, 2011; Dawson and Belitz, 2012; Fram and Belitz, 2012; Bennett and others, 2014; Parsons and others, 2014; Fram and Shelton, 2015). In those studies, the assessed area was defined as the combined area of 3-km buffers around PS wells in the SWRCB-DDW list. For those GAMA-PBP studies that used the 3-km buffers to define study areas, an average of more than 90 percent of the grid cells in those study areas had wells that were sampled by the GAMA-PBP, indicating that even though the buffers were defined using a subset of existing wells, they adequately captured the extent of the used resource. The buffered areas for DS and PS wells are not meant to represent the contributing recharge area of individual wells, but rather the extent of the area that is likely to have DS or PS wells presently or in the future.



Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 3. *A*, Domestic-supply wells overlaid on 1-kilometer buffer and *B*, public-supply wells overlaid on 3-kilometer buffer in the Central Valley, California.

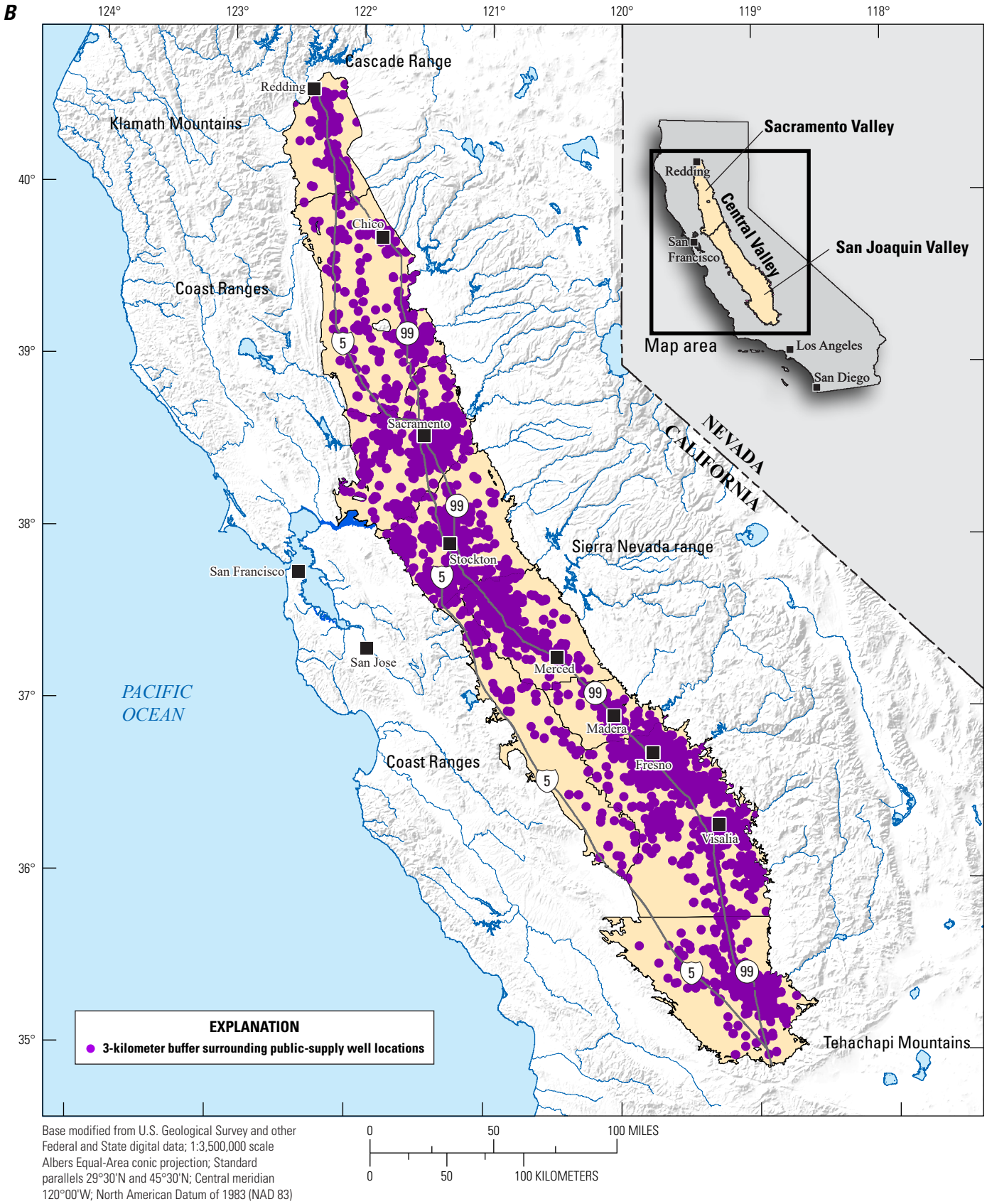


Figure 3. *A*, Domestic-supply wells overlaid on 1-kilometer buffer and *B*, public-supply wells overlaid on 3-kilometer buffer in the Central Valley, California.—Continued

Interpolation Method

Geographic information system raster surfaces of depth to top and bottom of screens for DS and PS were created by using EBK on a 1,600- by 1,600-meter (1 square-mile) grid (Voss and Jurgens, 2018). The geographic coordinates of the well locations in decimal degrees were projected into coordinates in meters using Albers Equal-Area Conic projection (well-known ID: 5070) with a central meridian of –120, and then they were rotated clockwise by 30.44 degrees about the point (38,818 m and 1,280,164 m). Prediction surfaces were computed using the following EBK parameters:

Input features: table of interest (for example, CV_DOMs);

Z-value field: parameter of interest (for example, SC_TOP_M);

Output geostatistical layer: (blank);

Output raster: name of surface (for example, DOMs_Top);

Output cell size: 1600;

Data transformation type: NONE;

Semivariogram model type: POWER;

Max number of points in each local model: 100;

Local model area overlap factor: 1;

Number of simulated semivariograms: 100;

Search neighborhood: standard circular;

Search radius: 176,950;

Maximum neighbors: 15;

Minimum neighbors: 10;

Angle: 0;

Sector type: 1 sector;

Output surface type: select surface of interest (for example, PREDICTION or QUANTILE);

Quantile value: 0.1 or 0.9;

In EBK, semivariograms are estimated with a restricted maximum likelihood method by dividing the data into overlapping subsets (100 points per subset) and producing a semivariogram for each subset (Esri, 2019). New data is then simulated at each input point of the semivariogram and this simulated data is used to generate a new semivariogram. This process is repeated several times (100 in this study) and the distribution of semivariograms at each location can be used to generate prediction surfaces of the mean value as well as values for different percentiles of the distribution. Prediction surfaces were computed for the 10th percentile of the top of screen and the 90th percentile of the bottom of screen. The 10th and 90th percentiles were selected because these depths typically include at least 80 percent of DS- and PS-well screen intervals and, therefore, may better represent the full extent of the aquifer used for DS and PS rather than an extent based on average values of screen intervals (fig. 4). Aquifer thickness was computed by subtracting the 10th percentile surface from the 90th percentile surface. All rasterized surfaces were clipped to the areal extent of the DS- and PS-buffered areas. Volumes of DS and PS were computed as the sum of the DS or PS area per grid cell, and then multiplied by the thickness in each of the nine study units.

Statistical Methods

Spearman's rank correlation, which is a nonparametric, rank-based method, was used to investigate correlations between well-construction characteristics. Spearman's rho (ρ) measures the strength of the monotonic relation between variables. The significance level used for all tests was 0.05.

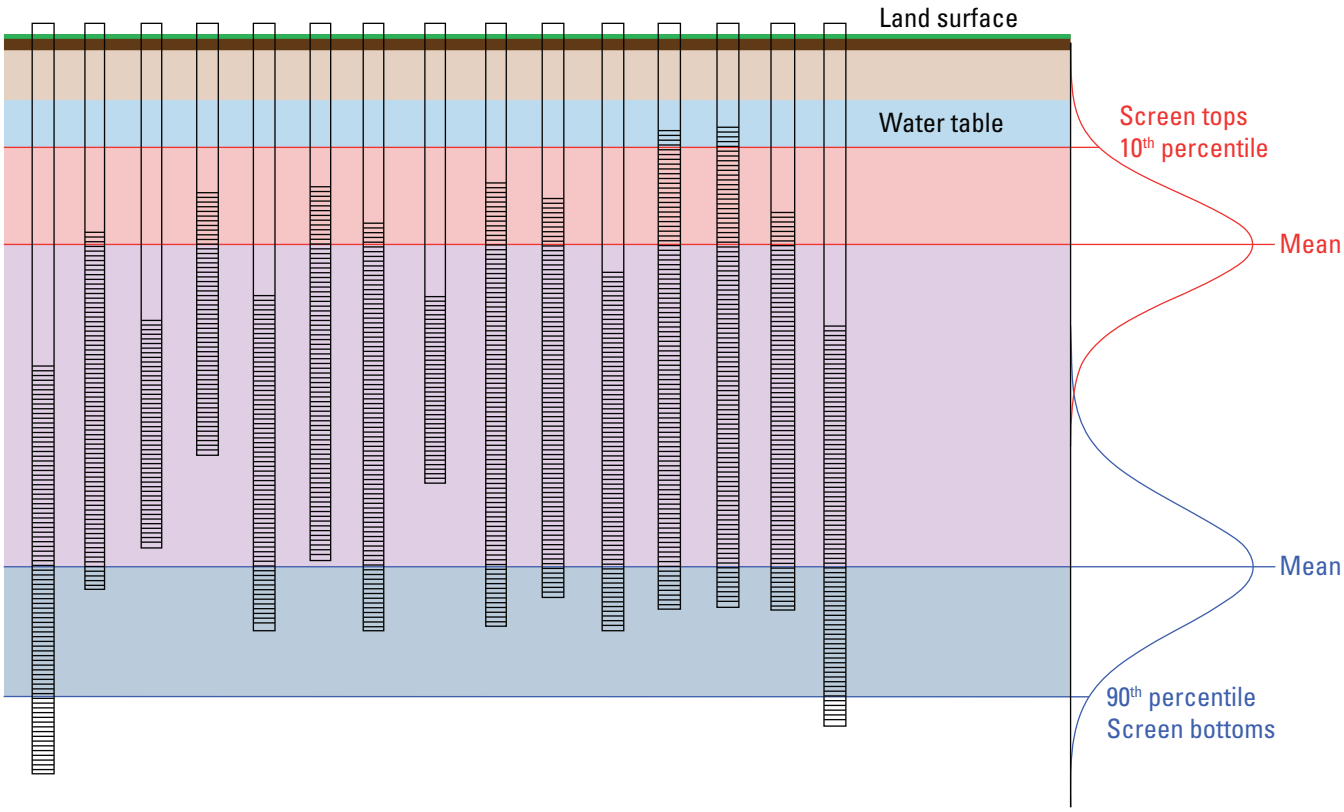


Figure 4. Example of 10th percentile (Q10) and 90th percentile (Q90) encompassing a broad range of depths to top and bottom of well screens compared to the arithmetic mean of depths to top and bottom of well screens.

Results

Statistics of DS and PS well construction characteristics were tabulated for tops and bottoms of screens for each of the nine regions in the Central Valley and presented in table 2. Interpolated surfaces produced from the data and statistics were produced for the 10th percentile of the well-screen tops and 90th percentile of the well-screen bottoms. These surfaces and their accompanying residual (error) surfaces show relative agreement between estimated and actual data. From the 10th and 90th percentiles of top and bottom of screen surfaces, estimated aquifer thickness was calculated for DS and PS wells.

Because these estimates are based on actual construction data of wells, the dataset is heavily constrained by access to well-construction records. Of the nearly 20,000 total DS- and PS-well records in the Central Valley, approximately 14,000 met the compilation criteria of having sufficient construction information and of being designated for withdrawal for drinking-water use. Of these well records, 11,725 were DS wells compared to only 2,376 PS wells. The smaller size of the dataset of PS wells, in contrast to the dataset of DS wells, can lead to predictive uncertainty in areas where well density is low, and variability and magnitude of depth are high.

Additionally, because top and bottom of screen interpolated surfaces are produced from all available data, and some wells have data for top or bottom of screen, but not for both, the aquifer-thickness estimates can be skewed by missing construction data; this is the case in the northern region of the Central Valley for DS wells where aquifer thickness was initially estimated to be negative. In this case, the interpolation of the well-screen bottoms and tops intersected at a few points where construction data are missing. In these grid cells, the thickness was given a floor of zero meters.

Overall, PS wells serving communities and municipalities tend to be screened deeper than DS wells. The depth to top of screen for DS wells ranged between 0.6 m (2 feet, ft) and 423 m (1,388 ft) below land surface, and depth to bottom of screen between 0.3 m (1 ft) and 1,341 m (4,400 ft) below land surface with overall study area medians of 44 m (145 ft) and 58 m (189 ft), respectively (table 2). Screened intervals of DS wells generally increase in depth from north to south (fig. 5), following the same north-south trend of increasing depth to water in the Central Valley (fig. 6). The shallowest DS wells and depth to water are in MSACV and the deepest wells and depth to water are in SOSJV.

Table 2. Summary of selected well-construction characteristics of domestic-supply (DS) and public-supply (PS) wells in meters.

[n, number of wells; columns ending in 'th', percentile value; NSACV, northern Sacramento Valley; MSACV, middle Sacramento Valley; SSACV, southern Sacramento Valley; NOSJV, northern San Joaquin Valley; CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; WSJV, western San Joaquin Valley]

Study area	n	Minimum	10th	25th	Median	75th	90th	Maximum
DS wells								
Depth to top of screen, rounded to nearest meter								
NSACV	334	1	12	20	36	55	84	198
MSACV	799	1	12	17	28	48	69	187
SSACV	711	2	12	23	35	52	75	226
NOSJV	767	2	20	28	41	57	73	304
CESJV	2,216	5	21	29	41	61	76	136
MIDSJV	148	3	29	46	61	74	93	121
SESJV	614	4	18	30	47	63	91	346
SOSJV	290	1	22	37	63	95	134	423
WSJV	397	3	19	30	46	72	135	346
Depth to bottom of screen, rounded to nearest meter								
NSACV	497	5	21	31	49	73	110	199
MSACV	1,546	1	13	18	29	49	76	228
SSACV	1,282	6	26	38	52	73	94	354
NOSJV	1,436	9	26	37	50	69	91	247
CESJV	2,498	6	27	36	49	69	87	245
MIDSJV	288	12	32	45	67	98	116	209
SESJV	1,678	0	24	37	56	84	149	783
SOSJV	978	9	37	62	114	168	247	1,341
WSJV	638	5	19	34	52	82	245	634

Study area	n	Minimum	10th	25th	Median	75th	90th	Maximum
PS wells								
Depth to top of screen, rounded to nearest meter								
NSACV	33	12	24	33	59	82	87	94
MSACV	136	2	20	30	48	65	89	213
SSACV	395	16	36	48	61	78	101	385
NOSJV	230	7	30	43	58	73	106	229
CESJV	267	12	27	31	40	59	79	122
MIDSJV	28	1	42	55	72	85	118	154
SESJV	356	12	35	46	55	72	101	346
SOSJV	190	2	49	61	79	118	152	319
WSJV	46	6	25	33	48	101	186	253
Depth to bottom of screen, rounded to nearest meter								
NSACV	36	21	34	67	96	137	165	256
MSACV	174	12	30	44	85	138	193	276
SSACV	484	20	60	80	107	143	177	443
NOSJV	275	22	47	71	120	152	174	369
CESJV	348	7	31	45	69	89	117	253
MIDSJV	41	40	49	88	115	142	222	253
SESJV	555	22	44	59	87	134	190	491
SOSJV	280	6	91	152	184	216	305	1,066
WSJV	64	7	45	65	94	197	308	549

In the southern and western regions of the SJV, DS-well (screen) depth variability is greater than elsewhere in the Central Valley (fig. 5). Some of the deepest wells in this region, which are DS wells, have been repurposed and converted from oil wells that were originally drilled to great depths for oil extraction. Because DS-well density is lowest in this portion of the Central Valley, depth uncertainty is greater here than elsewhere in the Central Valley.

Median screen length for DS wells range from 0.3 m (1 ft) in MSACV to 24 m (80 ft) in SOSJV with an overall median screen length of 6 m (20 ft). Screen length is strongly correlated with well depth (Spearman's rho = 0.49, p-value less than 0.001), but is less strongly correlated with depth to top of screen (Spearman's rho = 0.18, p-value less than 0.001). These correlations suggest that shallower wells are more often constructed with shorter screens and capture water from smaller, discrete sections of the aquifer, whereas deep wells are more likely to be constructed with longer screens to capture water from multiple conductive sections of the aquifer. Well depth and screen length are smallest in study units that have the shallowest depths to water (fig. 6).

The depth to top of screen for PS wells ranged between 1 m (3 ft) and 385 m (1,246 ft) below land surface, and the depth to bottom of screen ranged between 6 m (20 ft) and 1,066 m (3,498 ft) with medians of 58 m (190 ft) and 106 m (349 ft), respectively, for the overall study area. As with DS wells, well-screen depths for PS wells increased from north to south, and greater variability and magnitude were reported in the southern and western regions of the SJV. The shallowest PS wells are in CESJV and the deepest wells are in SOSJV (fig. 7).

Median screen length for PS wells across all study units is 51 m (166 ft), ranging from 29 m (96 ft) in CESJV to 108 m (355 ft) in SOSJV. As with DS wells, calculated screen length increased from north to south following the trend of depth to water (fig. 6). Public-supply-well calculated screen length is considerably greater across all study units than it is for DS wells, and screen depth also tends to be deeper in PS wells than in DS wells (fig. 7).

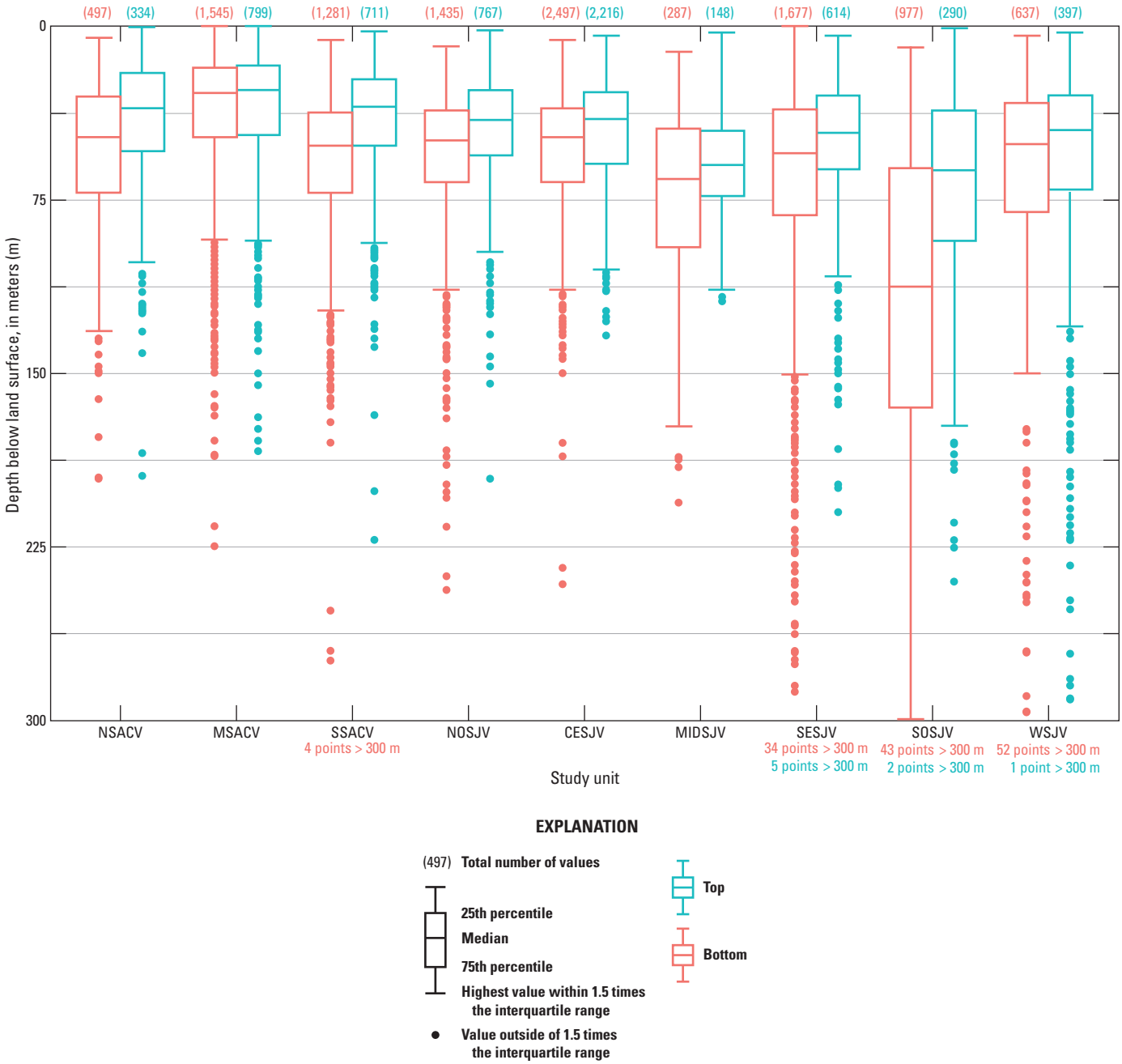
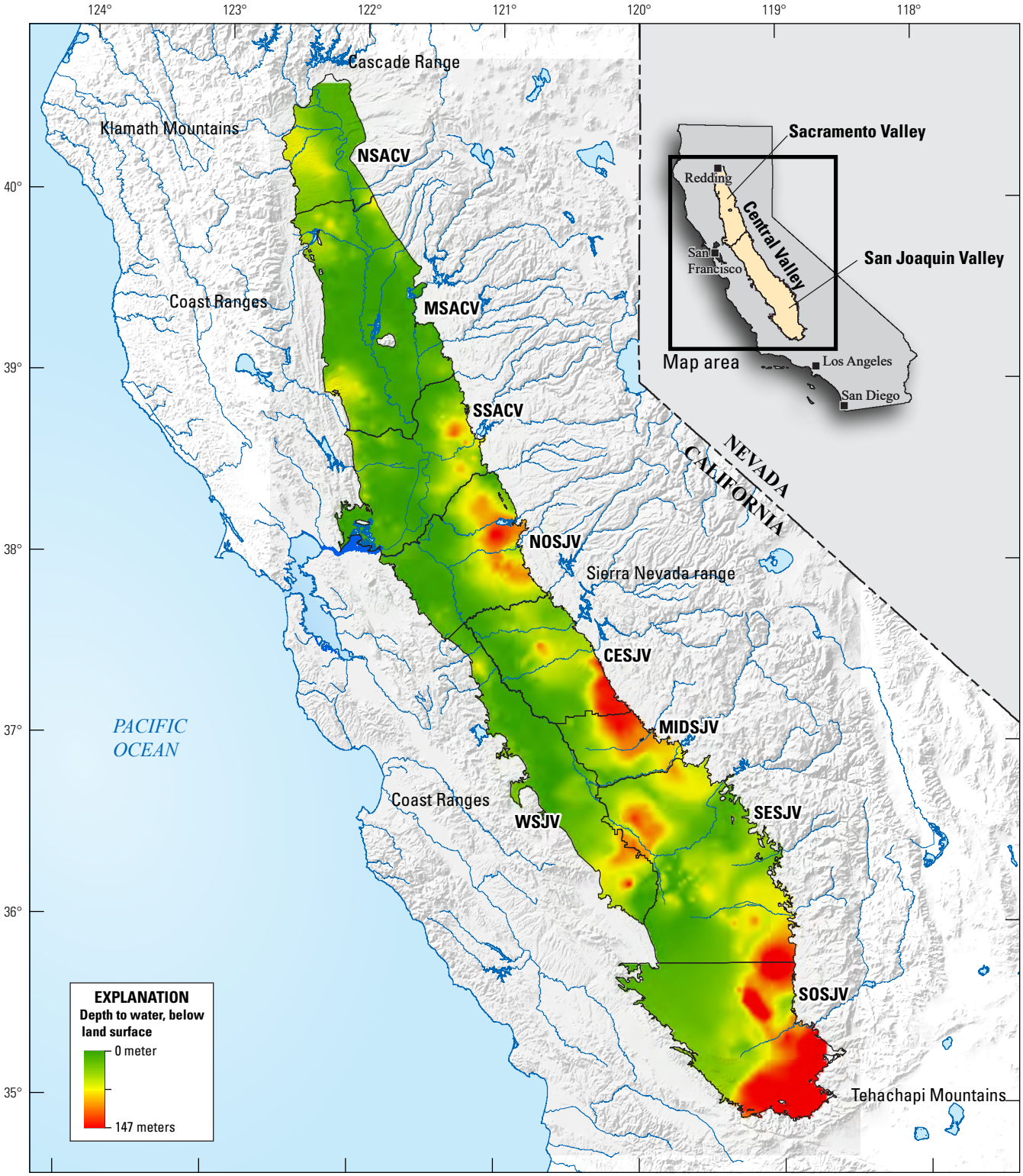


Figure 5. Selected construction data of depths to top and bottom of screen for domestic-supply wells by study unit in the Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley; >, greater than]



Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 6. Depth to water from the Central Valley Hydrogeologic Model, Central Valley, California (Faunt, 2009). [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]

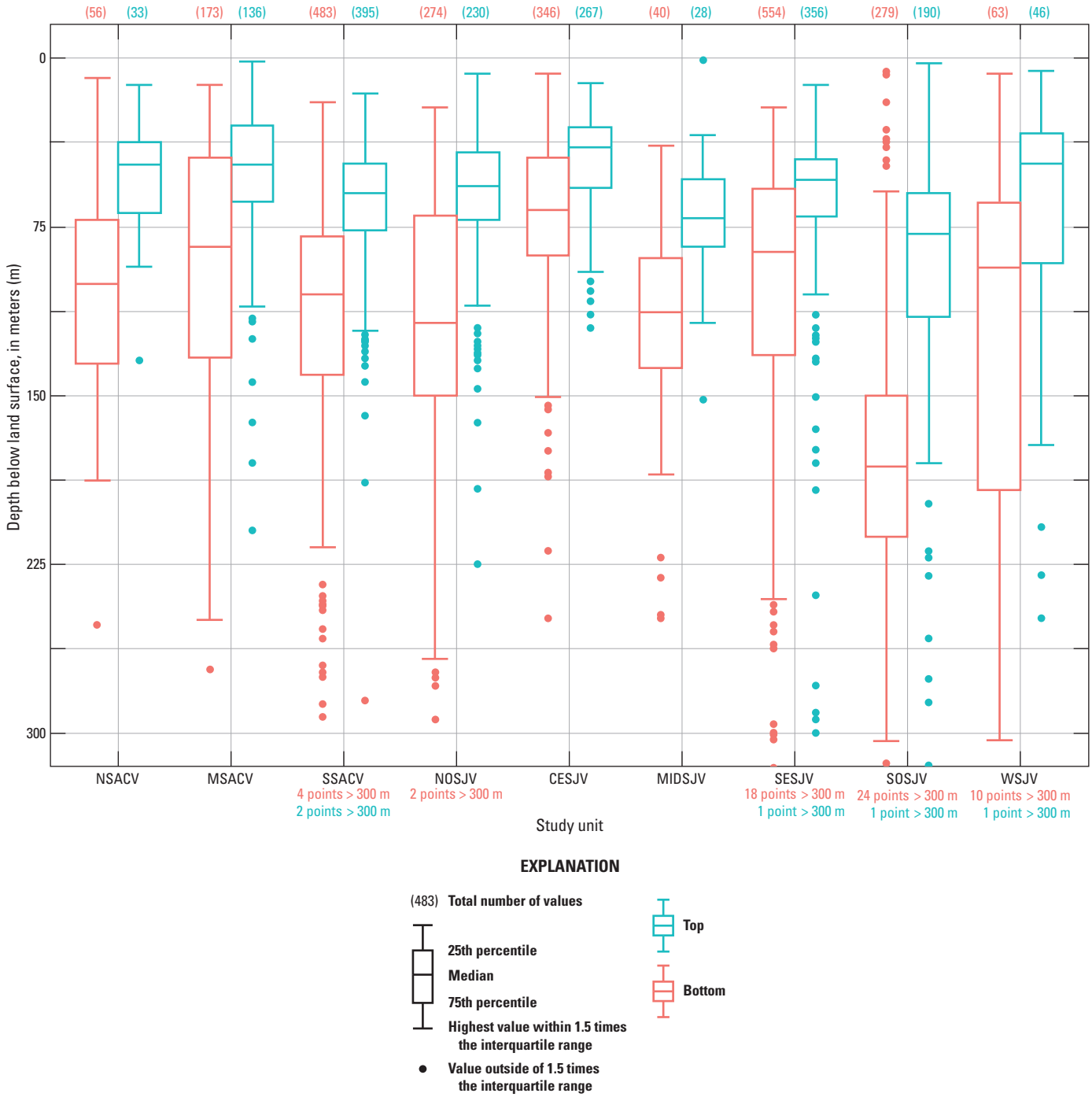


Figure 7. Selected construction data for public-supply wells by study unit in the Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley; >, greater than]

The Corcoran Clay is present along the trough of the SJV and can complicate the vertical delineation of the aquifer used for PS. Two GAMA-PBP reports that discussed the distribution of PS-well depths in relation to the Corcoran Clay are Shelton and others (2013; MIDSJV) and Fram (2017; WSJV). In these studies, selected PS wells were most often screened entirely above or below the Corcoran Clay, but some wells did have screens that crossed the Corcoran Clay. The number of PS wells screened above and below the Corcoran Clay were about equally split across the study area; however, more wells were screened above the Corcoran Clay in the WSJV, and more wells were screened below the Corcoran Clay in the MIDSJV. Because PS wells are installed above, below, and at times across the Corcoran Clay, separate aquifer volumes for the upper and lower aquifers bisected by the Corcoran Clay were not calculated for this study. Consequently, the vertical extent or thickness of an aquifer used for PS can be overestimated in areas where a combination of wells screened entirely above or below the Corcoran Clay were included in the interpolation.

Temporal Well-Depth Construction Patterns

In the Central Valley, periods of water well drilling often coincide with periods of drought because surface water is less available for use and because groundwater-level declines cause the abandonment or alteration of existing wells. Between periods of drought, water well drilling often occurs with the expansion of urban areas and new home construction in rural parts of the Valley.

To show temporal trends for the number of wells constructed and well-depth characteristics, the well-construction data were divided into three equally sized periods based on well completion date: 1905–1940, 1941–1975, and 1976–2010 (fig. 8). It is difficult to estimate the number of wells constructed before 1941 from the dataset compiled for this analysis because the records in the dataset relied heavily on electronic copies and digital images of hard-copy WCRs, and it is possible that not all hard-copy WCRs from before 1941 were included in our initial compilation. In addition, only 42 percent of DS wells and 79 percent of PS wells had a construction date, so the well-construction patterns of the binned data may not accurately represent well-construction patterns when the sample size is small.

Based on the data compiled for this report, the number of new constructions per year varied greatly across the Central Valley. Most of the new DS and PS wells in the Central Valley were constructed between 1941 and 1975, except for DS wells in CEJSV and NSACV where most of the new well construction occurred after 1975. Before 1941, new DS- and PS-well construction across the Central Valley was considerably less frequent.

Temporal trends of well depth for DS wells varied throughout the Central Valley. In the northern areas (NSACV, MSACV, SSACV) average well-construction depth remained relatively stable, with shallower construction overall between 1941 and 1975 (fig. 8). In the central portion of the Central Valley (NOSJV, CESJV, MIDSJV), average construction depth increased over time, with the deepest wells generally constructed after 1976 (fig. 8). In the southern regions of the Central Valley (SESJV, SOSJV), depth variability was greater resulting in no clear temporal pattern of depth of construction. The SESJV shows deeper construction after 1940, whereas SOSJV shows the reverse trend, with deepest well construction before 1940 (fig. 8). In the WSJV the depth trend followed a decrease in variability and generally decreased in average depth over time (fig. 8).

In contrast to trends of DS well depth, PS wells had more consistent trends of well depth throughout the Central Valley. Well depth generally increased for each time interval and the deepest wells tended to be drilled after 1975 (fig. 9). Exceptions to this trend are found in NSACV, which contained no new constructions in the dataset after 1975; in MSACV, which showed a trend of decreasing depth for each time interval, with the deepest wells constructed before 1941; and in MIDSJV, where the small number of wells drilled after 1975 prevented conclusion of any difference for the deepest wells between the periods after 1940 (fig. 9). In the WSJV the deepest wells were constructed after 1941, but well-construction trends cannot be determined because of insufficient data and because variability of well depth is high (fig. 9).

Although the number of wells drilled before 1941 and new PS wells drilled after 1975 were sparse in half the study units, well depth for DS and PS wells generally increased over time from north to south. Public-supply wells showed the greatest depth variability and the strongest temporal trends, whereas DS wells tended to be drilled with more consistent well depths in most of the Central Valley. In the southern and western regions, variability and depth of construction over time tended to increase for both sets of wells.

Interpolation was done with the entire dataset rather than for binned periods of data because the temporal trends were limited by the number of wells with construction dates. Although the entire dataset was used for interpolation, temporal trends in well depth could affect the interpretation of the interpolation results. In particular, areas with pronounced temporal trends likely have a changing aquifer volume accessible to the supply wells because of a nonstationary estimate of the production zone, and construction trends could have changed in response to California's drought that began in 2007. Consequently, the aquifer thickness determined from interpolated data generally represents the potential maximum volume of the drinking-water production zone accessed during the past century, rather than the actual volume accessed.

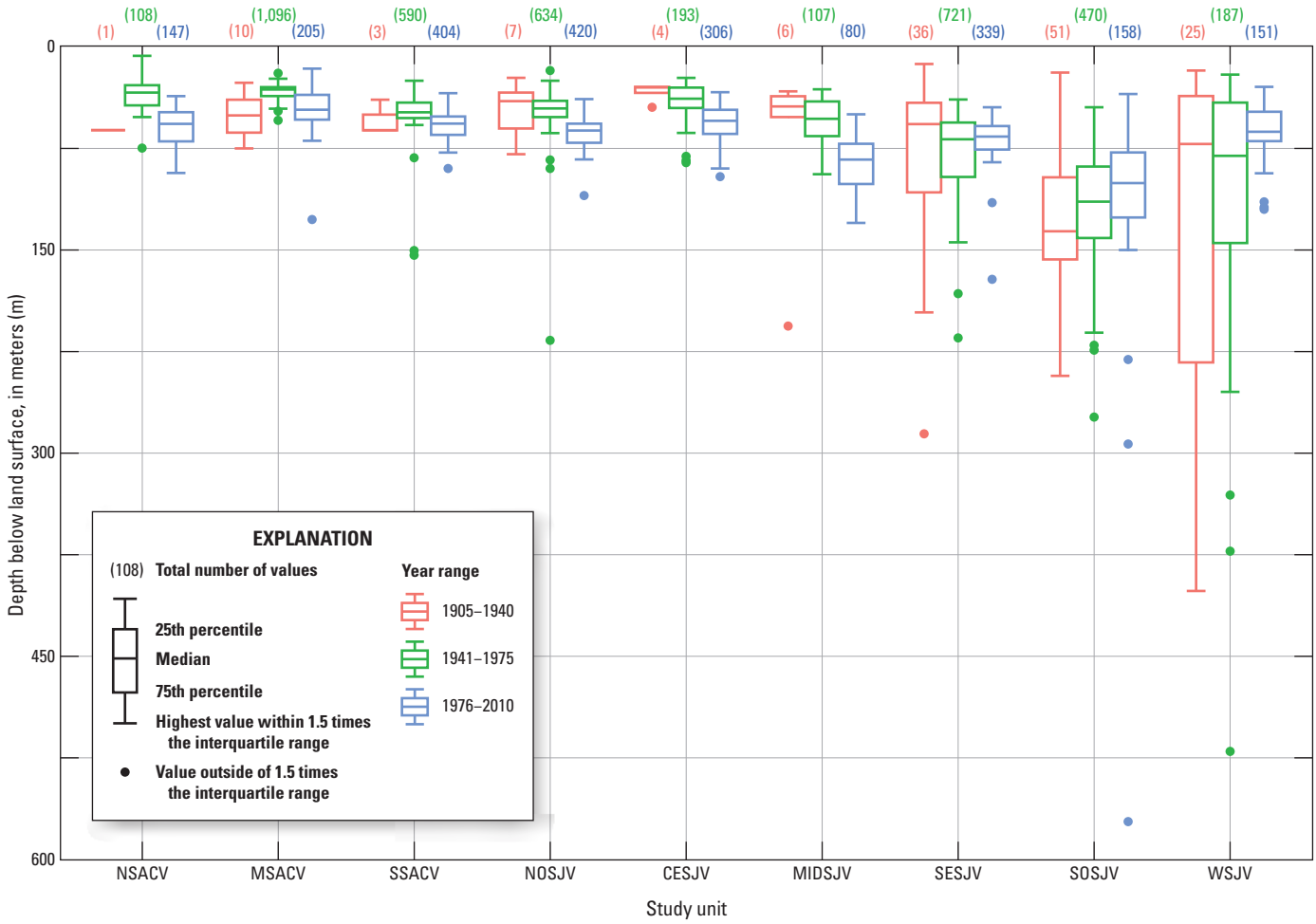


Figure 8. Domestic-supply well depths binned by a multidecadal period of well construction in the Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]

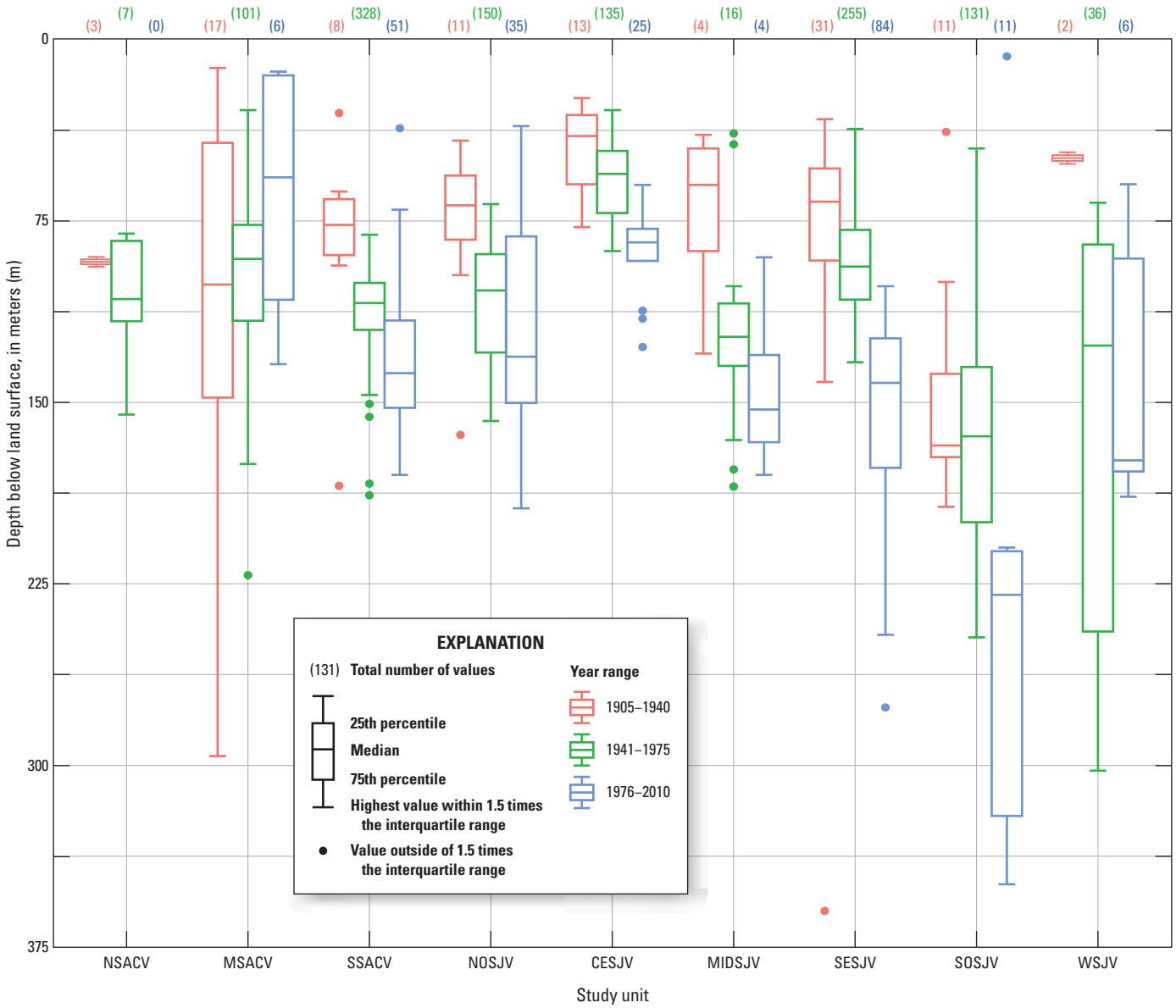
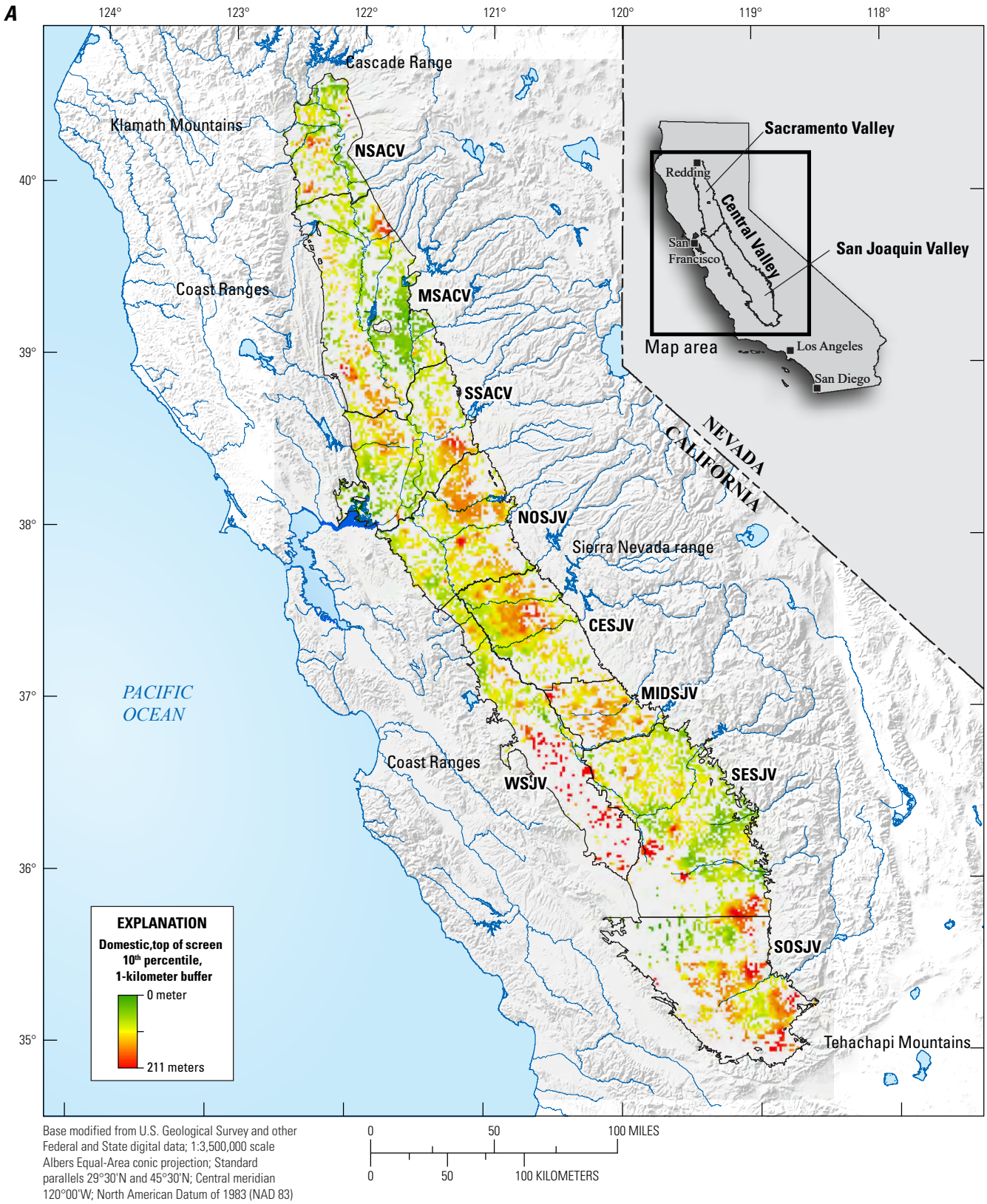


Figure 9. Public-supply well depths binned by a multidecadal period of well construction, Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]

Interpolated Maps of Depth to Top and Bottom of Domestic- and Public-Supply Well Screens

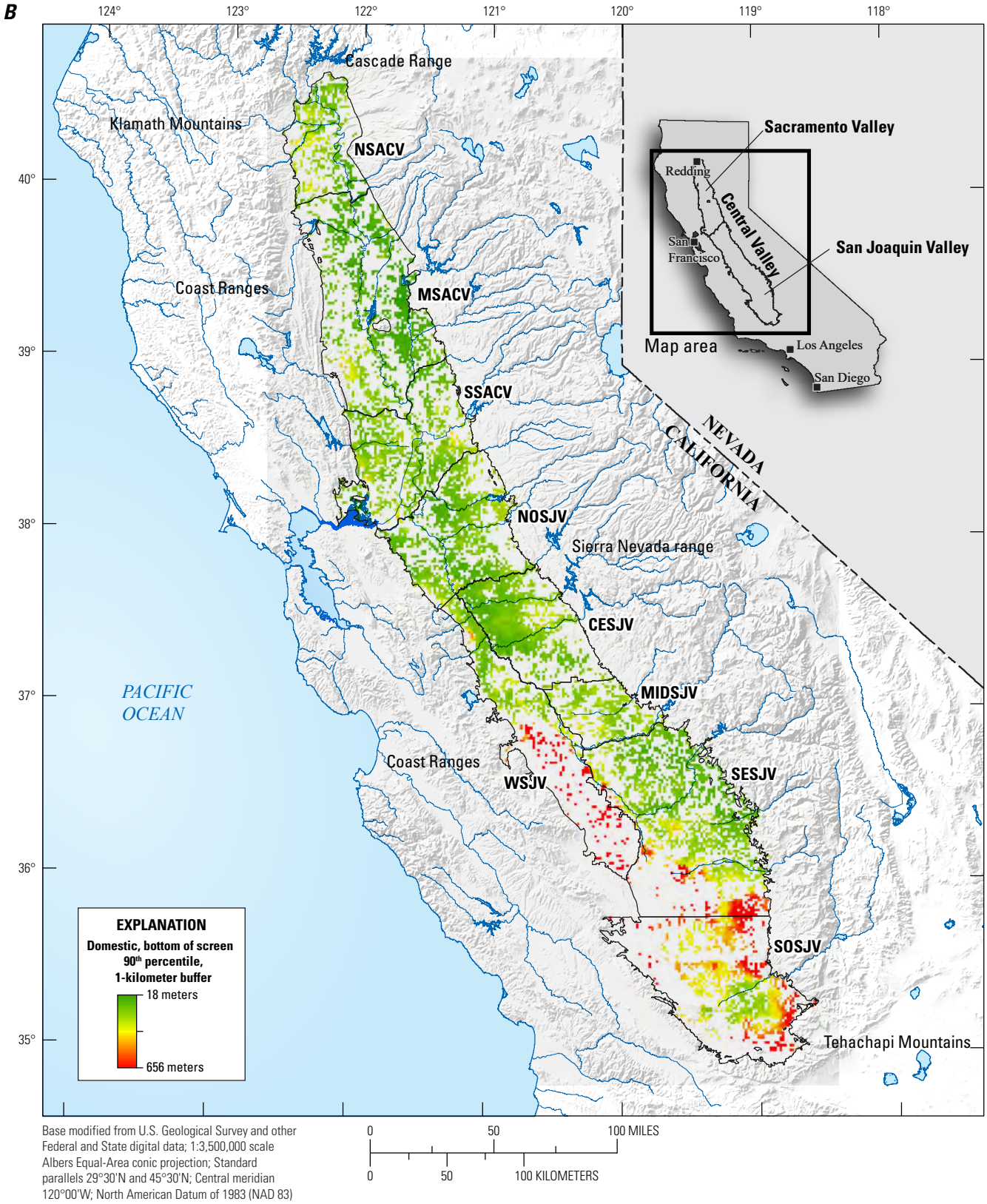
Interpolated surfaces of the depth to top (10th percentile) and bottom (90th percentile) of well screens were used as the estimated upper and lower boundaries of the drinking-water production zone. These surfaces provide a measure of the likely maximum vertical extent of the potential aquifer volume accessed for drinking water in the Central Valley during the past century. The term "potential" is associated with the aquifer volume because the volume defined is based on well construction rather than on physical dimensions of hydrogeologic features.

As discussed above, the greatest variability and uncertainty was in the southern and western regions of the SJV, where DS- and PS-well density was sparser and construction characteristics more variable. Elsewhere in the Central Valley, simulated well-screen depths and those from actual construction data showed better agreement (figs. 10, 11). The buffers used to restrict the interpolation to the likely area containing DS and PS wells limits the spatial extent of the PS-well surfaces, despite the larger buffer size, to a greater degree than DS-well surfaces because of the wider areal distribution of DS wells as compared to the PS wells and the overall smaller number of PS wells with available construction information.



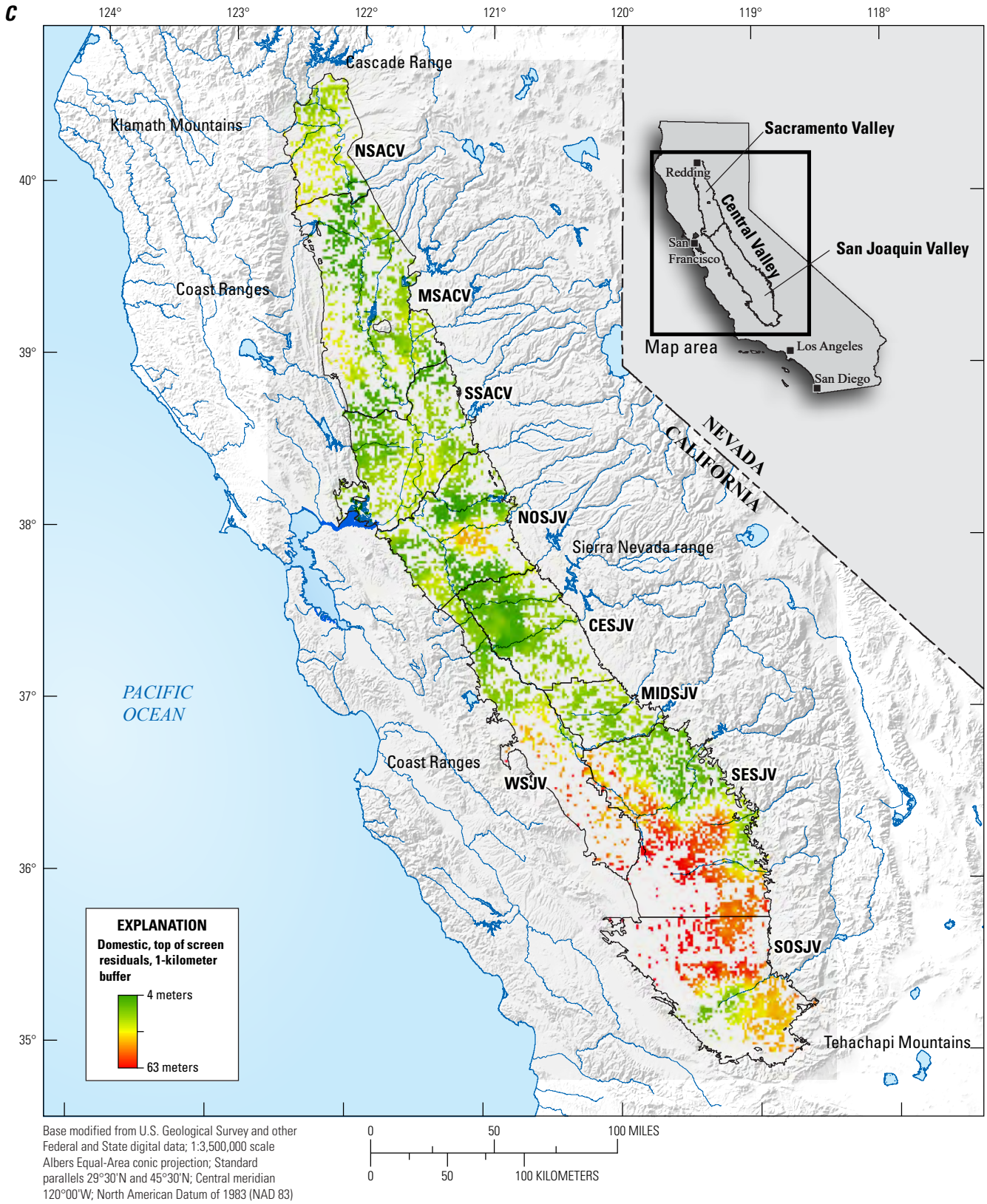
Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 10. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of *C*, the Q10 of depth to top of screen and *D*, the Q90 of depth to bottom of screen for domestic-supply wells in the Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]



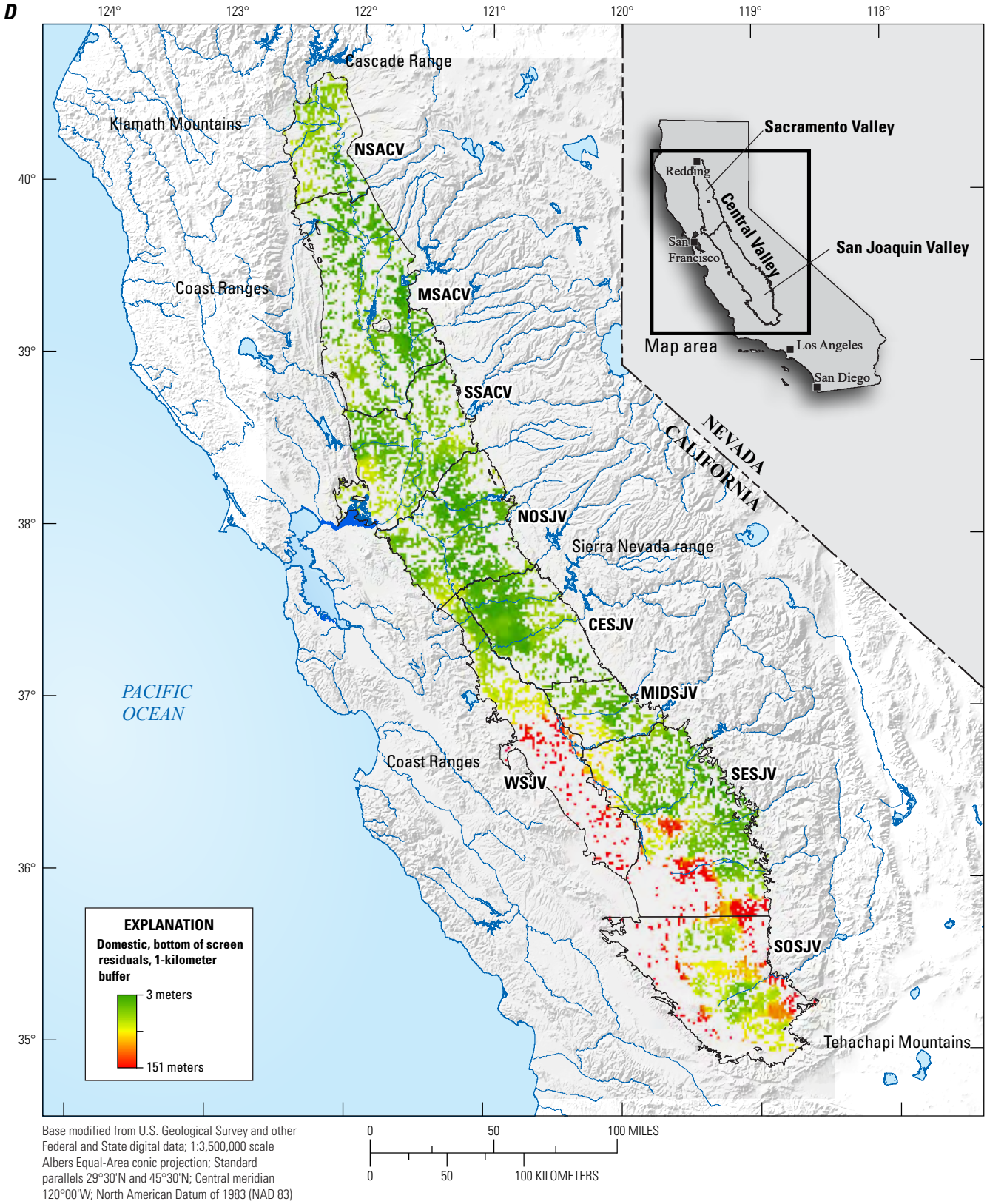
Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 10. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of *C*, the Q10 of depth to top of screen and *D*, the Q90 of depth to bottom of screen for domestic-supply wells in the Central Valley, California.—Continued. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]



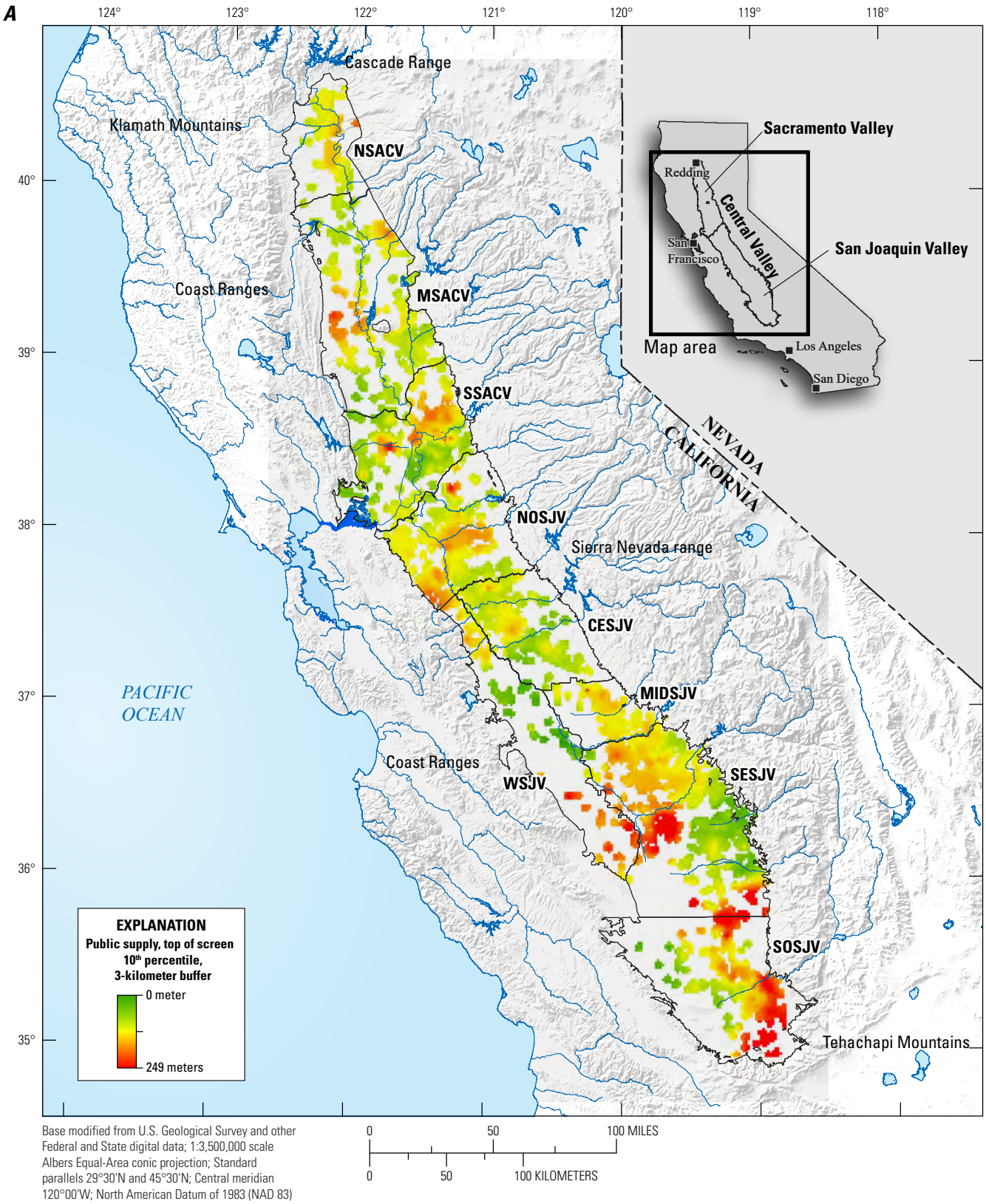
Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 10. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of *C*, the Q10 of depth to top of screen and *D*, the Q90 of depth to bottom of screen for domestic-supply wells in the Central Valley, California.—Continued. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]



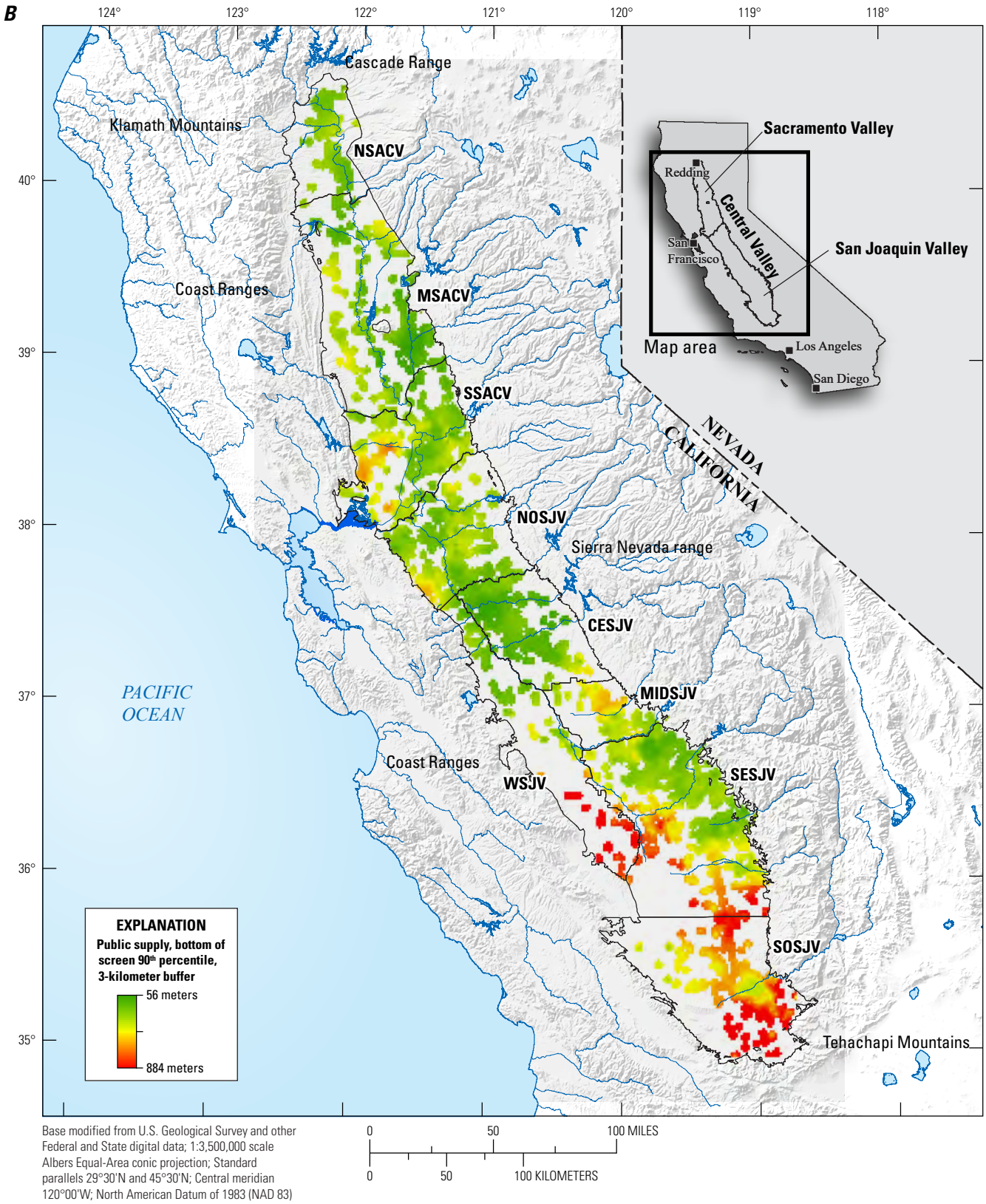
Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 10. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of *C*, the Q10 of depth to top of screen and *D*, the Q90 of depth to bottom of screen for domestic-supply wells in the Central Valley, California.—Continued. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]



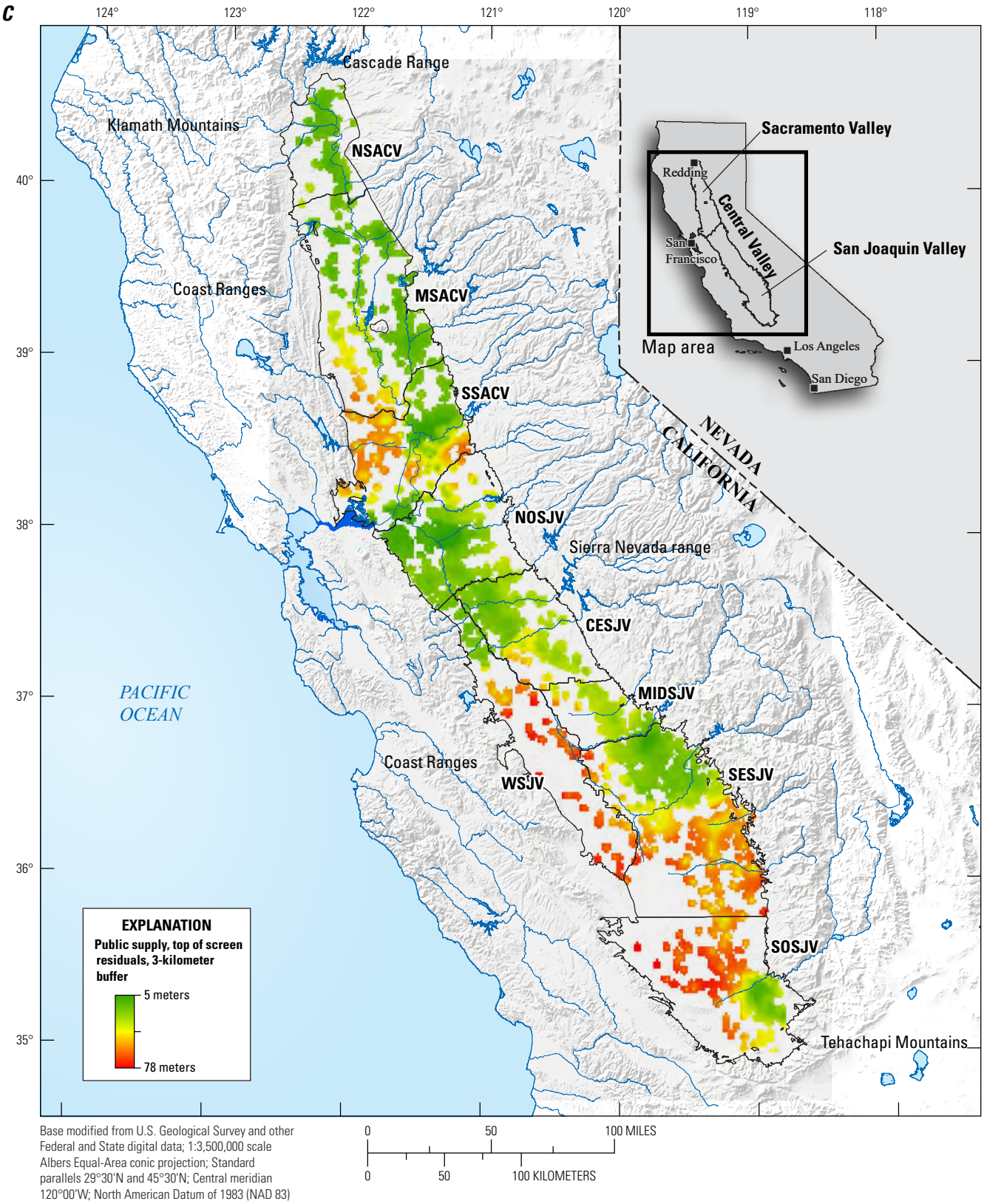
Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 11. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of *C*, the Q10 of depth to top of screen and *D*, the Q90 of depth to bottom of screen for public-supply wells in the Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]



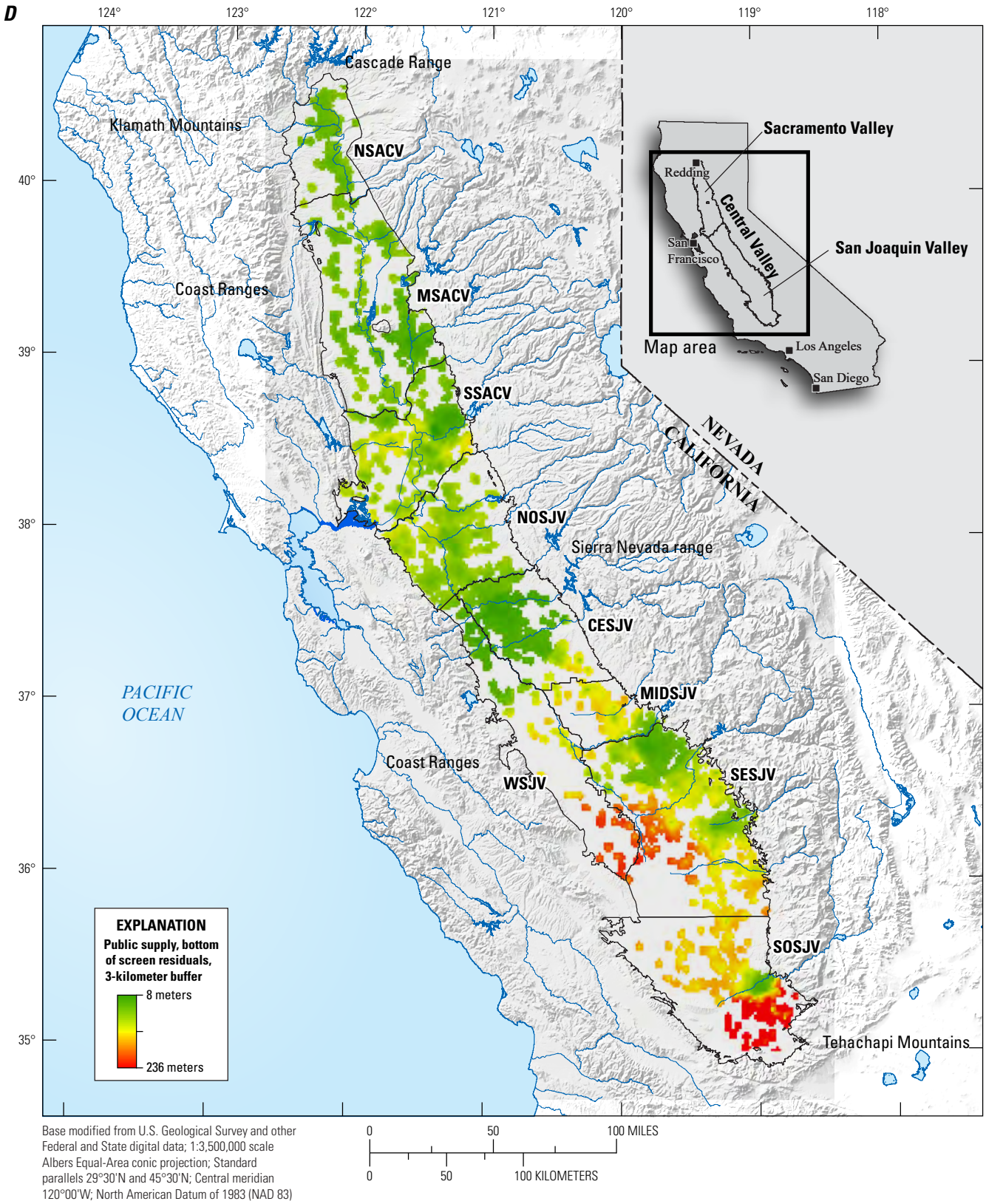
Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 11. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of *C*, the Q10 of depth to top of screen and *D*, the Q90 of depth to bottom of screen for public-supply wells in the Central Valley, California.—Continued. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]



Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 11. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of *C*, the Q10 of depth to top of screen and *D*, the Q90 of depth to bottom of screen for public-supply wells in the Central Valley, California.—Continued. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]



Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 11. Interpolated surfaces of *A*, the 10th percentile (Q10) of depth to top of screen and *B*, 90th percentile (Q90) of depth to bottom of screen; and interpolation residuals of *C*, the Q10 of depth to top of screen and *D*, the Q90 of depth to bottom of screen for public-supply wells in the Central Valley, California.—Continued. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]

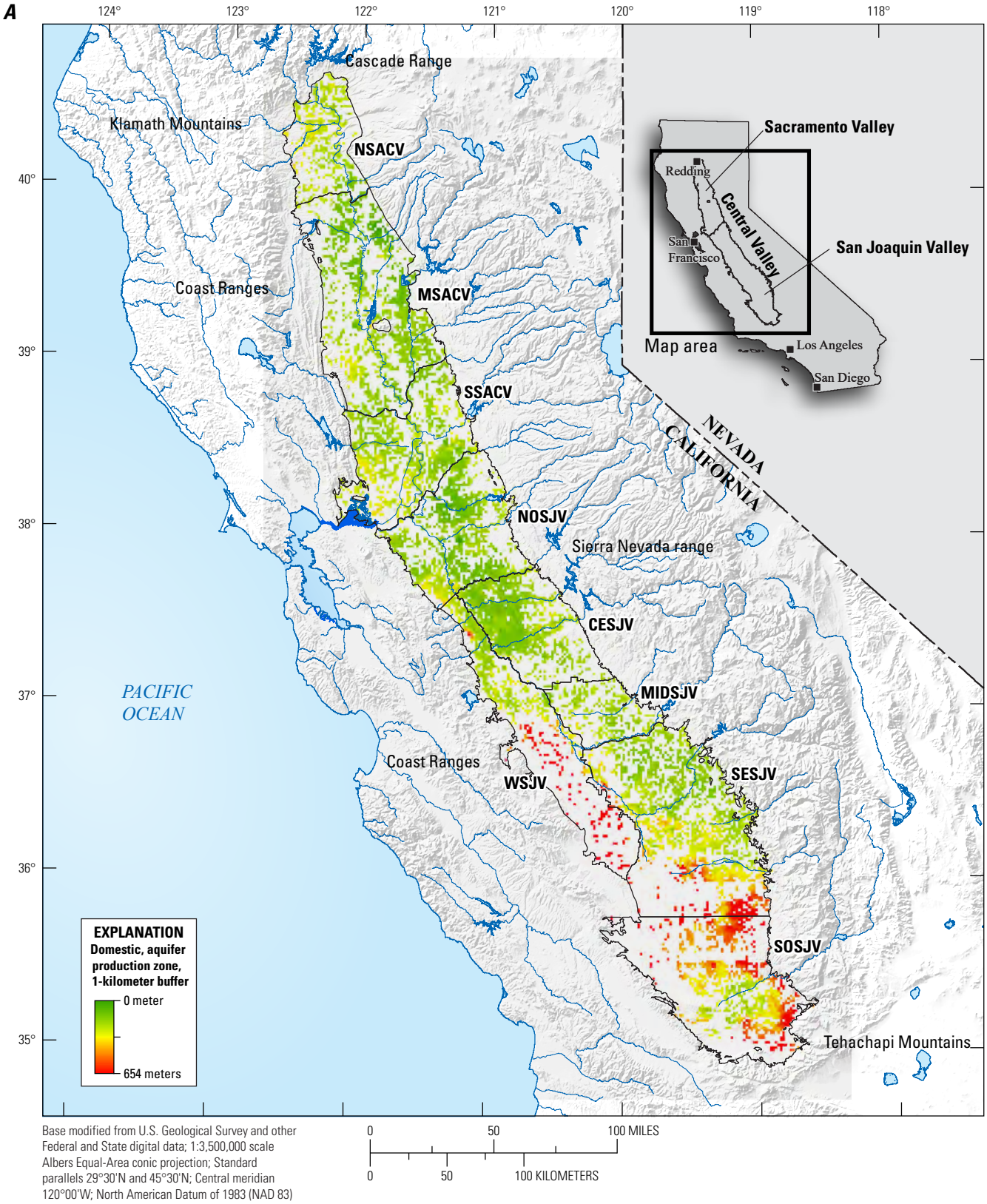
Thickness and Volume of Drinking-Water Production Zone Used for Domestic and Public Supply

Aquifer thickness was calculated per grid cell by subtracting the 10th percentile of the depth to top of well screen from the 90th percentile of the depth to bottom of well screen. These calculations provide an estimate of the thickness of the portion of the aquifer accessible for drinking water based on well-construction characteristics of the two different well categories (fig. 12).

Domestic-supply wells draw water from a relatively thin portion of the aquifer across the Central Valley. The deepest and thickest portions of the aquifer accessed for DS are in the southern and western SJV where well density is low and depth variability is high. Public-supply wells follow a pattern similar to DS wells across the Central Valley; however, the thickness of the aquifer accessed for PS tends to be greater throughout most of the Central Valley (fig. 13).

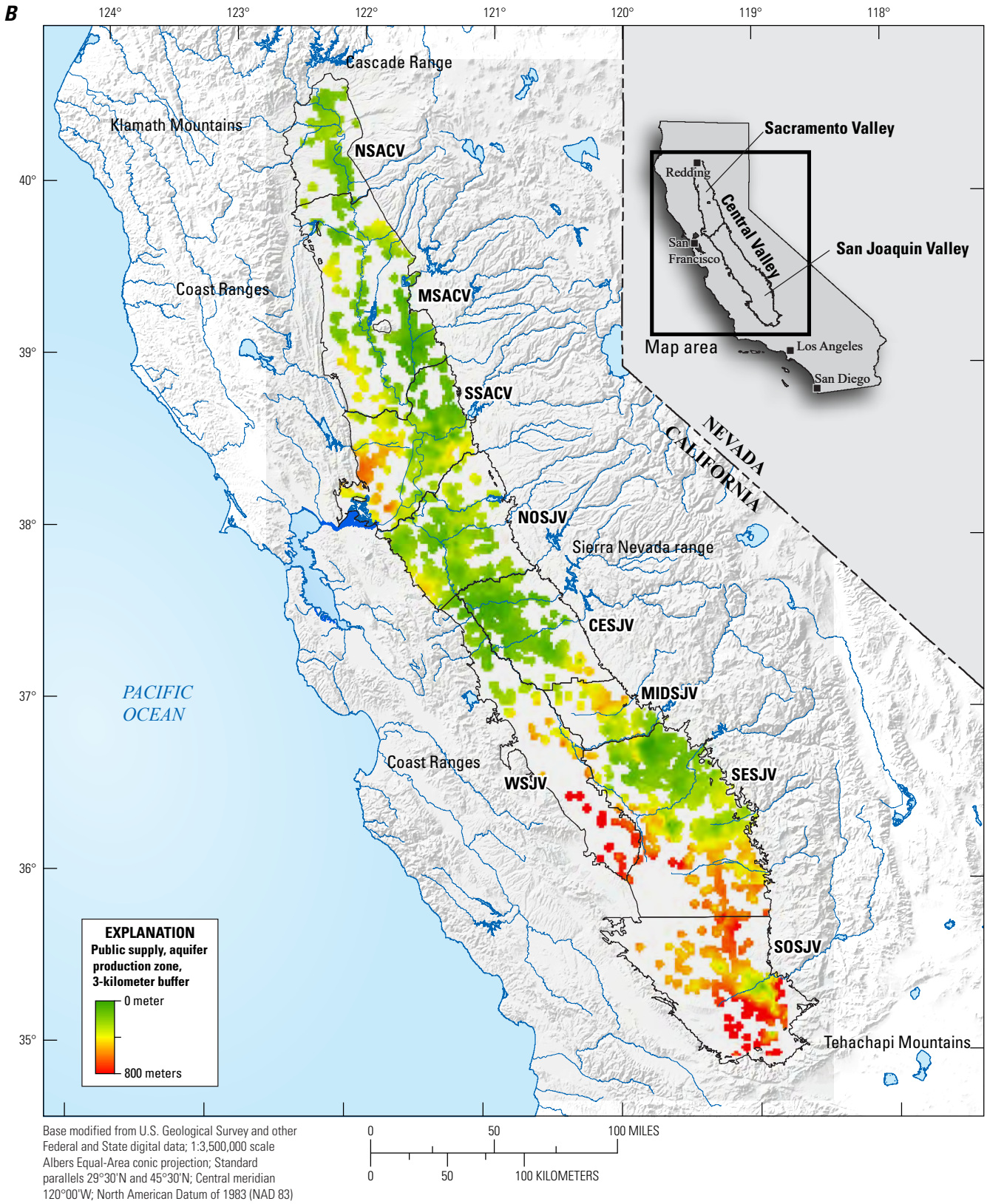
The potential volume of aquifer accessed for PS was 1.4 times greater than the potential volume of aquifer accessed for DS (table 3). The volume of aquifer accessed for DS and PS was computed from estimates of the aquifer thicknesses and the spatial extent of DS and PS areas. The spatial extent of DS was 1.5 times greater than the spatial extent of PS, but the aquifer thickness accessed for PS was 1.8 times greater than the aquifer thickness accessed for DS. This result indicates that the spatial extent is less important than well-screen length for estimating the potential volume of aquifer accessed by wells in the Central Valley.

Based on the uncertainty of the interpolated rasters, the potential volume of aquifer accessed for DS and PS may be overestimated or more uncertain in the south-western region covering WSJV and in parts of SOSJV and SESJV, where well density is low, and variability and magnitude of depth to well screens are high. The thickness calculation results represent a larger fraction of the frequency distribution than does the range of median screen intervals, however, it also results in higher uncertainty in regions of greater variability and magnitude of depths. The lower well density in these regions implies that the fewer wells withdrawing groundwater from the aquifer in these areas could have longer screens and greater pumping rates, thus representing a larger overall potential volume than other regions of the Central Valley. Although well density is higher and spatial extent of well locations greater elsewhere in the Central Valley, a shallower water-table tended to result in a potentially smaller accessible aquifer volume.



Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 12. Calculated interpolated surfaces representing thickness of the drinking-water production zone accessible for *A*, domestic-supply and *B*, public-supply wells in the Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]



Base modified from U.S. Geological Survey and other Federal and State digital data; 1:3,500,000 scale Albers Equal-Area conic projection; Standard parallels 29°30'N and 45°30'N; Central meridian 120°00'W; North American Datum of 1983 (NAD 83)

Figure 12. Calculated interpolated surfaces representing thickness of the drinking-water production zone accessible for *A*, domestic-supply and *B*, public-supply wells in the Central Valley, California.—Continued. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]

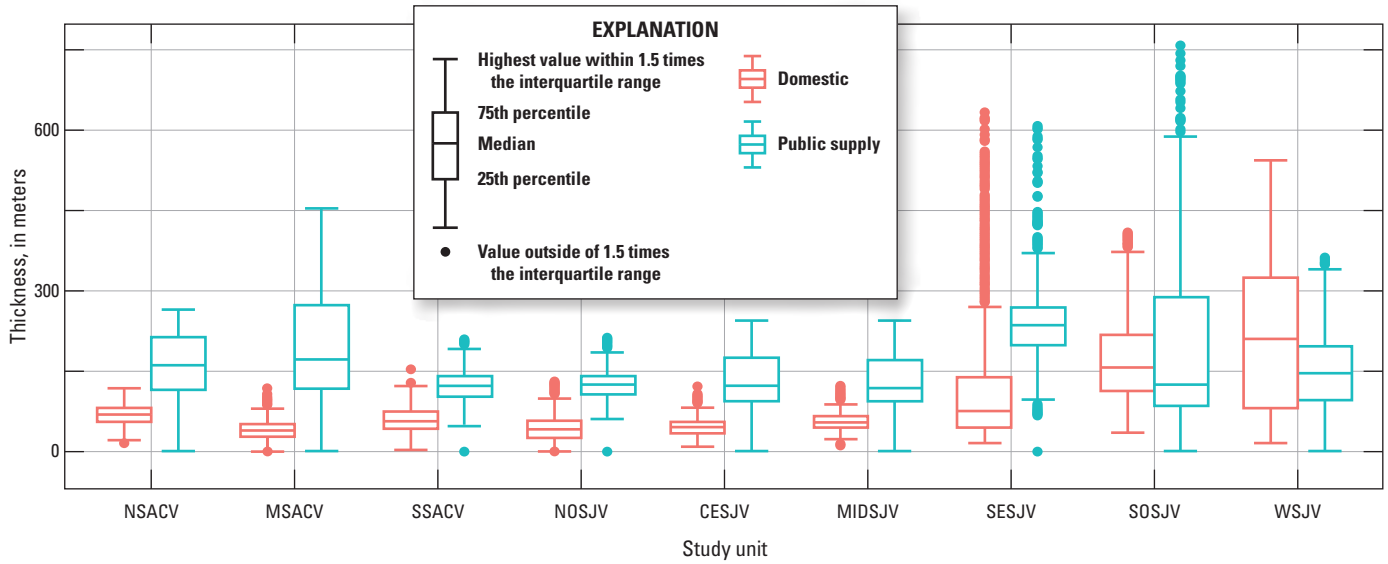


Figure 13. Estimated aquifer thickness accessible for domestic and public supply for study units in the Central Valley, California. [CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; MSACV, middle Sacramento Valley; NOSJV, northern San Joaquin Valley; NSACV, northern Sacramento Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; SSACV, southern Sacramento Valley; WSJV, western San Joaquin Valley]

Table 3. The estimated area at land surface and potential volume of aquifer accessible for domestic and public supply in the Central Valley, California.

[km², square kilometers; km³, cubic kilometers; NSACV, northern Sacramento Valley; MSACV, middle Sacramento Valley; SSACV, southern Sacramento Valley; NOSJV, northern San Joaquin Valley; CESJV, central eastside San Joaquin Valley; MIDSJV, middle San Joaquin Valley; SESJV, southeast San Joaquin Valley; SOSJV, southern San Joaquin Valley; WSJV, western San Joaquin Valley]

Study unit	Domestic supply		Public supply	
	Area (km²)	Volume (km³)	Area (km²)	Volume (km³)
NSACV	1,103	71	599	67
MSACV	2,962	110	1,737	182
SSACV	2,387	131	1,681	261
NOSJV	2,507	96	1,844	230
CESJV	2,282	89	1,732	153
MIDSJV	709	37	437	73
SESJV	3,937	326	2,868	473
SOSJV	2,213	313	1,243	323
WSJV	1,374	173	670	101
All	**19,474**	**1,346**	**12,811**	**1,863**

Summary and Conclusions

Although the primary use of groundwater in the Central Valley is for irrigation, reliance on groundwater as a source of drinking water is expected to increase in response to periods of drought, increased conversion of agricultural land through urbanization, and a 50-percent population increase in the Central Valley from 2016 to 2060. Prudent management of groundwater resources in the Central Valley is necessary to effectively address competing demands for groundwater and maintain the long-term availability of groundwater for drinking-water supply. To address these needs, the U.S. Geological Survey in cooperation with the California State Water Resources Control Board completed a study that defined the spatial extent, depth zones, and potential volumes of the Central Valley aquifer system that are accessible to wells for domestic supply (DS) and public supply (PS) of drinking water.

Selected DS and PS well construction characteristics were compiled for tops and bottoms of screens for each of the nine studied regions (study units) in the Central Valley. Interpolated raster surfaces produced from the compiled data were produced for the 10th percentile of depth to top of well screen and 90th percentile of depth to bottom of well screen. Aquifer thickness was calculated per grid cell as the vertical difference between the raster for 10th percentile of the depth to top of well screen and the raster for 90th percentile of the bottom of well screen. These calculations provide an estimate of the thickness of the aquifer section accessed for drinking water. To compute the volume of aquifer used for DS and PS, the spatial extent of the groundwater resource used for DS and PS was estimated by using a 1-kilometer (km) and 3-km buffer around DS and PS wells, respectively.

The potential volume of aquifer accessed for PS was 1.4 times larger than the potential volume of aquifer accessed for DS despite the greater spatial extent of DS wells in the Central Valley. In the south-western region covering the western San Joaquin Valley (WSJV), and in parts of the southern San Joaquin Valley (SOSJV) and the southeast San Joaquin Valley (SESJV) where well density is low and variability and magnitude of well depth are high, the volume of the potential drinking-water production zone is likely overestimated because when the resource used for drinking water is not well-defined spatially, the thickness calculation includes more data from disparate locations and results in the largest possible screen intervals. This results in higher uncertainty in regions of greater variability and magnitude of depths. The lower well density in these regions means that there are fewer wells with access to groundwater from the aquifer in these areas despite representing a larger overall potential volume than other regions of the Central Valley where well density is higher, areal extent is greater, and the water-table is shallower.

Of the nearly 18,000 total DS- and PS-well records compiled for the Central Valley from wells constructed between 1911 and 2008, approximately 14,000 wells met the inclusion criteria of having sufficient construction information and being designated for drinking-water supply. For DS wells the source data in large part come from studies designed to capture statistically unbiased assessments of water use or sediment-texture information from drillers logs throughout the Central Valley. This provided confidence that the spatial extent calculated from the DS-well data was representative. For PS wells, more than half of the active wells throughout the Central Valley (as of 2016) were included in the subset of PS wells used to estimate aquifer extent, thickness, and volume, suggesting the volume calculated with this dataset is representative.

Three periods, each representing about 35 years beginning in 1905, were used to examine changes in well-construction frequency by depth category for study units across the Central Valley. Well depth for DS and PS wells generally increased over time and from north to south. Public-supply wells showed the greatest depth variability and the strongest temporal trends, whereas DS wells tended to be drilled to more consistent depths in most of the Central Valley. In the southern and western regions, variability and depth of construction generally increased over time for PS wells.

The estimates of potentially accessed volumes of the drinking-water production zone in the Central Valley represent a temporal snapshot of potential drinking groundwater access. In addition to drinking-water use, groundwater withdrawals also supply crop irrigation, watering of livestock, power generation, industrial operations, and other uses. Further analysis of well-construction patterns in conjunction with water-level changes over time would result in better estimates of the actual vertical extent of the DS and PS aquifers. These estimates may be useful in understanding the net effect of groundwater withdrawal on thickness of the drinking-water production zone throughout the Central Valley.

References Cited

Belitz, K., Dubrovsky, N.M., Burow, K., Jurgens, B., and Johnson, T., 2003, Framework for a ground-water quality monitoring and assessment program for California: U.S. Geological Survey Water-Resources Investigations Report 2003–4166, 78 p., available at https://doi.org/10.3133/wri034166.

Belitz, K., and Heimes, F.J., 1990, Character and evolution of the ground-water flow system in the central part of the western San Joaquin Valley, California: U.S. Geological Survey Water-Supply Paper 2348, 28 p., https://doi.org/10.3133/wsp2348.

Bennett, G.L.,V, 2018, Status and understanding of groundwater quality in the north San Francisco Bay shallow aquifer study unit, 2012; California GAMA Priority Basin Project (ver. 1.1, February 2018): U.S. Geological Survey Scientific Investigations Report 2017–5051, 74 p., https://doi.org/10.3133/sir20175051.

Bennett, G.L.,V, Fram, M.S., Belitz, K., and Jurgens, B.C., 2010, Status and understanding of groundwater quality in the northern San Joaquin Basin, 2005—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2010–5175, 82 p., available at https://doi.org/10.3133/sir20105175.

Bennett, G.L.,V, Fram, M.S., and Belitz, K., 2011, Status of groundwater quality in the southern, middle, and northern Sacramento Valley study units, 2005–08—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2011–5002, 120 p., available at https://doi.org/10.3133/sir20115002.

Bennett, G.L.,V, Fram, M.S., and Belitz, K., 2014, Status and understanding of groundwater quality in the Klamath Mountains study unit, 2010—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2014–5065, 58 p., https://doi.org/10.3133/sir20145065.

Brandt, J., Sneed, M., Rogers, L.L., Metzger, L.F., Rewis, D., House, S., 2014, Water use in California: U.S. Geological Survey data website, https://doi.org/10.5066/F7KD1VXV.

Burow, K.R., Shelton, J.L., Hevesi, J.A., and Weissmann, G.S., 2004, Hydrogeologic characterization of the Modesto area, San Joaquin Valley, California: U.S. Geological Survey Scientific Investigations Report 2004–5232, 54 p., https://doi.org/10.3133/sir20045232.

Burton, C.A., Shelton, J.L., and Belitz, K., 2012, Status and understanding of groundwater quality in the two southern San Joaquin Valley study units, 2005–2006—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2011–5218, 150 p., https://doi.org/10.3133/sir20115218.

Burton, C.A., and Wright, M.T., 2018, Status and understanding of groundwater quality in the Monterey–Salinas shallow aquifer study unit, 2012–13—California GAMA Priority Basin Project (ver. 1.1, September 2018): U.S. Geological Survey Scientific Investigations Report 2018–5057, 116 p., https://doi.org/10.3133/sir20185057.

California Department of Finance, 2018, State and county population projections 2010–2060, Demographic Research Unit, available at http://www.dof.ca.gov/Forecasting/Demographics/Projections/.

California Department of Water Resources, 2003, California's groundwater: California Department of Water Resources Bulletin 118, 246 p., available at https://water.ca.gov/LegacyFiles/pubs/groundwater/bulletin_118/california's_groundwater__bulletin_118_-_update_2003_/bulletin118_entire.pdf.

California Department of Water Resources, 2018, 2018 Sustainable Groundwater Management Act (SGMA) basin prioritization, "Component 4 production wells" dataset, available at https://data.ca.gov/dataset/sustainable-groundwater-management-act-sgma-basin-prioritization.

California State Water Resources Control Board, 2018, California statutes related to drinking water: California State Water Resources Control Board, part 12, chapter 4, article 1, §116275, p. 76, available at https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/dwstatutes-2018_01_10.pdf.

Dawson, B.J.M., and Belitz, K., 2012, Status of groundwater quality in the California Desert Region, 2006–2008—California GAMA priority basin project: U.S. Geological Survey Scientific Investigations Report 2012–5040, 110 p., https://doi.org/10.3133/sir20125040.

Esri, 2019, What is Empirical Bayesian kriging: Esri website, available at http://desktop.arcgis.com/en/arcmap/10.3/guide-books/extensions/geostatistical-analyst/what-is-empirical-bayesian-kriging-.htm.

Faunt, C.C., ed., 2009, Groundwater availability of the Central Valley Aquifer, California, U.S. Geological Survey Professional Paper 1766 , 225 p., https://doi.org/10.3133/pp1766.

Fram, M.S., and Belitz, K., 2012, Status and understanding of groundwater quality in the Tahoe–Martis, central Sierra, and southern Sierra Study Units, 2006–2007—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2011–5216, 222 p., available at https://doi.org/10.3133/sir20115216.

Fram, M.S., and Shelton, J.L., 2015, Status and understanding of groundwater quality in the Cascade Range and Modoc Plateau study unit, 2010—California GAMA priority basin project: U.S. Geological Survey Scientific Investigations Report 2014–5238, 131 p., https://doi.org/10.3133/sir20145238.

Fram, M.S., 2017, Groundwater quality in the western San Joaquin Valley study unit, 2010—California GAMA priority basin project: U.S. Geological Survey Scientific Investigations Report 2017–5032, 130 p., https://doi.org/10.3133/sir20175032.

Franke, O.L., Reilly, T.E., Pollock, D.W., and LaBaugh, J.W., 1998, Estimating areas contributing recharge to wells, lessons from previous studies: U.S. Geological Survey Circular 1174, 14 p., https://doi.org/10.3133/cir1174.

Johnson, T.D., and Belitz, K., 2015a, Identifying the location and population served by domestic wells in California: Journal of Hydrology–Regional Studies, v. 3, p. 31–86, https://doi.org/10.1016/j.ejrh.2014.09.002.

Johnson, T.D., and Belitz, K., 2015b, Location and population served by domestic wells in California: U.S. Geological Survey data release, https://doi.org/10.5066/F70R9MFW.

Landon, M.K., Belitz, K., Jurgens, B.C., Kulongoski, J.T., and Johnson, T.D., 2010, Status and understanding of groundwater quality in the central–eastside San Joaquin Basin, 2006—California GAMA priority basin project: U.S. Geological Survey Scientific Investigations Report 2009–5266, 97 p., https://doi.org/10.3133/sir20095266.

Page, R.W., 1986, Geology of the fresh ground-water basin of the Central Valley, California, with texture maps and sections: U.S. Geological Survey Professional Paper 1401–C, 54 p., 5 pl., https://doi.org/10.3133/pp1401C.

Parsons, M.C., Hancock, T.C., Kulongoski, J.T., and Belitz, K., 2014, Status of groundwater quality in the Borrego Valley, central desert, and low-use basins of the Mojave and Sonoran Deserts study unit, 2008–2010—California GAMA priority basin project: U.S. Geological Survey Scientific Investigations Report 2014–5001, 88 p., https://doi.org/10.3133/sir20145001.

Phillips, S.P., Green, C.T., Burow, K.R., Shelton, J.L., and Rewis, D.L., 2007, Simulation of multiscale ground-water flow in part of the northeastern San Joaquin Valley, California: U.S. Geological Survey Scientific Investigations Report 2007–5009, 43 p., https://doi.org/10.3133/sir20075009.

Shelton, J.L., Fram, M.S., Belitz, K., and Jurgens, B.C., 2013, Status and understanding of groundwater quality in the Madera–Chowchilla study unit, 2008—California GAMA priority basin project: U.S. Geological Survey Scientific Investigations Report 2012–5094, 86 p., https://doi.org/10.3133/sir20125094.

U.S. Geological Survey, 2016, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), accessed April 15, 2015, at https://doi.org/10.5066/F7P55KJN.

Voss, S.A., and Jurgens, B.C., 2018, Spatial point data sets and interpolated surfaces of well construction characteristics for domestic and public supply wells in the Central Valley, California, USA: U.S. Geological Survey data release, https://doi.org/10.5066/F76Q1V9G.

Williamson, A.K., Prudic, D.E., and Swain, L.A., 1989, Ground-water flow in the Central Valley, California: U.S. Geological Survey Professional Paper 1401–D, 127 p., https://doi.org/10.3133/pp1401D.

Wright, M.T., and Belitz, K., 2011, Status and understanding of groundwater quality in the San Diego Drainages Hydrogeologic Province, 2004—California GAMA priority basin project: U.S. Geological Survey Scientific Investigations Report 2011–5154, 100 p., https://doi.org/10.3133/sir20115154.

For more information concerning the research in this report, contact the
Director, California Water Science Center
U.S. Geological Survey
6000 J Street, Placer Hall
Sacramento, California 95819
https://ca.water.usgs.gov

Publishing support provided by the U.S. Geological Survey
Science Publishing Network, Sacramento Publishing Service Center

Voss—**Delineation of Spatial Extent, Depth, Thickness, and Potential Volume of Aquifers Used for Domestic and Public Water-Supply in the Central Valley, California**—Scientific Investigations Report 2019–5076

ISSN 2328-0328 (online)
https://doi.org/10.3133/sir20195076