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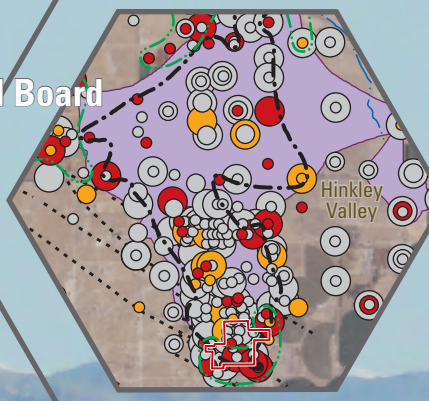
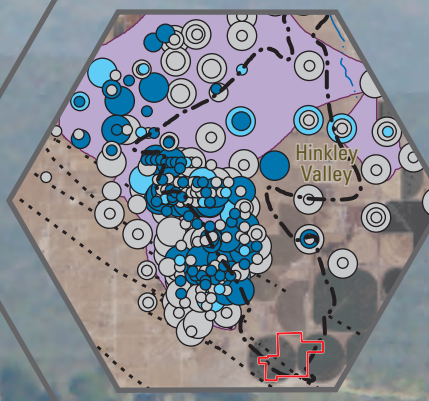
Analyses of Regulatory Water-Quality Data

Chapter D of

Natural and Anthropogenic (Human-Made) Hexavalent Chromium, Cr(VI), in Groundwater near a Mapped Plume, Hinkley, California





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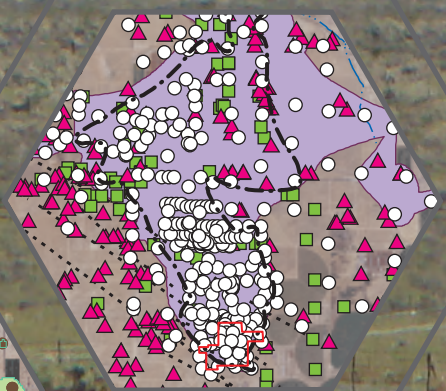

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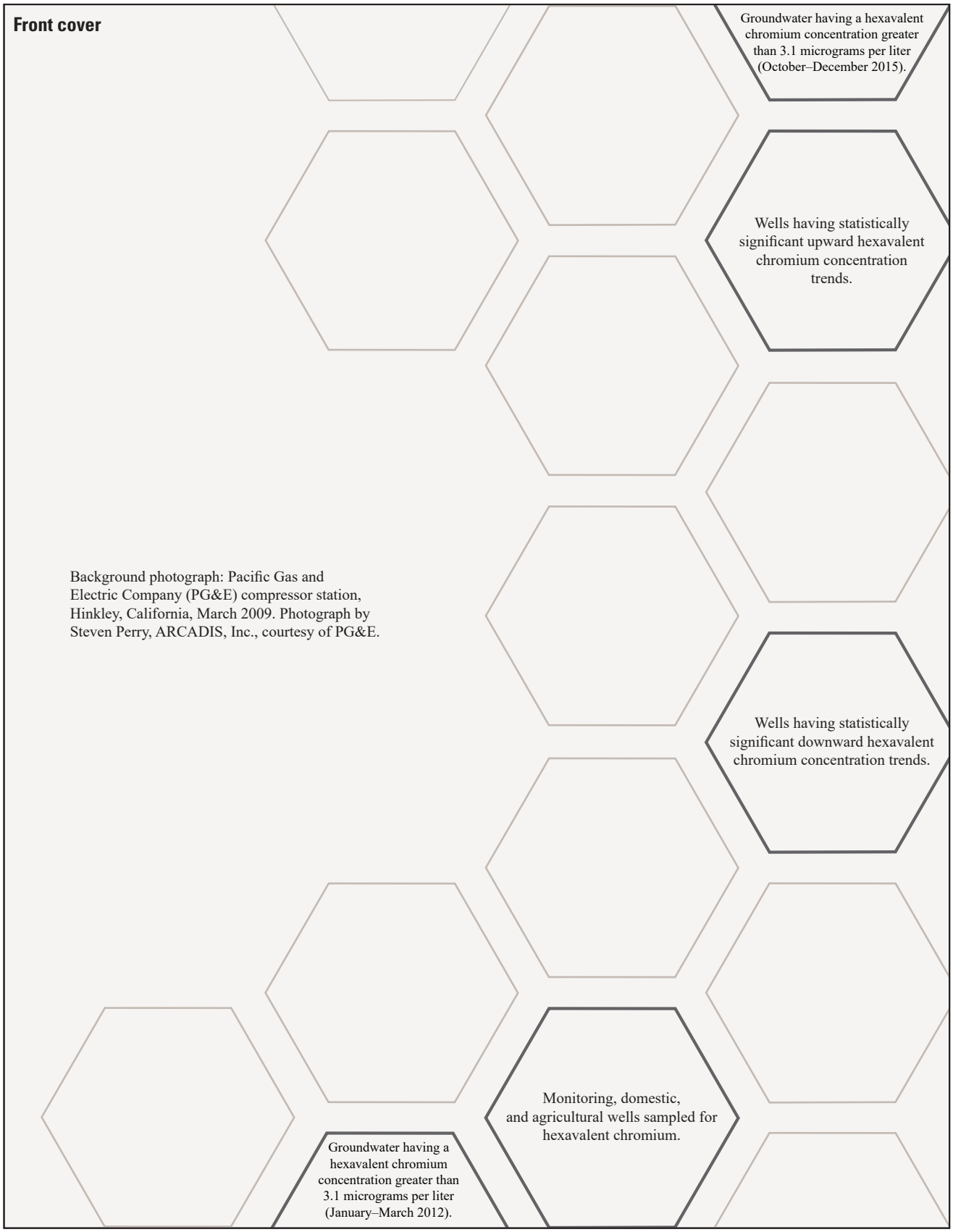

Background photograph: Pacific Gas and Electric Company (PG&E) compressor station, Hinkley, California, March 2009. Photograph by Steven Perry, ARCADIS, Inc., courtesy of PG&E.

Analyses of Regulatory Water-Quality Data

Chapter D of
Natural and Anthropogenic (Human-Made) Hexavalent Chromium, Cr(VI), in Groundwater near a Mapped Plume, Hinkley, California

By John A. Izbicki and Whitney Seymour

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This study was developed by the U.S. Geological Survey (USGS) with input from a technical working group (TWG) composed of community members, the Lahontan Regional Water Quality Control Board (RWQCB), the Independent Review Panel Manager (Project Navigator, Ltd.), Pacific Gas and Electric Company (PG&E), and consultants for PG&E. The study was funded cooperatively under an agreement between the Lahontan RWQCB and the USGS. Funding for the study was provided by PG&E to the Lahontan RWQCB. Logistical support for field work, including access to wells, was provided by PG&E. The TWG met approximately quarterly during the study to provide input to the study, and the Hinkley community was updated annually on study progress.

The authors thank the many people involved in the design and implementation of this study including the staff of the Lahontan RWQCB, the staff of PG&E and their consultants, and the staff of Project Navigator, Ltd. The authors also acknowledge and thank the many involved community members who allowed access to their properties for sample collection, and who collectively donated thousands of hours on behalf of the local community in support of this project and for resolution of other issues related to anthropogenic hexavalent chromium, Cr(VI), within the Hinkley area.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Concentrations of chemical constituents in water are given as micrograms per liter (µg/L).

Redox, a combination of the words reduction and oxidation, refers to chemical processes in which one substance or molecule gains an electron (is reduced and its oxidation state is decreased) and another loses an electron (is oxidized and its oxidation state is increased). The processes of oxidation and reduction occur simultaneously and cannot occur independently.

Abbreviations

BD-90/90	binomial distribution 90/90
Cr(III)	trivalent chromium having an oxidation state of +3
Cr(VI)	hexavalent chromium having an oxidation state of +6
EPA	U.S. Environmental Protection Agency
LRL	laboratory reporting level
NELAP	National Environmental Laboratory Accreditation Program
PG&E	Pacific Gas and Electric Company
p-value	probability value
Q4 2015	October–December 2015
RWQCB	Regional Water Quality Control Board
SRL	study reporting level
SSA	summative-scale analysis
USGS	U.S. Geological Survey

Analyses of Regulatory Water-Quality Data

By John A. Izbicki and Whitney Seymour

Abstract

Between 1952 and 1964, hexavalent chromium, Cr(VI), was released into groundwater from the Pacific Gas and Electric Company (PG&E) Hinkley compressor station in the Mojave Desert 80 miles northeast of Los Angeles, California. The Pacific Gas and Electric Company has monitored groundwater near Hinkley, California, for Cr(VI) and other constituents since the late 1980s. By June 2017, more than 20,000 samples had been collected and analyzed for Cr(VI) for regulatory purposes. Most Cr(VI) samples were analyzed using the U.S. Environmental Protection Agency (EPA) Method 218.6 with a laboratory reporting level (LRL) of 0.2 micrograms per liter (µg/L). Between July 2012 and June 2017, selected samples were analyzed for low-level Cr(VI) concentrations using a modified version of EPA Method 218.6 with an LRL of 0.06 µg/L. Field-blank data and duplicate samples collected during this period indicate a study reporting level (SRL) of 0.2 µg/L for most analyses and a SRL of 0.12 µg/L for low-level Cr(VI) analyses. The overall precision for Cr(VI) data analyzed by both methods at the interim regulatory Cr(VI) background concentration of 3.1 µg/L was 0.09 µg/L, or about 3 percent.

Hexavalent chromium concentration trends were calculated for 564 monitoring wells for the period from July 2012 through June 2017. Upward Cr(VI) concentration trends were present in water from 102 monitoring wells throughout Hinkley and Water Valleys. Upward Cr(VI) concentration trends in water from wells near the margins of the October–December 2015 (Q4 2015) regulatory Cr(VI) plume (1) within strands of the Lockhart fault east and southeast of the Hinkley compressor station and (2) in water from shallow wells within the northern subarea were consistent with expansion of the Cr(VI) plume in these areas between 2012 and 2017. Upward Cr(VI) concentration trends were widely distributed elsewhere in Hinkley and Water Valleys outside the Q4 2015 regulatory Cr(VI) plume and were commonly associated with declining water levels. These upward trends may result from natural Cr(VI) sources, including movement of Cr(VI) containing groundwater from (1) weathered bedrock, (2) fine-textured deposits, or (3) secondarily oxidized material distributed throughout aquifer deposits. Downward Cr(VI) concentration trends were observed in 146 monitoring wells. Downward trends were largely within the Q4 2015 regulatory Cr(VI) plume and can be attributed to remediation activities downgradient from the Hinkley compressor station. Hexavalent chromium concentration trends also were calculated for 219 domestic wells from July 2012 through June 2017. Upward Cr(VI) concentration trends in 8 domestic wells and downward trends in 23 domestic wells were clustered largely within former residential areas west of the Q4 2015 regulatory Cr(VI) plume. Results of Cr(VI) trend analyses (including upward, downward, and no trend) were used with other data as part of a summative-scale analysis (chapter G) to define the extent of anthropogenic Cr(VI) and natural Cr(VI) within Hinkley and Water Valleys.

D.1. Introduction

Between 1952 and 1964, hexavalent chromium, Cr(VI), was released into groundwater from the Pacific Gas and Electric Company (PG&E) Hinkley compressor station in the Mojave Desert 80 miles (mi) northeast of Los Angeles, California. The U.S. Geological Survey (USGS) was requested by the Lahontan Regional Water Quality Control Board to complete an updated background study of Cr(VI) concentrations in Hinkley and Water Valleys.

As part of cleanup and remediation activities, PG&E has monitored groundwater near Hinkley, California, for Cr(VI) and other constituents for regulatory purposes since the late 1980s (Ecology and Environment, Inc., 1988). By June 2017, more than 20,000 samples had been collected and analyzed for Cr(VI) from more than 770 monitoring wells at more than 410 locations in Hinkley and Water Valleys downgradient to the north (fig. D.1). Many of the monitoring-well locations are multiple-well sites, having wells completed at different depths within unconsolidated deposits and in underlying bedrock, that provide depth-specific water-level and water-quality data. Data collection from monitoring wells that have detailed construction and geologic data addresses one of the limitations of the 2007 PG&E Cr(VI) background study (CH2M Hill, 2007). This limitation was associated with collection of Cr(VI) data from domestic wells that often lack construction and geologic data (Lahontan Regional Water Quality Control Board, 2012).

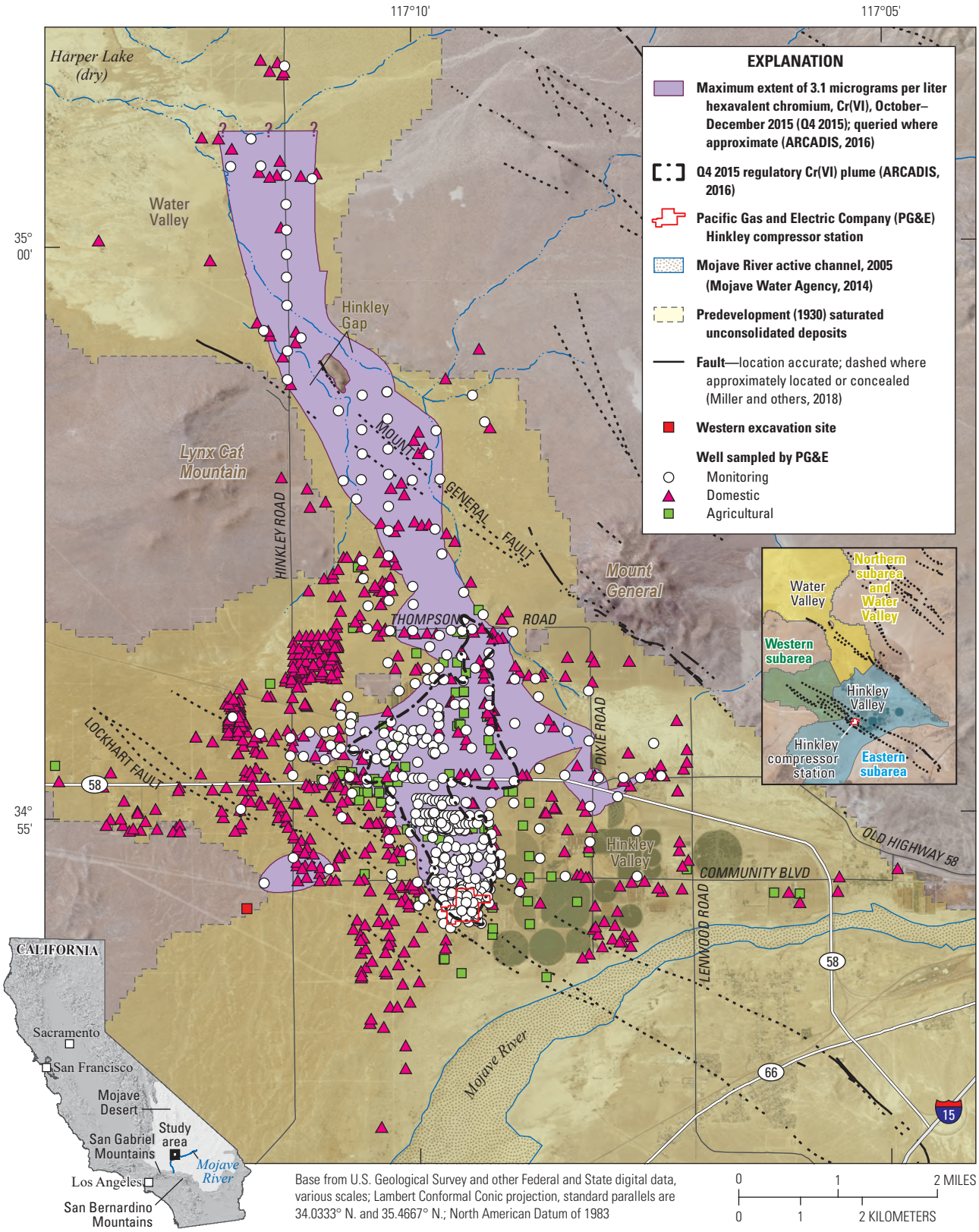


Figure D.1. Monitoring, domestic, and agricultural wells sampled for hexavalent chromium, Cr(VI), by the Pacific Gas and Electric Company (PG&E), Hinkley and Water Valleys, California, 1988–2017. Data were submitted for regulatory purposes by PG&E, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/.

Although construction and geologic data are often unavailable for domestic wells, sample collection from domestic wells provides information on the groundwater resources pumped for supply by the local community. Additionally, data from domestic wells provide information on Cr(VI) concentrations in areas where monitoring wells are not available (fig. D.1). By June 2017, more than 4,400 samples had been collected and analyzed for Cr(VI) from more than 580 domestic wells in Hinkley and Water Valleys (fig. D.1). In addition, more than 730 samples had been collected and analyzed for Cr(VI) from more than 100 agricultural wells in Hinkley and Water Valleys (fig. D.1). Numerous other wells (not shown in fig. D.1) installed by PG&E for other purposes (including water supply for PG&E facilities, in situ remediation, and land application and treatment of Cr(VI)-containing groundwater) also have been sampled for Cr(VI) since the late 1980s.

On the basis of a PG&E background study (CH2M Hill, 2007), a Cr(VI) concentration of 3.1 micrograms per liter (µg/L) was selected by the Lahontan Regional Water Quality Control Board (RWQCB; Lahontan Regional Water Quality Control Board, 2008) as the interim Cr(VI) background concentration to map the Cr(VI) plume extent for regulatory purposes. Quarterly maps showing Cr(VI) concentrations and the mapped regulatory Cr(VI) plume are available at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/. These maps appear to show rapid expansion of the extent of groundwater with Cr(VI) concentrations greater than 3.1 µg/L between 2008 and 2012 (fig. D.2). Increases in the extent of mapped Cr(VI) concentrations greater than 3.1 µg/L likely reflect changes in the extent of the monitoring-well network—expanding as new wells in previously unsampled areas were installed through time, rather than resulting from changes in groundwater Cr(VI) concentrations. However, it was uncertain if Cr(VI) in newer monitoring wells was associated with Cr(VI) released from the Hinkley compressor station, or if Cr(VI) was naturally present within previously unsampled parts of Hinkley and Water Valleys. By 2015, the mapped extent of Cr(VI) greater than 3.1 µg/L was shown as discontinuous features for regulatory purposes (fig. D.2). By October–December 2015 (Q4 2015) the maximum mapped extent of Cr(VI) concentrations greater than 3.1 µg/L included parts of the eastern, western, and northern subareas of Hinkley Valley and extended through Hinkley Gap into Water Valley more than 8 mi downgradient from the Hinkley compressor station (fig. D.2; ARCADIS, 2016).

Despite uncertainty in the interpretation of changes in the mapped extent of Cr(VI) concentrations greater than 3.1 µg/L through time, changes in Cr(VI) concentrations through time (trends) in individual wells can be important for understanding the extent of Cr(VI) released from the Hinkley compressor station. As distance from groundwater-recharge areas increases, native groundwater chemistry within undeveloped aquifers would normally be expected to be less variable over time and without statistically significant concentration trends. Increasing Cr(VI) concentrations through time (upward trends) in water from a well may reflect expansion of the extent of Cr(VI) released from the Hinkley compressor station into groundwater, and decreasing Cr(VI) concentrations through time (downward trends) may reflect contraction of the extent of Cr(VI)—as areas containing anthropogenic (human-made) Cr(VI) released from the Hinkley compressor station are remediated (cleaned up) through groundwater management and remediation activities at the site. Changes in Cr(VI) concentrations and groundwater chemistry also may result from other processes, including irrigation return flow, septic recharge, and changing groundwater levels from pumping that may facilitate movement of Cr(VI)-containing groundwater from weathered chromium-containing bedrock, fine-textured deposits, or other chromium-containing aquifer material (including secondary iron and manganese oxides) distributed throughout aquifer deposits distributed throughout aquifer deposits. Chromium concentrations within these materials are discussed in chapters B and C within this professional paper.

D.1.1. Site Description

Hinkley Valley is about 62 square miles (mi^2) and is underlain by about 36 mi^2 of unconsolidated deposits that were saturated under predevelopment (pre-1930) conditions (Seymour and Izbicki, 2018). Aquifers of interest in Hinkley Valley are composed primarily of unconsolidated deposits consisting of Mojave River stream and lake-margin deposits sourced from the Mojave River (Miller and others, 2018, 2020), referred to as “Mojave-type” deposits for the purposes of this report. Locally derived alluvium, fine-textured lacustrine (lake) deposits, groundwater-discharge deposits, mudflat/playa deposits, and weathered bedrock are important aquifers or confining units in some areas (chapter A, table A.1). On the basis of differences in geology and hydrology, Hinkley Valley was divided into eastern, western, and northern subareas and Water Valley (fig. D.1). The eastern subarea, closest to groundwater-recharge areas along the Mojave River, includes the Hinkley compressor station and most of the Q4 2015 regulatory Cr(VI) plume.

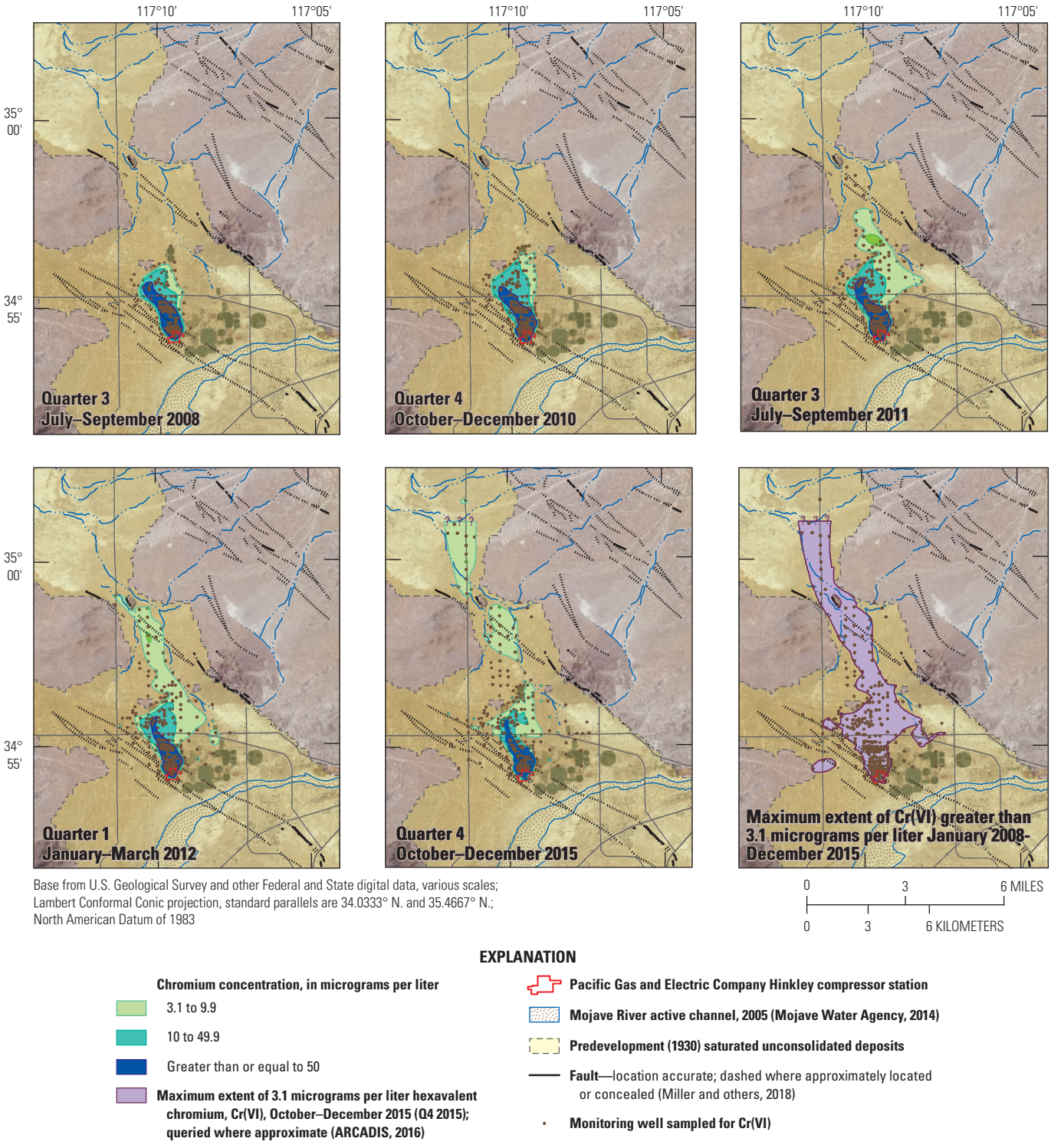


Figure D.2. Mapped extent of groundwater having a hexavalent chromium, Cr(VI), concentration greater than 3.1 micrograms per liter, Hinkley and Water Valleys, California, 2008–15. Maps were submitted for regulatory purposes by Pacific Gas and Electric Company, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/.

Mojave-type deposits in the eastern subarea compose the upper aquifer, which overlies fine-textured lake deposits, generally described as blue clay, present at depths commonly less than 160 feet (ft) below land surface (ARCADIS and CH2M Hill, 2011). Fine-textured deposits, generally described as brown clay, are interspersed throughout the upper aquifer, and in places, separate the upper aquifer into shallow and deep zones (ARCADIS and CH2M Hill, 2011; Miller and others, 2018, 2020). Mudflat/playa deposits are present at land surface and at depth within the eastern subarea near Mount General. The highest Cr(VI) concentrations, in excess of 1,000 µg/L, are within the eastern subarea near the Hinkley compressor station. The western subarea consists of Mojave-type deposits overlying groundwater-discharge deposits, lacustrine deposits, and weathered bedrock (CH2M Hill, 2013a; Miller and others, 2018, 2020). The northern subarea consists of Mojave-type deposits overlying lacustrine and mudflat/playa deposits (Stantec, 2013; Miller and others, 2018, 2020). Aquifers within Water Valley consist of lake-margin deposits sourced from the ancestral Mojave River along the margins of Harper (dry) Lake that overlie and interfinger with locally derived alluvium (Miller and others, 2018, 2020).

Recharge is primarily from intermittent flows in the Mojave River that occur, on average, once every 5 to 7 years (Lines, 1996;Stamos and others, 2001; Seymour, 2016). Under predevelopment conditions, groundwater flowed from the Mojave River north toward Hinkley Gap and into Water Valley, where groundwater discharged by evaporation along the margins of Harper (dry) Lake (fig. D.1). Predevelopment and 2015 water-level maps are provided in chapter H within this professional paper. The Lockhart fault impedes groundwater flow in Hinkley Valley; less is known about the effect of the Mount General fault on groundwater flow. Water-level declines, as a result of agricultural pumping since the early 1950s, were as great as 60 ft (Stone, 1957; California Department of Water Resources, 1967; Seymour and Izbicki, 2018). As a consequence of water-level declines, formerly saturated deposits are unsaturated. Under 2015 conditions, saturated unconsolidated deposits in much of the western subarea downgradient from the Lockhart fault were a thin veneer, commonly less than 10 ft thick, overlying weathered bedrock (CH2M Hill, 2013a). Similarly, saturated Mojave-type deposits in much of the northern subarea were a thin veneer, commonly less than 10 ft thick, overlying finer-textured lacustrine and mudflat/playa deposits (Stantec, 2013). Many monitoring wells in the western subarea are completed partly or entirely in weathered bedrock aquifers, and many monitoring wells in the northern subarea are completed partly or entirely in fine-textured lacustrine or mudflat/playa deposits. Coarse-textured Mojave-type deposits in much of the eastern, western, and northern subareas, and lake-margin deposits in Water Valley that formerly yielded water to agricultural wells, were above the water table at the time of this study (Stamos and others, 2001; Miller and others, 2018, 2020).

In Q4 2015, the regulatory Cr(VI) plume extended 3 mi downgradient from the release location within the Hinkley compressor station (ARCADIS, 2016). However, the actual extent of anthropogenic Cr(VI) was uncertain (fig. D.2); Cr(VI) concentrations greater than the interim regulatory background of 3.1 µg/L were present in water from wells as far downgradient as Water Valley, more than 8 mi downgradient from the Hinkley compressor station (fig. D.2; ARCADIS, 2016). The Pacific Gas and Electric Company disputed the mapped extent of the Q4 2015 regulatory Cr(VI) plume, asserting that Cr(VI) in water from some wells is naturally present, and the Lahontan Regional Water Quality Control Board (2012) agreed that the 2007 PG&E funded Cr(VI) background study be updated.

For regulatory purposes, the Lahontan Regional Water Quality Control Board (2014) treated Cr(VI) concentrations greater than 3.1 µg/L downgradient from the "western excavation site" in the western subarea (fig. D.1) as a separate release, and Cr(VI) concentrations in the eastern subarea east of Dixie Road (fig. D.1) were excluded from regulatory consideration (Lahontan Regional Water Quality Control Board, 2013a). These regulatory practices continued with the adoption of a new Cleanup and Abatement Order by the Lahontan Regional Water Quality Control Board (2015). However, the natural or anthropogenic occurrence of Cr(VI) within the upper aquifer system within Hinkley and Water Valleys, including areas excluded from regulatory consideration, was addressed as part of the USGS Cr(VI) background study (Izbicki and Groover, 2016, 2018). Remediation of Cr(VI) released from the Hinkley compressor station began in 1992, and in 2010, site cleanup was projected to require 10 to 95 years and was expected to cost between $36 and $176 million (Haley and Aldrich, Inc., 2010; Pacific Gas and Electric Company, 2011).

Monitoring wells installed by PG&E for regulatory purposes were commonly identified by the prefix, MW, with sites numbered sequentially in the order they were drilled (ARCADIS, 2016). Shallower wells at a site, commonly screened across or just below the water table, are identified with the suffix S or S1; older shallow monitoring wells are identified with the suffix A (ARCADIS, 2016). Deeper wells are identified with the suffix D, D1, or D2; the suffix S2 or S3 is used if a hydrologically important clay layer is not present between the screened intervals of wells at a multiple-well site; and older deep monitoring wells are identified with the suffix B (ARCADIS, 2016). The suffix R is used to identify a well that is a replacement for a well that had been destroyed (ARCADIS, 2016). Although drilling and well-construction methods changed over time in response to site conditions and regulatory requirements, most boreholes were drilled and monitoring wells installed using auger rigs.

D.1.2. Purpose and Scope

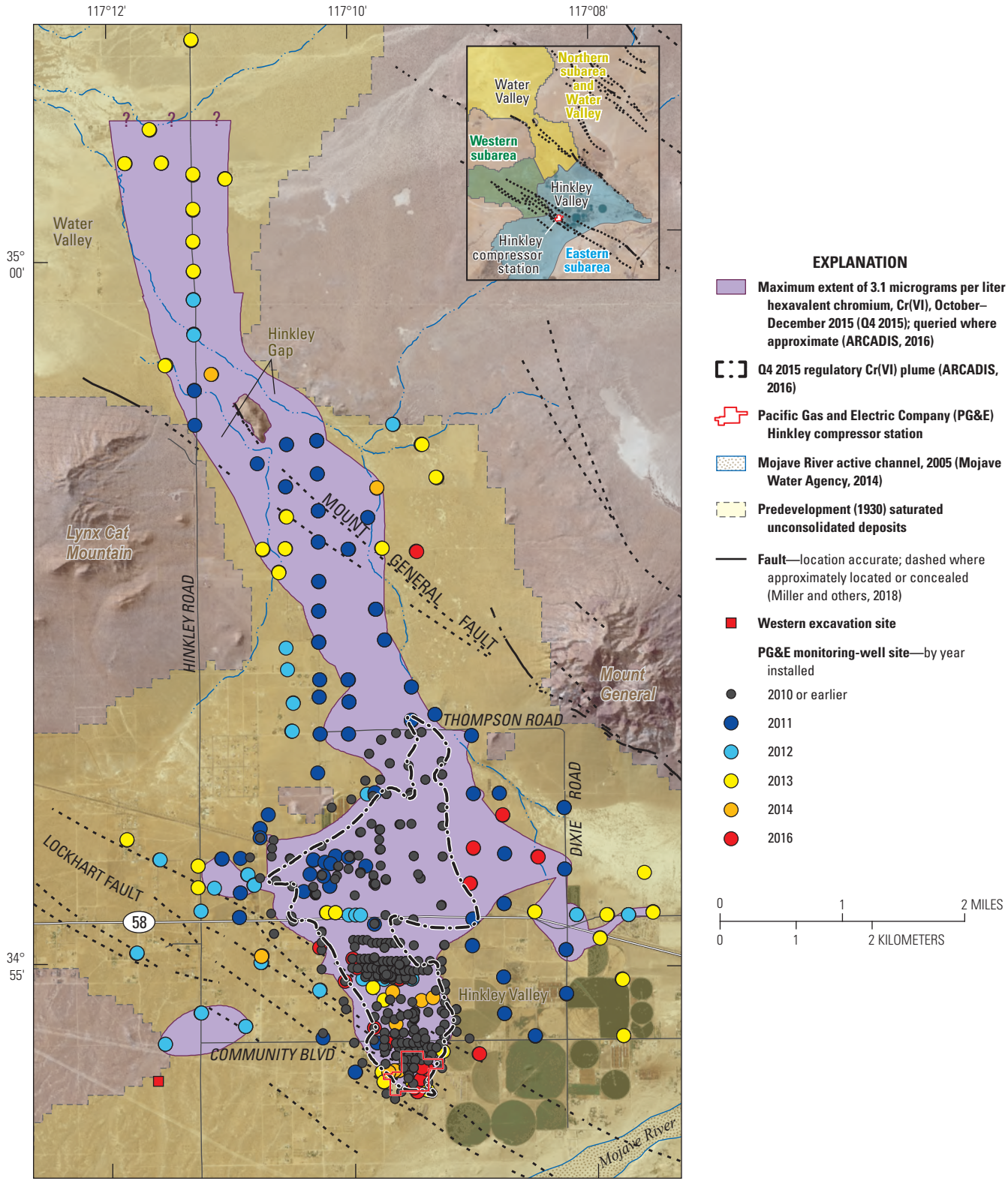
The purpose of this chapter is to provide information on temporal changes in Cr(VI) concentrations (trends) in water from selected monitoring wells within the upper aquifer and from selected domestic wells sampled by PG&E for regulatory purposes near the Cr(VI) regulatory plume. Scope of the work included (1) review of available Cr(VI) data and data quality through time, (2) calculation of changes in Cr(VI) concentration trends in water from selected monitoring wells and domestic wells, and (3) comparison of Cr(VI) concentration trends with water-level, pH, and specific-conductance data in water from selected wells. Results of Cr(VI) trend analyses (including upward, downward, and no trend) were used with other data as part of a summative-scale analysis (chapter G) to define the extent of anthropogenic Cr(VI) and natural Cr(VI) within Hinkley and Water Valleys.

D.2. Data Availability

Data collected by PG&E for regulatory purposes since the late 1980s include information on Cr(VI) concentrations in groundwater in Hinkley and Water Valleys during a longer period than data collected as part of the USGS Cr(VI) background study between March 2015 and November 2017. Although more than 20,000 Cr(VI) analyses are available from monitoring wells since the late 1980s, Cr(VI) trend calculations focused on monitoring-well and domestic-well data collected during the 5-year period from July 2012 through June 2017; this period is more simply referred to as 2012 through 2017 throughout this chapter. Given PG&E monitoring-well installation dates and availability of Cr(VI) data (fig. D.3), this 5-year period provides the maximum amount of data, from the maximum number of wells, having the greatest spatial coverage, and spanning the longest uniform time frame possible for the calculation of trends that are comparable from well to well throughout Hinkley and Water Valleys.

Samples were collected by PG&E for regulatory purposes from most monitoring wells approximately quarterly between 2011 and 2015. Sample collection from some wells having either low or unchanging Cr(VI) concentrations or from wells at locations that were less important for regulatory purposes was reduced in frequency, or eliminated entirely for some wells, in January 2016 as part of the November 2015 Cleanup and Abatement Order (Lahontan Regional Water Quality Control Board, 2015).

Samples were collected by PG&E from selected domestic wells approximately twice yearly between 2011 and 2017. Samples were not consistently collected from some domestic wells depending on access, availability, or permission to sample from the landowner. A domestic well abandonment and destruction program developed by PG&E and accepted by the Lahontan Regional Water Quality Control Board (2013b), intended to remove possible conduits for Cr(VI) transport from shallower to deeper aquifers, limited the period of record available from some domestic wells.



Base from U.S. Geological Survey and other Federal and State digital data, various scales; Lambert Conformal Conic projection, standard parallels are 34.0333° N. and 35.4667° N.; North American Datum of 1983

Figure D.3. Well-installation dates for Pacific Gas and Electric Company (PG&E) monitoring-well sites, Hinkley and Water Valleys, California. Data were submitted by PG&E for regulatory purposes, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/.

D.3. Sample Collection, Laboratory Analyses, Data Quality, and Statistical Methods

From 2008 through 2017, water-quality data from PG&E monitoring wells were collected for regulatory purposes by contract sample collection crews. Sample collection, preservation, and handling procedures were similar throughout this period. Samples for Cr(VI) were analyzed at two different contract laboratories between 2008 and 2017, although only one laboratory was used during the period tested for trends between July 2012 and June 2017 (fig. D.4).

D.3.1. Sample Collection and Laboratory Analyses

Prior to sample collection from monitoring wells, water levels were measured using an electric tape. Monitoring wells were purged using 2-inch diameter positive-displacement submersible pumps. Typically, one casing volume was purged from a monitoring well prior to sample collection for regulatory purposes. Water levels were monitored during purging, and field parameters (including temperature, pH, specific conductance, dissolved oxygen, and oxidation reduction potential) were monitored in flow-through cells during well purging. Samples were collected after field parameters stabilized. Low-yielding wells were pumped to the extent possible and allowed to recover (over several days if needed) prior to sample collection. Pumps were cleaned and decontaminated between wells. Tubing connecting the pump to the surface was dedicated to each well.

Samples for Cr(VI) were collected in bottles containing a preservative provided by a contract laboratory and stored on ice in coolers. Samples and chain-of-custody forms were shipped by courier to the contract laboratory for analyses of Cr(VI) within 24 hours of collection. Samples for other constituents were occasionally collected for specific purposes using appropriate collection, preservation, and handling techniques. With the exception of water-level, pH, and specific conductance data, data for other constituents are not discussed in this section. Field duplicates and field blanks were collected and analyzed for Cr(VI) in approximately 8 and 4 percent of samples, respectively.

Although procedures for sample collection, preservation, and handling were relatively unchanged between 2008 and 2017, there were changes in laboratory analytical methods and changes in the contract laboratories used by PG&E that could complicate interpretation of trends. From 2008 through 2017, samples were analyzed using the U.S. Environmental Protection Agency (EPA) Method 218.6 (1994), having a LRL of 0.2 µg/L. Low-level Cr(VI) analyses, using a modified version of the EPA Method 218.6, having a LRL of 0.06 µg/L, began in 2011 for water samples from selected wells expected to have Cr(VI) concentrations less than 0.2 µg/L. Samples expected to have Cr(VI) concentrations greater than 0.2 µg/L continued to be analyzed using the unmodified EPA Method 218.6. The laboratory analyzing the samples changed in 2012, and the contractor overseeing sample collection and data management changed in January 2016 (fig. D.4).

D.3.2. Data Quality

More than 1,600 duplicate pairs with Cr(VI) concentrations ranging from less than the LRL of 0.06 to 8,820 µg/L were collected by PG&E between July 2008 and June 2017 (appendix D.1, table D.1.1). The mean Cr(VI) concentration of the duplicate data was 105 µg/L, and the overall root mean squared error estimated from least-squares regression analyses of the duplicate pairs was 36 µg/L. Between 2008 and 2017, analyses of 1,100 duplicate pairs with Cr(VI) concentrations less than 10 µg/L had precisions associated with sample collection and laboratory practices [estimated as the 95-percent predictive interval about the least-squares regression line fit through the first and second replicate paired values at a Cr(VI) concentration of 3.1 µg/L] ranging annually from 0.07 to 0.88 µg/L, with a median precision of 0.1 µg/L (fig. D.4*B*). Precision improved after the contract laboratory changed in 2012; thereafter, median precision for Cr(VI) at 3.1 µg/L during the period of trend calculations, shown as ±1 standard deviation (fig. D.4*D*), was 0.09 µg/L, or about 3 percent.

Between 2012 and 2017, 276 of more than 880 field blanks (31 percent) collected by PG&E and analyzed at commercial laboratories for low-level Cr(VI), using the modified version of EPA Method 218.6 with a LRL of 0.06 µg/L, had detectable Cr(VI) concentrations (appendix D.1, table D.1.2). About half of the detections were less than 0.1 µg/L, and all but three Cr(VI) detections in field blanks were less than 0.22 µg/L. The study reporting level (SRL) for Cr(VI) estimated using the binomial distribution 90/90 (BD-90/90) was 0.12 µg/L. The binomial distribution 90/90 is a nonparametric statistic commonly used to estimate the upper confidence limit for the 90th percentile of potential extrinsic contamination for a constituent, with 90-percent or greater confidence (Olsen and others, 2010; Davis and others, 2014). The SRL estimated from the BD-90/90 controls for false positive (type I) and false negative (type II) statistical error. Another way of stating the BD-90/90 is that, on the basis of the field blank data, the estimate provides 90 percent confidence that 90 percent of the field blank data have Cr(VI) concentrations less than the SRL of 0.12 µg/L. The BD-90/90 was calculated using the computer program Microsoft Excel.

Between July 2012 and June 2017, 25 of more than 1,390 field blank samples (less than 2 percent) collected by PG&E and analyzed at commercial laboratories for Cr(VI), using EPA Method 218.6 (U.S. Environmental Protection Agency, 1994) and a LRL of 0.2 µg/L, had detectable Cr(VI), and the BD-90/90 was equal to the LRL of 0.2 µg/L. The highest concentration in a blank sample was 0.43 µg/L.

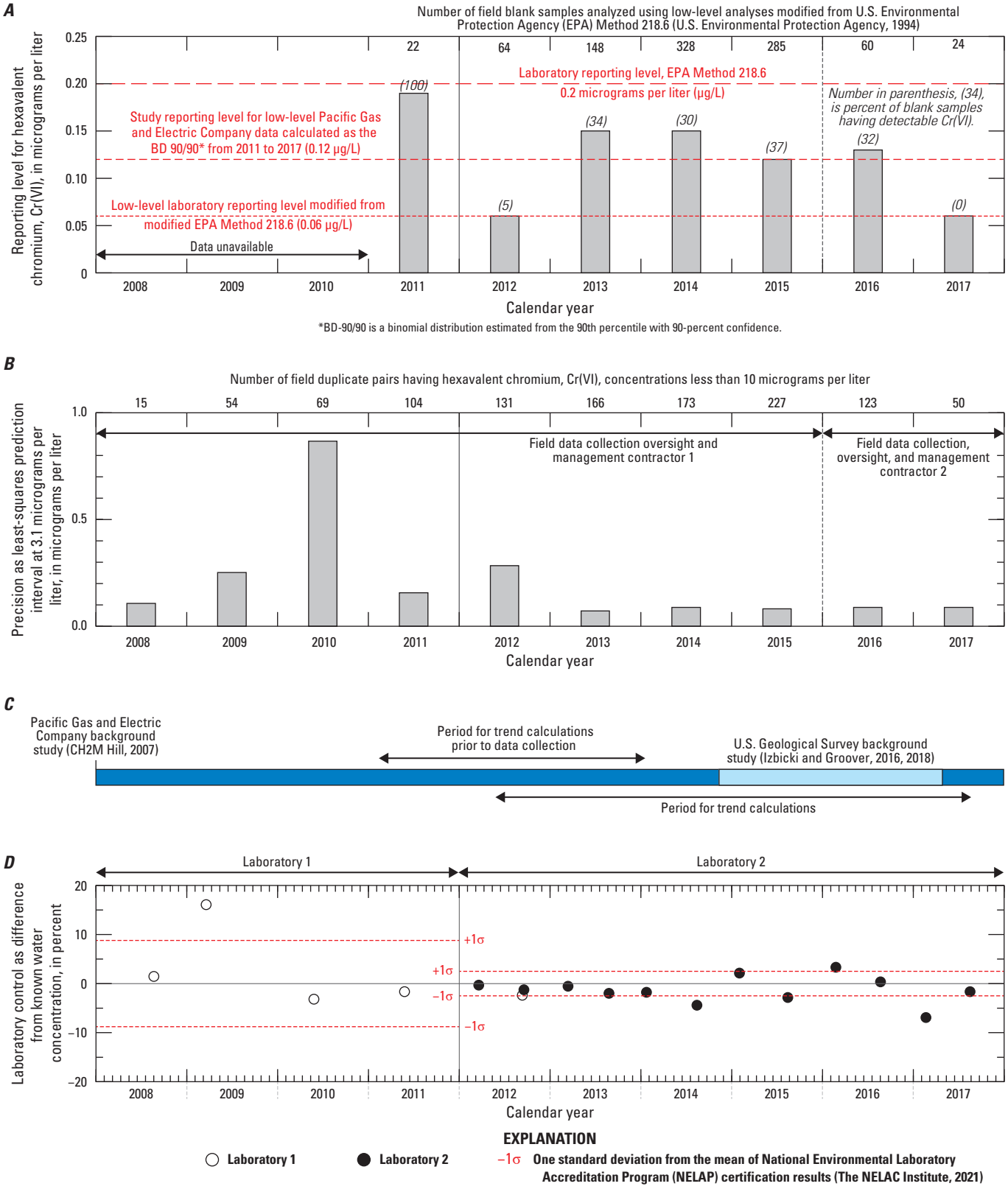


Figure D.4. Summary of field blank, field duplicate, and laboratory-certification data for hexavalent chromium, Cr(VI), collected by Pacific Gas and Electric Company (PG&E) between 2008 and 2017, Hinkley and Water Valleys, California. Statistics were calculated from data submitted by PG&E for regulatory purposes, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/. Data are available in appendix D.1 (tables D.1.1 and D.1.2).

Reference waters having certified Cr(VI) concentrations, traceable to National Institute of Standards and Technology standards, were not analyzed as part of PG&E regulatory data collection. However, both contract laboratories that analyzed Cr(VI) data from the site analyzed reference water as part of the National Environmental Laboratory Accreditation Program (NELAP; The NELAP Institute, 2021). Analyses were done using EPA Method 218.6 rather than the modified low-level method as part of NELAP certification for samples having Cr(VI) concentrations ranging from 30.8 to 783 µg/L. Although reference concentrations were higher than those expected for natural Cr(VI) and were within ranges expected for anthropogenic Cr(VI) within the regulatory Cr(VI) plume, NELAP data provide a measure of laboratory proficiency. Both laboratories used by PG&E for regulatory purposes between 2008 and 2017 were NELAP certified during their respective contract periods, although laboratory proficiency improved after the contract laboratory changed in 2012 (fig. D.4*D*).

On the basis of field duplicate, field blank, and other information, Cr(VI) data collected by PG&E for regulatory purposes were determined to be of high quality and suitable for the evaluation of trends from 2012 through 2017. In addition, review of sample collection, laboratory analyses, and data quality showed that Cr(VI) data collected by PG&E for regulatory purposes were appropriately collected, analyzed, managed, and reviewed; changes made in field or analytical procedures during this period were appropriate to ensure data quality (fig. D.4).

D.3.3. Statistical Methods

Most statistics presented in this chapter were calculated using software from the Statistical Analysis System (SAS Institute, Cary, North Carolina). Monotonic (consistently upward or consistently downward) trends in Cr(VI) concentrations in water from selected monitoring wells and selected domestic wells, sampled by PG&E for regulatory purposes, were evaluated on the basis of the Mann-Kendall test for trend (Kendall, 1938; Mann, 1945; Helsel and Hirsch, 2002; Helsel and others, 2020). Kendall's tau calculated by the test is a nonparametric statistic and less influenced by outlier values within the data than more commonly used parametric statistics. Temporal trends of increasing concentrations (positive Kendall's tau values) and decreasing concentrations (negative Kendall's tau values) were identified as statistically significant or highly significant on the basis of two-tailed significance criteria (significance level) of α=0.05 and 0.01, respectively. The monotonic rate of increase or decrease in Cr(VI) concentrations was evaluated using the Theil-Sen slope estimator (Theil, 1950; Sen, 1968) calculated using the computer program R (Logan, 2010). The Theil-Sen slope estimator is a non-parametric estimator of the magnitude of Cr(VI) concentration trends and is calculated as the median slope of the lines through all pairs of points. The Theil-Sen slope estimator is less sensitive to outlier values than least-squares estimators or other parametric approaches commonly used to estimate the magnitude of trends. Probability values (p-values) associated with Kendall's tau trend results for selected wells where the magnitude of the Cr(VI) trend was calculated are provided. Hexavalent chromium concentrations less than the SRL of 0.12 µg/L for low-level Cr(VI) analysis were treated as values of 0.12 µg/L for the purposes of trend analyses and estimation of the rate of increase or decrease in Cr(VI) concentration. Samples analyzed, using the unmodified EPA Method 218.6, that were below the SRL of 0.2 µg/L were assigned values of 0.2 for the purposes of Cr(VI) concentration trend analyses and estimation of the rate of increase or decrease in Cr(VI) concentration.

D.4. Hexavalent Chromium Concentration Trends in Water from Wells

With increasing distance from sources of groundwater recharge, groundwater chemistry at a given location within undisturbed aquifers commonly becomes increasingly stable and unchanging with time. In the Hinkley and Water Valley areas, changes with time (trends) in Cr(VI) concentrations in water from wells may result from movement of anthropogenic Cr(VI) within groundwater. Changes in Cr(VI) concentrations with time also may result from groundwater-management activities intended to control anthropogenic Cr(VI) released from the Hinkley compressor station—possibly resulting in downward Cr(VI) concentration trends as Cr(VI) is removed from groundwater. Because aquifers in Hinkley and Water Valleys are pumped for water supply, other factors, such as declining water levels from pumping or changes in groundwater chemistry associated with irrigation return, septic discharges, or other activities, also may result in changes in Cr(VI) concentrations and cause apparent trends that are unrelated, or only indirectly related, to anthropogenic Cr(VI) released from the Hinkley compressor station.

Selection of 2012 through 2017 as the period tested for trends allowed the largest number of wells, having the greatest spatial coverage, and spanning the longest uniform time frame possible for the calculation of trends that are comparable from well to well throughout Hinkley and Water Valleys. Hexavalent chromium concentration trends reflect, in part, the hydrologic conditions and groundwater-management activities during the 2012 through 2017 period. The Mojave River did not flow during this period, and groundwater recharge from the river had last occurred in January 2011. Water levels generally declined between 2012 and 2017 as a result of agricultural pumping and the absence of recharge from the Mojave River. Groundwater-management activities used by PG&E to control the plume increased during 2012 through 2017.

The 2012 through 2017 period also included the period of data collection for the USGS background Cr(VI) study between March 2015 and November 2017. Prior to the start of data collection for this study, Cr(VI) values from monitoring and domestic wells collected during the 3-year period of January 2011 through December 2013 were used to estimate Cr(VI) concentration trends. Hexavalent chromium concentration trend results from 2011 through 2013 were used to guide data collection for the USGS Cr(VI) background study. Those trend results are compared to trend results from the 2012 through 2017 period in section D.4.1.

D.4.1. Hexavalent Chromium Concentration Trends in Water from Monitoring Wells

More than 10,000 analyses from 564 selected monitoring wells, in the shallow and deep zones within the upper aquifer underlying Hinkley and Water Valleys, were selected for Cr(VI) concentration trend analyses between 2012 and 2017 (appendix D.1, table D.1.3). Hexavalent chromium concentrations in regulatory data from selected monitoring wells were as high as 7,300 µg/L within the regulatory Cr(VI) plume and the footprint of the Hinkley compressor station. Hexavalent chromium concentrations were as high as 22 µg/L in water from well MW-154S1 outside the regulatory Cr(VI) plume in the northern subarea. Hexavalent chromium concentrations equaled or exceeded 10 µg/L in water from wells MW-207S1 in the northern subarea, MW-203D in the western subarea, and MW-163S downgradient from the western excavation site (figs. D.5*A,B*).

Water from wells MW-193S2 and S3 and wells MW-196S1, S2, and S3 outside the regulatory Cr(VI) plume in Water Valley, had unusual Cr(VI) concentrations as high as 42 and 275 µg/L in the MW-193 wells and 14, 35, and 54 µg/L at the MW-196 wells, respectively. Concentrations declined to values ranging from 0.31 to 4.7 by the end of the period tested for trends (appendix D.1, table D.1.3). It is possible that high Cr(VI) concentrations in water from these wells may be related to unusual geochemical conditions within the aquifer. Manganese sorbed on core material from MW-193S3 was present at high ranges and within ranges measured for strongly oxidized core material within the Cr(VI) plume (chapter C), and abundant manganese oxides may have oxidized trivalent chromium, Cr(III), to Cr(VI) after disturbance during well installation. However, wells MW-193S1, S2, and S3 and wells MW-196S1, S2, and S3 also were affected by tampering after installation and initial sample collection, which affected Cr(VI) concentrations and redox status within water from the wells (Pacific Gas and Electric Company, 2013b). Hexavalent chromium concentration trends in wells affected by tampering were not used as part of the summative-scale analyses (SSA) used to define the Cr(VI) plume later within this professional paper (chapter G).

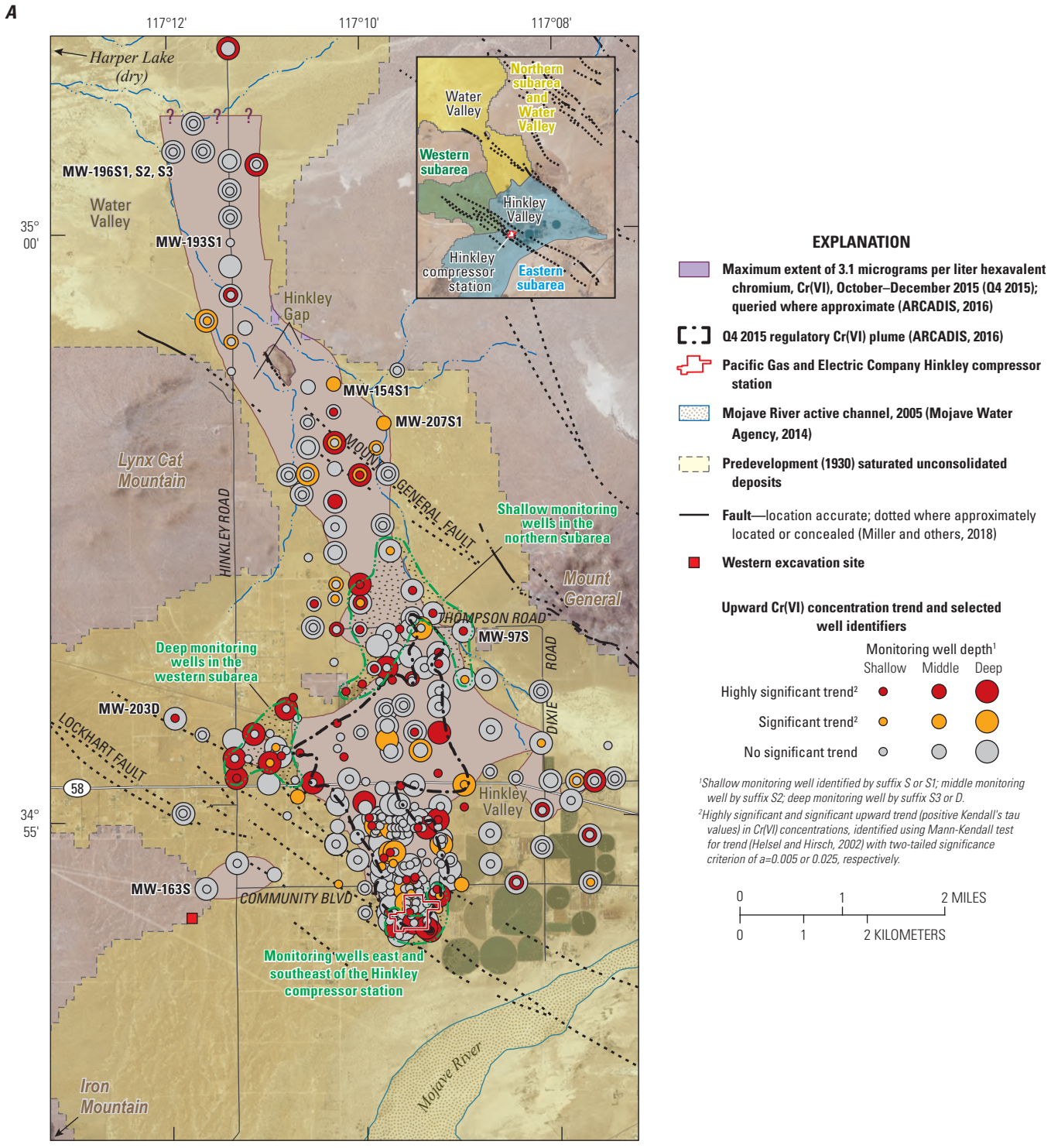
Monitoring wells selected for calculation of Cr(VI) concentration trends commonly had 20 data points uniformly distributed through time. Data from monitoring wells drilled after July 2012 had shorter periods of record and were used for the Cr(VI) trend analyses as long as at least eight data points, representing at least 2 years of data, were available. A minimum of eight data points is consistent with recommendations for trend analyses by Grath and others (2001). Monitoring wells installed after 2014 (fig. D.3) had too little data to calculate Cr(VI) concentration trends as part of this study. Laboratory and field quality-assurance data for Cr(VI) during the 2012–17 sample period showed data were of comparable quality (fig. D.4) and suitable for analyses of trends.

Of the more than 10,000 analyses selected for use in Cr(VI) concentration trend analyses between 2012 and 2017, 6 percent were analyzed using the modified EPA Method 218.6 low-level technique; 71 percent of those samples were below the LRL of 0.06 µg/L, and an additional 19 percent were below the SRL of 0.12 µg/L. As previously discussed, Cr(VI) concentrations less than the SRL for low-level Cr(VI) analysis were assigned values of 0.12 µg/L for the purposes of Cr(VI) concentration trend analyses. In contrast, only 10 percent of samples analyzed using the unmodified EPA Method 218.6 were below the SRL of 0.2 µg/L; these samples were assigned values of 0.2 for the purposes of Cr(VI) concentration trend analyses.

Statistically significant upward Cr(VI) concentration trends were identified in water from 102 of the 564 PG&E monitoring wells tested in Hinkley and Water Valleys (appendix D.1, table D.1.4); of these, 69 upward trends were highly significant. Although statistically significant upward Cr(VI) concentration trends were widely distributed throughout Hinkley and Water Valleys (fig. D.5*A*), clusters of upward trends were present in water from (1) shallow monitoring wells near the leading edge of the Q4 2015 mapped plume in the northern subarea; (2) monitoring wells in the eastern subarea, east and southeast of the Hinkley compressor station within strands of the Lockhart fault; and (3) deep monitoring wells in the western subarea downgradient from the Lockhart fault (fig. D.5*A*).

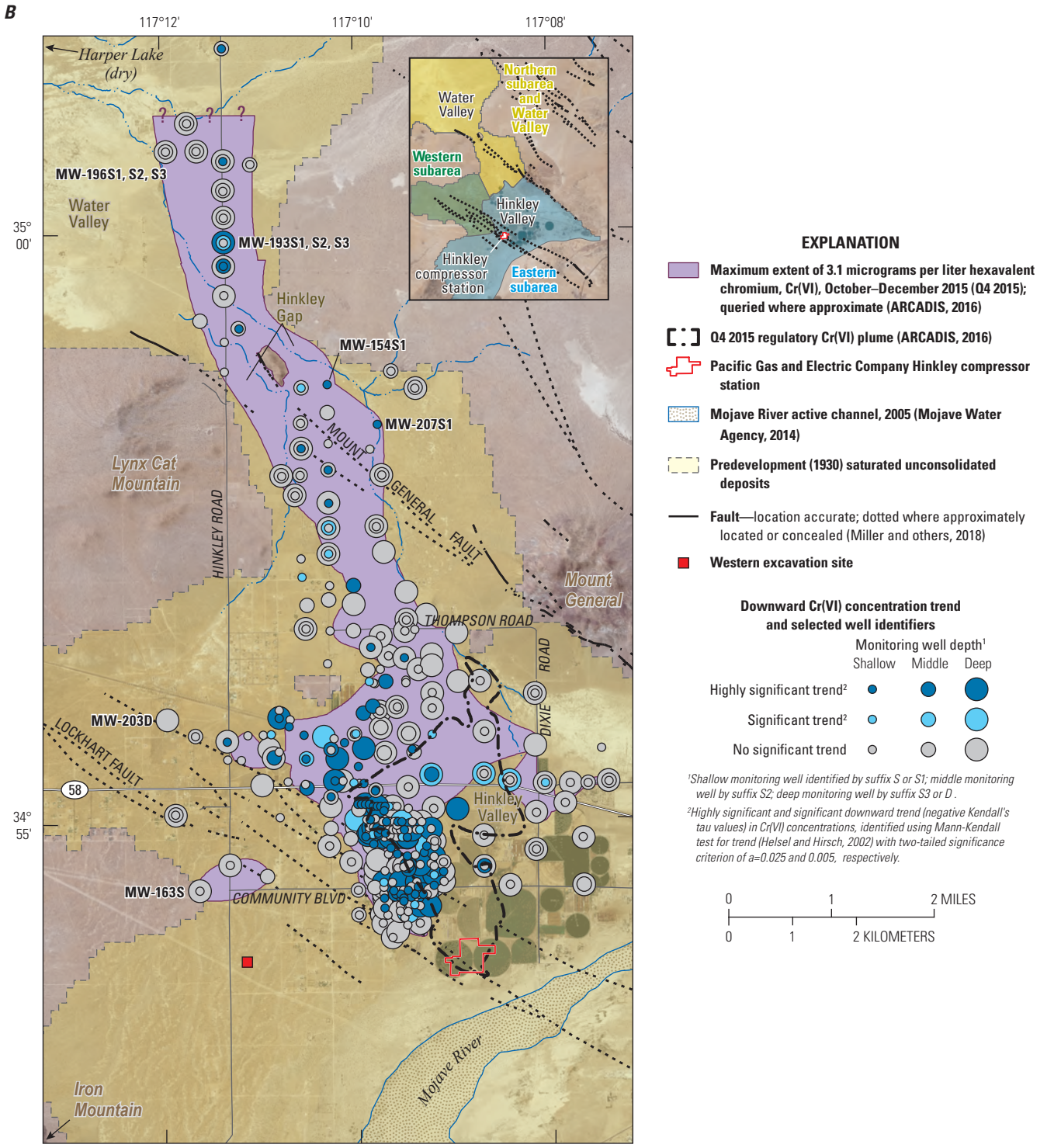
Increasing Cr(VI) concentrations in individual wells in the northern subarea had been previously observed (Pacific Gas and Electric Company, 2013a), and Cr(VI) concentrations greater than 3.1 µg/L prompted investigation of Cr(VI) occurrence in the northern subarea (Stantec, 2013). Shallow and deep monitoring wells farther downgradient in the northern subarea also showed upward Cr(VI) concentration trends (fig. D.5*A*).

Increasing Cr(VI) concentrations east and southeast of the Hinkley compressor station within strands of the Lockhart fault (fig. D.5*A*) also had been previously observed. Increasing Cr(VI) concentrations in this area prompted regulatory concern (Lahontan Regional Water Quality Control Board, 2018), including measures to control increasing Cr(VI) concentrations in that area (ARCADIS, 2018).



Base from U.S. Geological Survey and other Federal and State digital data, various scales; Lambert Conformal Conic projection, standard parallels are 34.0333° N. and 35.4667° N.; North American Datum of 1983

Figure D.5. Wells having statistically significant *A*, upward and *B*, downward hexavalent chromium, Cr(VI), concentration trends, Hinkley and Water Valleys, California, July 2012 through June 2017. Statistics were calculated from data submitted by Pacific Gas and Electric Company for regulatory purposes, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/. Data are available in appendix D.1 (table D.1.3), and calculated statistics are available in appendix D.1 (table D.1.4).



Base from U.S. Geological Survey and other Federal and State digital data, various scales; Lambert Conformal Conic projection, standard parallels are 34.0333° N. and 35.4667° N.; North American Datum of 1983

Figure D.5.—Continued

Increasing Cr(VI) concentrations in water from wells in the western subarea had been previously observed and prompted investigation of Cr(VI) occurrence in that area (CH2M Hill, 2013a, b; ARCADIS, 2014), including investigations of the performance of the Northwest Injection Barrier (chapter A, fig. A.6; Lahontan Regional Water Quality Control Board, 2013c). Deep monitoring wells in the western subarea overlie mafic chromium-containing bedrock and penetrate material containing visually abundant iron and manganese oxides on the surfaces of mineral grains that contain chromium (chapters B and C).

Fewer increasing Cr(VI) concentrations were observed in monitoring wells in Water Valley than in Hinkley Valley (fig. D.5*A*). Increasing Cr(VI) concentrations reported in water from wells completed in the lower aquifer were attributed to flow through long-screened irrigation wells or to movement of water containing Cr(VI) around the margins of the blue clay that separated the upper aquifer from the lower aquifer (Stantec, 2011; ARCADIS and CH2M Hill, 2014). Evaluation of these processes was beyond the scope of this study.

Statistically significant downward Cr(VI) concentration trends were identified in water from 146 of the 564 PG&E monitoring wells (appendix D.1, table D.1.4); of these, 116 downward trends were highly significant. Statistically significant downward Cr(VI) concentration trends between July 2012 and June 2017 were largely within the footprint of the Q4 2015 regulatory Cr(VI) plume (fig. D.5*B*) and likely resulted from PG&E plume management practices, including in situ reduction of Cr(VI) to Cr(III) intended to control the extent of Cr(VI) in groundwater. Downward Cr(VI) concentration trends present elsewhere in the study area often co-occurred with upward Cr(VI) concentration trends in monitoring wells at the same site completed at different depths.

Statistically significant upward or downward Cr(VI) concentration trends were present in about 45 percent of the monitoring wells (102 and 146 of 564 monitoring wells, respectively)—this is greater than the 5 percent of wells (approximately 28 wells) expected to have statistically significant Cr(VI) concentration trends by chance alone (fig. D.6). The percent of PG&E monitoring wells having statistically significant upward or downward Cr(VI) concentration trends for the period 2012–17 (fig. D.6*B*) was greater than the 26 percent of monitoring wells having statistically significant upward or downward Cr(VI) trends from 2011 through 2013 (38 and 98 of 530 monitoring wells, respectively; fig. D.6*A*). Between 2011 and 2013, upward Cr(VI) concentration trends were clustered in water from monitoring wells along the plume margin downgradient from the compressor station and were not widely distributed through Hinkley and Water Valleys (not shown on fig. D.5*A*). Similar to 2012–17, downward Cr(VI) concentration trends during 2011–13 were largely within the mapped plume (not shown on fig. D.5*B*) and likely indicate groundwater-management practices used to control Cr(VI) concentrations downgradient from the compressor station. More upward Cr(VI) concentration trends in 2012–17 compared to 2011–13 are likely related to time since recharge from the Mojave River and progressively greater water-level declines during the 2012–17 period, although the length of period tested for trends (3 years as opposed to 5 years) also may have affected the results.

D.4.2. Hexavalent Chromium Concentration Trends in Water from Domestic Wells

More than 2,500 analyses from 219 domestic wells within Hinkley and Water Valleys were selected for Cr(VI) concentration trend analyses between 2012 and 2017 (appendix D.1, table D.1.5). Domestic wells were selected for trend analyses as long as at least four data points, representing at least 2 years of data, were available. Although fewer than the eight data points recommended for trend analyses by Grath and others (2001), the use of fewer data points for Cr(VI) trend analyses in domestic wells is consistent with criteria developed by Kent and Landon (2013), who demonstrated that statistically significant trends could be calculated using the Mann-Kendall test with as few as four data points. Hexavalent chromium data from domestic wells sampled by PG&E between 2012 and 2017 were collected using similar techniques and analyzed at the same laboratories as monitoring-well data and are comparable in quality. Many domestic wells do not have enough data for trend analyses because it was not always possible for PG&E to obtain permission from landowners to sample. Pumping from domestic wells decreased between 2012 and 2017 as the population of the Hinkley area declined as a result of land purchases by PG&E near the mapped extent of the regulatory Cr(VI) plume. Based on regulatory guidance from the Lahontan Regional Water Quality Control Board (2013b), and assuming nearby monitoring wells were available for sample collection, PG&E destroyed abandoned domestic wells on property they purchased within Hinkley and Water Valleys, and the continued monitoring of destroyed domestic wells was not possible. Domestic wells available for trend analyses in Hinkley and Water Valleys were largely outside the mapped Q4 2015 regulatory Cr(VI) plume and outside the area having Cr(VI) data available from monitoring wells. Domestic wells provide information on Cr(VI) concentrations in groundwater in areas not sampled at monitoring wells (fig. D.7); however, consistent with limitations of the 2007 PG&E Cr(VI) background study (Lahontan Regional Water Quality Control Board, 2012), well-construction and geologic data were not available for most domestic wells evaluated for Cr(VI) concentration trends.

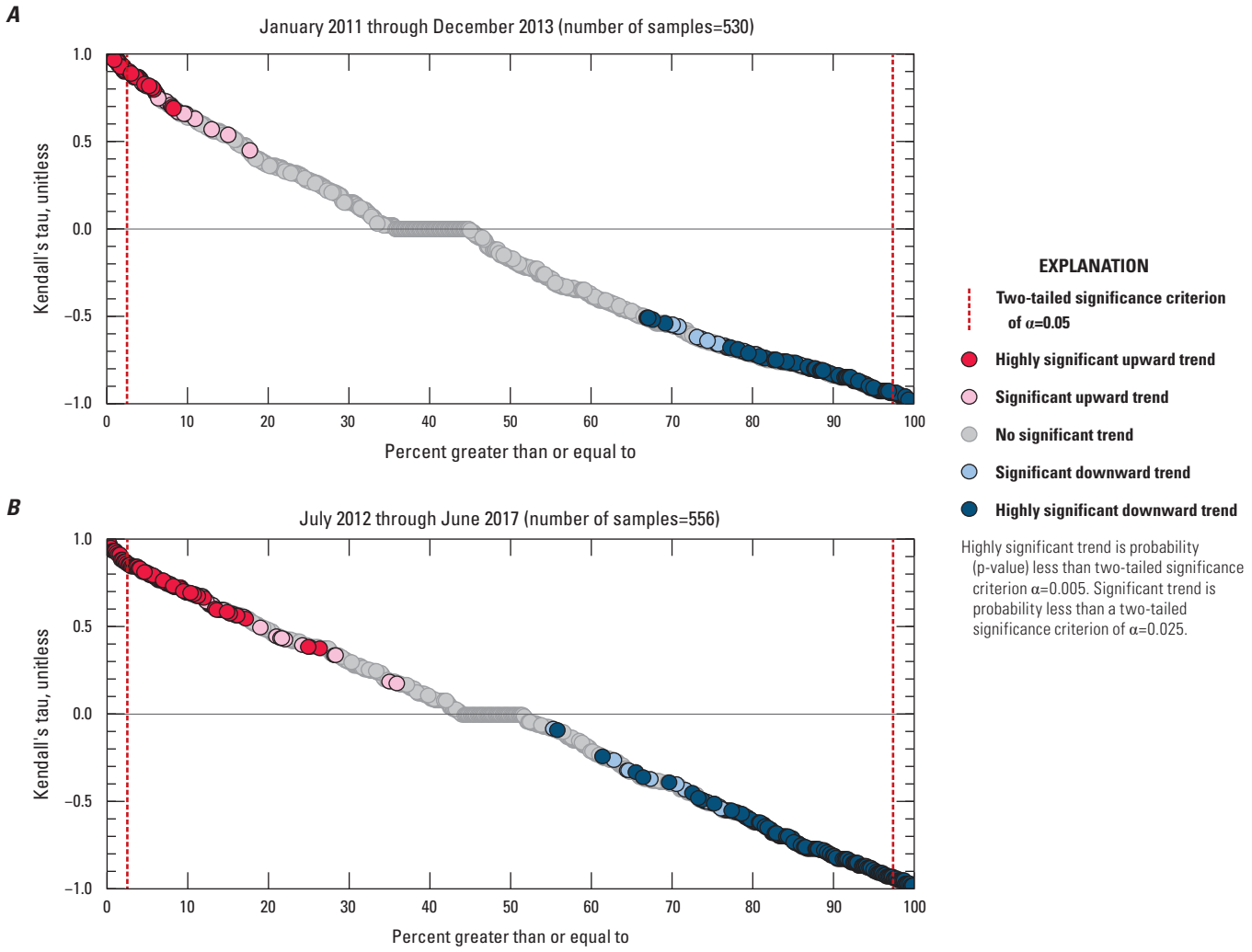
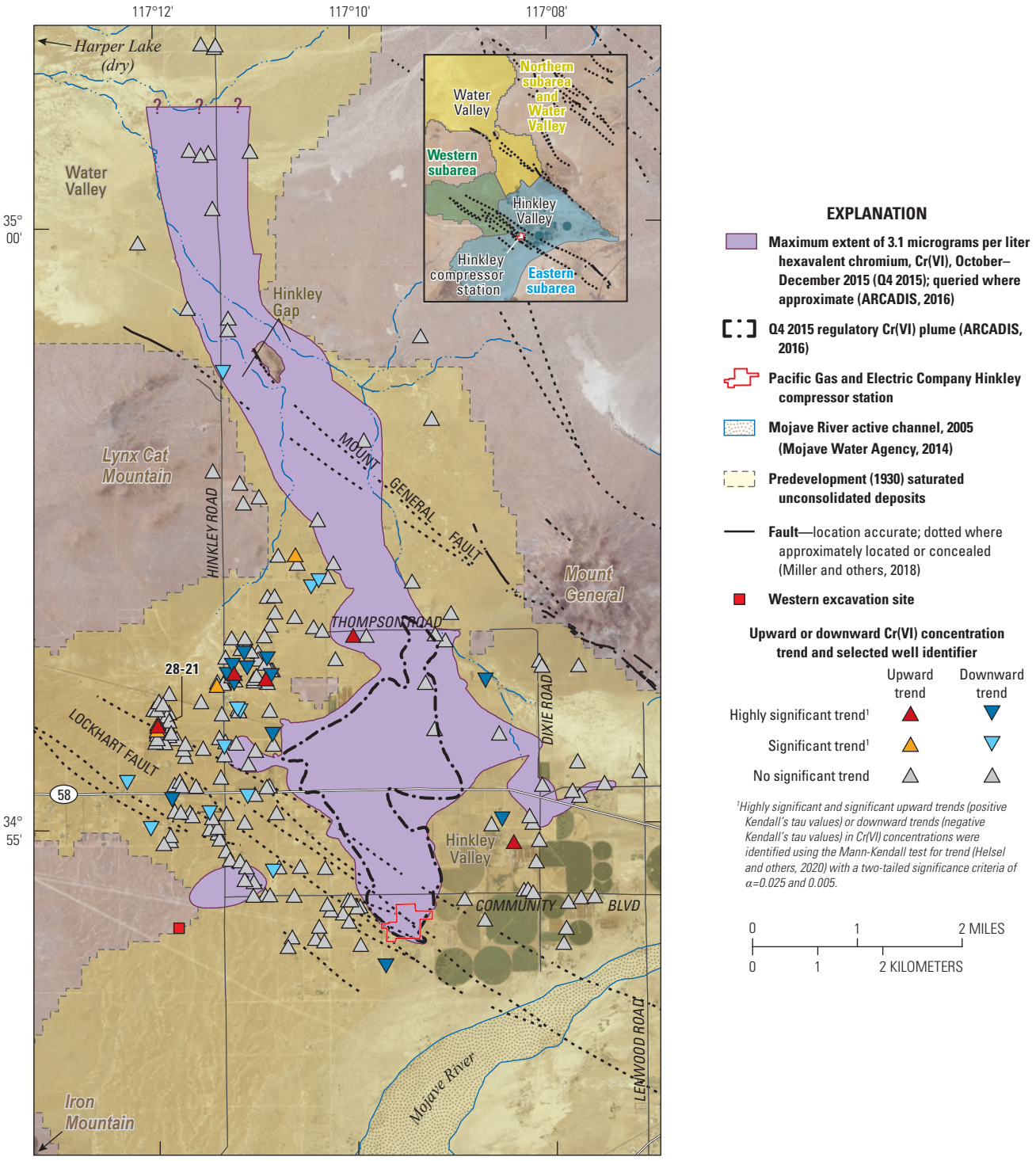


Figure D.6. Cumulative frequency distribution of Kendall's tau and wells having statistically significant upward and downward hexavalent chromium, Cr(VI), concentration trends, Hinkley and Water Valleys, California: *A*, January 2011 through December 2013 and *B*, July 2012 through June 2017. Statistics were calculated from data submitted by Pacific Gas and Electric Company for regulatory purposes, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/. Data are available in appendix D.1 (table D.1.3), and calculated statistics are available in appendix D.1 (table D.1.4).

Hexavalent chromium concentrations in more than 2,500 analyses of water from 219 domestic wells selected for use in Cr(VI) concentration trend analyses between 2012 and 2017 were as high as 8.6 µg/L in water from well 28-21 in the western subarea (fig. D.7). Twenty percent of samples were analyzed using the modified EPA Method 218.6 low-level technique; 62 percent of these samples had concentrations below the LRL of 0.06 µg/L, and an additional 13 percent were below the SRL of 0.12 µg/L. Less than 1 percent of samples analyzed using the unmodified EPA Method 218.6 were below the LRL and SRL of 0.2 µg/L.

Statistically significant (two-tailed significance criterion of α=0.05) upward Cr(VI) concentration trends were identified in 8 of the 219 domestic wells in Hinkley and Water Valleys selected for analyses (fig. D.7); of these, Cr(VI) trends in 5 wells were highly significant (two-tailed significance criterion of α=0.01). Statistically significant downward Cr(VI) concentration trends were identified in 23 domestic wells (fig. D.7); of these, Cr(VI) trends in 12 domestic wells were highly significant. Both upward and downward concentration trends for Cr(VI) occurred more frequently, and with greater statistical significance, in former residential areas within the western subarea where PG&E purchased property near the mapped extent of the greater than 3.1 µg/L Cr(VI) plume (fig. D.7). Decreased domestic pumping as population declined is a likely cause of trends in Cr(VI) concentrations in this area—with upward or downward Cr(VI) concentration trends in individual wells controlled by site-specific geologic factors, well construction, and previous pumping patterns. Results of trend analyses for domestic wells are available in appendix D.1 (table D.1.6).



Base from U.S. Geological Survey and other Federal and State digital data, various scales; Lambert Conformal Conic projection, standard parallels are 34.0333° N. and 35.4667° N.; North American Datum of 1983

Figure D.7. Domestic wells having statistically significant upward or downward hexavalent chromium, Cr(VI), concentration trends, Hinkley and Water Valleys, California, July 2012 through June 2017. Statistics were calculated from data submitted by Pacific Gas and Electric Company for regulatory purposes, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/. Data are available in appendix D.1 (table D.1.5), and calculated statistics are available in appendix D.1 (table D.1.6).

Statistically significant upward or downward trends in Cr(VI) concentrations were present in about 13 percent of the domestic wells—although less than the 45 percent of monitoring wells having statistically significant trends, this frequency is greater than the 5 percent of wells (approximately nine wells) that would be expected to have significant trends by chance alone. The distribution of downward trends in domestic wells between 2012 and 2017 was similar to the distribution in 2011–13 (not shown on fig. D.7), with most wells having statistically significant Cr(VI) concentration trends clustered in formerly residential areas where PG&E purchased property near the mapped extent of the greater than 3.1-µg/L mapped Cr(VI) regulatory plume.

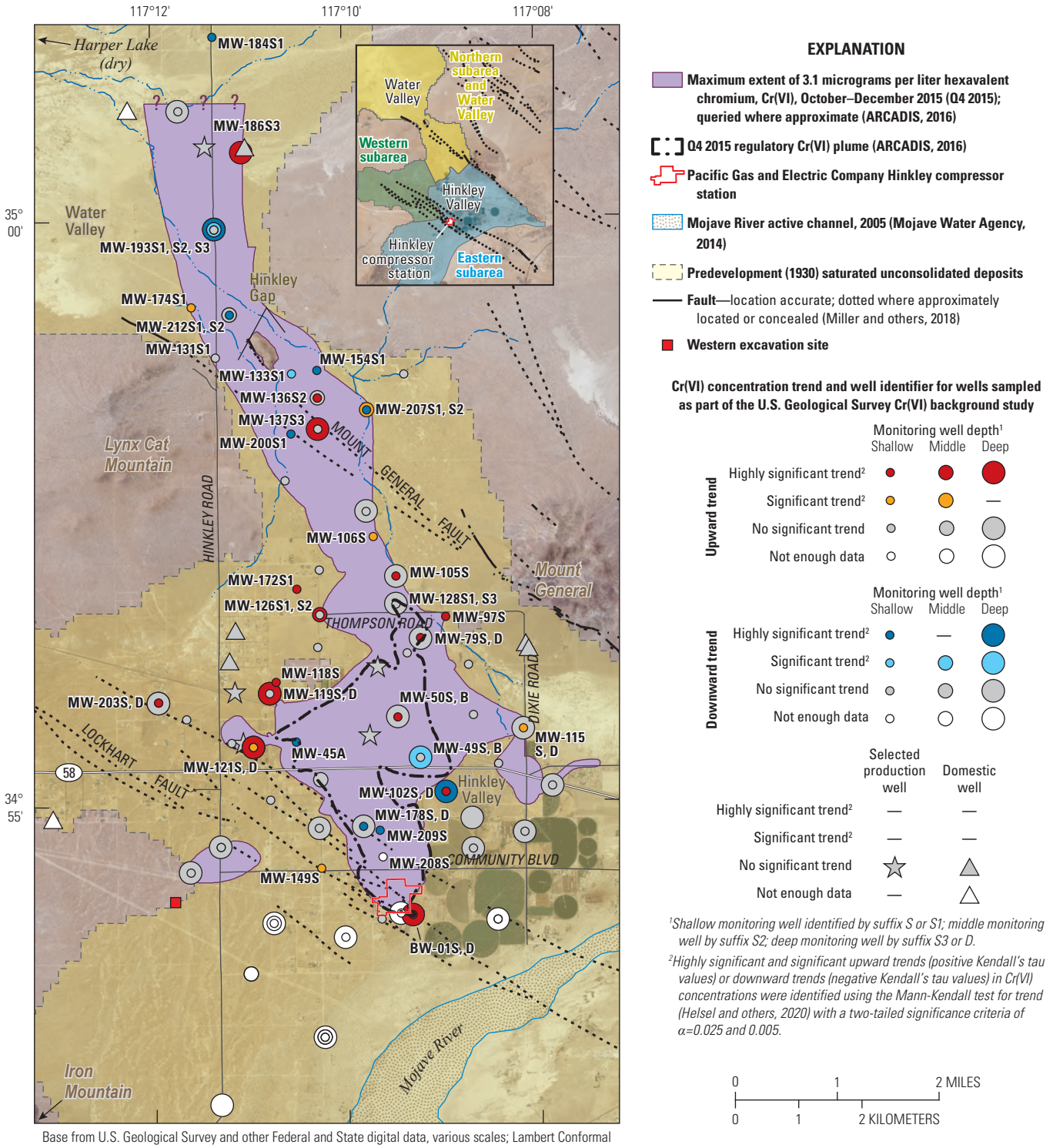
D.4.3. Magnitude of Hexavalent Chromium Concentration Trends

The magnitude of Cr(VI) concentration trends, the monotonic upward slope or downward slope of the trend, for the period 2012–17 in water from wells sampled as part of the USGS Cr(VI) background study (fig. D.8) was calculated using the Theil-Sen slope estimator (Theil, 1950; Sen, 1968; table D.1). The Theil-Sen slope estimator is a non-parametric estimator of the magnitude of changing Cr(VI) concentration trends, calculated as the median slope of all lines through all pairs of points. The Theil-Sen slope estimator is less sensitive to outliers than the parametric or least-squares approaches commonly used to estimate the magnitude of trends. The longer period of record available for Cr(VI) data collected for regulatory purposes by PG&E provides temporal context for samples collected as part of the USGS Cr(VI) background study discussed in chapter E within this professional paper.

Upward Cr(VI) concentration trends, ranging from 0.91 to 1 µg/L per year, were identified in water from wells BW-01D, BW-01S, and MW-50S within the mapped Cr(VI) plume in the eastern subarea (table D.1). Monitoring wells BW-01S and D are nominally upgradient from the Hinkley compressor station within strands of the Lockhart fault and had been previously used to assess background Cr(VI) concentrations in groundwater upgradient from the release. Well MW-50S is downgradient from the Hinkley compressor station. Increases in Cr(VI) concentrations of 0.64 and 0.33 µg/L per year also were identified in wells MW-97S and MW-172S1, respectively, near the leading edge of the mapped regulatory plume in the northern subarea. Other wells sampled as part of the USGS Cr(VI) background study had upward Cr(VI) concentration trends commonly less than 0.3 µg/L per year (table D.1). Although statistically significant, increases in Cr(VI) concentrations less than 0.02 µg/L per year in water from well MW-174S1 (table D.1) correspond to an increase in Cr(VI) concentrations less than 0.1 µg/L in the 5-year period tested for trends. This increase is approximately equal to the precision of low-level analytical data for Cr(VI) of 0.09 mg/L. Although statistically significant, Cr(VI) concentration trends from well MW-174S1 were not considered analytically significant for use in the SSA used to define the Cr(VI) plume later within this professional paper.

Large-magnitude downward Cr(VI) concentration trends greater than 25 µg/L per year were identified in water from wells MW-209S and MW-178S within the Q4 2015 regulatory Cr(VI) plume less than 1 mile downgradient from the Hinkley compressor station; hexavalent chromium concentrations in water from these wells were as high as 98 and 270 µg/L, respectively (table D.1). Downward Cr(VI) concentration trends also were identified in water from wells MW-49B and MW-45A farther downgradient within the Q4 2015 regulatory Cr(VI) plume. Statistically significant (upward or downward) Cr(VI) concentration trends were not identified in water from well MW-208S within the Cr(VI) regulatory plume. In March 2016, water from well MW-208S had a Cr(VI) concentration of 2,500 µg/L—the highest concentration in water from a well sampled as part of the USGS Cr(VI) background study.

Large magnitude downward Cr(VI) concentration trends of 1.4 and 39 µg/L per year were identified in water from wells MW-193S2 and S3, respectively, in Water Valley (table D.1). Shortly after installation in 2013, water from wells MW-193S2 and S3 had unusual Cr(VI) concentrations as high as 42 and 275 µg/L, respectively; Cr(VI) concentrations declined to 4.7 and 0.31 µg/L, respectively, by the end of the period tested for trends. As previously discussed, it is possible that unusually high Cr(VI) concentrations in water from these wells may be related to unusual geochemical conditions within the aquifer, and manganese oxides may have oxidized Cr(III) to Cr(VI) after well installation (chapter C). However, after initial sample collection, wells MW-193S1, S2, and S3 were affected by tampering, which affected Cr(VI) concentrations and the redox status of water from the wells; results from these wells were not used as part of the SSA used to define the Cr(VI) plume later within this professional paper.



Base from U.S. Geological Survey and other Federal and State digital data, various scales; Lambert Conformal Conic projection, standard parallels are 34.0333° N. and 35.4667° N.; North American Datum of 1983

[1]*Shallow monitoring well identified by suffix S or S1; middle monitoring well by suffix S2; deep monitoring well by suffix S3 or D.*

[2]*Highly significant and significant upward trends (positive Kendall's tau values) or downward trends (negative Kendall's tau values) in Cr(VI) concentrations were identified using the Mann-Kendall test for trend (Helsel and others, 2020) with a two-tailed significance criteria of α=0.025 and 0.005.*

Figure D.8. Upward and downward hexavalent chromium, Cr(VI), concentration trends from July 2012 through June 2017 in water from wells sampled for complete chemical and isotopic data as part of the U.S. Geological Survey Cr(VI) background study, Hinkley and Water Valleys, California, March 2015 through March 2017 (Izbicki and Groover, 2016, 2018). Statistics were calculated from data submitted for regulatory purposes by Pacific Gas and Electric Company, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/. Data are available in appendix D.1 (tables D.1.3 and D.1.5), and calculated statistics are available in appendix D.1 (tables D.1.4 and D.1.6).

Table D.1. Kendall's tau trend value, significance (probability value), and Theil-Sen slope estimator for hexavalent chromium, Cr(VI), concentration trends in water from wells sampled as part of the U.S. Geological Survey Cr(VI) background study that have statistically significant upward or downward Cr(VI) concentration trends, Hinkley and Water Valleys, California. Statistics were calculated from data submitted for regulatory purposes by Pacific Gas and Electric Company, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/. Data are available in appendix D.1 (tables D.1.3 and D.1.5), and calculated statistics are available in appendix D.1 (tables D.1.4 and D.1.6).

[Wells ranked within each subarea on the basis of Kendall's tau-β value. Total period of record and total number of samples may be greater than period of record and number of samples used to calculate trends. Kendall's tau β calculated using Statistical Analysis System (SAS) and Sen slope estimator calculated using the computer program R (Logan, 2010). Kendall's tau β is significant if significance probability (p-value) is less than 0.025 and highly significant if less than 0.005, on the basis of a two-tailed significance criteria of α=0.05 and 0.01, respectively. On the basis of replicate Cr(VI) data analyses as part of this study, calculated Sen slope estimators having less than 2-sigma analytical precision (0.02 micrograms per liter) could be caused by analytical uncertainty. **Abbreviations**: PG&E, Pacific Gas and Electric Company; mm/dd/yyyy, month/day/year; <, less than]

PG&E well identification	Period used to calculate Cr(VI) concentration trend (mm/dd/yyyy)		Number of samples	Hexavalent chromium, Cr(VI), concentration range, in micrograms per liter		Kendall's tau trend value, unitless	Significance probability (p-value), unitless	Theil-Sen slope estimator, in micrograms per liter per year
	Begin date	End date		Minimum	Maximum			
Eastern subarea (including October–December 2015 [Q4 2015] mapped plume extent)								
BW-01D	07/23/2012	04/19/2017	20	1.4	6.0	0.94	<0.001	0.96
MW-102S	07/25/2012	04/17/2017	22	0.80	2.2	0.93	<0.001	0.28
MW-79S	07/23/2012	04/18/2017	20	4.4	6.2	0.75	<0.001	0.26
BW-01S	07/23/2012	04/19/2017	20	0.48	6.9	0.64	<0.001	1.0
MW-50S	07/17/2012	04/12/2017	20	11.9	17	0.53	0.002	0.91
MW-115S	07/25/2012	04/17/2017	15	0.82	2.3	0.50	0.011	0.22
MW-149S	07/19/2012	04/06/2017	15	0.88	1.6	0.55	0.008	0.06
MW-49B	07/30/2012	04/13/2017	10	1.7	2.0	−0.68	0.011	−0.06
MW-102D	07/25/2012	04/17/2017	20	2.5	2.8	−0.63	<0.001	−0.50
MW-45A	07/20/2012	04/19/2017	20	1.5	8.1	−0.67	<0.001	−0.61
MW-209S	12/18/2014	04/06/2017	11	98	40	−0.81	<0.001	−25
MW-178S	07/01/2013	04/06/2017	16	160	270	−0.97	<0.001	−27
Western subarea								
MW-119D	07/25/2012	04/12/2017	20	1.1	1.7	0.71	<0.001	0.12
MW-121D	07/10/2012	04/17/2017	22	2.9	3.8	0.61	<0.001	0.13
MW-203S	09/30/2013	04/05/2017	17	1.1	3.0	0.59	0.002	0.29
MW-118S	07/25/2012	04/12/2017	21	1.6	2.8	0.66	<0.001	0.10
Northern subarea (including Water Valley)								
MW-172S1	03/13/2013	04/05/2017	19	1.4	3.0	0.77	<0.001	0.33
MW-207S2	10/16/2014	04/04/2017	10	2.6	3.4	0.67	0.009	0.24
MW-97S	07/26/2012	04/18/2017	22	2.1	7.0	0.57	<0.001	0.64
MW-126S2	07/30/2012	06/06/2017	19	1.2	1.6	0.53	0.003	0.05
MW-186S3	08/01/2013	04/04/2017	15	2.7	4.1	0.58	0.003	0.24
MW-174S1	03/12/2013	04/03/2017	18	2.9	3.4	0.47	0.010	<0.02
MW-136S1	07/26/2012	04/04/2017	20	1.4	3.9	0.63	<0.001	0.20
MW-105S	07/25/2012	04/06/2017	23	1.8	2.9	0.45	0.005	0.09
MW-106S	10/09/2012	04/05/2017	20	2.5	3.2	0.42	0.015	0.08
MW-137S3	07/30/2012	04/04/2017	20	1.5	8.7	0.52	0.002	0.56
[1]MW-193S2	09/25/2013	04/03/2017	18	3.8	42	−0.40	0.020	−1.4
MW-133S1	04/18/2013	04/20/2017	15	7.1	9.8	−0.44	0.019	−0.27

Table D.1. Kendall's tau trend value, significance (probability value), and Theil-Sen slope estimator for hexavalent chromium, Cr(VI), concentration trends in water from wells sampled as part of the U.S. Geological Survey Cr(VI) background study that have statistically significant upward or downward Cr(VI) concentration trends, Hinkley and Water Valleys, California. Statistics were calculated from data submitted for regulatory purposes by Pacific Gas and Electric Company, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/. Data are available in appendix D.1 (tables D.1.3 and D.1.5), and calculated statistics are available in appendix D.1 (tables D.1.4 and D.1.6).—Continued

[Wells ranked within each subarea on the basis of Kendall's tau-β value. Total period of record and total number of samples may be greater than period of record and number of samples used to calculate trends. Kendall's tau β calculated using Statistical Analysis System (SAS) and Sen slope estimator calculated using the computer program R (Logan, 2010). Kendall's tau β is significant if significance probability (p-value) is less than 0.025 and highly significant if less than 0.005, on the basis of a two-tailed significance criteria of α=0.05 and 0.01, respectively. On the basis of replicate Cr(VI) data analyses as part of this study, calculated Sen slope estimators having less than 2-sigma analytical precision (0.02 micrograms per liter) could be caused by analytical uncertainty. **Abbreviations**: PG&E, Pacific Gas and Electric Company; mm/dd/yyyy, month/day/year; <, less than]

PG&E well identification	Period used to calculate Cr(VI) concentration trend (mm/dd/yyyy)		Number of samples	Hexavalent chromium, Cr(VI), concentration range, in micrograms per liter		Kendall's tau trend value, unitless	Significance probability (p-value), unitless	Theil-Sen slope estimator, in micrograms per liter per year
	Begin date	End date		Minimum	Maximum			
Northern subarea (including Water Valley)—Continued								
MW-154S1	08/08/2012	04/20/2017	20	7.0	22	−0.56	<0.001	−2.3
MW-184S1	07/24/2013	04/04/2017	16	1.5	5.2	−0.59	0.002	−0.62
[1]MW-193S3	09/25/2013	06/07/2017	21	0.12	275	−0.72	<0.001	−39
MW-200S1	09/30/2013	04/11/2017	18	0.74	4.2	−0.70	<0.001	−0.51
MW-212S1	03/03/2015	04/03/2017	11	3.1	3.8	−0.61	0.011	−0.20

[1]Wells MW-193S1, S2, and S3 were affected by tampering. Cr(VI) concentration trend results from these wells were not used as part of the "Summative Scale Analysis" section in chapter G within this professional paper.

D.5. Comparison of Hexavalent Chromium Concentration Trends with Water-Level and Other Data

Hexavalent chromium concentration trends in water from selected wells sampled as part of the USGS background study (fig D.8) were compared to water level, pH, and specific conductance data collected by PG&E between 2012 and 2017 (fig. D.9). These comparisons show how Cr(VI) concentrations changed in representative wells within different parts of the study area with changes in groundwater levels and other constituents over time. Redox data, an important control on Cr(VI) concentrations in groundwater, are not discussed because water from most wells in the study area was oxic (contained dissolved oxygen) throughout the period tested for trends. Samples that did not contain measurable dissolved oxygen generally did not contain Cr(VI) concentrations above the SRL.

D.5.1. Eastern Subarea

In the eastern subarea, water levels in wells near agricultural pumping along the Mojave River declined more than 10 ft between 2012 and 2017 (fig. D.9). As water levels declined, Cr(VI) concentrations in water from well MW-102S outside the Q4 2015 regulatory Cr(VI) plume increased in near-monotonic fashion at a rate of 0.28 µg/L per year from 0.8 to 2.2 µg/L (table D.1). Increasing Cr(VI) concentrations, and even the presence of Cr(VI) at concentrations greater than 1 µg/L, in water from well MW-102S and other wells in the eastern subarea were unexpected, given pH values that ranged from slightly acidic to neutral during this period (fig. D.9). Hexavalent chromium is strongly sorbed at slightly acidic to neutral pH (Rai and Zachara, 1984; Motzer, 2005) and does not commonly occur at concentrations greater than 1 µg/L in water from wells in California having slightly acidic to neutral pH—even in areas where local geology is high in chromium (Izbicki and others, 2015). Similar increases in Cr(VI) concentrations did not occur in the deeper well at the site, MW-102D (not shown on fig. D.9). Increasing Cr(VI) concentrations with declining water levels also were present in other wells in the eastern subarea, such as MW-115S.

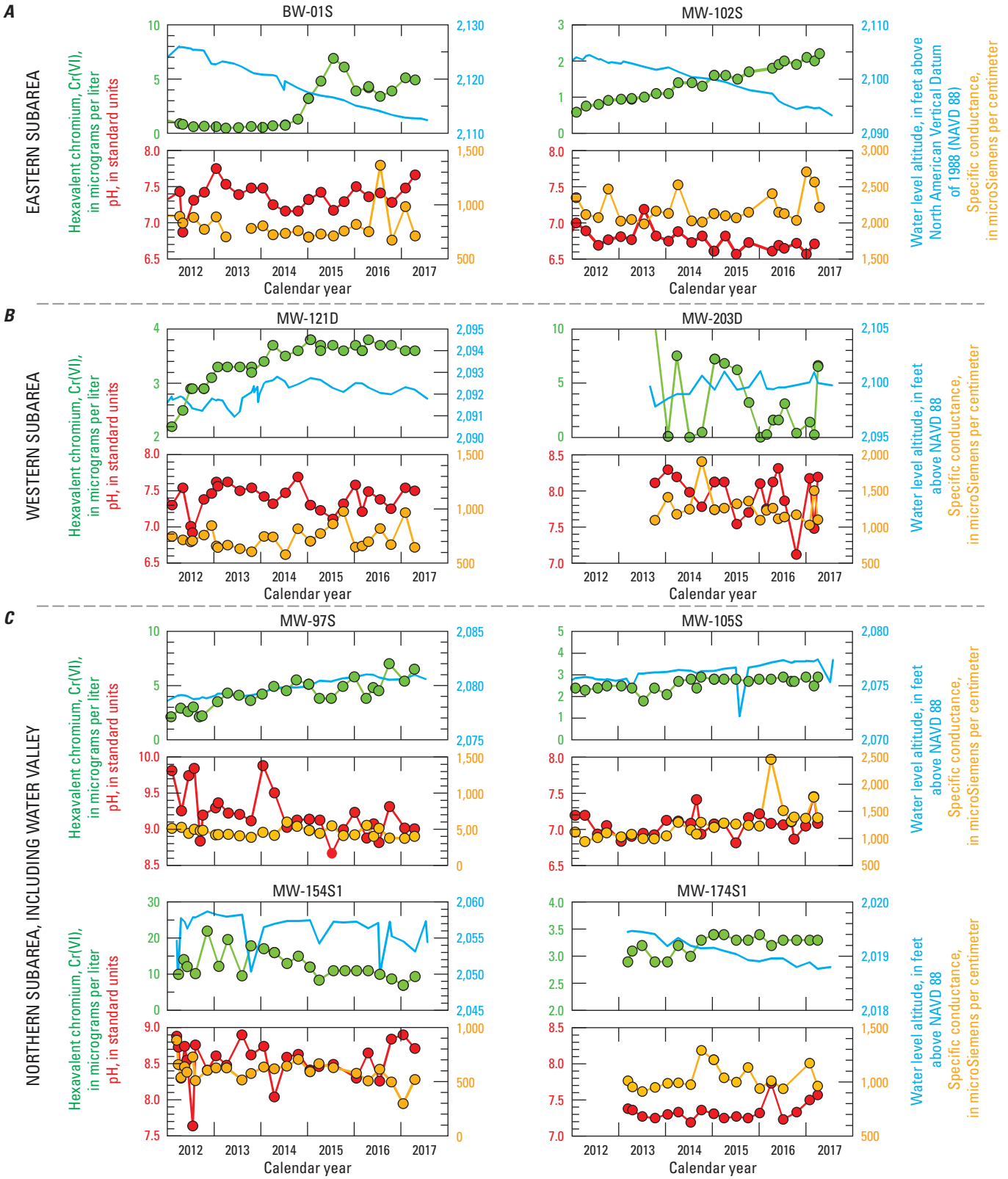


Figure D.9. Selected wells from each subarea showing changing hexavalent chromium, Cr(VI), concentrations with changing water levels, pH, and specific conductance in the *A,* eastern subarea, *B,* western subarea, and *C,* northern subarea, including Hinkley and Water Valleys, California. Data were submitted for regulatory purposes by Pacific Gas and Electric Company, accessed January 12, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/.

In contrast to well MW-102S, water from well MW-115S was alkaline with pH greater than 7.6. Alkaline conditions and Cr(VI) concentrations in water from well MW-115S may be related to fine-textured mudflat/playa deposits in that part of the eastern subarea (chapters B and C).

In contrast to increasing Cr(VI) concentrations in water from wells MW-102S and MW-115S, increases in Cr(VI) concentrations in water from wells BW-01S (fig. D.9) and BW-01D (not shown on fig. D.9), within splays of the Lockhart fault upgradient from the Hinkley compressor station, were not simple monotonic trends. Instead, Cr(VI) concentrations in water from these wells increased rapidly from less than 1 µg/L to almost 7 µg/L between 2014 and 2015, followed by decreasing and subsequently stable Cr(VI) concentrations. Initially low Cr(VI) concentrations, and low specific conductance, in water from these wells in 2012 may be associated with the proximity of these wells to recharge sources along the Mojave River. Although nominally upgradient from the Hinkley compressor station, increasing Cr(VI) concentrations in water from wells BW-01S and BW-01D exceeded the interim background Cr(VI) concentration of 3.1 mg/L by January 2015 and October 2014, respectively. Increasing Cr(VI) concentrations in these wells may be related to releases from the Hinkley compressor station; consequently, groundwater-management plans were established to control increasing Cr(VI) concentrations in this area (ARCADIS, 2018; Lahontan Regional Water Quality Control Board, 2018).

Water-level declines in the eastern subarea decreased with distance from agricultural pumping along the Mojave River, and water-level rises of about 2 ft between 2012 and 2017 accompanied upward Cr(VI) concentration trends in well MW-79S (not shown on fig. D.9) within the Q4 2015 regulatory Cr(VI) plume to the north. Water levels rose almost 2 ft in well MW-128S1 (not shown on fig. D.9) near the leading edge of the Q4 2015 regulatory Cr(VI) plume. Hexavalent chromium concentration trends were not present in water from well MW-128S1 between 2012 and 2017, although Cr(VI) concentrations ranged from 8.1 to 2.5 µg/L during this period. Hexavalent chromium concentrations in water from well MW-128S1 were as high as 20.1 µg/L in July 2011, shortly after the well was installed, and decreased rapidly thereafter. Similar changes in Cr(VI) concentrations were not observed in water from the deeper well MW-128S3 at the site (not shown on fig. D.9), which ranged less widely from 2.1 to 1.4 µg/L between 2011 and 2017. Near neutral to slightly acidic pH in wells, such as MW-50S and MW-79S, remained nearly stable, but specific conductance generally increased with distance from the Mojave River to the leading edge of the Q4 2015 regulatory Cr(VI) plume.

D.5.2. Western Subarea

In the western subarea, no consistent pattern of increasing or decreasing water levels in wells was observed between 2012 and 2017. Where present, water-level changes commonly ranged from 1 to 2 ft and were smaller in magnitude than water-level changes in wells in the eastern subarea. In water from wells where Cr(VI) concentration trends were present, such as MW-121D (fig. D.9), Cr(VI) concentrations increased more rapidly in the early part of the period tested for trends than in the later part of the period. Seasonally higher Cr(VI) concentrations in the winter and spring were associated with seasonal changes in water levels and were observed in shallow and deep wells, including MW-118S, MW-119D, and MW-121S and D. Unlike most wells in the eastern subarea, the pH of water from wells in the western subarea is commonly slightly alkaline to alkaline.

Hexavalent chromium concentrations in water from well MW-203D (fig. D.9), completed in partly consolidated deposits underlying alluvium in the western subarea, varied widely during 2012–17, ranging from less than the SRL of 0.12 to 10 µg/L. However, no Cr(VI) concentration trend was observed for well MW-203D during 2012-17 (appendix D.1, table D.1.4). Water levels in well MW-203D did not vary widely, and Cr(VI) concentrations in MW-203D changed as a result of other factors, including the pumping of water during sample collection as part of the USGS Cr(VI) background study (chapter E).

D.5.3. Northern Subarea and Water Valley

Increases in water levels accompanied upward Cr(VI) concentration trends in monitoring wells near the leading edge of the Q4 2015 regulatory Cr(VI) plume in the northern subarea. Water-level rises of about 1.5 to 3.5 ft were measured between 2012 and 2017 in wells MW-97S and MW-105S (fig. D.9) and wells MW-106S and MW-126S1 (not shown on fig. D.9) near the leading edge of the PG&E Q4 2015 regulatory Cr(VI) plume. This part of the northern subarea downgradient from the Q4 2015 regulatory Cr(VI) plume is the only area in Hinkley and Water Valleys where upward Cr(VI) concentration trends are accompanied by increasing water levels. Increasing water levels in these wells may be related to recharge infiltrated from stormflow in the Mojave River in 2010 or to changes in pumping or groundwater-management activities by PG&E used to control the Cr(VI) plume. Although the rate of the Cr(VI) increases were as high as 0.64 µg/L per year in well MW-97S near the Q4 2015 regulatory Cr(VI) plume margin, most wells in the northern subarea had smaller increases ranging from 0.05 to 0.09 µg/L per year (table D.1).

Farther to the north near Water Valley, water levels declined between 2012 and 2017, and fewer wells showed statistically significant upward Cr(VI) concentration trends (fig. D.9). The upward Cr(VI) concentration trend in water from well MW-174S1 in Water Valley was small in magnitude, less than 0.02 µg/L per year, and although statistically significant, it was within the range of analytical uncertainty for Cr(VI) measurements (table D.1). In the northern subarea and Water Valley near Hinkley Gap, a number of wells sampled as part of the USGS Cr(VI) background study had downward Cr(VI) concentration trends. Many wells in this area, such as MW-154S1, MW-133S1, or MW-193S3, are screened in low permeability aquifer materials that do not readily yield water to wells during pumping. Hexavalent chromium concentrations as high as 20 µg/L in well MW-154S1 (fig. D.9) may have declined as Cr(VI)-containing groundwater was removed from the aquifer by pumping and sample collection. Similar to well MW-203D in the western subarea, Cr(VI) concentrations in water from low-yielding wells in the northern subarea showed large changes after sample collection as part of the USGS Cr(VI) background study (chapter E).

D.6. Conclusions

Between 1952 and 1964, hexavalent chromium, Cr(VI), was released into groundwater from the Pacific Gas and Electric Company (PG&E) Hinkley compressor station in the Mojave Desert 80 miles northeast of Los Angeles, California. Since the late 1980s, PG&E has monitored groundwater near Hinkley, California, for Cr(VI) and other constituents. The U.S. Geological Survey (USGS) was requested by the Lahontan Regional Water Quality Control Board to complete an updated background study of Cr(VI) concentrations in Hinkley and Water Valleys.

From the late 1980s until June 2017, PG&E collected and analyzed more than 20,000 samples for Cr(VI) from more than 770 monitoring wells for regulatory purposes. Analyses of more than 1,100 duplicate pairs of samples having Cr(VI) concentrations less than 10 micrograms per liter (µg/L), collected between July 2012 and June 2017, showed a precision of 0.09 µg/L at a Cr(VI) concentration of 3.1 µg/L, or about 3 percent. Analyses of more than 1,720 field blanks for Cr(VI) using U.S. Environmental Protection Agency (EPA) Method 218.6 showed a study reporting level (SRL) equal to the laboratory reporting level (LRL) of 0.2 µg/L. Analyses of more than 880 field blanks showed a SRL of 0.12 µg/L for low-level Cr(VI) analyzed using a modified version of EPA Method 218.6; the LRL for this method was 0.06 µg/L; for these samples, Cr(VI) concentrations less than the SRL of 0.12 µg/L were treated as values of 0.12 µg/L for the purposes of trend analyses. Review of sample collection, laboratory analyses, and data quality shows that Cr(VI) data collected by PG&E for regulatory purposes were collected, analyzed, managed, and reviewed appropriately; changes were made in field or analytical procedures as needed through time to ensure data quality. Hexavalent chromium data collected by PG&E for regulatory purposes between July 2012 and June 2017 were of suitable quality for evaluation of trends.

Data collected during the 5-year period between July 2012 and June 2017 were used to calculate Cr(VI) concentration trends in 564 monitoring wells and in 219 domestic wells. The July 2012 to June 2017 period provided for the maximum amount of Cr(VI) data from the maximum number of wells, having the greatest spatial coverage, and spanning the longest uniform timeframe possible for the calculation of trends that are comparable from well to well throughout Hinkley and Water Valleys. Monitoring wells selected for calculation of Cr(VI) concentration trends commonly had 20 data points uniformly distributed through time. Some wells with shorter periods of record were included in the trend analyses as long as a minimum of eight data points representing at least 2 years of record were available. The period tested for Cr(VI) concentration trends included the period of sample collection for the USGS Cr(VI) background study. The Mojave River did not flow between 2012 and 2017, with the last recharge from the river occurring in January 2011, and water levels in most monitoring wells declined as a result of pumping during the period tested for Cr(VI) trends.

Upward Cr(VI) concentration trends were present in water from 102 monitoring wells. Upward Cr(VI) concentration trends were clustered in (1) shallow wells in the northern subarea near the leading edge of the October–December 2015 (Q4 2015) regulatory Cr(VI) plume; (2) in the eastern subarea, east and southeast of the Hinkley compressor station within strands of the Lockhart fault; and (3) deeper wells in the western subarea downgradient from the Lockhart fault. Additional wells having upward Cr(VI) concentration trends were widely distributed throughout Hinkley and Water Valleys and were commonly associated with declining water levels.

Upward Cr(VI) concentration trends as large as 1 µg/L per year were present in water from wells near the Hinkley compressor station where water levels declined 10 feet during the 5-year period tested for trends. Upward Cr(VI) concentration trends as large as 0.67 µg/L per year measured within and near the leading edge of the mapped Q4 2015 regulatory Cr(VI) plume in the northern subarea were accompanied by increasing water levels. Increasing Cr(VI) concentrations and water levels in this part of the northern subarea may be related to propagation of recharge infiltrated from stormflow in the Mojave River in January 2011 through the Hinkley Valley or to changes in pumping or groundwater-management activities by PG&E used to control plume movement in this area. Increasing Cr(VI) concentrations in water from deep wells in the western subarea, downgradient from the Lockhart fault, and other areas outside the mapped regulatory Cr(VI) plume may be related to mafic chromium-containing bedrock and aqueous geochemical conditions in those areas.

Downward Cr(VI) concentration trends were observed in 146 monitoring wells. Wells having downward Cr(VI) trends were largely within the Q4 2015 regulatory Cr(VI) plume, and Cr(VI) concentration trends can be attributed to PG&E's groundwater-management and remediation activities downgradient from the Hinkley compressor station. Rates of decrease in Cr(VI) concentrations in water from some wells were greater than 25 µg/L per year.

Upward Cr(VI) concentration trends were present in 8 domestic wells, and downward Cr(VI) concentration trends were present in 23 domestic wells for the period from July 2012 to June 2017. The number of domestic wells having upward or downward trends in Cr(VI) concentrations exceeded the number expected by chance alone. Domestic wells having upward or downward trends were largely clustered within formerly residential areas west of the Q4 2015 regulatory Cr(VI) plume. Decreased pumping from domestic wells, as residents left after PG&E purchased the property, is a possible cause of the trends in Cr(VI) concentrations in this area—with upward or downward Cr(VI) concentration trends in individual wells controlled by site-specific geologic conditions, well construction, and previous pumping patterns. Based on regulatory guidance from the Lahontan Regional Water Quality Control Board, PG&E destroyed domestic wells on property that they purchased within Hinkley and Water Valleys; continued monitoring of destroyed wells is not possible, thereby limiting Cr(VI) data available from some domestic wells for trend analyses.

The number of monitoring wells having upward or downward Cr(VI) concentration trends exceeds the number expected by chance alone. Upward Cr(VI) concentration trend data suggest that the Cr(VI) plume east and southeast of the Hinkley compressor station and near the leading edge of the Q4 2015 regulatory Cr(VI) plume within the northern subarea of Hinkley Valley may have expanded between 2012 and 2017. The large number of monitoring wells having downward Cr(VI) concentration trends within the Q4 2015 regulatory Cr(VI) plume is attributable to management practices intended to control the plume. However, it is not possible to distinguish between natural or anthropogenic sources of Cr(VI) and processes controlling Cr(VI) concentrations (including changes in plume-management practices) based solely on the basis of Cr(VI) concentration trend data. However, statistically significant Cr(VI) concentration trends (either upward or downward) were used to identify wells of interest within the summative-scale analyses (SSA) used to define the margins of the Cr(VI) plume (chapter G). Hexavalent chromium concentrations in water from wells having no statistically significant trend also were used within the SSA to identify wells potentially unaffected by Cr(VI) releases from the Hinkley compressor station.

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Appendix D.1. Quality Assurance and Environmental Hexavalent Chromium Data from Selected Monitoring and Domestic Wells Sampled for Regulatory Purposes by Pacific Gas and Electric Company, Hinkley and Water Valleys, Western Mojave Desert, California, July 2008 through June 2017

This appendix contains tables (available for download at https://doi.org/10.3133/pp1885) of (1) duplicate hexavalent chromium, Cr(VI), data (table D.1.1), (2) field blank Cr(VI) data (table D.1.2), (3) Cr(VI) data from monitoring wells (table D.1.3), (4) Kendall's tau and significance probability data for Cr(VI) concentration trends from selected monitoring wells (table D.1.4), (5) Cr(VI) data from domestic wells (table D.1.5), and (6) Kendall's tau and significance probability data for Cr(VI) concentration trends from selected domestic wells (table D.1.6). Duplicate Cr(VI) and field blank Cr(VI) data were collected by Pacific Gas and Electric Company (PG&E) for regulatory quality assurance purposes; Cr(VI) data from monitoring and domestic wells were collected for regulatory purposes by PG&E. Samples were collected using field protocols developed by PG&E for the site. Hexavalent chromium samples were analyzed using the U.S. Environmental Protection Agency (EPA) Method 218.6 (U.S. Environmental Protection Agency, 1994) with a laboratory reporting level of 0.2 micrograms per liter (µg/L) at a commercial laboratory; low-level Cr(VI) analyses were analyzed using a modified version of the EPA Method 218.6 with a laboratory reporting level of 0.06 µg/L at the same commercial laboratory. Kendall's tau and significance probability data were from the Mann-Kendall test for trend (Helsel and Hirsch, 2002; Helsel and others, 2020) calculated using the Statistical Analysis System (SAS Institute, Cary, North Carolina) as part of this study.

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