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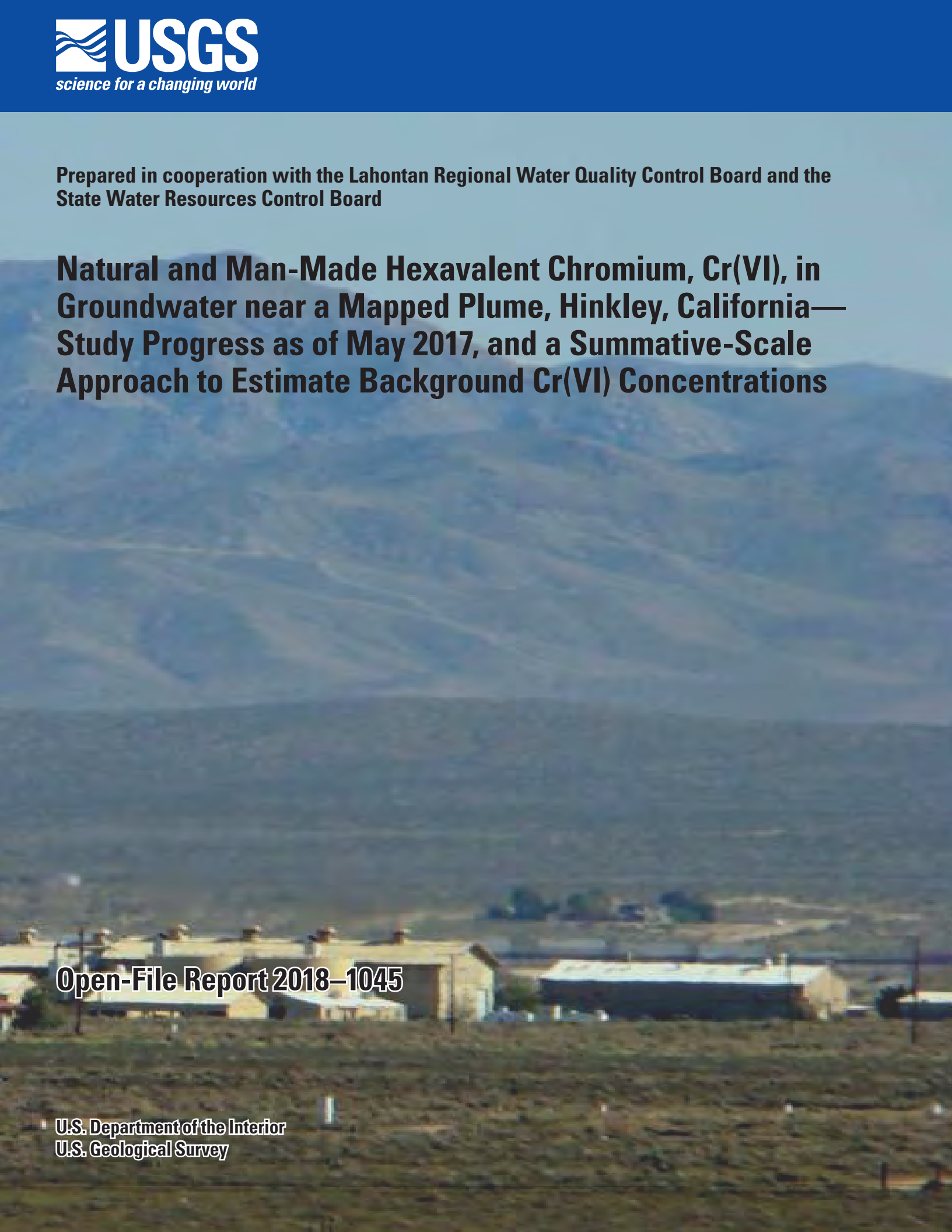
Natural and Man-Made Hexavalent Chromium, Cr(VI), in Groundwater near a Mapped Plume, Hinkley, California—Study Progress as of May 2017, and a Summative-Scale Approach to Estimate Background Cr(VI) Concentrations



Open-File Report 2018–1045

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

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U.S. Department of the Interior
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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
micrometer (µm)	0.00003937	inch (in.)
kilometer (km)	0.6214	mile (mi)
	Volume	
liter (L)	33.81402	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
	Mass	
microgram (µg)	0.00000003527	ounce, avoirdupois (oz)

Datum

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

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 micrograms per liter (µg/L).

Abbreviations

CPT	cone penetrometer
Cr(III)	trivalent chromium
Cr(t)	total dissolved chromium
Cr(VI)	hexavalent chromium
IRP	Independent Review Panel
IRZ	in situ reductive zone
NWIS	National Water Information System
PG&E	Pacific Gas and Electric Company
Q4 2015	fourth quarter 2015
RWQCB	Regional Water Quality Control Board
SSRL	Stanford Synchrotron Radiation Light Source
TWG	Technical Working Group
USGS	U.S. Geological Survey

Natural and Man-Made Hexavalent Chromium, Cr(VI), in Groundwater near a Mapped Plume, Hinkley, California—Study Progress as of May 2017, and a Summative-Scale Approach to Estimate Background Cr(VI) Concentrations

By John A. Izbicki and Krishangi Groover

Abstract

This report describes (1) work done between January 2015 and May 2017 as part of the U.S. Geological Survey (USGS) hexavalent chromium, Cr(VI), background study and (2) the summative-scale approach to be used to estimate the extent of anthropogenic (man-made) Cr(VI) and background Cr(VI) concentrations near the Pacific Gas and Electric Company (PG&E) natural gas compressor station in Hinkley, California. Most of the field work for the study was completed by May 2017. The summative-scale approach and calculation of Cr(VI) background were not well-defined at the time the USGS proposal for the background Cr(VI) study was prepared but have since been refined as a result of data collected as part of this study. The proposed summative scale consists of multiple items, formulated as questions to be answered at each sampled well. Questions that compose the summative scale were developed to address geologic, hydrologic, and geochemical constraints on Cr(VI) within the study area. Each question requires a binary (yes or no) answer. A score of 1 will be assigned for an answer that represents data consistent with anthropogenic Cr(VI); a score of –1 will be assigned for an answer that represents data inconsistent with anthropogenic Cr(VI). The areal extent of anthropogenic Cr(VI) estimated from the summative-scale analyses will be compared with the areal extent of anthropogenic Cr(VI) estimated on the basis of numerical groundwater flow model results, along with particle-tracking analyses. On the basis of these combined results, background Cr(VI) values will be estimated for "Mojave-type" deposits, and other deposits, in different parts of the study area outside the summative-scale mapped extent of anthropogenic Cr(VI).

Introduction

The Pacific Gas and Electric Company (PG&E) Hinkley Compressor Station (also referred to as the compressor station), in the Mojave Desert, 80 miles northeast of Los Angeles, California (fig. 1), is used to compress natural gas as it is transported through a pipeline from Texas to California. Between 1952 and 1964, cooling water used at the compressor station was treated with a compound containing hexavalent chromium, Cr(VI), to prevent corrosion. The cooling-tower waste was discharged to unlined ponds, releasing Cr(VI) to soil and groundwater in the underlying alluvial aquifer (Lahontan Regional Water Quality Control Board, 2013). Since 1964, cooling-water management practices that do not release chromium to groundwater have been used at the site.

In 2007, a PG&E study of the background Cr(VI) concentrations in groundwater estimated average Cr(VI) concentrations in the Hinkley, Calif., area to be 1.2 micrograms per liter (µg/L), with a 95-percent upper-confidence limit of 3.1 µg/L (CH2M-Hill, 2007). The 3.1-µg/L upper-confidence limit was adopted by the Lahontan Regional Water Quality Control Board (RWQCB) as the maximum background Cr(VI) concentration. This concentration was used to map the plume extent for regulatory purposes. In response to criticism of the PG&E 2007 study's methodology (Lahontan Regional Water Quality Control Board, 2011), and to an increase in the mapped extent of Cr(VI) greater than 3.1 mg/L between 2008 and 2011, the Lahontan RWQCB (2012) agreed with staff recommendations that the 2007 PG&E background Cr(VI) concentration study be updated. Maps of the Cr(VI) extent in groundwater are available at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/archive.html, accessed February 21, 2018, and regulatory orders, studies, and other information pertaining to PG&E Hinkley Compressor Station Cr(VI) cleanup are available at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/, accessed March 6, 2018.

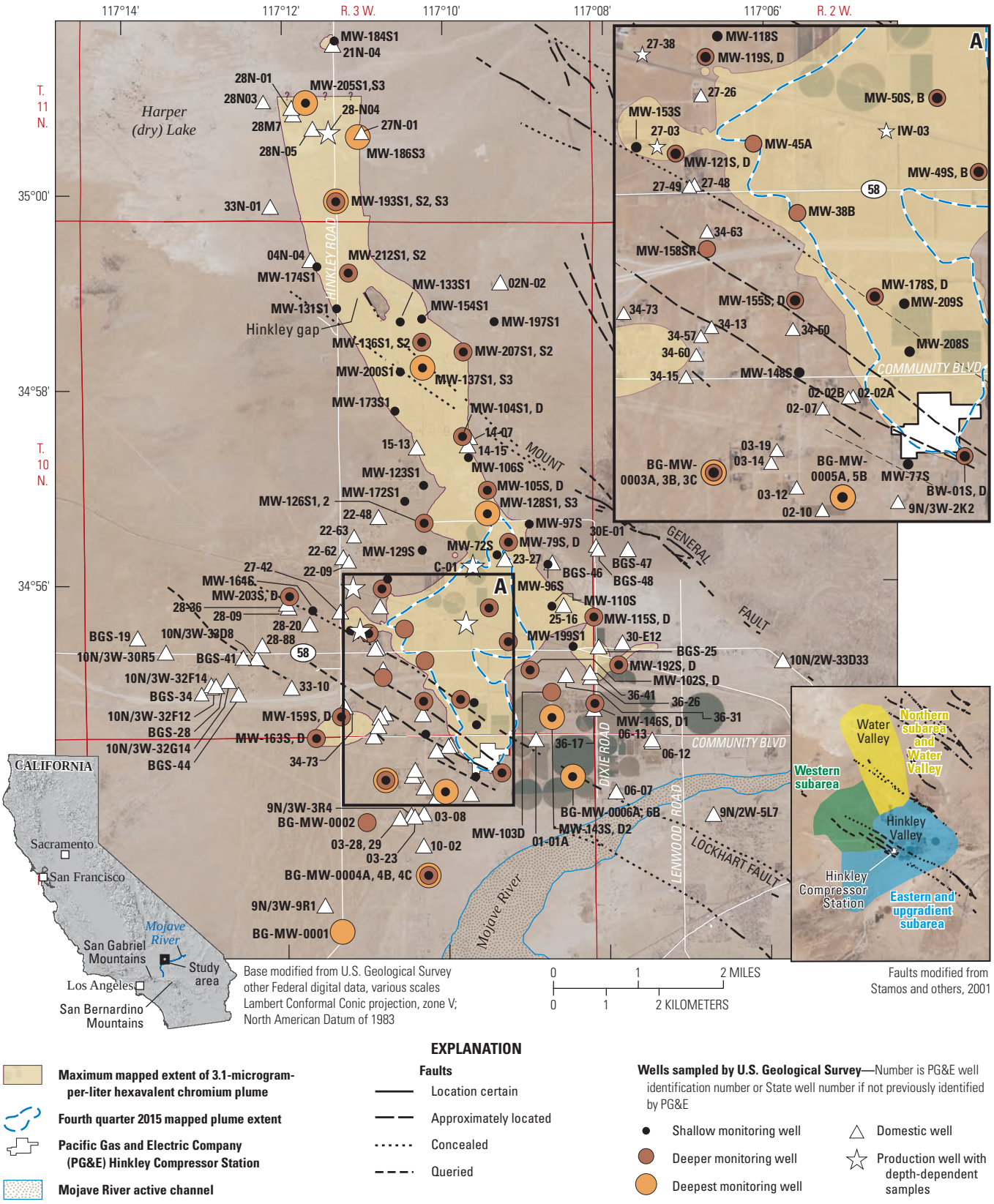

Figure 1. Location of study area and wells sampled by the U.S. Geological Survey, Hinkley and Water Valleys, California, March 2015 to March 2017. (Maximum mapped extent of 3.1-microgram-per-liter hexavalent chromium plume and fourth quarter 2015 mapped plume extent from Pacific Gas and Electric Company, data accessed February 22, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/.)

The U.S. Geological Survey (USGS) background Cr(VI) study was developed in collaboration with a Technical Working Group (TWG) composed of community members, the Independent Review Panel (IRP) Manager (Project Navigator, Ltd.), the Lahontan RWQCB, PG&E, and consultants for PG&E. Community participation on the TWG is open to the public. The purposes of the updated background Cr(VI) concentration study are to (1) evaluate the extent of anthropogenic Cr(VI) associated with releases from the PG&E compressor station and (2) estimate background Cr(VI) concentrations in the aquifer upgradient, downgradient, and cross-gradient from the mapped Cr(VI) plume near Hinkley, Calif. (Izbicki and Groover, 2016). The study has eight tasks (table 1), and the proposal for the USGS study, in cooperation with the Lahontan RWQCB, is available at https://ca.water.usgs.gov/projects/hinkley/. Experimental data (Task 8) collected as part of the USGS Cr(VI) background study does not specifically address background Cr(VI) concentrations, but instead addresses the potential for chromium—reduced from soluble Cr(VI) to insoluble trivalent chromium, Cr(III), as part of PG&E remediation activities within their in situ reductive zone(s) (IRZ) downgradient from the compressor station—to reoxidize to Cr(VI) over time.

This report describes (1) work done between January 2015 and May 2017 as part of the USGS Cr(VI) background study and (2) the summative-scale approach to be used to estimate the extent of anthropogenic (man-made) Cr(VI) and to estimate Cr(VI) background near the Pacific Gas and Electric Company (PG&E) natural gas compressor station in Hinkley, Calif. Estimation of the extent of anthropogenic (man-made) Cr(VI) is Task 6, and calculation of Cr(VI) background is Task 7 of the USGS Cr(VI) background study (table 1). Information needed to fully define the scope of these tasks was not available at the time of preparation for the USGS proposal for this work but has since been collected as part of Tasks 1 through 5 (fig. 2).

This report partially fulfills "mid-term" report requirements described in the USGS proposal and cooperative agreement with the State Water Resources Control Board. Additional items submitted to the Lahontan RWQCB and the Technical Working Group (TWG) on June 27, 2017, in fulfillment of the "mid-term" report requirements include

1. an annotated outline describing the proposed content of the final report, and
2. a presentation describing the status of the work and the report process.

Table 1. Tasks and questions addressed by the U.S. Geological Survey hexavalent chromium, Cr(VI), background study, January 2015 to the proposed study end in December 2019, Hinkley and Water Valleys, California.

[Modified from Izbicki and Groover, 2016. **Abbreviations**: Cr(III), trivalent chromium; Cr(VI), hexavalent chromium; PG&E, Pacific Gas and Electric Company]

Task		Purpose	Status, May 2017
Task 1:	Evaluation of existing data.	Identify areas near the mapped Cr(VI) plume having water quality of concern to the study.	To be updated.
Task 2:	Analyses of rock and alluvium.	Determine if there are natural geologic sources of chromium in the area and if these sources are contributing Cr(VI) to groundwater.	Field work complete, lab analyses pending.
Task 3:	Analyses of chemical and environmental tracers in water from wells.	Determine the chemical and isotopic composition (including age dating) of water from selected wells throughout the study area—with respect to (1) the sources and chemical processes controlling Cr(VI) and (2) the source, movement, and age of the groundwater relative to the timing of Cr(VI) associated with PG&E.	Field work complete, lab analyses pending.
Task 4:	Evaluation of local hydrogeologic conditions.	Determine how differences in local geohydrology within the western, northern (including Water Valley), and eastern (including the plume and upgradient area) subareas influence Cr(VI) concentrations in groundwater and the movement of anthropogenic (man-made) Cr(VI) associated with PG&E.	Field work complete, lab analyses pending.
Task 5:	Evaluation of groundwater movement.	Evaluate how changing hydrologic conditions in the study area through time influence the movement of water and Cr(VI) through aquifers underlying Hinkley and Water Valleys.	In progress.
Task 6:	Evaluation of natural and anthropogenic Cr(VI).	Identify areas within the aquifer containing man-made Cr(VI) from releases associated with PG&E and areas that contain Cr(VI) from other sources.	In progress.
Task 7:	Estimation of background Cr(VI) concentrations.	Estimate background Cr(VI) in parts of the study area not affected by discharges associated with PG&E.	In progress.
Task 8:	Fate of chromium during and after in situ reduction.	Determine if Cr(VI) converted to Cr(III) within the in situ reductive zone (IRZ) is permanently removed from solution.	In progress.

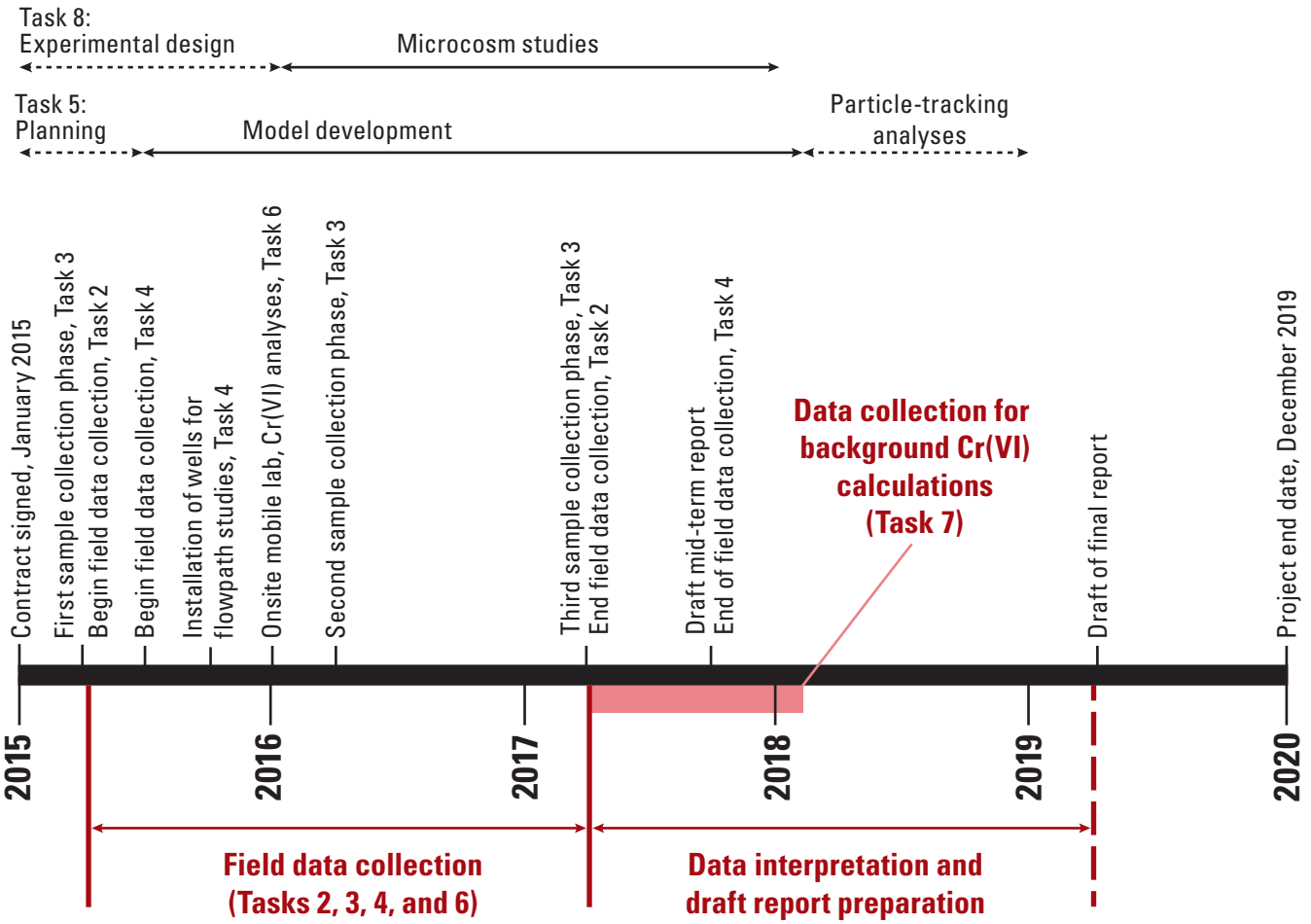

Figure 2. Simplified project timeline, May 2017 (modified from Izbicki and Groover, 2016).

Comments by the TWG on the May 2017 draft version of this report were addressed to the TWG on September 13, 2017. Preliminary interpretations of data from the USGS Cr(VI) background study are not provided in this report.

Study Progress

The agreement for the Cr(VI) background study between the USGS and the State Water Resources Control Board was signed January 7, 2015. The study was funded cooperatively by the State Water Resources Control Board and the USGS for $5,379,300 and is scheduled to be completed December 31, 2019. Quarterly progress reports submitted to the Lahontan RWQCB are available at https://geotracker.waterboards.ca.gov/profile_report.asp?global_id=T10000010367 (accessed February 21, 2018), and a summary of the work completed by study task as of May 2017 is provided in appendix 1.

Most of the field work described in Tasks 1 through 5 (table 1) was completed by May 2017, although small amounts of data collection and some laboratory work associated with these tasks were not complete at that time. Field work associated with Task 7, which will provide the data to be used to calculate the background Cr(VI) concentration, began in April 2017 and is scheduled to be completed January 2018. Study progress was facilitated by cooperation with PG&E and their consultants who provided site access, sample-collection support, drilling and well installation, access to data, and access to archived core material. Study progress on the various tasks has been shared with the TWG during (approximately) quarterly meetings, and with the community in quarterly newsletters prepared by the IRP Manager, at evening meetings hosted by the Lahontan RWQCB or the IRP Manager, and at Saturday breakfast meetings hosted by local community groups.

Procedures to Estimate the Extent of Anthropogenic Cr(VI) and to Estimate Background Cr(VI)

The following describes collection and availability of selected data and how those data will be used to (1) estimate the areal extent of anthropogenic (man-made) Cr(VI) associated with releases from the PG&E compressor station using a summative-scale approach, including comparison with numerical groundwater flow model results; (2) calculate background Cr(VI) concentrations; (3) compare monitoring-well data with domestic-well data; (4) evaluate data from wells that may be of special concern with respect to study objectives; and (5) limitations of the approach.

Data Collection and Availability

Between March 2015 and May 2017, the USGS collected water samples for measurement of chemical and isotopic composition (including age dating) from approximately 100 wells in Hinkley and Water Valleys, Calif. (fig. 3; table 2). Most sampled wells were selected from more than 600 monitoring wells installed by PG&E for regulatory purposes; samples also were collected from monitoring wells installed by PG&E consultants as part of the USGS Cr(VI) background study upgradient from the PG&E compressor station (for the purposes of the study, these wells are known as "flowpath wells"). Additional samples were collected from domestic wells in areas where monitoring wells were not available. Concentrations of Cr(VI) in water from sampled wells are shown in figure 3; average concentrations are shown for wells sampled by the USGS more than once between March 2015 and May 2017.

Wells sampled by the USGS for complete chemical and isotopic composition (including age dating) as part of this study were selected in collaboration with the TWG. The selected wells represent a mutually agreed upon, spatially distributed set of wells covering a range of geologic, hydrologic, and geochemical settings within and near the mapped PG&E Cr(VI) plume. Data collection was done in three phases in March 2015, March 2016, and March 2017. This allowed preliminary interpretation of earlier data to guide the collection of later data. In addition to chemical and isotopic analyses of groundwater, core material from the wells (available for most PG&E monitoring wells and the flowpath wells) was examined to determine its geologic provenance (depositional source and history). Chromium and selected trace element concentrations in available core material also were measured using handheld (portable) X-ray fluorescence (pXRF; Groover and Izbicki, 2016). Additional mineralogic and chemical analyses (including elemental and mineralogic analyses of mineral grains by particle size and particle density, and sequential chemical extraction and analyses of elements sorbed on the surfaces of mineral grains) were done on selected core material from some wells. These data also were used to guide well selection and data collection.

Collectively, the wells sampled by the USGS between March 2015 and March 2017 represent the most complete, independent set of geologic, chemical, and isotopic data available near the mapped PG&E Cr(VI) plume. Wells used to calculate background Cr(VI) concentrations will be selected from the set of approximately 100 wells sampled as part of the USGS Cr(VI) background study (table 2). Data collected from wells sampled in 2015 and 2016 were provided to the TWG on December 14, 2016, and are publically available from the USGS National Water Information System (NWIS) online database (https://waterdata.usgs.gov/nwis). Data from the March 2017 sample collection will be provided to the TWG and released publicly through NWIS after analyses are completed, reviewed, quality-assured, and uploaded to NWIS.

In addition to wells sampled quarterly for regulatory purposes, PG&E continued to sample monitoring wells included in the USGS Cr(VI) background study quarterly until January 2018. The USGS also continued to sample wells (including the flowpath wells upgradient of the compressor station and selected domestic wells) quarterly until January 2018. Water from wells collected by PG&E and the USGS during this time as part of the Cr(VI) background study will be analyzed for field parameters (including water temperature, dissolved oxygen, pH, specific conductance) and Cr(VI) and total dissolved chromium, Cr(t), concentrations.

Not all wells sampled as part of the USGS Cr(VI) background study are suitable for calculation of background Cr(VI) concentrations. For example, some of the sampled monitoring wells are within the fourth quarter 2015 (Q4 2015) footprint of the mapped Cr(VI) plume (fig. 1; table 2). Many of these wells were selected to provide end-member data on mapped plume chemical and isotopic compositions. These wells (including deeper monitoring wells within the footprint of the plume that may have low Cr(VI) concentrations and may appear unaffected by Cr(VI) releases) will be excluded from the background Cr(VI) calculation.

The Q4 2015 mapped plume (https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/docs/chromium_plume/4q_2015_11x17.pdf, accessed February 21, 2018) was selected as a benchmark for comparison with data collected by the USGS Cr(VI) background study because

1. Q4 2015 (October 2015) is within the Cr(VI) background study data collection period (March 2015 through March 2017), and

2. the Q4 2015 dataset is the most complete set of regulatory data available at the site before the approval of the November 2015 Cleanup and Abatement Order (Lahontan Regional Water Quality Control Board, 2015) that reduced regulatory sampling requirements.

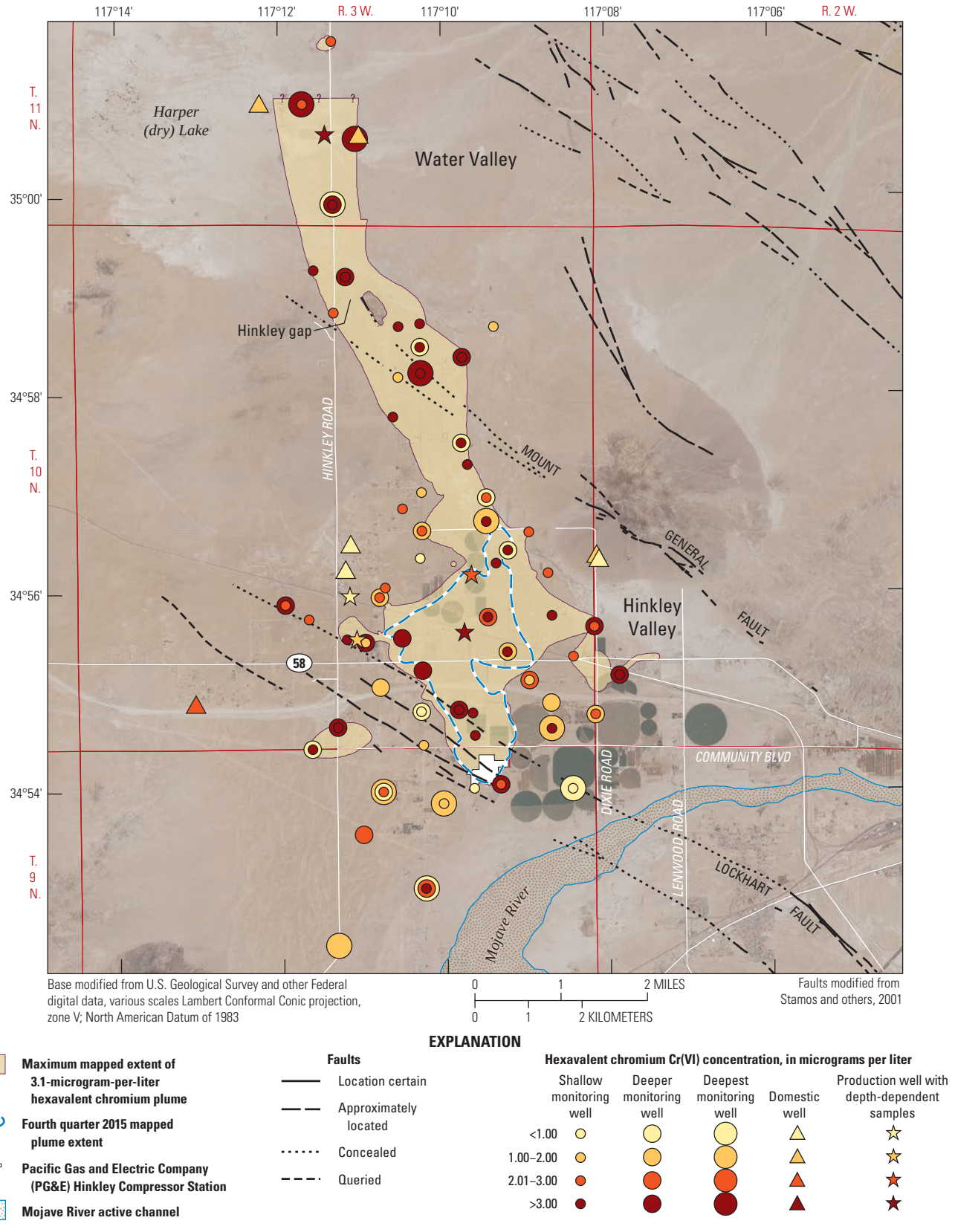

Figure 3. Hexavalent chromium, Cr(VI), concentrations in wells sampled for chemical and isotopic composition (including age dating), Hinkley and Water Valleys, California, March 2015 to March 2017. (Maximum mapped extent of 3.1-microgram-per-liter hexavalent chromium plume and fourth quarter 2015 mapped plume extent from Pacific Gas and Electric Company, PG&E, data accessed February 22, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/.)

Table 2. Hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from wells sampled for chemical and isotopic composition (including age dating) by the U.S. Geological Survey, Hinkley and Water Valleys, California, March 2015 through March 2017.

[Cr(VI) and Cr(t) filtered through 0.45-micrometer pore-sized filter with analysis by Assett Laboratories, Las Vegas, Nevada. Well included as older groundwater if carbon-14 activity is less than 90 percent modern carbon after accounting for the addition of carbon not containing carbon-14 from aquifer solids. Carbon-14, adjusted for carbon-13, using mixing model with measured carbon-13 composition from aquifer solids of –4 per mil for inorganic carbon, or –25 per mil for organic carbon. Samples from depth-dependent wells collected from surface discharge of tempory production pump. Depth-specific samples not shown. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; <, less than value shown]

PG&E site name	State well identification number	USGS well identification number	Date (mm/dd/yyyy)	Altitude of land surface, in feet above sea level	Depth of well, in feet below land surface datum	Arsenic, As, in micrograms per liter	Hexavalent chromium, Cr(VI), in micrograms per liter	Total chromium, Cr(t), in micrograms per liter	Uranium (natural), U, in micrograms per liter
Eastern subarea									
MW-77 S	009N003W02G013S	345401117093902	03/05/2015	2,212	100	1.3	0.93	0.88	3.6
MW-143 D2	010N003W36P008S	345437117084201	03/14/2016	2,191	134	1.8	1.6	1.9	34
MW-143 S	010N003W36P010S	345437117084203	03/15/2016	2,191	94	2.3	3.2	2.9	47
MW-146 D1	010N003W31M004S	345446117081002	03/08/2017	2,182	114	1.9	1.4	1.7	28
MW-146 S	010N003W3100M5S	345446117081003	03/08/2017	2,182	85	2.6	2.5	2.6	38
MW-102 D	010N003W36D004S	345507117085901	03/07/2016	2,182	136	1.3	2.5	2.8	32
MW-102 S	010N003W36D005S	345507117085902	03/07/2016	2,182	111	1.2	1.8	2.2	64
MW-102 S	010N003W36D005S	345507117085902	03/10/2017	2,182	111	1.3	1.6	2.0	54
MW-192 D	010N002W31D004S	345509117075201	03/06/2015	2,177	110	2.2	4.1	4.1	114
MW-192 S	010N002W31D005S	345509117075202	03/06/2015	2,177	78	2.0	3.9	3.4	92
MW-199 S1	010N003W25R009S	345520117082604	03/17/2017	2,179	85	2.9	2.5	2.9	27
MW-115 D	010N003W25J001S	345539117081001	03/08/2017	2,172	113	3.2	3.5	3.9	6.6
MW-115 S	010N003W25J002S	345539117081002	03/08/2017	2,172	90	4.0	2.1	3.4	12
MW-110 S	010N003W25G004S	345545117084102	03/04/2015	2,172	90	0.88	3.8	3.9	33
MW-96 S	010N003W25C006S	345611117084402	03/04/2015	2,166	95	1.6	2.2	2.2	11
BGS-48	010N002W19N002S	345620117080601	03/09/2016	2,217	258	122	0.44	0.11	3.0
30E-01	010N002W19N001S	345622117080801	03/11/2015	2,221	224	114	1.8	1.7	3.4
Eastern subarea (flowpath wells)									
BG-MW-0001	009N003W15E0002S	345226117111902	05/11/2016	2,312	198	2.6	1.8	1.6	8.3
BG-MW-0004 C	009N003W11M004S	345300117101502	05/05/2016	2,212	165	13	0.70	0.65	4.3
BG-MW-0004 B	009N003W11M005S	345300117101503	05/05/2016	2,212	115	4.5	2.7	2.7	16
BG-MW-0004 A	009N003W11M006S	345300117101504	05/06/2016	2,212	65	1.4	3.1	3.1	9.2
BG-MW-0002	009N003W10C002S	345333117110102	05/11/2016	2,270	115	1.6	2.5	2.2	8.8
BG-MW-0005 B	009N003W02M006S	345352117100202	05/02/2016	2,243	182	8.4	1.1	1.1	14
BG-MW-0005 A	009N003W02M007S	345352117100203	05/02/2016	2,243	116	2.8	1.9	2.0	6.8
BG-MW-0003 C	009N003W03K004S	345359117104602	05/04/2016	2,251	190	11	1.1	0.91	66

Table 2. Hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from wells sampled for chemical and isotopic composition (including age dating) by the U.S. Geological Survey, Hinkley and Water Valleys, California, March 2015 through March 2017.—Continued

[Cr(VI) and Cr(t) filtered through 0.45-micrometer pore-sized filter with analysis by Assett Laboratories, Las Vegas, Nevada. Well included as older groundwater if carbon-14 activity is less than 90 percent modern carbon after accounting for the addition of carbon not containing carbon-14 from aquifer solids. Carbon-14, adjusted for carbon-13, using mixing model with measured carbon-13 composition from aquifer solids of –4 per mil for inorganic carbon, or –25 per mil for organic carbon. Samples from depth-dependent wells collected from surface discharge of tempory production pump. Depth-specific samples not shown. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; <, less than value shown]

PG&E site name	State well identification number	USGS well identification number	Date (mm/dd/yyyy)	Altitude of land surface, in feet above sea level	Depth of well, in feet below land surface datum	Arsenic, As, in micrograms per liter	Hexavalent chromium, Cr(VI), in micrograms per liter	Total chromium, Cr(t), in micrograms per liter	Uranium (natural), U, in micrograms per liter
Eastern subarea (flowpath wells)—Continued									
BG-MW-0003 B	009N003W03K005S	345359117104603	05/04/2016	2,251	167	9.8	0.67	0.48	6.6
BG-MW-0003 A	009N003W03K006S	345359117104604	05/03/2016	2,251	121	1.3	1.9	2.2	7.7
BG-MW-0006 B	009N003W01G002S	345401117082702	05/10/2016	2,192	167	7.9	0.31	0.13	6.0
BG-MW-0006 A	009N003W01G003S	345401117082703	05/10/2016	2,192	101	1.8	0.63	0.49	29
Eastern subarea (or within fourth quarter 2015 mapped plume)									
BW-01 S	009N003W02H015S	345404117092002	03/06/2017	2,203	104	3.5	2.5	2.7	14
MW-208 S	010N003W35Q034S	345433117093901	03/18/2016	2,199	107	107	2,500	2,700	33
MW-209 S	010N003W35K030S	345447117094001	03/11/2016	2,195	109	0.92	63	61	30
MW-178 D	010N003W35L003S	345449117095001	03/22/2017	2,201	135	1.8	190	240	76
MW-178 S	010N003W35L004S	345449117095002	03/22/2017	2,201	113	0.64	150	160	38
MW-103 D	010N003W36L002S	345453117084201	03/16/2017	2,186	120	1.7	1.0	1.8	44
MW-38 B	010N003W34A005S	345513117101601	03/05/2015	2,191	126	0.77	27	26	52
MW-49 D	010N003W26R009S	345524117091401	03/07/2017	2,178	146	1.1	1.6	1.8	46
MW-49 S	010N003W26R010S	345524117091403	03/07/2017	2,178	105	0.91	4.1	4.1	19
MW-45 A	010N003W27J010S	345532117103102	03/13/2015	2,178	105	1.2	3.1	3.2	25
MW-50 D	010N003W26J006S	345545117092901	03/07/2017	2,174	162	1.8	2.8	2.8	27
MW-50 S	010N003W26J005S	345545117092903	03/07/2017	2,174	95	0.50	16	16	31
MW-72 S	010N003W23R015S	345617117092202	03/04/2015	2,161	100	0.52	4.8	4.4	59
MW-79 D	010N003W23J007S	345625117091301	03/03/2015	2,160	165	6.7	<0.06	0.13	2.4
MW-79 S	010N003W23J004S	345625117091302	03/03/2015	2,160	120	0.86	5.6	5.3	61
MW-128 S3	010N003W23H011S	345642117092901	03/02/2015	2,156	134	0.87	1.8	1.8	38
MW-128 S1	010N003W23H013S	345642117092903	03/02/2015	2,156	97	0.95	4.4	4.5	19
Western subarea									
MW-163 D	009N003W04B002S	345425117113801	03/10/2015	2,235	111	7.3	<0.06	0.19	5.3
MW-163 S	009N003W04B001S	345425117113802	03/10/2015	2,235	95	1.7	10.0	11.0	12
MW-149 S	010N003W35N004S	345428117101701	03/10/2017	2,226	122	0.65	1.4	1.5	13
MW-159 D	010N003W34N010S	345438117111902	03/11/2015	2,225	120	1.4	5.7	5.0	9.1

Table 2. Hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from wells sampled for chemical and isotopic composition (including age dating) by the U.S. Geological Survey, Hinkley and Water Valleys, California, March 2015 through March 2017.—Continued

[Cr(VI) and Cr(t) filtered through 0.45-micrometer pore-sized filter with analysis by Assett Laboratories, Las Vegas, Nevada. Well included as older groundwater if carbon-14 activity is less than 90 percent modern carbon after accounting for the addition of carbon not containing carbon-14 from aquifer solids. Carbon-14, adjusted for carbon-13, using mixing model with measured carbon-13 composition from aquifer solids of –4 per mil for inorganic carbon, or –25 per mil for organic carbon. Samples from depth-dependent wells collected from surface discharge of tempory production pump. Depth-specific samples not shown. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; <, less than value shown]

PG&E site name	State well identification number	USGS well identification number	Date (mm/dd/yyyy)	Altitude of land surface, in feet above sea level	Depth of well, in feet below land surface datum	Arsenic, As, in micrograms per liter	Hexavalent chromium, Cr(VI), in micrograms per liter	Total chromium, Cr(t), in micrograms per liter	Uranium (natural), U, in micrograms per liter
Western subarea—Continued									
MW-159 D	010N003W34N010S	345438117111902	03/21/2017	2,225	120	1.4	5.3	7.7	9.4
MW-155 D	010N003W34J007S	345448117101801	03/09/2017	2,207	152	5.0	<0.06	0.42	0.62
MW-159 S	010N003W34N011S	345438117111903	03/11/2015	2,225	105	0.85	6.6	6.3	10
MW-159 S	010N003W34N011S	345438117111903	03/21/2017	2,225	105	1.0	6.0	7.2	9.8
MW-155 S	010N003W34J008S	345448117101802	03/09/2017	2,207	128	2.3	0.54	0.69	7.3
BGS-34	010N003W32F004S	345453117130401	03/10/2016	2,237	147	14	2.3	2.4	8.8
MW-158 SR	010N003W34G006S	345503117104802	03/16/2017	2,201	116	5.3	1.4	4.6	21
MW-121 D	010N003W27P005S	345529117105801	03/12/2015	2,185	119	2.8	3.9	3.6	14
MW-121 D	010N003W27P005S	345529117105801	03/14/2017	2,185	119	3.4	3.4	4.0	13
MW-121 S	010N003W27P006S	345529117105802	03/17/2015	2,185	101	1.2	2.0	1.9	16
MW-121 S	010N003W27P006S	345529117105802	03/14/2017	2,185	101	1.6	2.0	2.0	14
MW-153 S	010N003W27N011S	345531117111201	03/18/2015	2,185	109	1.7	3.3	3.4	8.6
MW-164 S	010N003W28K020S	345544117114002	03/14/2016	2,175	90	3.9	2.2	2.1	38
MW-203 D	010N003W28F032S	345552117115702	03/17/2015	2,170	118	300	8.9	9.1	17
MW-203 D	010N003W28F032S	345552117115702	03/15/2017	2,170	118	320	5.4	8.2	15
MW-203 S	010N003W28F033S	345552117115703	03/19/2015	2,170	84	18	2.8	2.9	19
MW-203 S	010N003W28F033S	345552117115703	03/13/2017	2,170	84	21	2.6	3.6	19
MW-119 D	010N003W27G010S	345557117104801	03/13/2015	2,164	120	2.6	1.7	1.7	8.5
MW-119 D	010N003W27G010S	345557117104801	03/15/2017	2,164	120	3.3	1.5	1.8	8.3
MW-119 S	010N003W27G011S	345557117104802	03/18/2015	2,164	90	3.3	2.3	2.4	9.9
MW-118 S	010N003W27B002S	345603117104401	03/16/2016	2,162	90	1.6	2.5	2.6	13
22-09	010N003W22N014S	345614117111301	03/11/2015	2,161	150	3.5	<0.06	0.13	9.8
22-63	010N003W22M022S	345629117110901	03/10/2015	2,158	200	8.2	0.89	0.97	8.5
Northern subarea									
MW-129 S	010N003W22RX00XS	345621117101901	03/18/2016	2,162	95	2.2	0.93	0.96	15
MW-97 S	010N003W24M010S	345636117085802	03/05/2015	2,166	95	7.2	2.7	2.6	6.5
MW-126 S2	010N003W23M007S	345637117101701	03/15/2016	2,159	116	1.6	1.7	1.7	86

Table 2. Hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from wells sampled for chemical and isotopic composition (including age dating) by the U.S. Geological Survey, Hinkley and Water Valleys, California, March 2015 through March 2017.—Continued

[Cr(VI) and Cr(t) filtered through 0.45-micrometer pore-sized filter with analysis by Assett Laboratories, Las Vegas, Nevada. Well included as older groundwater if carbon-14 activity is less than 90 percent modern carbon after accounting for the addition of carbon not containing carbon-14 from aquifer solids. Carbon-14, adjusted for carbon-13, using mixing model with measured carbon-13 composition from aquifer solids of –4 per mil for inorganic carbon, or –25 per mil for organic carbon. Samples from depth-dependent wells collected from surface discharge of tempory production pump. Depth-specific samples not shown. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; <, less than value shown]

PG&E site name	State well identification number	USGS well identification number	Date (mm/dd/yyyy)	Altitude of land surface, in feet above sea level	Depth of well, in feet below land surface datum	Arsenic, As, in micrograms per liter	Hexavalent chromium, Cr(VI), in micrograms per liter	Total chromium, Cr(t), in micrograms per liter	Uranium (natural), U, in micrograms per liter
Northern subarea—Continued									
MW-126 S1	010N003W23M008S	345637117101702	03/15/2016	2,159	95	1.3	2.5	2.6	65
MW-172 S1	010N003W22G010S	345651117103002	03/17/2016	2,149	90	2.5	2.8	2.9	18
MW-105 D	010N003W23A002S	345657117092901	03/03/2015	2,155	130	23	<0.06	0.32	6.5
MW-105 S	010N003W23A003S	345657117092902	03/03/2015	2,155	95	0.70	2.9	2.7	28
MW-123 S1	010N003W23D004S	345701117101702	03/16/2016	2,152	95	1.7	2.0	1.9	22
MW-106 S	010N003W14K005S	345717117094202	03/19/2015	2,152	95	1.5	3.1	2.9	12
MW-104 D	010N003W14F005S	345730117094701	03/18/2015	2,149	140	25	0.12	0.16	12
MW-104 S1	010N003W14F004S	345730117094703	03/18/2015	2,149	90	2.1	3.6	3.7	8.1
MW-173 S1	010N003W15B003S	345747117103703	03/09/2016	2,133	80	3.0	3.7	3.0	23
MW-200 S1	010N003W10J006S	345810117103303	03/17/2016	2,130	80	18	1.4	1.4	48
MW-137 S3	010N003W11M010S	345812117101601	03/10/2015	2,133	117	21	3.6	3.7	4.1
MW-137 S1	010N003W11M012S	345812117101603	03/10/2015	2,133	80	8.0	4.8	4.8	8.1
MW-137 S1	010N003W11M012S	345812117101603	03/09/2017	2,133	80	9.9	4.2	5.6	7.4
MW-207 S2	010N003W11L012S	345822117094601	03/17/2016	2,128	110	48	3.5	3.5	8.7
MW-207 S1	010N003W11L013S	345822117094602	03/17/2016	2,128	80	19	7.7	8.2	8.4
MW-136 S2	010N003W11E001S	345828117101701	03/09/2015	2,130	127	46	<0.06	0.55	3.7
MW-136 S1	010N003W11E002S	345828117101702	03/09/2015	2,130	82	2.8	3.9	3.7	8.4
MW-136 S1	010N003W11E002S	345828117101702	03/09/2017	2,130	82	3.4	3.6	4.0	8.0
MW-197 S1	010N003W11A004S	345841117092303	03/16/2016	2,132	69	200	1.1	1.1	4.5
MW-133 S1	010N003W10A002S	345841117103302	03/15/2016	2,127	80	71	8.8	8.1	6.0
MW-154S1	010N003W11D004S	345842117101702	03/12/2015	2,126	85	510	11	9.8	4.0
Northern subarea/Water Valley									
MW-131 S1	010N003W10D002S	345850117112001	03/08/2016	2,116	83	23	2.1	2.4	31
MW-212 S2	010N003W03M005S	345912117111201	03/16/2016	2,114	123	3.8	3.2	3.1	30
MW-212 S1	010N003W03M006S	345912117111202	03/14/2016	2,114	105	5.4	3.3	3.6	15
MW-174 S1	010N003W04J004S	345916117113603	03/09/2016	2,096	90	3.8	3.1	3.4	24
MW-193 S3	011N003W33R002S	345955117112002	03/12/2015	2,084	145	910	0.19	2.8	56

Table 2. Hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from wells sampled for chemical and isotopic composition (including age dating) by the U.S. Geological Survey, Hinkley and Water Valleys, California, March 2015 through March 2017.—Continued

[Cr(VI) and Cr(t) filtered through 0.45-micrometer pore-sized filter with analysis by Assett Laboratories, Las Vegas, Nevada. Well included as older groundwater if carbon-14 activity is less than 90 percent modern carbon after accounting for the addition of carbon not containing carbon-14 from aquifer solids. Carbon-14, adjusted for carbon-13, using mixing model with measured carbon-13 composition from aquifer solids of –4 per mil for inorganic carbon, or –25 per mil for organic carbon. Samples from depth-dependent wells collected from surface discharge of tempory production pump. Depth-specific samples not shown. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; <, less than value shown]

PG&E site name	State well identification number	USGS well identification number	Date (mm/dd/yyyy)	Altitude of land surface, in feet above sea level	Depth of well, in feet below land surface datum	Arsenic, As, in micrograms per liter	Hexavalent chromium, Cr(VI), in micrograms per liter	Total chromium, Cr(t), in micrograms per liter	Uranium (natural), U, in micrograms per liter
Northern subarea/Water Valley—Continued									
MW-193 S3	011N003W33R002S	345955117112002	03/09/2016	2,084	145	970	0.48	0.61	55
MW-193 S2	011N003W33R003S	345955117112003	03/12/2015	2,084	122	110	5.1	6.2	20
MW-193 S2	011N003W33R003S	345955117112003	03/08/2016	2,084	122	110	4.3	4.5	19
MW-193 S1	011N003W33R004S	345955117112004	03/11/2015	2,084	86	67	4.3	4.3	13
MW-193 S1	011N003W33R004S	345955117112004	03/08/2016	2,084	86	78	4.1	4.4	14
MW-193 S1	011N003W33R004S	345955117112004	03/20/2017	2,084	86	82	4.0	5.7	13
MW-186 S3	011N003W34C002S	350035117110401	03/08/2016	2,082	134	42	3.7	3.3	13
27N-01	011N003W27P001S	350036117110301	03/09/2016	2,085	175	47	1.7	2.0	36
MW-205 S3	011N003W28K002S	350056117114301	03/10/2016	2,061	153	49	4.2	4.1	15
MW-205 S1	011N003W28K004S	350056117114303	03/10/2016	2,062	80	48	2.7	2.8	9.0
28N-03	011N003W28X00XS	350057117121401	03/09/2017	2,055	250	40	1.7	1.8	4.9
MW-184 S1	011N003W21R008S	350135117112103	03/09/2016	2,090	113	7.2	2.3	2.7	2.8
Depth-dependent wells									
28-04	011N003W28R011S	350038117112601	11/04/2015	2,076	265	46.1	4.4	4.2	12.7
C-01	010N003W26B010S	345611117094101	03/23/2016	2,166	180	1.84	2.8	3.0	83.9
27-38	010N003W27D007S	345558117111001	11/12/2015	2,167	260	8.90	0.13	0.22	10.1
IW-03	010N003W26L034S	345536117094501	12/03/2015	2,177	160	0.78	5.1	5.0	44.5
27-03	010N003W27M003S	345532117110501	06/02/2015	2,182	131	1.90	1.4	1.3	15.4

It is possible that the Q4 2015 mapped Cr(VI) plume extent may incorrectly portray the extent of anthropogenic Cr(VI), and there may be wells that have Cr(VI) associated with PG&E releases that are outside the Q4 2015 mapped plume or wells shown inside the Q4 2015 mapped plume that do not contain Cr(VI) associated with PG&E releases.

Summative-Scale Analyses

A summative scale will be used as part of the USGS Cr(VI) background study to determine the extent of anthropogenic Cr(VI) associated with PG&E's releases. For the purposes of this study, the summative scale will consist of multiple items formulated as questions (table 3). Each question will require a binary (yes or no) answer for each well sampled as part of the USGS Cr(VI) background study. The answer will be assigned a score. A score of 1 for an item in the scale represents data consistent with anthropogenic Cr(VI); a score of –1 represents data inconsistent with anthropogenic Cr(VI). Items within the scale address geologic, hydrologic, and geochemical criteria on the basis of data collected as part of the USGS Cr(VI) background study and as part of ongoing regulatory data collection. These data include (1) geologic source and chromium concentrations of aquifer materials at the well screen, evaluated on the basis of aquifer lithology, depositional provenance, X-ray fluorescence, and strontium isotope data; (2) the source of water, evaluated on the basis of the stable isotope ratios of oxygen and hydrogen, $\delta^{18}O$ and δD, respectively; (3) the age (time since recharge) of water relative to the timing of the Cr(VI) release, evaluated on the basis of chlorofluorocarbon, sulfur hexafluoride, tritium, helium-3/helium-4, and carbon-14 data; (4) presence of Cr(VI) in alkaline, oxic groundwater, evaluated on the basis of pH and Cr(VI) concentrations; and (5) source and geochemical history of chromium, evaluated on the basis of Cr(VI) concentration trends and $\delta^{52}Cr$ data. Additional items may be added to the proposed summative scale as data interpretation proceeds. For example, summative-scale interpretation of groundwater saturation indexes with respect to selected chromium-containing minerals may be useful in defining the extent of natural versus anthropogenic Cr(VI).

Hydraulic gradient data are not used as an item in the summative scale because there is concern that there may have been releases of Cr(VI) at locations within the study area other than the compressor station, including possible releases near wells MW-159 and MW-163 west of the compressor station (Lahontan Regional Water Quality Control Board, 2014). The movement of Cr(VI) with groundwater downgradient from the PG&E compressor station is addressed separately from the summative scale using a groundwater flow model developed by PG&E and their consultants (Task 5). Interpretation of groundwater flow model and summative-scale results is discussed in the following section.

The summative-scale questions in table 3 will be refined and more fully discussed in the final report, which will explain (1) the relevance of each question, (2) the science behind each question, and (3) how data collected as part of the USGS Cr(VI) background study were used to develop appropriate metrics for each question. The goal of this process is to define the extent of anthropogenic Cr(VI) on the basis of relevant questions associated with simple quantitative metrics that are objectively supportable by data rather than on the basis of arbitrary metrics not based in quantitative data. The TWG suggested that a sensitivity analysis in support of the summative-scale approach be included in the overall data analyses.

After the questions and associated metrics are finalized, scores for each item in the summative scale will be summed for each of the sampled wells. Water from wells having higher magnitude positive scores will be considered affected by anthropogenic Cr(VI), whereas water from wells having higher magnitude negative scores will be considered background Cr(VI). The value selected to represent the extent of the summative-scale plume in the final report will be the lowest score that produces a coherent/mappable plume extent. Wells selected for use in the background Cr(VI) calculations will be outside the summative-scale mapped plume extent. This approach is expected to yield a greater number of wells having suitable data for background Cr(VI) calculations than the 30 wells called for in Task 7 of the cooperative agreement. If the summative-scale approach fails to produce a coherent/mappable plume extent, the data from wells having the lowest summative scores will be used to calculate background.

Use of a summative scale to evaluate the areal extent of anthropogenic Cr(VI) associated with the PG&E compressor station is intended to

1. provide a transparent framework for initial data interpretation in which all stakeholders can participate;
2. provide unbiased initial interpretation that is traceable to numerical measurements and data;
3. force data to be considered collectively, thereby minimizing "cherry-picking" of selected data; and
4. consolidate different data types into simple, easy-to-understand figures that facilitate initial interpretation.

A successful summative scale will correctly identify areas and wells within Hinkley and Water Valleys where anthropogenic Cr(VI) is accepted by stakeholders to be present. For example, summative scores calculated for wells within the Q4 2015 mapped plume extent that have high Cr(VI) concentrations are expected to have high-magnitude positive values that identify Cr(VI) in water from those wells as anthropogenic. Similarly, older groundwater (table 4), recharged many thousands of years prior to Cr(VI) releases from sources associated with the PG&E compressor station (table 4), are expected to have low-magnitude summative scores that identify Cr(VI) in water from those wells as naturally occurring Cr(VI).

Table 3. Proposed summative scale to be used by the U.S. Geological Survey (USGS) hexavalent chromium, Cr(VI), background study to determine the extent of anthropogenic (man-made) and natural Cr (VI), Hinkley and Water Valleys, California.

[Items in the scale are formulated as questions requiring a binary, yes or no, answer for each well sampled as part of the USGS Cr(VI) background study. A score of 1 is consistent with an anthropogenic source. A score of –1 is consistent with a natural source]

	Item	Data source	Answer and score	
			Yes	No
1	Do geologic materials at the well screen contain more chromium than the average continental abundance?	Handheld (portable) X-ray fluorescence (pXRF) measurements of core material.	–1	1
2	Do geologic materials at the well screen contain more manganese than the average continental abundance?	Handheld (portable) X-ray fluorescence (pXRF) measurements of core material.	–1	1
3	Was water from the well recharged from the Mojave River?	delta oxygen-18, $\delta^{18}O$, and delta deuterium, δD, data.	1	–1
4	Does water from the well contain some fraction of "modern" (post 1952 recharge) water?	Tritium, helium-3, helium-4, carbon-14, carbon-13, chlorofluorocarbons (CFC-11, CFC-12, and CFC-113), and sulfur hexafluoride data interpreted using TracerLPM.	1	–1
5	Are Cr(VI) concentrations in water from the well trended with time?	Historic site data interpreted with Kendall's Tau correlation coefficient.	1	–1
6	Is there an excess of Cr(VI) with respect to pH in water from the well?	pH and Cr(VI) values compared to geochemistry and pH and Cr(VI) data in wells statewide.	1	–1
7	Is there an excess of Cr(VI) with respect to other trace elements in water from the well?	Principal component analyses (PCA) including arsenic, hexavalent chromium [Cr(VI)], total dissolved chromium [Cr(t)], iron, mangansese, uranium, and vanadium data.	1	–1
8	Are geologic materials at the well screen fine-grained (predominately clay)?	Consultant and USGS lithologic descriptions.	–1	1
9	Is the chromium isotopic composition in water from the well consistent with fractionation, advective mixing, and longitudinal dispersion of chromium in groundwater?	Cr(VI) and delta chromium-53, $\delta^{53}Cr$, isotopic data.	1	–1
	Sample to be flagged, but no score assigned			
	Is there evidence of anthropogenic contamination from other sources in water from the well (septic, irrigation return)?	Nitrate, specific conductance, delta oxygen-18, delta deuterium.	Samples having high fractions of septic or irrigation return may not be considered for background Cr(VI) calculation.	

NOTE: Proposed questions and associated metrics will be refined, and additional questions may be added to the proposed summative scale as the report process and data interpretation proceeds. For example, summative-scale interpretation of groundwater saturation indexes with respect to selected chromium-containing minerals may be useful in defining plume extent.

Table 4. Field data and hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from wells having older groundwater, Hinkley and Water Valleys, California, March 2015 through March 2017.

[Cr(VI) and Cr(t) are filtered through 0.45-micrometer pore-sized filter with analysis by Assett Laboratories, Las Vegas, Nevada. Well included as older groundwater if carbon-14 activity is less than 90 percent modern carbon after accounting for the addition of carbon from aquifer solids that does not contain carbon-14. Carbon-14 was adjusted for carbon-13, using mixing model with measured carbon-13 composition from inorganic aquifer solids of –4 per mil, or –25 per mil for organic carbon. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; USGS, U.S. Geological Survey; <, less than value shown]

PG&E site name	USGS well identification number	Date (mm/dd/yyyy)	Depth of well, in feet below land surface datum	Dissolved oxygen, in milligrams per liter	pH, in standard units	Specific conductance, in microsiesmens per centimeter	Cr(VI), in micrograms per liter	Cr(t), in micrograms per liter	Carbon-14, in percent modern carbon	Carbon-13, in per mil	Carbon-14, in percent modern carbon, adjusted for carbon-13 composition
Eastern subarea (or within footprint of fourth quarter 2015 mapped plume extent)											
BG-MW-0004 C	345300117101502	05/05/2016	165	1.3	8.1	462	0.70	0.65	26	–10.6	34
BG-MW-0003 C	345359117104603	05/04/2016	190	2.6	7.9	530	0.67	0.48	47	–12.7	48
BGS-48	345620117080601	03/09/2016	258	1.9	8.9	448	0.44	0.11	22	–8.4	43
30E-01	345622117080801	03/11/2015	224	0.8	8.9	373	1.8	1.7	29	–8.5	56
MW-79 D	345625117091301	03/03/2015	165	<0.2	7.9	429	<0.06	0.13	65	–10.9	81
Western subarea											
MW-155 D	345448117101801	03/09/2017	152	<0.2	7.5	423	<0.06	0.42	49	–10.2	67
BGS-34	345453117130401	03/10/2016	147	7.3	8.0	639	2.3	2.4	27	–9.7	42
MW-203 D	345552117115702	03/17/2015	118	3.7	8.3	1,080	8.9	9.1	14	–10.0	20
MW-203 D	345552117115702	03/15/2017	118	1.8	8.3	1,044	5.4	8.2	14	–10.5	19
MW-203 S	345552117115703	03/19/2015	84	6.4	7.7	1,200	2.8	2.9	28	–9.7	41
MW-203 S	345552117115703	03/13/2017	84	6.5	7.8	1,101	2.6	3.6	30	–10.4	40
Northern subarea											
MW-105 D	345657117092901	03/03/2015	130	<0.2	8.0	490	<0.06	0.32	43	–13.5	38
MW-104 D	345730117094701	03/18/2015	140	0.2	8.2	428	0.12	0.16	8.6	–7.9	19
MW-137 S3	345812117101601	03/10/2015	117	0.2	9.1	400	3.6	3.7	58	–10.2	81
MW-207 S2	345822117094601	03/17/2016	110	1.4	8.8	484	3.5	3.5	47	–8.6	88
MW-136 S2	345828117101701	03/09/2015	127	0.2	9.4	455	<0.06	0.55	40	–8.8	71
MW-197 S1	345841117092303	03/16/2016	69	1.9	8.2	1,620	1.1	1.1	34	–7.6	82
MW-154 S1	345842117101702	03/12/2015	85	3.0	8.5	705	11	9.8	31	–8.6	58
Northern subarea/Water Valley											
MW-193 S3	345955117112002	03/12/2015	145	0.3	8.5	2,020	0.19	2.8	13	–5.6	71
MW-193 S3	345955117112002	03/09/2016	145	0.3	8.4	2,000	0.48	0.61	14	–5.9	65

The summative-scale approach is intended to be flexible, and it can be modified as consensus on background Cr(VI) concentrations in the study area increases within the TWG. This process may ultimately allow the use of weighted responses, typical of traditional summative scales, as opposed to simple binary responses. Weighted summative-scale responses also may allow higher scores to be associated with more relevant questions—ultimately producing more refined understanding of plume extent than summative scores based on simple binary responses.

Quarterly meetings with the TWG will continue while the summative-scale analysis is being completed, data are interpreted, and the final report is prepared. These meetings will provide an opportunity for the TWG to review and understand study results, provide additional input on the final formulation of summative-scale questions and associated metrics, and understand preliminary findings as they become available. Public participation in this process is welcome.

Comparison of Summative-Scale Results with Numerical Model Results

An existing numerical groundwater flow model of Hinkley Valley (ARCADIS/CH2M-Hill, 2011) is being updated by PG&E and their consultants as part of Task 5 within the USGS Cr(VI) background study. Updates to the model include (1) increasing the areal extent of the flow model by extending the model grid and model boundaries to hydrologic boundaries along the margins of the alluvial aquifer within Hinkley and Water Valleys and (2) extending the time period of the simulation to include predevelopment (about 1930) to present-day conditions. Model updates will be guided by data from the existing PG&E groundwater flow model (ARCADIS/CH2M-Hill, 2011), the USGS regional groundwater flow model (Stamos and others, 2001), and by data collected as part of this study (appendix 1). Once completed, the updated model will be evaluated relative to its performance with water-level data (including long-term hydrograph data, along with predevelopment water-level data compiled as part of this study), water-budget data, and new data collected as part of the study—including age-dating information that defines the extent of groundwater recharged from the Mojave River near and after the time of Cr(VI) release, between 1952 and 1964. Age-dating data (including tritium, tritium/helium-3, helium-4, chlorofluorocarbons [CFC-11, -12, and -113], sulfur hexafluoride, and carbon-14) will be interpreted using the computer program TracerLPM (Jurgens and others, 2012) to evaluate mixtures of water recharged at different times in sampled water from wells. Although the timing of recharge from the Mojave River is important, not all water infiltrated from the Mojave River since 1952 passed near the compressor station and became associated with anthropogenic Cr(VI) from the compressor station.

There are no questions in the summative-scale analyses (table 3) derived from hydraulic data or the groundwater flow model results. Instead, the extent of the plume estimated from the groundwater flow model on the basis of forward particle tracking from the release near the compressor station, and from reverse particle tracking from large pumping centers within the valley, will be compared and contrasted with the mapped plume extent estimated on the basis of the summative-scale analyses (fig. 4). The differences between results from the two approaches, if any, will be reconciled in the final report in light of the performance, and inherent limitations, of each approach.

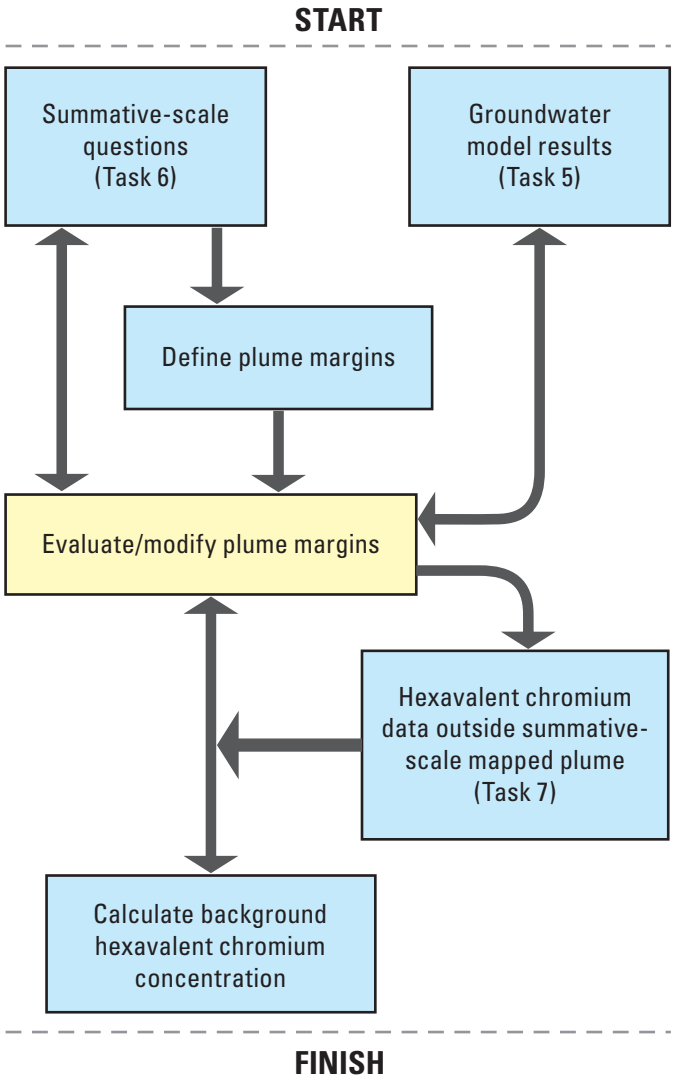

Figure 4. Approach to estimate plume extent and calculate background hexavalent chromium, Cr(VI), concentrations, Hinkley and Water Valleys, California.

Background Cr(VI) Calculations

For the purpose of the background Cr(VI) calculations, data from outside the mapped plume extent (as defined after comparison of and reconciliation of differences between the summative-scale analyses and numerical groundwater flow model results) will be grouped into three categories representing the eastern, western, and northern subareas within Hinkley and Water Valleys (fig. 1). Average, median, 95th percentile, and maximum Cr(VI) and Cr(t) concentrations will be calculated for "Mojave type" deposits within each subarea using quarterly data collected from each well outside the mapped plume between April 2017 (PG&E, second quarter sample collection) and January 2018 (PG&E, first quarter sample collection). "Mojave-type" deposits include Mojave stream and delta/lake margin deposits to be described for the purposes of this study by Dave Miller, USGS. For wells that do not have core material available, "Mojave-type" deposits will be identified on the basis of strontium-87/86 data or other water-chemistry data as appropriate. If the geologic provenance of some wells cannot be determined, a null-score of 0 will be assigned to that question in the summative scale. Average, median, 95th percentile, and maximum Cr(VI) and Cr(t) concentrations also will be calculated for other types of deposits including local fan deposits within the eastern and northern subareas and bedrock or weathered bedrock within the western subarea. For the purposes of this study, within each subarea, the 95th percentile concentrations, adjusted for analytical uncertainty, will be considered the Cr(VI) and Cr(t) background for "Mojave-type" and other deposits present within that subarea.

The calculation of background Cr(VI) using a summative-scale approach may yield different values for "Mojave-type" deposits in the different subareas within the study area as a result of local differences in geology and geochemistry (including the natural occurrence of manganese oxides on the surfaces of mineral grains). For example, it is possible that

1. In the western subarea, alluvial deposits may have higher chromium abundance as a result of greater abundance of easily-weathered chromium-containing minerals, such as actinolite eroded from the San Gabriel Mountains; as a consequence, Cr(VI) concentrations in groundwater may be higher in this area.

2. In the northern subarea and Water Valley, alkaline, oxic groundwater may increase desorption of Cr(VI) from oxide coatings on the surfaces of mineral grains; as a consequence, Cr(VI) concentrations in groundwater may be higher in this area.

3. Conversely, in the eastern subarea, slightly acidic to near-neutral pH of groundwater may increase sorption of Cr(VI) onto oxide coatings on the surfaces of mineral grains; as a consequence, Cr(VI) concentrations in groundwater may be lower in this area.

In parts of the northern subarea and Water Valley, "Mojave-type" deposits interfinger with alluvium eroded from other sources, and groundwater originally recharged from the Mojave River is present throughout much of the area (Izbicki and others, 2004). Summative scores from wells completed in alluvium eroded from local sources will be examined in the same manner as "Mojave-type" deposits to determine if anthropogenic Cr(VI) associated with releases from the PG&E compressor station is present in that area.

Background Cr(VI) concentrations calculated as part of this study are intended to guide selection of background Cr(VI) concentrations to be used by the Lahontan RWQCB for regulatory purposes. Values presented as part of the USGS Cr(VI) background study are not background Cr(VI) concentrations for regulatory purposes, and the authority to establish regulatory values resides solely with the Lahontan RWQCB.

Comparison of Background Cr(VI) Calculations with Data from Domestic Wells

After background Cr(VI) concentrations are calculated, the results will be compared to and contrasted with Cr(VI) concentrations measured in water from more than 70 domestic and agricultural wells sampled within Hinkley and Water Valleys during January 2016 (figs. 5 and 6; table 5). Water from these wells was analyzed for fewer constituents than water from wells sampled between March 2015 and April 2017 and used for summative-scale analyses and background Cr(VI) calculations. Constituents analyzed from sampled domestic and agricultural wells included

1. Cr(VI) and Cr(t) concentrations;

2. field data including dissolved oxygen (a measure of redox status), pH, and specific conductance;

3. selected trace elements (including iron, manganese, arsenic, vanadium, and uranium); and

4. the stable isotopes of oxygen and hydrogen ($\delta^{18}O$ and δD, respectively).

Summative-scale scores for water from these wells will be calculated for items 3, 7, and 8 in table 3. The distribution of those scores will be compared and contrasted with similar scores from wells analyzed for more complete constituents to provide greater areal coverage and increased certainty in estimates of plume extent and background Cr(VI) concentrations.

Data from sampled domestic and agricultural wells were provided to the TWG on December 14, 2016, and are publically available from the USGS NWIS online database. Drillers' logs and well-construction data are not available for most domestic and agricultural wells sampled as part of this study; as a consequence, it will not be possible to categorize these wells by geology or depositional provenance.

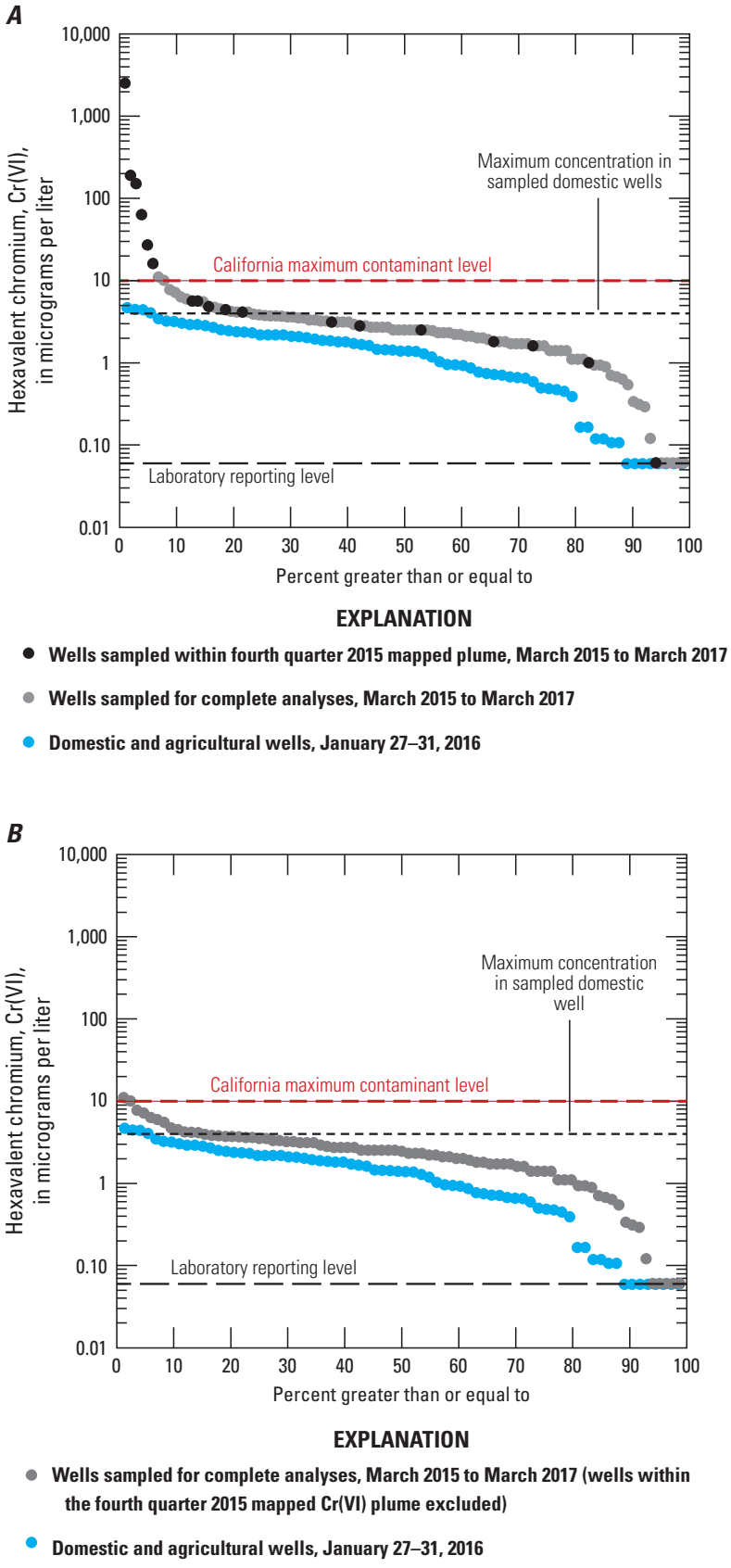

Figure 5. Hexavalent chromium, Cr(VI), concentrations in water from wells sampled as part of the U.S. Geological Survey background Cr(VI) study: *A*, all data, and *B*, data from within the fourth quarter 2015 mapped Cr(VI) plume excluded, Hinkley, California, March 2015 to March 2017.

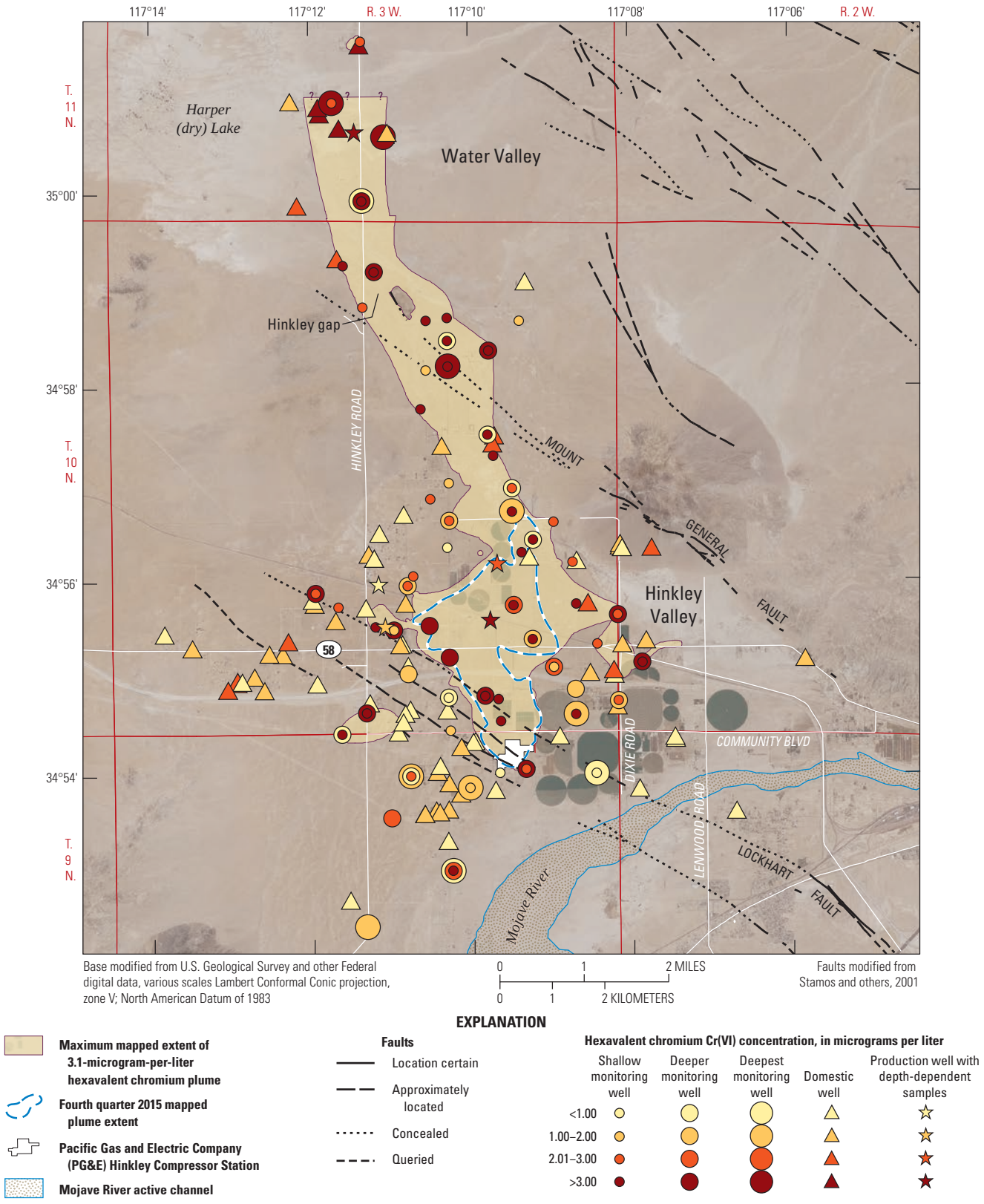

Figure 6. Hexavalent chromium, Cr(VI), concentrations in water from monitoring and domestic wells sampled for complete chemical and isotopic (including age dating) data, March 2015 to March 2017; domestic and irrigation wells sampled for fewer constituents, January 2016, Hinkley and Water Valleys, California. (Maximum mapped extent of 3.1-microgram-per-liter hexavalent chromium plume and fourth quarter 2015 mapped plume extent from Pacific Gas and Electric Company, PG&E, data accessed February 22, 2018, at https://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/.)

Table 5. Hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from domestic and agricultural wells sampled by the U.S. Geological Survey (USGS), Hinkley and Water Valleys, California, January 27–31, 2016.

[Cr(VI) and Cr(t), filtered in the field through 0.45-micrometer pore-sized filter. Field-speciated Cr(t) and Cr(VI) processed at time of sample collection using anion exchange resins. Analysis of Cr(VI) in field laboratory by USGS using U.S. Environmental Protection Agency Method 218.6; analyses of field-speciated Cr(VI) and Cr(t) by the USGS National Research Program Trace Metals Research Laboratory, Boulder, Colorado. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; <, less than value shown; —, no data]

PG&E site name	State well identification number	USGS well identification number	Date (mm/dd/yyyy)	Altitude of land surface, in feet above sea level	Depth of well, in feet below land surface datum	Arsenic, As, in micrograms per liter	Cr(VI), in micrograms per liter	Field speciated		Uranium (natural), U, in micrograms per liter
								Cr(VI), in micrograms per liter	Cr(t), in micrograms per liter	
Eastern subarea										
—	009N002W05L007S	345337117064201	01/28/2016	2,189	224	5.7	0.81	0.8	1.3	8.9
06-13	009N002W06B007S	345423117072801	01/30/2016	2,183	—	0.98	0.09	0.4	0.8	1.6
06-12	009N002W06B010S	345422117072801	01/30/2016	2,183	—	1.4	0.10	0.3	0.5	1.3
06-07	009N002W06M009S	345352117075501	01/30/2016	2,191	—	1.2	0.14	0.3	0.3	1.1
01-01A	009N003W01C002S	345424117085501	01/31/2016	2,195	—	1.7	0.55	2.7	1.8	19
02-02A	009N003W02C002S	345421117095801	01/31/2016	2,215	—	11	0.60	2.0	1.0	1.3
02-02B	009N003W02C007S	345420117100001	01/31/2016	2,218	—	16	<0.05	0.7	1.2	3.0
02-07	009N003W02D004S	345418117100901	01/29/2016	2,231	200	1.4	1.4	1.4	1.8	7.4
02-13	009N003W02K002S	345351117094301	01/31/2016	2,231	160	16	<0.05	0.3	0.3	1.2
02-10	009N003W02M002S	345349117100901	01/29/2016	2,244	218	0.76	1.7	1.8	1.9	16
03-14	009N003W03H003S	345402117102701	01/30/2016	2,243	—	0.66	1.6	1.7	2.1	9.9
03-19	009N003W03H007S	345406117102501	01/30/2016	2,243	—	1.1	0.56	0.8	1.0	8.0
03-12	009N003W03J004S	345355117101801	01/28/2016	2,238	250	0.75	1.8	1.5	2.4	16
03-28	009N003W03Q004S	345336117103601	01/28/2016	2,253	150	0.64	1.9	1.9	2.0	11
03-29	009N003W03Q007S	345336117103602	01/28/2016	2,253	200	7.8	1.1	1.1	1.3	9.2
03-08	009N003W03R002S	345338117101801	01/28/2016	2,252	120	1.6	1.2	1.2	2.1	40
—	009N003W03R004S	345338117102701	01/28/2016	2,254	150	1.1	1.6	1.5	3.6	27
03-23	009N003W03R005S	345337117102501	01/28/2016	2,255	200	2.9	1.2	1.3	1.8	9.3
—	009N003W09R001S	345243117113301	01/28/2016	2,305	260	3.0	0.80	1.0	1.0	8.8
10-02	009N003W10H002S	345309117101901	01/30/2016	2,223	200	0.94	0.78	1.0	1.1	14
30E-01	010N002W19N001S	345622117080801	01/27/2016	2,217	224	140	1.5	1.5	2.2	3.5
BGS-48	010N002W19N002S	345620117080601	01/27/2016	2,217	258	120	0.09	<0.1	<0.1	2.9
BGS-47	010N002W19P002S	345620117074501	01/28/2016	2,216	—	21	2.1	1.8	1.9	4.3
BGS-25	010N002W30N005S	345521117080701	01/31/2016	2,178	255	1.6	1.9	5.9	2.4	45
30E-12	010N002W30P002S	345523117074901	01/28/2016	2,177	110	1.9	1.6	1.2	2.1	12
—	010N002W33D033S	345511117055001	01/29/2016	2,183	200	3.3	2.0	1.9	2.4	9.4

Table 5. Hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from domestic and agricultural wells sampled by the U.S. Geological Survey (USGS), Hinkley and Water Valleys, California, January 27–31, 2016.—Continued

[Cr(VI) and Cr(t), filtered in the field through 0.45-micrometer pore-sized filter. Field-speciated Cr(t) and Cr(VI) processed at time of sample collection using anion exchange resins. Analysis of Cr(VI) in field laboratory by USGS using U.S. Environmental Protection Agency Method 218.6; analyses of field-speciated Cr(VI) and Cr(t) by the USGS National Research Program Trace Metals Research Laboratory, Boulder, Colorado. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; <, less than value shown; —, no data]

PG&E site name	State well identification number	USGS well identification number	Date (mm/dd/yyyy)	Altitude of land surface, in feet above sea level	Depth of well, in feet below land surface datum	Arsenic, As, in micrograms per liter	Cr(VI), in micrograms per liter	Field speciated		Uranium (natural), U, in micrograms per liter
								Cr(VI), in micrograms per liter	Cr(t), in micrograms per liter	
Eastern subarea—Continued										
23-27	010N003W23R009S	345615117091701	01/30/2016	2,163	—	300	<0.05	0.2	0.4	1.8
BGS-46	010N003W24P005S	345613117084101	01/30/2016	2,168	—	4.1	0.57	0.9	1.1	7.5
25-16	010N003W25G002S	345546117083301	01/31/2016	2,172	—	1.8	2.4	2.1	2.6	8.1
36-31	010N003W36G001S	345503117083201	01/30/2016	2,184	—	2.3	1.2	1.2	1.6	27
36-26	010N003W36H004S	345502117081301	01/29/2016	2,182	—	1.3	0.40	1.0	1.9	28
36-41	010N003W36H005S	345506117081301	01/30/2016	2,182	—	2.4	2.1	2.1	2.9	56
Western subarea										
22-09	010N003W22N014S	345614117111301	01/28/2016	2,161	150	8.2	0.38	0.7	0.7	9.2
22-62	010N003W22N034S	345617117111701	01/27/2016	2,161	128	7.1	1.2	1.1	1.7	9.4
27-26	010N003W27F001S	345546117104601	01/30/2016	2,169	130	2.9	1.5	1.4	1.6	8.8
27-42	010N003W27M005S	345543117111901	01/28/2016	2,174	—	8.6	0.33	0.5	0.7	8.8
27-48	010N003W27P003S	345521117105201	01/30/2016	2,189	—	2.1	0.61	0.8	1.0	5.4
27-49	010N003W27P004S	345521117105401	01/30/2016	2,190	—	2.3	1.8	1.8	2.0	8.1
28-09	010N003W28F021S	345546117115701	01/28/2016	2,174	150	28	2.0	2.2	2.4	11
28-36	010N003W28F31S	345549117120001	01/27/2016	2,172	174	25	0.42	0.4	1.8	11
28-20	010N003W28K014S	345536117114201	01/27/2016	2,181	—	27	1.2	1.2	1.4	7.7
28-88	010N003W28N003S	345523117121801	01/29/2016	2,197	160	16	2.3	2.1	2.5	6.4
BGS-19	010N003W30Q009S	345528117135101	01/30/2016	2,219	90	9.8	0.73	1.0	2.6	62
—	010N003W30R005S	345519117133001	01/30/2016	2,221	—	10	1.2	1.2	1.2	17
BGS-41	010N003W32A016S	345516117123201	01/29/2016	2,209	—	5.3	1.0	1.2	1.7	23
—	010N003W32F012S	345458117125601	01/27/2016	2,229	119	12	2.5	2.3	2.3	8.1
—	010N003W32F014S	345459117125601	01/27/2016	2,227	154	8.2	2.6	2.2	2.7	9.4
BGS-28	010N003W32G011S	345458117125301	01/27/2016	2,226	—	8.0	0.65	0.9	1.0	8.4
—	010N003W32G014S	345501117124401	01/28/2016	2,221	100	10	1.5	1.5	2.0	8.8
BGS-44	010N003W32H018S	345453117123601	01/28/2016	2,231	201	8.6	1.8	1.7	1.8	8.8
—	010N003W33D008S	345515117122201	01/29/2016	2,206	140	13	1.8	1.7	1.9	7.6

Table 5. Hexavalent chromium, Cr(VI), and total dissolved chromium, Cr(t), concentrations in water from domestic and agricultural wells sampled by the U.S. Geological Survey (USGS), Hinkley and Water Valleys, California, January 27–31, 2016.—Continued

[Cr(VI) and Cr(t), filtered in the field through 0.45-micrometer pore-sized filter. Field-speciated Cr(t) and Cr(VI) processed at time of sample collection using anion exchange resins. Analysis of Cr(VI) in field laboratory by USGS using U.S. Environmental Protection Agency Method 218.6; analyses of field-speciated Cr(VI) and Cr(t) by the USGS National Research Program Trace Metals Research Laboratory, Boulder, Colorado. **Abbreviations**: mm/dd/yyyy, month/day/year; PG&E, Pacific Gas and Electric Company; <, less than value shown; —, no data]

PG&E site name	State well identification number	USGS well identification number	Date (mm/dd/yyyy)	Altitude of land surface, in feet above sea level	Depth of well, in feet below land surface datum	Arsenic, As, in micrograms per liter	Cr(VI), in micrograms per liter	Field speciated		Uranium (natural), U, in micrograms per liter
								Cr(VI), in micrograms per liter	Cr(t), in micrograms per liter	
Western subarea—Continued										
33-10	010N003W33F005S	345457117115601	01/27/2016	2,221	—	—	—	0.1	0.4	—
33-10	010N003W33F005S	345457117115601	01/27/2016	2,221	—	3.8	—	0.5	1.0	4.4
34-63	010N003W34B007S	345508117104801	01/30/2016	2,199	—	10	<0.05	0.3	0.4	2.7
34-50	010N003W34J009S	345440117101901	01/30/2016	2,215	140	1.3	0.87	1.0	1.1	8.3
34-13	010N003W34K001S	345441117104701	01/27/2016	2,224	160	15	0.14	0.5	0.7	2.3
34-73	010N003W34M011S	345445117111701	01/29/2016	2,120	—	2.4	0.63	0.9	1.6	6.9
34-15	010N003W34P002S	345427117105601	01/29/2016	2,236	206	16	<0.05	0.1	0.2	1.0
34-60	010N003W34P007S	345433117105201	01/29/2016	2,232	—	13	<0.05	0.2	0.2	1.3
34-57	010N003W34P008S	345438117105001	01/29/2016	2,226	200	11	<0.05	0.2	0.5	0.17
Northern subarea										
02N-02	010N003W02J003S	345905117091801	01/29/2016	2,155	250	110	0.05	0.3	0.6	33
04N-04	010N003W04G001S	345923117114201	01/29/2016	—	—	9.7	2.5	2.2	2.7	19
14-07	010N003W14K001S	345730117094201	01/30/2016	2,149	300	1.4	2.9	2.9	3.2	14
14-15	010N003W14K003S	345725117094401	01/30/2016	2,152	—	1.8	2.7	2.5	2.7	12
15-13	010N003W15H005S	345724117102202	01/30/2016	2,146	—	2.1	1.4	1.5	1.7	11
22-48	010N003W22F003S	345641117105101	01/30/2016	2,157	—	4.2	0.41	0.6	0.7	11
Northern subarea/Water Valley										
21N-04	011N003W21R009S	350132117112201	01/29/2016	2,092	—	82	4.0	3.8	4.4	8.1
27N-01	011N003W27P001S	350036117110301	01/29/2016	2,085	175	50	2.0	2.0	2.3	33
28N-01	011N003W28L001S	350053117115301	01/29/2016	2,063	200	38	3.7	3.7	3.7	10
—	011N003W28M007S	350049117115601	01/29/2016	2,064	—	180	3.8	3.6	4.1	8.3
28N-05	011N003W28Q005S	350040117113801	01/29/2016	2,071	—	26	3.4	3.2	3.6	8.3
33N-01	011N003W33N002S	345953117121001	01/29/2016	2,079	—	3.8	2.7	2.7	2.9	13

Wells of Special Concern

The design of the study included steps to ensure well purging and sample collection protocols used by the USGS between March 2015 and March 2017 were compatible with protocols for quarterly sample collection used by PG&E for regulatory purposes. However, the larger number of analyses done on samples collected by the USGS required a greater volume of water removed from wells and longer pumping times compared to quarterly sample collection by PG&E for regulatory purposes. In addition, to ensure representative dissolved-gas sample collection, care was taken by the USGS to ensure (when possible) water levels did not fall below the top of the screened interval of the well during purging and sample collection. This resulted in slower pumping rates and longer pumping times in some wells. Wells having differences in Cr(VI) concentrations that may result from differences in well purging and sample collection protocols will be identified by comparing USGS data with PG&E regulatory data collected during the quarter before and after the USGS samples were collected. Similarly, if groundwater quality changed as a result of management practices used to control the plume or other factors, some wells sampled by the USGS between March 2015 and March 2017 may have Cr(VI) concentrations that differ from Cr(VI) concentrations in water from those wells during quarterly sample collection between April 2017 and January 2018. In either case, wells having differing Cr(VI) concentrations preceding and following USGS sample collection will be identified for the TWG. However, summative-scale scores will (by necessity) be calculated from the USGS data collected between March 2015 and March 2017, and the Cr(VI) concentration used to estimate background will be calculated from quarterly data collected between April 2017 and January 2018. Differences in Cr(VI) concentrations in water from sampled wells (if any), resulting from well purging, sample collection, or other factors, will be discussed in the final report.

Water from some wells in Hinkley and Water Valleys shows evidence of septic or agricultural return water on the basis of relatively high nitrate, dissolved solids, or evaporative shifts in δD and $\delta^{18}O$ composition. Wells showing evidence of septic or agricultural return water will be identified for the TWG (table 3). However, it is unclear at this time if these sources would affect Cr(VI) concentrations, and exclusion of wells (if any) from background Cr(VI) calculations will be made on a well-by-well basis.

Cr(VI) concentrations in water from wells at monitoring sites MW-159 and MW-163 are higher than concentrations in water from wells elsewhere in the floodplain aquifer along the Mojave River (Metzger and others, 2015). At present, the origin of high Cr(VI) concentrations in water from these wells is poorly understood. However, data are available to address this issue in the final report. If identified as naturally occurring, Cr(VI) concentrations in water from these wells appear to be uniquely high and may not be representative of geologic and geochemical conditions elsewhere within Hinkley and Water Valleys or within the floodplain aquifer along the Mojave River. As a consequence, data from these wells would not be used to calculate background for the purposes of this study. Possible anthropogenic sources of Cr(VI) in water from these wells has been investigated by the Lahontan RWQCB (2014).

It is possible that the summative-scale approach used to estimate plume extent and calculate background Cr(VI) may identify some wells that have anthropogenic Cr(VI) at concentrations below background Cr(VI) concentration for their respective subarea and depositional provenance. The decision to regulate anthropogenic Cr(VI) in wells with low concentrations of Cr(VI), below background concentrations established as part of this study, resides solely with the Lahontan RWQCB.

Limitations of the Approach

The summative scale and numerical groundwater flow model developed for this study are interpretation tools intended to facilitate preliminary interpretation of complex data collected as part of the USGS background Cr(VI) study. Ultimately, the extent of anthropogenic Cr(VI) associated with PG&E releases (and the uncertainty associated with that extent) is a science-based question. The answer to the question, "Is Cr(VI) in groundwater associated with releases from the PG&E compressor station or is it naturally occurring?" is process oriented. The summative-scale and numerical-modeling approaches described in this report aid in data interpretation, but they are only tools to help understand the geologic, geochemical, and hydrologic processes that contribute to the presence and movement of natural and anthropogenic Cr(VI).

Users are cautioned that data used to estimate background Cr(VI) concentrations are representative of conditions at the time of the study—March 2015 to March 2017 for estimation of plume extent and April 2017 to January 2018 for calculation of Cr(VI) and Cr(t) background concentrations. It is likely that groundwater quality, including Cr(VI) and other trace element concentrations, in groundwater from wells in Hinkley and Water Valleys may differ through time, especially under predevelopment conditions prior to the onset of groundwater pumping for agriculture and subsequent water-level declines.

Conclusions

The purposes of the U.S. Geological Survey background hexavalent chromium, Cr(VI), study are to (1) evaluate the extent of anthropogenic Cr(VI) associated with releases from the Pacific Gas and Electric Company (PG&E) compressor station and (2) estimate background Cr(VI) concentrations in the aquifer upgradient, downgradient, and cross-gradient from the mapped Cr(VI) plume near Hinkley, California. The study has eight tasks. As of May 2017, the background Cr(VI) study was proceeding on schedule and on budget, with most of the proposed field work completed by May 2017. Sample collection for Task 7, estimation of background Cr(VI) concentrations, is scheduled to be completed by January 2018.

The data analyses described in this report have two steps. First, a summative scale will be used to evaluate data collected as part of the USGS background study to determine the areal extent of the Cr(VI) plume. Questions that compose the summative scale and associated metrics will be refined and discussed with the Technical Working Group (TWG) as the final report is prepared. A successful summative scale will correctly identify areas and wells within Hinkley and Water Valleys where anthropogenic Cr(VI) is accepted as being present. Summative-scale results will be compared to numerical groundwater flow model results that define plume extent on the basis of particle-tracking simulations. The differences between the two approaches will be evaluated and reconciled. Second, background Cr(VI) values will be calculated from wells completed in "Mojave-type" deposits and other deposits outside the anthropogenic Cr(VI) plume mapped by the summative-scale approach. Background Cr(VI) concentrations may differ in different geologic materials and in different subareas within Hinkley and Water Valleys.

The summative scale and numerical groundwater flow model developed for this study are interpretation tools intended to facilitate preliminary interpretation of complex data collected as part of the U.S. Geological Survey Cr(VI) background study. Estimates of background Cr(VI) concentrations and plume extent are representative of conditions at the time of the study. Background Cr(VI) concentrations calculated as part of this U.S. Geological Survey study are not background Cr(VI) concentrations for regulatory purposes, and the authority to establish regulatory values resides solely with the Lahontan Regional Water Quality Control Board.

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Appendix 1. Study Progress by Task, May 2017

Study progress by task was summarized from quarterly progress reports submitted by the U.S. Geological Survey (USGS) to the Lahontan Regional Water Quality Board (RWQCB) between January 2015 and May 2017. Quarterly progress reports are publically available (https://geotracker.waterboards.ca.gov/profile_report.asp?global_id=T10000010367). Additional information, including regulatory data collected by Pacific Gas and Electric Company (PG&E; including quarterly maps of hexavalent chromium, Cr(VI), concentration data), the 2013 Environmental Impact Report, cleanup orders, and permits relevant to PG&E Hinkley Compressor Station cleanup are available at https://www.waterboards.ca.gov/rwqcb6/water_issues/projects/pge/index.html.

Task 1: Evaluation of Existing Data

PG&E water-quality data (including blank and replicate samples) were evaluated with respect to laboratory analytical performance. Trends were calculated for total dissolved chromium, Cr(t), Cr(VI), and water levels for the period 2011 through 2013. These data were used to select wells for the March 2015 Task 3 sample collection. The trend analyses will be updated for the final report.

Task 2: Analyses of Rock and Alluvium

Core material from more than 100 wells drilled by PG&E was described with respect to its depositional provenance and geologic source. These descriptions were used to evaluate the geologic framework of the study area, including the depositional history of alluvium within Hinkley and Water Valleys. More than 1,000 samples of rock, alluvium, and core material from the screened intervals of wells sampled as parts of Tasks 3 and 4 (and other wells in the study area) were analyzed for 27 elements, including chromium, using a handheld (portable) X-ray fluorescence spectrometer, pXRF (Groover and Izbicki, 2016). Measurements were associated with descriptions of lithology, texture, and other features including presence of oxide coatings on the mineral grains. For selected samples, minerals were identified optically. Coatings on the surfaces of mineral grains from more than 40 samples of core material and alluvium were extracted using progressively stronger extraction solutions intended to measure iron, manganese, aluminum, arsenic, chromium, vanadium, and uranium associated with weakly sorbed, specifically sorbed (pH dependent), amorphous, and well-crystalized fractions. Selected samples were sent to USGS laboratories, where they were sorted by particle size and density and the resulting subsamples were analyzed for elemental concentration and mineral composition. Not all laboratory analyses are complete at this time.

Task 3: Analyses of Chemical and Environmental Tracers in Water from Wells

Water samples from 100 wells were collected and analyzed for field parameters and chemical constituents including major ions, selected minor ions, and selected trace elements, including arsenic, Cr(t), Cr(VI), and uranium. Samples also were analyzed for a number of environmental tracers. Types of environmental tracers collected and analyzed include (1) tracers of the source and movement of water, (2) tracers of the "age" (time since recharge) of water, and (3) tracers of chemical reactions and environmental processes affecting constituents dissolved in water. These tracers are discussed by Izbicki and Groover (2016). Forty wells were sampled in March 2015, thirty wells were sampled in March 2016, and twenty wells sampled in March 2017. Wells were selected after discussion and input from the Technical Working Group (TWG). Data collection over several years as part of the study was designed to allow preliminary interpretation of earlier data to guide the collection of later data. Field blanks and replicate samples were collected, and by design, some wells were sampled multiple times during the study. Sample collection was coordinated with PG&E to ensure similar sample collection procedures were used for the Cr(VI) background study and regulatory data collection. Most analyses are complete and results are publicly available from the USGS National Water Information System (NWIS) online database (https://waterdata.usgs.gov/nwis).

Task 4: Evaluation of Local Hydrogeologic Conditions

A predevelopment water-level map was prepared on the basis of USGS historical water-level data collected in the area between 1900 and about 1930. A thickness of alluvium map was prepared from gravity data collected and interpreted as part of the USGS Cr(VI) background study. Areal and focused recharge from local sources within Hinkley and Water Valleys was estimated using the computer program Basin Characteristic Model (BCM; Flint and Flint, 2014). Results were compared to water-extractable chloride concentrations from unsaturated alluvium at selected sites. Twelve wells (known as the flowpath wells) were drilled by PG&E consultants at six sites upgradient from the PG&E Hinkley Compressor Station (also referred to as the compressor station). Pore water was hydraulically (pressure) extracted from selected core materials at the time of drilling and analyzed for field parameters, selected trace elements, and the stable isotopes of oxygen and hydrogen. The flowpath wells were equipped with pressure transducers to monitor water levels. Water from the flowpath wells was sampled quarterly for field parameters, Cr(t), and Cr(VI) for 1 year,

and then sampled for more complete chemical and isotopic constituents described in Task 3. Borehole geophysical data were collected from more than 90 existing polyvinyl chloride (PVC)-cased monitoring wells throughout Hinkley and Water Valleys to evaluate subsurface geologic conditions. The most frequently collected borehole geophysical logs collected consist of a suite of conventional logs including natural gamma, electromagnetic (EM) resistivity, fluid temperature, and fluid resistivity logs; these were collected to support interpretation of lithologic data collected during the drilling of monitoring wells by PG&E and their consultants. Nuclear Magnetic Resonance (NMR) logs were collected from 13 selected wells to evaluate the hydraulic properties of saturated alluvium and formerly saturated alluvium above the present-day water table but below the predevelopment water table. These data were compared with core material, estimates of hydraulic properties estimated from slug-test data, and cone-penetrometer (CPT) data collected as part of the study. Additional CPT data were collected near Hinkley Gap to evaluate groundwater movement between Hinkley and Water Valleys. Point-velocity-probe (colloidal boroscope) data were collected from 22 wells near the Lockhart Fault to evaluate groundwater movement near the fault. At one site near the compressor station, colloidal boroscope data collection were coordinated with pumping from nearby PG&E wells. Six existing monitoring wells along a section across the Lockhart Fault were instrumented with pressure transducers to monitor water levels and sampled for chemical and isotopic constituents, including age dating, described in task 3. Coupled well-bore-flow and depth-dependent water-quality data were collected from five wells distributed through Hinkley and Water Valleys. Data were interpreted with the aid of the computer program AnalyzeHOLE to estimate aquifer properties and evaluate layering of aquifer materials. Conceptual numerical simulations based on aquifer property data estimated using AnalyzeHOLE (Halford, 2009) and intended to refine understanding of groundwater movement in response to recharge were done using the computer program MODFLOW.

Task 5: Evaluation of Groundwater Movement

PG&E consultants are updating the groundwater flow model developed for the site by CH2M-Hill (ARCADIS/CH2M-Hill, 2011). The updates include (1) increasing the areal extent of the model to extend the model grid and boundaries to hydrologic boundaries along the margins of the alluvial aquifer within Hinkley and Water Valleys and (2) extending the period of simulation to include predevelopment (about 1930) to present day. Model updates will be guided by data from the existing PG&E groundwater flow model (ARCADIS/CH2M-Hill, 2011) and the USGS regional groundwater flow model (Stamos and others, 2001). As part of Task 5, archived files from the USGS regional groundwater flow model were assembled, and model simulations were done to ensure accurate duplication of model-calculated water levels from the original model. Water-budget information, including recharge, discharge, and pumping data, for relevant areas in Hinkley and Water Valley was extracted from simulations done using the archived model files with the computer program ZoneBudget (Harbaugh, 1990). Water-budget data by model zone were provided to PG&E in support of model development. Data from Task 4 also were used in support of model development. A subset of the TWG tasked with guiding development of the updated model has met (approximately) semi-annually to discuss model progress and data issues.

Task 6: Evaluation of Natural and Man-Made Chromium(VI); and Task 7: Estimation of Background Cr(VI) Concentrations

More than 70 domestic wells were sampled during January 27–31, 2016, to evaluate the presence of Cr(VI), arsenic, and other selected constituents in Hinkley and Water Valleys. In addition to traditional laboratory analyses, Cr(VI) samples were analyzed on site within minutes of collection in a USGS mobile laboratory using U.S. Environmental Protection Agency method 218.6 (1994). This allowed interested residents to follow samples collected from their well through the mobile laboratory analysis to Cr(VI) results. Data were provided to participating well owners and summarized in a September 2016 letter to the Independent Review Panel (IRP) Manager (http://www.hinkleygroundwater.com/wp-content/themes/hinkleygw/documents/usgs/USGS-Letter-to-IRP-2016-09-15.pdf). Quarterly sample collection and analyses for field parameters, Cr(t), and Cr(VI) from wells to be used for background Cr(VI) calculations began in April 2017 and was scheduled to end in January 2018. Additional progress on Tasks 6 and 7 and how data from these tasks will be used to estimate background Cr(VI) concentrations are discussed in the body of this report.

Task 8: Fate of Chromium During and After In Situ Reduction

Although not directly part of the estimation of background Cr(VI) for regulatory purposes, this task was included in the USGS Cr(VI) background study to evaluate the permanence of in situ reduction used by PG&E to remove Cr(VI) from groundwater downgradient of the compressor station. In situ reduction to remove Cr(VI) in groundwater downgradient from the PG&E Hinkley Compressor Station is done by injection of ethanol into the groundwater to create reduced conditions that convert soluble, toxic Cr(VI) to insoluble, non-toxic trivalent chromium, Cr(III). Although chromium is removed from solution by in situ reduction, it remains within the aquifer on the surfaces of mineral grains.

Task 8 has three parts: (1) chromium sequestration experiments, (2) chromium reoxidation experiments, and (3) comparison of the surface chemistry of native aquifer materials outside the plume with aquifer materials within the plume and with in situ treated aquifer materials within the plume. Design of these experiments, including thermodynamic calculations used to predict geochemical conditions within the experiments, procedures to control redox and pH within the experiments, preparation of artificial substrates used as experimental controls, and quality assurance of sequential extraction procedures used in experiment 1 (the chromium sequestration experiments) were done during the first year of the study with input from the TWG.

As part of experiment 1, almost 160 microcosms were prepared from alluvium collected from wells BG-004 and BG-005 and from artificial substrates. Experiment 1 has been ongoing for more than 1 year, with harvests of microcosms collected at 0, 41, 83, 168, and 350 days from the start of the experiment. Experiment 1 is to continue for about 2 years with one additional harvest scheduled.

As part of experiment 2 (the chromium reoxidation experiments), more than 290 microcosms were prepared from alluvium collected from wells BG-004, BG-005, and well SA-SB-01 within the Q4 2015 mapped plume (not shown on fig. 1); artificial substrates consisted of iron-coated and manganese-coated Ottawa sand in proportions ranging from pure iron and manganese end-members to mixtures bracketing the natural abundance of these elements in alluvium from Hinkley Valley. Isotopically labeled chromium was added to these materials, which were then held under reduced conditions for almost 1 year before being exposed to oxic conditions. After exposure to oxic conditions, Cr(VI) concentrations were measured in the aqueous phase and sorbed to the solid phase using U.S. Environmental Protection Agency Method 3060A (1996). Preliminary results for experiment 2, intended to test experimental methodology, have been completed for a 14-day incubation period. Experiment 2 is to continue for about 2 years with additional harvests scheduled.

The third part of Task 8 was addressed on the basis of sequential extraction data from aquifer materials used in experiments 1 and 2 and aquifer materials from well SA-RW-48 within the Q4 2015 mapped plume (not shown on fig. 1). Although extractions are complete, results of analyses from well SA-RW-48 are not yet complete. A range of native aquifer materials, aquifer materials from within the plume, and materials from experiments 1 and 2 will be examined on the Stanford Synchrotron Radiation Light Source (SSRL). The USGS submitted a highly ranked proposal for beam time on the SSRL. At present, beam time has been used for examining primarily native materials; beginning in October 2017, beam time will be used to examine experimental material from Task 8.

Reports and Public Outreach

The USGS presented the study design and scope to the Lahontan RWQCB in January 2014 and to the Hinkley, California, community in July 2014. A fact-sheet style open-file report describing the study approach was released in January 2016 and is available at https://doi.org/10.3133/ofr20161004 (Izbicki and Groover, 2016). Because the report may be too detailed for some community members, a short one-page handout version was prepared. A video describing the study also was prepared (https://ca.water.usgs.gov/media/hinkley-groundwater-chromium.html). Updates at project milestones were presented to the community on April 2015, January 2016, and January 2017. Informal presentations were made to members of the Hinkley community at Saturday pancake breakfasts in January 2016 and August 2017. Members of the Hinkley community have gone into the field with the USGS field teams on numerous occasions to observed data collection. USGS background Cr(VI) study progress and other information about the PG&E Hinkley Compressor Station site also were reported to the Hinkley community in quarterly newsletters prepared by the IRP Manager (http://www.hinkleygroundwater.com/). As part of Task 6, the USGS, with the assistance of the IRP Manager, contacted more than 70 members of the community for permission to sample their domestic wells as part of the study. Analytical results were provided to the landowners by letter and summarized for the IRP Manager.

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Director, California Water Science Center
U.S. Geological Survey
6000 J Street, Placer Hall
Sacramento, California 95819
https://ca.water.usgs.gov

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