Pacific Gas & Electric Company

SOIL HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT - ERRATA

Topock Compressor Station
Needles, California

February 19, 2020

February 19, 2020

Errata – Soil Human Health and Ecological Risk Assessment, Pacific Gas and Electric Company (PG&E) Topock Compressor Station, Needles, California.

This submittal provides five minor revisions and additional information to supplement Sections 6 and 8, and Table 3-1 of Appendix RBC of the Soil Human Health and Ecological Risk Assessment (HHERA), submitted in October 2019.

1. **Revised language for plant community based on the floristic surveys** to address U.S. Department of the Interior / U.S. Fish and Wildlife Service (DOI/USFWS) comment (Main report Section 6.6.2.1.1; Section 6.6.2.4; Section 6.6.2.5; Section 6.6.2.6.1; Section 6.6.2.7; Section 6.6.2.9; Section 6.6.2.10; Section 6.6.2.13; Section 6.6.2.14; and Section 8.2; Sections 5.6.2.1 and 6.2.1 in Appendices BCW, AOC4; AOC9, AOC11, AOC14, AOC27,UA2, and TT).

    Text in HHERA: The floristic surveys report a diverse assemblage of plants species found in typical abundance, density, cover, and vigor of plant communities in undisturbed desert habitat. These observations are not consistent with impairment of the plant community at the site. The floristic surveys provide site-specific observations that support the health of plant communities at the site and is considered a stronger line of evidence (LOE) than the exceedances of low-confidence generic plant screening values, which are widely acknowledged to have low ability to predict toxicity in plants.

    Revised Text: The floristic survey observations indicate relatively sparse vegetative cover with a variety of species representative of the region, consistent with desert habitats in general and the Lower Colorado River Valley subdivision of the Sonoran Desert in particular (MacMahon 1988, Brown 1994). Although sparse, no obvious impairment of the plant community was observed in the vicinity of the Site, and it provides the important habitat functions necessary for ecological receptors that inhabit the area. However, it should be noted that adverse effects to plant community composition would be difficult to detect given that the habitat is dominated by low density species like creosote bush. The lack of any noticeable impairment does not mean that plants have not been affected at the Site. Plant communities have been affected by human impacts related to over 60 years of transportation and energy development activities and remedial activities at the Topock Site, potentially resulting in the creation of environments that favor the establishment/dominance of certain plant species. Since plant community composition, distribution, and diversity is affected by human disturbance, it would be very difficult to distinguish between changes in the plant community due to human activities versus contaminant impacts on growth or reproduction due to chemical releases associated with the Site. Because chemical impacts, if they are occurring, are difficult to distinguish from changes associated with physical human disturbances, the potential for adverse effects to the health of the plant community can be considered low; therefore, risk drivers were not identified for plants. The exceedances of low-confidence generic plant screening values are widely acknowledged to have low ability to predict toxicity in plants.

    Additional References

    Brown, D. (ed). 1994. Biotic communities: southwestern US and northwestern Mexico. University of Utah Press, Salt Lake City.

    MacMahon, James A. 1988. Warm deserts. In: Barbour, Michael G.; Billings, William Dwight, eds. North American terrestrial vegetation. Cambridge; New York: Cambridge University Press: 231-264.

2. **Updated hexavalent chromium ecological risk-based concentrations (RBCs) for plants and soil invertebrates in Table 3-1 of Appendix RBC.**

   To assist the agencies in making soil management decisions, the plant and soil invertebrate RBCs were updated for hexavalent chromium. A technical memorandum prepared by Arcadis was submitted to the agencies in October 2019 and revised to address agency comments in January and February 2020 (Arcadis 2020; Attachment Errata-1). Based on more recent studies, additional toxicity data were identified for plants and soil invertebrates. The updated RBCs are 8.1 milligrams per kilogram (mg/kg) for plants and 25.7 mg/kg for soil invertebrates.

3. **Updated Background Threshold Value for thallium in Table 3-1 of Appendix RBC and added a footnote "c".**

   PG&E calculated an ambient/background threshold value (BTV) of 4.56 mg/kg for thallium to assist the agencies in making practical ambient/background soil management decisions. A technical memorandum prepared by Jacobs Engineering Group, Inc. (Jacobs) was submitted to the agencies in August 2019 (Jacobs 2019; Attachment Errata-2). DOI forwarded the memorandum to the Consultative Workgroup on August 16, 2019.

   Footnote "c" was added to Table 3-1: Based on the BTV developed for thallium by Jacobs Engineering Group, Inc. in August 2019 (Jacobs 2019).

4. **Updated footnote "a" in Table 3-1 of Appendix RBC.**

   A technical memorandum prepared by Arcadis providing the rationale for the low confidence in the plant-based screening level of 1 mg/kg for thallium was submitted by PG&E to DOI and the Department of Toxic Substances Control (DTSC) on July 12, 2019 (Attachment Errata-3). For the purposes of soil management, this screening level of 1 mg/kg was not selected as the basis of the thallium RBC.

   Footnote "a" was updated to include the following:

   > Note: The ecological RBCs for plants and soil invertebrates are equivalent to the media-based screening levels for these receptors. As stated in the main report (Sections 6.7.5 and 8.2) and Appendix RBC, these screening levels are generic and often below background threshold values, and their ability to predict risk to communities of plants and soil invertebrates is poor. Ecological RBCs were derived for wildlife populations following U.S. Environmental Protection Agency (USEPA) guidance (USEPA 1997, 2008) using the dietary dose model integrating site-specific parameters and population-level assessment endpoints (described in Sections 6.2 and 6.3 of the main report).
   >
   > - A technical memorandum prepared by Arcadis providing the rationale for the low confidence in the plant-based screening level of 1 mg/kg for thallium was submitted by PG&E to DOI and DTSC in July 2019 (Arcadis 2019).
   > - A technical memorandum prepared by Arcadis for the updated plant and invertebrate-based screening levels for hexavalent chromium reported in this table was submitted by PG&E to DOI and DTSC in February 2020 (Arcadis 2020).

5. **References updated for Table 3-1 of Appendix RBC.**

   References in Table 3-1 were updated to include Arcadis 2019, Arcadis 2020, Jacobs 2019, and USEPA 1997.

Table RBC-3.1
Ecological Risk-based Concentrations (Plants and Soil Invertebrates; Wildlife SUF = 1, Selected LOAEL TRVs)
(See Note a)

Soil Human Health and Ecological Risk Assessment
PG&E Topock Compressor Station
Needles, California

Category	Constituent	Units	BTV	Plants	Soil Invertebrates	Gambel's Quail SUF = 1 LOAEL	Cactus Wren SUF = 1 LOAEL	Desert Shrew SUF = 1 LOAEL	Merriam's Kangaroo Rat SUF = 1 LOAEL	Red-tailed Hawk SUF = 1 LOAEL	Desert Kit Fox SUF = 1 LOAEL	Nelson's Desert Bighorn Sheep SUF = 1 LOAEL	Lowest Wildlife RBC SUF = 1 LOAEL	Lowest Overall RBC
Inorganics	Aluminum	mg/kg	16400	pH<5.5	pH<5.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
Inorganics	Antimony	mg/kg	NC	5	78	NA	NA	**2.8**	135	NA	594	95	2.8	2.8
Inorganics	Arsenic	mg/kg	11	**18**	60	654	128	162	462	2823	1561	358	128	18
Inorganics	Barium	mg/kg	410	500	**330**	NA	NA	3666	5582	NA	83415	13198	3666	330
Inorganics	Beryllium	mg/kg	0.672	**10**	40	NA	NA	48	29	NA	636	62	29	10
Inorganics	Cadmium	mg/kg	1.1	32	140	1294	**5.9**	6.8	2180	4627	7106	1278	5.9	5.9
Inorganics	Calcium	mg/kg	66500	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Inorganics	Chromium, hexavalent	mg/kg	0.83	**8.1**	25.7	4498	342	580	7186	9143	24846	8205	342	8.1
Inorganics	Chromium, total	mg/kg	39.8	NA	**57**	2807	213	145	1800	5205	5257	2056	145	57
Inorganics	Cobalt	mg/kg	12.7	**13**	NA	4281	464	652	7259	1795	3220	4455	464	13
Inorganics	Copper	mg/kg	16.8	**70**	80	2618	109	145	5262	8857	8417	2135	109	70
Inorganics	Cyanide	mg/kg	NC	NA	**0.9**	100	23	3079	6335	360	12623	2135	23	0.9
Inorganics	Iron	mg/kg	29303	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Inorganics	Lead	mg/kg	8.39	120	1700	716	**36**	131	3445	1179	7049	1508	36	36
Inorganics	Magnesium	mg/kg	12100	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Inorganics	Manganese	mg/kg	402	**220**	450	53678	18235	18065	17203	137680	84931	28006	17203	220
Inorganics	Mercury	mg/kg	NC	0.3	**0.1**	25	1.0	589	1275	11	514	666	1.0	0.1
Inorganics	Molybdenum	mg/kg	1.37	**2**	NA	2601	300	22	115	31794	2620	217	22	2
Inorganics	Nickel	mg/kg	27.3	38	280	4137	88	**16**	957	12275	2388	478	16	16
Inorganics	Potassium	mg/kg	4400	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Inorganics	Selenium	mg/kg	1.47	**0.52**	4.1	19	4.4	2.3	6.0	185	89	16	2.3	0.52
Inorganics	Silver	mg/kg	NC	560	NA	4466	**52**	209	26890	14156	53195	13969	52	52
Inorganics	Sodium	mg/kg	2070	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Inorganics	Thallium	mg/kg	4.56[c]	**1**	NA	845	30	12	621	350	289	250	12	1
Inorganics	Vanadium	mg/kg	52.2	**2**	NA	165	28	660	3503	330	5831	1284	28	2
Inorganics	Zinc	mg/kg	58	160	**120**	29178	1050	4719	60824	141512	293694	64818	1050	120
Volatile Organic Compounds	1,2,4-Trimethylbenzene	mg/kg	NC	NA	**0.09**	NA	NA	NA	NA	NA	NA	NA	NA	0.09
Volatile Organic Compounds	1,3,5-Trimethylbenzene	mg/kg	NC	NA	**0.16**	NA	NA	NA	NA	NA	NA	NA	NA	0.16
Volatile Organic Compounds	Acetone	mg/kg	NC	NA	**0.04**	NA	NA	12315	25340	NA	50494	8856	8856	0.04
Volatile Organic Compounds	Bromomethane	mg/kg	NC	NA	**0.002**	NA	NA	NA	NA	NA	NA	NA	NA	0.002
Volatile Organic Compounds	Chloro methane	mg/kg	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Volatile Organic Compounds	Chloroform	mg/kg	NC	NA	**0.05**	NA	NA	10098	20779	NA	41405	7262	7262	0.05
Volatile Organic Compounds	Ethyl- benzene	mg/kg	NC	NA	**0.27**	NA	NA	71675	147478	NA	293872	51543	51543	0.27
Volatile Organic Compounds	Isopropylbenzene	mg/kg	NC	NA	**0.04**	NA	NA	NA	NA	NA	NA	NA	NA	0.04
Volatile Organic Compounds	Methyl acetate	mg/kg	NC	NA	NA	NA	NA	88670	182447	NA	363553	**63764**	63764	63764
Volatile Organic Compounds	Methyl ethyl ketone	mg/kg	NC	NA	**1**	NA	NA	1125857	2316568	NA	4616115	809625	809625	1
Volatile Organic Compounds	Methylene chloride	mg/kg	NC	1600	**0.21**	NA	NA	12315	25340	NA	50494	8856	8856	0.21
Volatile Organic Compounds	N-Butylbenzene	mg/kg	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Volatile Organic Compounds	N-Propylbenzene	mg/kg	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Volatile Organic Compounds	sec-Butylbenzene	mg/kg	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Volatile Organic Compounds	Toluene	mg/kg	NC	200	**0.15**	NA	NA	64039	131767	NA	262566	39740	39740	0.15
Volatile Organic Compounds	Xylene, m,p-	mg/kg	NC	100	**0.1**	NA	NA	640	1318	NA	2626	397	397	0.1
Volatile Organic Compounds	Xylene, o-	mg/kg	NC	100	**0.1**	NA	NA	640	1318	NA	2626	397	397	0.1
Volatile Organic Compounds	Xylenes, total	mg/kg	NC	100	**0.1**	NA	NA	640	1318	NA	2626	397	397	0.1

Table RBC-3.1
Ecological Risk-based Concentrations (Plants and Soil Invertebrates; Wildlife SUF = 1, Selected LOAEL TRVs)
(See Note a)

Soil Human Health and Ecological Risk Assessment
PG&E Topock Compressor Station
Needles, California

Category	Constituent	Units	BTV	Plants	Soil Invertebrates	Gambel's Quail SUF = 1 L O A E L	Cactus Wren SUF = 1 L O A E L	Desert Shrew SUF = 1 L O A E L	Merriam's Kangaroo Rat SUF = 1 L O A E L	Red-tailed Hawk SUF = 1 L O A E L	Desert Kit Fox SUF = 1 L O A E L	Nelson's Desert Bighorn Sheep SUF = 1 L O A E L	Lowest Wildlife RBC SUF = 1 L O A E L	Lowest Overall RBC
Semi-Volatile Organic Compour	2,4-Dimethylphenol	mg/kg	NC	NA	**0.04**	NA	NA	NA	NA	NA	NA	NA	NA	0.04
Semi-Volatile Organic Compour	4-Methylphenol	mg/kg	NC	10	**0.08**	NA	NA	NA	NA	NA	NA	NA	NA	0.08
Semi-Volatile Organic Compour	Bis (2-ethylhexyl) phthalate	mg/kg	NC	200	200	2759	**29**	447	92744	9911	184806	27971	29	29
Semi-Volatile Organic Compour	Butylbenzylphthalate	mg/kg	NC	NA	**0.59**	NA	NA	NA	NA	NA	NA	NA	NA	0.59
Semi-Volatile Organic Compour	Carbazole	mg/kg	NC	NA	**2800**	NA	NA	NA	NA	NA	NA	NA	NA	2800
Semi-Volatile Organic Compour	Dibenzofuran	mg/kg	NC	6.1	**0.15**	NA	NA	48.9	21	NA	30296	92	48.9	0.15
Semi-Volatile Organic Compour	Di-n-butyl phthalate	mg/kg	NC	200	200	276	**0.47**	709.9	928959	991	1851091	280168	0.47	0.47
Semi-Volatile Organic Compour	Isophorone	mg/kg	NC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Semi-Volatile Organic Compour	Pentachlorophenol	mg/kg	NC	**5**	31	291	25	7.6	46	10592	6817	265	7.6	5
Polycyclic Aromatic Hydrocarbo	PAH Low molecular weight	mg/kg	0.2674	**10**	29	56818	397	528	163626	205428	331237	79514	397	10
Polycyclic Aromatic Hydrocarbo	PAH High molecular weight	mg/kg	0.0376	**1.2**	18	12157	203	5.8	233	90100	3100	519	5.8	1.2
Pesticides	4,4-DDE	mg/kg	NC	0.9	**0.01**	487	1.0	0.26	194	0.036	0.02	109	0.02	0.01
Pesticides	4,4-DDT	mg/kg	NC	0.9	**0.01**	487	1.5	0.38	194	2.7	1.6	109	0.38	0.01
Pesticides	Alpha-Chlordane	mg/kg	NC	0.224	**0.0043**	949	2.4	1.9	523	111	212	861	1.9	0.0043
Pesticides	Dieldrin	mg/kg	NC	1	**0.05**	192	1.4	0.01	0.84	39	0.69	2.1	0.01	0.05
Pesticides	Gamma-Chlordane	mg/kg	NC	0.224	**0.0043**	949	2.4	1.9	523	111	212	861	1.9	0.0043
Polychlorinated Biphenyls	Total PCBs	mg/kg	NC	40	**1**	291	1.5	1.4	458	40	71	189	1.4	1
Dioxins	2,3,7,8-TCDD	ng/kg	NC	NA	**8800**	NA	NA	NA	NA	NA	NA	NA	NA	8800
Dioxins	TEQ Avian (U S E P A 1999 BAFs) b	ng/kg	5.98	NA	NA	31441	**217**	NA	NA	Not applicable	NA	NA	217	217
Dioxins	TEQ Avian (Fagervold et al. 2010 BAFs) [b]	ng/kg	5.98	NA	NA	NA	721	NA	NA	Not applicable	Not applicable	Not applicable	NA	NA
Dioxins	TEQ Mammals (U S E P A 1999 BAFs) b	ng/kg	5.58	NA	NA	NA	NA	**192**	13689	NA	Not applicable	Not applicable	192	192
Dioxins	TEQ Mammals (Fagervold et al. 2010 BAFs) [b]	ng/kg	5.58	NA	NA	NA	NA	358	NA	Not applicable	Not applicable	Not applicable	NA	NA

Notes:
[a] The lowest overall RBC (based on plants, invertebrates, and wildlife) is **bolded** and presented in the Lowest Overall RBC column. The lowest wildlife RBC is underlined and presented in the Lowest Wildlife RBC column.
Note: The ecological RBCs for plants and soil invertebrates are equivalent to the media-based screening levels for these receptors. As stated in the main report (Sections 6.7.5 and 8.2) and Appendix RBC, these screening levels are generic and often below BTVs, and their ability to predict risk to communities of plants and soil invertebrates is poor. Ecological RBCs were derived for wildlife populations following U S E P A guidance (U S E P A 1997, 2008) using the dietary dose model integrating site-specific parameters and population-level assessment endpoints (described in Sections 6.2 and 6.3 of the main report).
- A technical memorandum prepared by Arcadis providing the rationale for the low confidence in the plant-based screening level of 1 mg/kg for thallium was submitted by PG&E to DOI and DTSC in July, 2019 (Arcadis 2019).
- A technical memorandum prepared by Arcadis for the updated plant and invertebrate-based screening levels for hexavalent chromium reported in this table was submitted by PG&E to DOI and DTSC in February 2020 (Arcadis 2020).
[b] For the desert shrew, kangaroo rat, Gambel's quail, and cactus wren, alternate and more robust uptake models and TRVs were developed for dioxin TEQ (See Section 8.2 of the main report). The following assumptions were applied:
- For invertivorous/insectivorous species (cactus wren and desert shrew), the congener-specific BAFs (U S E P A 1999 and Fagervold et al. 2010) were used.
- For herbivorous species (Gambel's quail and Merriam's kangaroo rat), the congener-specific BAFs (U S E P A 1999) were used. Vegetation BAFs are not available from Fagervold et al. (2010).
- A recommended mammalian dioxin TRV of 30 ng/kg bw-day was used to calculate the RBC protective of small mammals, and the selected dioxin L O A E L TRV (140 ng/kg bw-day) was used to calculate the RBC protective of birds.
- The surface soil EPCs (0 to 0.5 foot bgs) calculated for Bat Cave Wash exposure area were used to develop the congener-specific dioxin TEQ tissue concentrations.
[c] Based on the BTV developed for thallium by Jacobs Engineering Group, Inc. in August 2019 (Jacobs 2019).

Abbreviations:
BAF = bioaccumulation factor
BTV = background threshold value
EPC = exposure point concentration
HQ = hazard quotient
L O A E L = lowest observed adverse effect level
mg/kg = milligrams per kilogram
NA = no toxicity value available, RBC could not be estimated
NC = not calculated
ng/kg bw-day = nanograms per kilogram body weight per day
NOAEL = no-observed adverse effect level
PAH = polycyclic aromatic hydrocarbon
PCBs = polychlorinated biphenyls
RBC = risk-based concentration
SUF = site use factor
TEQ = toxicity equivalent
TRV = toxicity reference value
U S E P A = U.S. Environmental Protection Agency

References:
Arcadis. 2019. Memorandum: Rationale for not recommending the plant-based ecological RBC of 1 mg/kg for thallium, Topock Compressor Station, Needles, California. July 12.
Arcadis. 2020. Memorandum: Revised Alternate Plant Risk-based Concentrations for Plants, Topock Compressor Station, Needles, California. February.
Fagervold, SK, Y Chai, JW Davis, M Wilken, G Cornelissen, and U Ghosh. 2010. Bioaccumulation of polychlorinated dibenzo-p-dioxins/dibenzofurans in E. fetida from floodplain soils and the effect of activated carbon amendment. Environ Sci Technol. 44(14):5546-52.
Jacobs. 2019. Memorandum: Determination of Thallium Ambient/Background Concentration at the Pacific Gas and Electric Company Topock Compressor Station, Needles, California. August 13.
U S E P A. 1997. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment. EPA 540-R-97-0C5. Office of Solid Waste and Emergency Response, Washington, DC.
U S E P A. 1999. Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities. U S E P A Peer Review Draft. August.

ATTACHMENT Errata-1

Revised Alternate Hexavalent Chromium Risk-based Concentrations for Plants, Pacific Gas and Electric Company Topock Compressor Station, Needles, California

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Date:

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Subject:

Revised Alternate Hexavalent Chromium Risk-based Concentrations for Plants, Topock Compressor Station, Needles, California

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Introduction

This memorandum presents an alternate soil risk-based concentration (RBC) for hexavalent chromium (chromium-6) for plants and updates the draft memorandum submitted on October 10, 2019 and revised draft memorandum submitted on January 23, 2020 to address comments from U.S. Department of Interior (DOI) and California Department of Toxic Substances Control (DTSC). This RBC will be used to support decisions for the handling, management, and storage of potentially contaminated and displaced soil during implementation of the groundwater remedy at the Topock Compressor Station, Needles, California (the Site), to address chromium contamination in groundwater.

As noted in the Soil Human Health and Ecological Risk Assessment (HHERA; Arcadis 2019), only generic risk-based screening levels are available for plants and these are below background levels. Typically, published screening levels are based on toxicity data (typically using agriculturally important produce or crop species and conducted in laboratory settings) that have limited relevance for the Site. For chromium, the plant screening value of 1 milligram per kilogram (mg/kg) presented in the Draft Soil HHERA (Arcadis 2018) is not based on specific toxicity data, but rather the authors' lower bound estimate of potential for toxicity in plants (more detail provided below). The screening levels are designed for use in conservative screening level risk assessments and for Site-characterization purposes (as was done for determining nature and extent for the RCRA Facility Investigation/Remedial Investigation [RFI/RI]).

Vegetation communities observed at the Site during floristic surveys conducted in 2013 (Garcia and Associates [GANDA] and CH2M Hill [CH2M] 2013) and 2017 (CH2M 2017) are typical of Mojave Desert plant communities. More than 100 different vascular plant species have been observed at the Site and documented in these survey reports. The floristic survey observations indicate relatively sparse vegetative cover with a variety of species representative of the region, consistent with desert habitats in general and the Lower Colorado River Valley subdivision of the Sonoran Desert in particular (MacMahon 1988, Brown 1994). Although sparse, no obvious impairment of the plant community was observed in the vicinity of the Site and it provides the important habitat functions necessary for ecological receptors that inhabit the area. However, it should be noted that adverse effects to plant community composition would be difficult to detect given that the habitat is dominated by low density species like creosote bush. The lack of any noticeable impairment does not mean that plants have not been affected at the Site. Plant communities have been affected by human impacts related to over 60 years of transportation and energy development activities and remedial activities at the Topock Site, potentially resulting in the creation of environments that favor the establishment/dominance of certain plant species. Since plant community composition, distribution, and diversity is affected by human disturbance, it would be very difficult to distinguish between changes in the plant community due to human activities versus contaminant impacts on growth or reproduction due to chemical releases associated with the Site. Because chemical impacts, if they are occurring, are difficult to distinguish from changes associated with physical human disturbances, the potential for adverse effects to the health of the plant community can be considered low and therefore, risk drivers were not identified for plants. The exceedances of low-confidence generic plant screening values, which are widely acknowledged to have low ability to predict toxicity in plants (including the original chromium-6 RBC for plants presented in the Draft Soil HHERA [Arcadis 2018]), are not recommended for soil management decisions.

The information from the floristic surveys (GANDA and CH2M 2013, CH2M 2017) was used as a stronger line of evidence in the Draft Soil HHERA (Arcadis 2018) to assess plant community health at the Site rather than simply using the exceedances of generic and low-confidence screening levels. It is not feasible to incorporate information from floristic surveys at the Site as a line of evidence for soil management decision-making because soil samples collected as part of the groundwater remedy may be from areas or depths where plants are not currently present/exposed. Therefore, a more robust plant RBC was developed for this purpose.

The remainder of this memorandum provides the basis of the chromium-6 plant screening level of 1 mg/kg and presents the process and results for developing an alternate chromium-6 RBC for plants.

Basis of the Plant Screening Level of 1 mg/kg for chromium-6

The plant screening value of 1 mg/kg presented in the Draft Soil HHERA (Arcadis 2018) was obtained from the Oak Ridge National Laboratory (ORNL) in Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants (Efroymson et al. 1997). This document summarizes two studies that looked at effects to plants from exposure to chromium-6 in soil. This document reports a range of toxicity values based on growth effects, ranging from 1.8 mg/kg for lettuce to 31 mg/kg for oats. The screening level of 1 mg/kg reported by Efroymson et al. (1997) is assumed to be based on a rounded-down value from the lowest reported toxicity values from a study by Adema and Henzen (1989), in which the authors note low confidence in this screening level:

> "If chemical concentrations reported in field soils that support vigorous and diverse plant communities exceed one or more of the benchmarks presented in this report or if a benchmark is exceeded by background soil concentrations, it is generally safe to assume that the benchmark is a poor measure of risk to the plant community at that site."

Additionally, the U.S. Environmental Protection Agency (USEPA) identified several studies for the development of a plant ecological soil screening level (EcoSSL) for chromium-6 (USEPA 2005). However, the USEPA concluded the data were insufficient to develop a plant EcoSSL.

Alternate chromium-6 RBC for Plants

To derive an alternate chromium-6 RBC for plants, the following studies, which were identified by ORNL and USEPA for developing a chromium-6 screening level for plants, were reviewed:

- Adema and Henzen (1989)
- Gunther and Pestemer 1990)
- Kadar and Morvai (1998)
- Turner and Rust (1971).

Additionally, a literature search was conducted to identify potentially relevant plant toxicity data published since release of the Interim Chromium EcoSSL (USEPA 2008). The search was conducted on 96 bibliographic databases and Google Scholar for studies published in 2006 or later using combinations of the following relevant keywords:

- Plants
- Toxicity, phytotoxicity
- Hexavalent chromium, chromium-6, Cr(VI)
- Soil, pot experiment
- Phytoremediation, bioremediation or NOT phytoremediation, bioremediation.

The literature search identified more than 13,000 potentially relevant studies, sorted by relevance. The titles and abstracts for the first 200 studies were reviewed and this group was considered likely to contain all appropriate studies for updating the plant chromium-6 RBC. Studies with lower relevance (i.e., beyond the first 200 studies) were not likely to contain appropriate plant toxicity data and were not reviewed. Of the top 200 most relevant studies, 21 papers were fully reviewed, and citations are included in Attachment A. Older potentially relevant studies cited in these papers were also reviewed. The abstracts for the remaining 179 studies were reviewed and found to not contain relevant toxicity information; therefore, these studies were not fully reviewed and data from those studies are not included in this memo.

Consistent with the EcoSSL data selection approach (USEPA 2008), and taking site-specific soil characteristics into consideration (discussed below), the following steps were taken to select studies for including in the dataset for the alternate plant chromium-6 RBC:

- Studies conducted with natural or artificial soil and soil pH greater than 7 and low organic matter (OM) were considered acceptable. Studies with no reported pH or OM were excluded from the dataset.
- Effects related to plant reproduction, growth, and survival were included.
- Studies with a single test concentration or without an appropriate negative control group were not included. These studies tended to be tests with various soil amendments for phytoremediation.

- The phytoremediation literature also tended to test relatively high chromium-6 concentrations in soil; therefore, exclusion of these data is appropriate to avoid artificially increasing the RBC by including elevated effects levels.
- Biochemical and physiological changes were not included.

Based on the selection process, data from four published studies (Adema and Henzen 1989, Amin et al. 2013, Kadar and Morvai 1998, and Singh 2001,) were included in the dataset for the calculation of the revised plant chromium-6 RBC.

Table 1 summarizes the toxicity endpoints/values reported in these studies. Toxicity endpoints reported were no-observed-adverse-effects concentrations (NOAECs) or equivalent values associated with less than 20% effect levels (e.g., EC5, EC10), lowest-observed-adverse-effects concentrations (LOAECs) or equivalent values associated with at least 20% effect levels (e.g., EC20), and/or values associated with at 50% effect levels (EC50). The EcoSSL approach (USEPA 2005) identifies the EC20 as the preferred effect level for developing plant screening levels, but also considers additional endpoints including LOAECs, NOAECs, maximum acceptable threshold concentrations (MATCs)[1], and effect levels values less than 20%. The ORNL approach considers all available effect concentrations including EC50 data to develop plant screening levels. Geometric means of the toxicity endpoints were calculated and are presented in Table 1.

The speciation and bioavailability, and therefore toxicity, of chromium in soil are dependent on multiple soil factors, such as pH, soil OM, and relative abundance of a variety of essential plant nutrients. Soil pH is inversely correlated with chromium-6 reduction to chromium-3 (i.e., low pH favors chromium-6 reduction) whereas OM is positively correlated with chromium-6 reduction (Chen et al. 2010, 2012; Zhu et al. 2019). In plants, chromium is a non-essential element and plants lack a specific uptake mechanism for chromium (Zayed and Terry 2003). Instead, chromium (Cr) uptake occurs via carriers for structurally-related elements, such as sulfate, phosphorus, and nitrate, which compete with Cr for carrier binding in plant roots. Thus, the presence of these essential nutrients can reduce chromium-6 uptake and mitigate toxicity associated with chromium-6 exposure in plants (Lopez-Bucio et al. 2014).

The available toxicity data represent a range of soil types and plant species, which may not be representative of soils and plant species present at the Site. Surface soils in the upland areas of the Site are primarily quaternary and recent alluvial materials, consisting of unconsolidated sandy gravel and silty/clayey gravel (CH2M 2007) and typical of other Mojave desert soils in the region. Soil pH is alkaline, ranging from about 7.4 to greater than 10 in areas sampled as part of the Draft Soil HHERA dataset. Soil OM and nutrient content are expected to be low at the Site. Based on these conditions, rates of chromium-6 reduction to trivalent chromium (chromium-3) would be expected to be relatively low in soil. As shown in Table 1, plant toxicity depends strongly on soil factors as well as species-specific sensitivity to chromium-6, as a range of effects values are observed for various species and soil types. The toxicity values measured for soils with low OM and higher pH may be most relevant to the Site and were included in the dataset for calculation of the alternate soil chromium-6 RBC for plants. Studies with test soil pH greater than 7 and low OM or studies with no reported pH or OM were excluded from the dataset. However, because no plant species known to be present at the Site were tested, it is uncertain whether these species would be more or less sensitive to chromium-6 than the species tested.

[1] The MATC is the geometric mean of the NOAEC and LOAEC values.

For some studies (i.e., Turner and Rust 1971, Lopez-Luna et al. 2009, Mohanty et al. 2015), the soil type was noted by the authors, but soil characteristics such as pH and/or OM were not reported. Loam, the soil type used in the Turner and Rust (1971) study, is typically a desirable soil type for gardening and agriculture, because it contains a mixture of sand, clay, and silt that result in a good balance of drainage and moisture retention. Loam soils typically contains 28 to 50% silt, the soil fraction that contains organic material. Thus, loam soils generally contain a higher proportion of organic material than sandy or clayey soils. Productive agricultural soils typically contain between 3% and 6% OM (Cornell University Cooperative Extension 2008). The organic material is associated with increased reductive rates for conversion of chromium-6 to chromium-3 relative to soils lower in OM. However, as the exposure duration tested in the Turner and Rust (1971) study was only 3 days, the effect of OM on the chromium-6 exposures in soil may not be substantial. Similarly, Lopez-Luna et al. (2009) and Mohanty et al. (2015) exposed plants to “garden soil” to which chromium-6 was added. A soil pH of 6.7 was reported by Lopez-Luna et al. (2009), but OM was not reported in either study. Based on the soil description, it was assumed that the garden soil would be similar to loam and contain a relatively high proportion of OM, although loam soils tested in Table 1 did not consistently contain higher fractions of soil OM (Adema and Henzen 1989).

Data from nine studies (Turner and Rust 1971, Lopez-Luna et al. 2009, Mohanty et al. 2015, Gunther and Pestemer 1990, Chen et al. 2010, 2012, Wyszkowski et al. 2013, Su et al. 2005, and Han et al. 2003), and some tests conducted by Adema and Henzen 1989 are listed in Table 1 but because the soil pH/OM from these studies are not specific to the site, they were not included in the dataset for the alternate soil chromium-6 RBC for plants.

The USEPA’s EcoSSL approach (USEPA 2008) recommends the following hierarchy in selecting the recommended toxicity endpoint from each study for plants: EC20 > MATC > EC10; a geometric mean of the recommended effect level was also calculated and is presented in Table 1.

The alternate RBCs calculated as described above include:

- 6.8 mg/kg – based on the geometric mean of NOAECs (n = 6)
- 20.8 mg/kg – based on the geometric mean of LOAECs (n = 3)
- 10.5 mg/kg – based on the geometric mean of EC50s (n = 4)
- 8.1 mg/kg – based on the geometric mean of the recommended effect level (n = 7).

Because no federal- or state-listed threatened or endangered plant species were observed at the Site, the RBC based on the NOAEC may be considered very conservative. While the RBC of 20.8 mg/kg based on the LOAEC-equivalent values is consistent with the EcoSSL approach, the LOAEC-equivalent values result in an RBC is greater than the RBC based on the EC50 data. The RBC of 8.1 mg/kg based on recommended effect levels, which are based on appropriate toxicity endpoints and soil conditions specific to the Site, is recommended as an alternate chromium-6 RBC for plants at the Site.

The alternate RBC is expected to be used to evaluate soils generated as part of the groundwater remedy. The alternate RBC will be applied as a threshold value below which no adverse effects on plants due to hexavalent chromium are expected.

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Table 1. Alternate Plant Risk-Based Concentration for Hexavalent Chromium
Soil Human Health and Ecological Risk Assessment
PG&E Topock Compressor Station
Needles, California

Primary Study	Soil Type	Included in dataset for Alternate RBC?[a]	Species	Exposure Duration	N O A E C-equivalent (mg/kg)	L O A E C-equivalent (mg/kg)	EC50 (mg/kg)	EcoSSL-Recommended Effect Level EC20 > MATC> EC10 - Value	EcoSSL-Recommended Effect Level EC20 > MATC> EC10 - Basis	Effect	Notes
Turner and Rust (1971)	loam (pH and OM not reported)	No	soybeans	3 d	10	30	NA	17.3	MATC	growth	Soil study reports lowest effect concentration of 5 ppm as significantly different from control, with 11% reduced growth. The 10 ppm treatment was not significantly different than 5 ppm. Similar to ORNL, we assumed 10 ppm as N O A E C-equivalent and 30 ppm as L O A E C-equivalent.
Adema and Henzen (1989)	humic sand (pH 5.1; OM 3.7%)	No	lettuce	14 d	11	NA	11	NA	--	growth	Reported as > 11 mg/kg in study; study based on potassium dichromate (chromium-6).
Adema and Henzen (1989)	humic sand (pH 5.1; OM 3.7%)	No	tomato	14 d	10	NA	21	10	N O A E C	growth	Values from Table 2 of study; study based on potassium dichromate (chromium-6).
Adema and Henzen (1989)	humic sand (pH 5.1; OM 3.7%)	No	oats	14 d	11	NA	31	11	N O A E C	growth	Values from Table 2 of study; study based on potassium dichromate (chromium-6).
Adema and Henzen (1989)	**loam (pH 7.4; OM 1.4%)**	**Yes**	**lettuce**	**14 d**	**0.35**	**NA**	**1.8**	**0.35**	**N O A E C**	**growth**	**Values from Table 2 of study; study based on potassium dichromate (chromium-6).**
Adema and Henzen (1989)	**loam (pH 7.4; OM 1.4%)**	**Yes**	**tomato**	**14 d**	**3.2**	**NA**	**6.8**	**3.2**	**N O A E C**	**growth**	**Values from Table 2 of study; study based on potassium dichromate (chromium-6).**
Adema and Henzen (1989)	**loam (pH 7.4; OM 1.4%)**	**Yes**	**oats**	**14 d**	**3.5**	**NA**	**7.4**	**3.5**	**N O A E C**	**growth**	**Values from Table 2 of study; study based on potassium dichromate (chromium-6).**
Gunther and Pestemer (1990)	(pH 6.1, OM 2.2%)	No	oats	14 d	9	NA	30	9	N O A E C	growth	N O A E C-equivalent based on EC5; study based on potassium dichromate (chromium-6).
Gunther and Pestemer (1990)	(pH 6.1, OM 2.2%)	No	turnip	10 d	3	NA	8.25	3	N O A E C	growth	N O A E C-equivalent based on EC5; study based on potassium dichromate (chromium-6).
Kadar and Morvai (1998)	**(pH 7.0, OM 1.0%)**	**Yes**	**carrot**	**field growing season**	**NA**	**15**	**NA**	**15**	**L O A E C**	**growth**	**Value from Table 5 of the study; study based on potassium dichromate (chromium-6).**
Kadar and Morvai (1998)	**(pH 7.0, OM 1.0%)**	**Yes**	**pea**	**field growing season**	**109**	**NA**	**NA**	**109**	**N O A E C**	**growth**	**Value from Table 5 of the study; study based on potassium dichromate (chromium-6).**
Amin et al. 2013	**(pH 7.5, OM 0.24%)**	**Yes**	**okra**	**30 d from seed**	**5**	**10**	**NA**	**7.07**	**MATC**	**growth**	**Values from Table 3 of study; Statistically significant effects in root and shoot growth for potassium dichromate (chromium-6).**
Lopez-Luna et al. 2009	garden soil (pH 6.7, OM not reported)	No	wheat	7 days from seed	50	100	186.86	70.7	MATC	growth	Values from Figures 2e,f of study; L O A E C reported by authors (25 mg/kg) not selected, as growth in 50 mg/kg treatment better than control. Root growth effects values for potassium dichromate (chromium-6); shoots growth and seed germination not affected until 500 mg/kg.
Lopez-Luna et al. 2009	garden soil (pH 6.7, OM not reported)	No	sorghum	7 days from seed	50	100	126.12	70.7	MATC	growth	Values from Figures 2e,f of study; Root growth effects values fo.r potassium dichromate (chromium-6); shoots less sensitive; seed germination not affected until 500 mg/kg.
Lopez-Luna et al. 2009	garden soil (pH 6.7, OM not reported)	No	oat	7 days from seed	50	100	316.23	70.7	MATC	growth	Values from Figures 2e,f of study; Root growth effects values for potassium dichromate (chromium-6); shoots less sensitive; seed germination not affected until 500 mg/kg.
Chen et al. 2012, 2010	(pH 4.5, 5.0, 6.2 OM 2.73%)	No	wheat	25 d	150	300	NA	212	MATC	growth	Values from Table 4 of study (for pH 5, lime treatment). Soil spiked with potassium dichromate. N O A E C/L O A E C 300/500 mg/kg without lime (but soil pH of 4.5 within EcoSSL range); selected more conservative N O A E C/L O A E C.

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PG&E Topock Compressor Station
Needles, California

Primary Study	Soil Type	Included in dataset for Alternate RBC?[a]	Species	Exposure Duration	N O A E C-equivalent (mg/kg)	L O A E C-equivalent (mg/kg)	EC50 (mg/kg)	EcoSSL-Recommended Effect Level EC20 > MATC> EC10 - Value	EcoSSL-Recommended Effect Level EC20 > MATC> EC10 - Basis	Effect	Notes
Wyszkowski et al. 2013	(pH 5.0, OM 0.078%?)	No	oats	"grown until ripe"	50	100	NA	70.7	MATC	growth	Values from Table 3 of study; for grain weight without additional substances. Growth enhancement at lower concentrations. Mass reduced by 45% at 100 mg/kg treatment.
Mohanty et al. 2015	garden soil (pH and SOM not reported)	No	sesban	21 d	10	100	NA	31.6	MATC	growth	Values from Table 1 of study; L O A E C for 29% reduction in root growth (% phytotoxicity to roots); shoot L O A E C is 300 mg/kg.
Su et al. 2005, Han et al. 2003	(pH 4.1, OM 4%)	No	brake fern	4 weeks	100	250	NA	158	MATC	growth	Values from Table 2 of study; L O A E C for shoot dry weight. Growth enhancement at lower concentrations. Weight reduced by 21% at 250 mg/kg treatment.
Singh 2001	**(pH 7.8, OM 0.4%)**	**Yes**	**spinach**	**65 d**	**45**	**60**	**>135**	**52.0**	**MATC**	**growth**	**Values from Table 2 of study; "LOAEL" of 30 mg/kg reported in text only, associated with 5% reduction in yield. Treatment of 45 mg/kg associated with 12% reduction in growth, and 60 mg/kg associated with 30% reduction in growth.**
Available Plant Screening Levels (mg/kg)											
EcoSSL for plants:	NA		Insufficient data								
ORNL screening level	1		rounded down based on the lowest EC50 from Adema and Henzen (1989)								
Alternate Risk-Based Concentrations (mg/kg):											
	6.8		geomean N O A E C								
	20.8		geomean L O A E C								
	8.1		**geomean Recommended Effect Level**								
	10.5		geomean EC50								

Notes:

[a] Data excluded from the dataset for the estimation of the alternate RBC because test soils had pH <7 or high organic matter; studies included are in bold.

Full references provided in the text.

Abbreviations:

d = days
EC = effects concentration
EcoSSL = Ecological soil screening level (USEPA 2005)
L O A E C = lowest-observed-adverse-effects concentration
MATC = maximum acceptable threshold concentration (geometric mean of N O A E C and L O A E C)
mg/kg = milligrams per kilogram
N O A E C = no-observed-adverse-effects concentration
OM = organic matter
ORNL = Oak Ridge National Laboratory
ppm = parts per million
RBC = risk-based concentration

Attachment A: Citations for Additional Studies Reviewed in Development of the Revised Plant Risk-Based Concentration (RBC) for Hexavalent Chromium (Chromium-6)

Additional Studies Used in Derivation of the Plant RBC

1. **Amin, H., B.A. Arain, F. Amin, and M.A. Surhio. 2013. Phytotoxicity of chromium on germination, growth and biochemical attributes of Hibiscus esculentus L. *American Journal of Plant Sciences*.** Abstract: Chromium (Cr) is found in all phases of the environment, including air, water and soil. The contamination of environment by chromium has become a major area of concern. Chromium effluent is highly toxic to plant and is harmful to their growth and development. In present study, a pot experiment was carried out to assess the phytotoxicity of chromium in *Hibiscus esculentus* at different concentration (0.5, 2.5, 5, 10, 25, 50 and 100 $mg \cdot kg^{-1}$) of chromium metal. The phytotoxic effect of chromium was observed on seed germination, seedling growth, seedling vigor index, chlorophyll content and tolerance indices of *Hibiscus esculentus*. All results when compared with control show that chromium metal adversely affects the growth of *Hibiscus esculentus* by reducing seed germination and decreasing seedling growth. The toxic effects of chromium metal to seed germination and young seedling are arranged in order of inhibition as: 0.5 > 2.5 > 5 > 10 > 25 > 50 > 100 $mg \cdot kg^{-1}$ respectively. The toxicity of chromium metal to young seedling and their effects on chlorophyll content were increased with higher concentration of chromium in the soil system. The major inhibitory effect of chromium in *Hibiscus esculentus* seedling was determined as stress tolerance index (%). The present study represents that the seed and seedling of *Hibiscus esculentus* has potential to counteract the deleterious effects of chromium metal in soil.
2. **Chen, C.P., K.W. Juang, T.H. Lin, and D.Y. Lee. 2010. Assessing the phytotoxicity of chromium in chromium-6-spiked soils by chromium speciation using XANES and resin extractable chromium-3 and chromium-6. *Plant and soil*, *334*(1-2), pp.299-309.** Abstract: The phytotoxicity of soil chromium usually depends on the plant availability of chromium-6 in chromium-contaminated soils. However, chromium-6 is favorably reduced to chromium-3 under acidic conditions, and increased availability of chromium-3 in acid soils can also cause phytotoxicity. The objective of this study was to determine the chromium phytotoxicity in acid soils in relation to their oxidation state and availability. Chromium X-ray absorption near edge structure spectroscopy (XANES), Dowex-M4195 and Chelex-100 resins, and wheat seedling growth experiments were used to determine the extent of chromium-6 reduction, extractable chromium-6 and chromium-3, and the phytotoxicity in two chromium-6-spiked acid soils. The results of the XANES spectra showed that chromium-6 added into the Neipu soil, which had a high content of organic matter, was completely reduced to chromium-3. In addition, both resin extractable chromium-6 and chromium-3 were very low. Meanwhile, no toxic effect of chromium on the wheat seedlings was observed and the wheat seedling growth increased with the increase in pH as a result of chromium addition. However, for the Pinchen soil which has a low content of organic matter, the XANES spectra showed that chromium-6 could not be reduced completely and that both resin-extractable chromium-6 and chromium-3 increased with the addition of chromium. The growth of the wheat seedlings also decreased with the addition of chromium-6 >500 mg kg−1soil. The significant retardation of the wheat seedlings grown in the Pinchen soil was the result of both chromium-3 and chromium-6 simultaneously. The speciation of total chromium by XANES and using resin extraction for determination of available chromium-3 and chromium-6, as demonstrated using chromium-6-spiked acid soils in this study, can be used to assess the phytotoxicity of chromium in chromium -contaminated soils.
3. **Chen, C.P., K.W. Juang, and D.Y. Lee. 2012. Effects of liming on chromium-6 reduction and chromium phytotoxicity in chromium-6-contaminated soils. *Soil science and plant nutrition*, *58*(1), pp.135-143.** Abstract: Liming is the most common approach for the amelioration of soil acidity in agriculture, and is widely used to reduce the mobility and bioavailability of heavy metals in soil. The purpose of this study was to investigate the hexavalent chromium (chromium-

6) reduction and chromium phytotoxicity in chromium-6-contaminated soils at different pH levels as a result of liming. Calcium carbonate ($CaCO_3$) was added to two acid agricultural soils of Taiwan (Neipu and Pinchen) at their natural pH of about 4, to adjust soil pH to approximately 5 and 6, respectively. The soils were then spiked with six levels of chromium-6 (0, 150, 300, 500, 1000 and 1500 mg kg^{-1}). X-ray absorption near edge structure spectroscopy (XANES) of chromium was used to determine the extent of the reduction of chromium-6 at different pH levels. At the same time, extractions of chromium by Dowex M4195 and Chelex 100 resins were carried out to determine the availability of chromium-6 and trivalent chromium [chromium-3] in the chromium-6-spiked soils, respectively. Also, a pot experiment with wheat (Triticum vulgare) seedlings was carried out to test the phytotoxicity of the chromium-6-spiked soils. The results showed that for chromium-6-contaminated soils which contain a high amount of organic matter, such as the Neipu soil, the effect of liming on chromium-6 reduction and chromium phytotoxicity is insignificant. However, for chromium-6-contaminated soils which have a low amount of organic matter, such as the Pinchen soils, liming could decrease the extent of chromium-6 reduction and increase the availability of chromium-6, thereby enhancing the phytotoxicity of chromium.

4. **Han, F.X., B.M. Sridhar, D.L. Monts, and Y. Su. 2004. Phytoavailability and toxicity of trivalent and hexavalent chromium to *Brassica juncea*. *New Phytologist*, *162*(2), pp.489-499**. Abstract: Brassica juncea is a potential candidate plant for phytoremediation of a number of heavy metals, but little is known about the phytotoxicity of chromium for this plant in chromium-3- and chromium-6-contaminated soils. Chromium distribution and phytotoxicity at the whole plant and cellular levels were studied using chemical, light microscopy, scanning electron microscopy and transmission electron microscopy analyses. Bioavailability of chromium in soils was low, but the uptake significantly increased at phytotoxic levels. Chromium from chromium-6-contaminated soils was more phytotoxic than from chromium-3-contaminated soils. Chromium causes growth retardation, reduces the number of palisade and spongy parenchyma cells in leaves, results in clotted depositions in the vascular bundles of stems and roots, and increases the number of vacuoles and electron dense materials along the walls of xylem and phloem vessels. Our results suggest that *B. juncea* is not a good candidate for phytoremediation of soils with lower chromium. However, it is able to accumulate significant amounts of chromium in both shoots and roots at higher soil-chromium concentrations despite severe phytotoxic symptoms.
5. **Lopez-Luna, J., M.C. Gonzalez-Chavez, F.J. Esparza-Garcia, and R. Rodriguez-Vazquez. 2009. Toxicity assessment of soil amended with tannery sludge, trivalent chromium and hexavalent chromium, using wheat, oat and sorghum plants. *Journal of Hazardous Materials*, *163*(2-3), pp.829-834**. Abstract: This work assessed the effect of soil amended with tannery sludge (0, 500, 1000, 2000, 4000 and 8000 mg Cr kg^{-1} soil), Cr^{3+} as $CrCl_3{\cdot}6H_2O$ (0, 100, 250, 500, 1000 and 2000 mg Cr kg^{-1} soil), and Cr^{6+} as $K_2Cr_2O_7$ (0, 25, 50, 100, 200 and 500 mg Cr kg^{-1} soil) on wheat, oat and sorghum plants. Seed germination, seedling growth (root and shoot) and chromium accumulation in dry tissue were measured. Toxicological parameters; medium effective concentration, no observed adverse effect concentration and low observed adverse effect concentration were determined. Root growth was the most sensitive assessment of chromium toxicity ($P < 0.05$). There was a significant correlation ($P < 0.0001$) between chromium accumulation in dry tissue and toxic effects on seedling growth. The three chromium sources had different accumulation and mobility patterns; tannery sludge was less toxic for all three plant species, followed by $CrCl_3{\cdot}6H_2O$ and $K_2Cr_2O_7$.
6. **Mohanty, M., C. Pradhan, and H. Patra. 2015. Chromium translocation, concentration and its phytotoxic impacts in *in vivo* grown seedlings of *Sesbania sesban L*. Merrill. *Acta Biologica Hungarica*, *66*(1), pp.80-92**. Abstract: The present *in vivo* pot culture study showed hexavalent chromium (Cr^{+6}) induced phytotoxic impacts and its translocation potential in 21 days old sesban (*Sesbania sesban* L. Merrill.) seedlings. Cr^{+6} showed significant growth retardation in 21 days old sesban (*Sesbania sesban* L. Merrill.) seedlings. Germination of seeds at 10,000 mg L^{-1} of Cr^{+6} exhibit 80% inhibition in germination. Seedling survival was 67% after 7 days of seedling exposure to 300 mg kg^{-1} of Cr^{+6}. Shoot phytotoxicity was enhanced from 6% to 31%

with elevated supply of Cr^{+6} from 10 mg kg^{-1} to 300 mg kg^{-1}. Elevated supply of Cr^{+6} exhibited increasing and decreasing trends in % phytotoxicity and seedling tolerance index, respectively. Elevated supply of chromium showed decreased chlorophyll and catalase activities. Peroxidase activities in roots and leaves were significantly higher at increased supply of Cr^{+6}. Chromium bioconcentration in roots was nearly 10 times more than stems whereas leaves showed nearly double accumulation than stems. Tissue specific chromium bioaccumulation showed 53 and 12 times more in roots and shoots respectively at 300 mg kg^{-1} Cr^{+6} than control. The present study reveals potential of sesban for effective chromium translocation from roots to shoots as evident from their translocation factor and Total Accumulation Rate values.

7. **Singh, A.K. 2001. Effect of trivalent and hexavalent chromium on spinach (*Spinacea oleracea* L). *Environment and Ecology*, *19*(4), pp.807-810**. Abstract: A pot culture experiment was conducted to study the effect of 0, 15.30, 45, 60, 75.90, 105, 120, and 135 mg/kg trivalent and hexavalent chromium on yield and accumulation of chromiurn by spinach *(Spinacea oleracea* L.). Chromium content in spinach leaves Increased from nil in control to 2.8 and 3.14 mg/kg due to 135 mg/kg chromium-3 and chromium-6 respectively at 25 days of growth. The control plants contained highest amount of N and P and both decreased with increasing levels of chromium-3 and chromium-6 application. The amount chromium in spinach leaves decreased with progressive cuttings. Chromium-6 applied at 30 mg/kg reduced the spinach yield to greater extent than chromium-3. Chromium induced reduced leaf size, burning and firing of leaf tips or margin and slower growth were observed.
8. **Su, Y., F.X. Han, B.M. Sridhar, and D.L. Monts. 2005. Phytotoxicity and phytoaccumulation of trivalent and hexavalent chromium in brake fern. *Environmental Toxicology and Chemistry: An International Journal*, *24*(8), pp.2019-2026.** Abstract: A recently recognized hyperaccumulator plant, Chinese brake fern (*Pteris vittata*), has been found to extract very high concentration of arsenic from arsenic-contaminated soil. Chromium usually is a coexisting contaminant with arsenic in most contaminated soils. The potential application of ferns for phytoremediation of chromium-3- and chromium-6-contaminated soils and their phytotoxicity to ferns has not been studied before. In this study, chromium distribution and phytotoxicity at the plant and cellular levels of brake ferns were studied using chemical analyses and scanning electron microscopy. The results show a higher phytotoxicity of chromium from chromium-6-contaminated soil to Chinese brake fern than from chromium-3-contaminated soil. Phytotoxicity symptoms included significant decreases both in fresh biomass weight and relative water content (RWC), and also in leaf chlorosis during the late stage of growing. At higher concentrations (500 mg/kg chromium-6 and 1,000 mg/kg chromium-3 addition), plants showed reduction in the number of palisade and spongy parenchyma cells in leaves. Compared with other plant species reported for phytoremediation of chromium-6-contaminated soil, brake fern took up and accumulated significant amounts of chromium (up to 1,145 mg/kg in shoots and 5,717 mg/kg in roots) and did not die immediately from phytotoxicity. Our study suggests that Chinese brake fern is a potential candidate for phytoremediation of chromium-6-contaminated soils, even though plants showed severe phytotoxic symptoms at higher soil chromium concentrations.
9. **Wyszkowski, M. and M. Radziemska. 2013. Assessment of tri-and hexavalent chromium phytotoxicity on Oats (Avena sativa L.) biomass and content of nitrogen compounds. *Water, Air, & Soil Pollution*, *224*(7), p.1619.** Abstract: The purpose of this study was to determine the effect of soil contamination with tri- and hexavalent chromium and soil application of compost, zeolite, and CaO on the mass of oats and content of nitrogen compounds in different organs of oats. The oats mass and content of nitrogen compounds in the crop depended on the type and dose of chromium and alleviating substances incorporated to soil. In the series without neutralizing substances, chromium-6, unlike chromium-3, had a negative effect on the growth and development of oats. The highest doses of chromium-6 and chromium-3 stimulated the accumulation of total nitrogen but depressed the content of $N\text{-}NO_3^-$ in most of organs of oats. Among the substances added to soil in order to alleviate the negative impact of chromium-6 on the mass of plants, compost had a particularly beneficial effect on the growth and

development of oats. The application of compost, zeolite, and CaO to soil had a stronger effect on the content of nitrogen compounds in grain and straw than in roots. Soil enrichment with either of the above substances usually raised the content of nitrogen compounds in oats grain and straw, but decreased it in roots.

Studies NOT Used in Derivation of the Plant RBC

1. **Ahmad, M.A.Q.S.O.O.D., A. Wahid, S.S. Ahmad, Z.A. Butt, and M. Tariq. 2011. Ecophysiological responses of rice (Oryza sativa L.) to hexavalent chromium. *Pak. J. Bot*, *43*(6), pp.2853-2859.** Abstract: The effects of hexavalent chromium (Cr) were studied in rice plants by applying its different concentrations ranging from 50-500 mg/kg of soil. Cr significantly altered growth of rice plants and reduced dry weights of shoot (7-58%) and roots (7-73%) in different treatments. Cr impact was remarkably high on photosynthetic rate (21-62%), transpiration rate (5-59%), and stomatal conductance (21-66%). Chlorophyll *a* and *b* and carotenoid contents were also reduced in Cr-treatment plants by 17-47%, 12-43%, 31-50%, respectively. Highly pronounced reductions were recorded in nitrogen (23-82%), phosphorous (4-37%), and potassium (6-42%) content of treated plant leaves. Cr accumulation was extremely higher in shoots (3575-19150%), roots (1023-5869%), and seeds (21-249%) of treated plants compared with control. Present investigation has reported injurious effects of Cr^{6+} on different aspect of rice plants. Cr accumulation in threshold amounts in plant parts and seeds is a matter of serious concern to human health as it causes cardiovascular diseases, kidney failure and cancer.
2. **Arshad, M., A.H.A. Khan,, I. Hussain, M. Anees, M. Iqbal, G. Soja, C. Linde, and S. Yousaf. 2017. The reduction of chromium-6 phytotoxicity and phytoavailability to wheat (Triticum aestivum L.) using biochar and bacteria. *Applied Soil Ecology*, *114*, pp.90-98.** Abstract: Chromium is considered a serious environmental pollutant due to its wide industrial use. Toxicity of chromium to plants depends on its valence state. chromium-6 is highly toxic and mobile whereas chromium-3 is less toxic. Chromium accumulation in plants causes high toxicity in terms of alterations in the germination process, reduction in the growth of roots, stems, and leaves, which may affect total dry matter production and yield. We performed a pot experiment to investigate chromium (50 mg kg^{-1}) induced phytotoxicity in wheat (*Triticum aestivum* L.) and to reduce its phytoavailability by amending the contaminated soil with chromium reducing bacteria (CRB) and 1% or 5% biochar. For the phytotoxicity assay, wheat was grown at different concentrations of chromium (10, 20, 30, 40 and 50 mg L^{-1}). After 3 weeks a subsequent reduction in root and shoot length, fresh and dry biomass, percentage germination, total chlorophyll, and carbohydrates was observed. Our results showed reduction in phytotoxic effects of chromium-6 mainly due to a reduction of toxic chromium-6 to chromium-3. Highest reductive transformation of chromium-6 to chromium-3 was observed in T9 (5% biochar with bacterial consortia) in all three matrices i.e. soil (99%), root (98%) and shoots (97%). The highest (90%) chromium retention within soil was also observed in T9 with the addition of 5% biochar and bacterial consortia. Of the remaining 10% chromium retention (entering into the plant), 3 mg kg^{-1} and 1.3 mg kg^{-1} was found in roots and shoots (on dry weight basis), respectively. Soil inoculation with consortia showed 33% higher stabilization than individual strain application. Soil amendment with biochar and bacteria showed an improvement in plant height, biomass production, seed germination, chlorophyll, protein, and carbohydrate content ($p < 0.05$). Findings of this study may help to reduce food chain availability of potentially toxic chromium by employing cost-effective bioremediation amendments.
3. **Choppala, G.K., N.S. Bolan, M. Megharaj, Z. Chen, and R. Naidu. 2012. The influence of biochar and black carbon on reduction and bioavailability of chromate in soils. *Journal of Environmental Quality*, *41*(4), pp.1175-1184**. Abstract: The widespread use of chromium has a deleterious impact on the environment. A number of pathways, both biotic and abiotic in character, determine the fate and speciation of chromium in soils. Chromium exists in two predominant species in the environment: trivalent [(chromium-3] and hexavalent [chromium-6]. Of

these two forms, chromium-3 is nontoxic and is strongly bound to soil particles, whereas chromium-6 is more toxic and soluble and readily leaches into groundwater. The toxicity of chromium-6 can be mitigated by reducing it to chromium-3 species. The objective of this study was to examine the effect of organic carbon sources on the reduction, microbial respiration, and phytoavailability of chromium-6 in soils. Organic carbon sources, such as black carbon (BC) and biochar, were tested for their potential in reducing chromium-6 in acidic and alkaline contaminated soils. An alkaline soil was selected to monitor the phytotoxicity of chromium-6 in sunflower plant. Our results showed that using BC resulted in greater reduction of chromium-6 in soils compared with biochar. This is attributed to the differences in dissolved organic carbon and functional groups that provide electrons for the reduction of chromium-6. When increasing levels of chromium were added to soils, both microbial respiration and plant growth decreased. The application of BC was more effective than biochar in increasing the microbial population and in mitigating the phytotoxicity of chromium-6. The net benefit of BC emerged as an increase in plant biomass and a decrease in chromium concentration in plant tissue. Consequently, it was concluded that BC is a potential reducing amendment in mitigating chromium-6 toxicity in soil and plants.

4. **Chen, N.C., S. Kanazawa, and T. Horiguchi. 2001. Effect of chromium on some enzyme activities in the wheat rhizosphere. *Soil Microorganisms*, *55*(1), pp.3-10**. Abstract: We investigated the effect of chromium-6 on the rhizosphere enzymes of wheat seedlings by using the rhizobox setup developed by Youssef and Chino (1988). In this system, 20 mg chromium-6 kg^<-1> soil as K_2Cr_2O_7 was placed in several compartments separated from each other by a 500 mesh nylon cloth. Wheat seedlings were transplanted, was placed in a growth chamber under 33.6 μ mol m^<-2> S^<-1> light and 24/20℃ day/night, for one month. Plant growth, plant height, total root weight, total shoot weight and number of total tillers were lower, but the root/shoot ratio was higher in the chromium treatment than in the control, indicating that the addition of chromium-6 exerted an adverse effect on plant growth, especially on roots. There was a decrease in the pH across the rhizosphere within a range of 5 mm wide from the rhizoplane, which was most pronounced in the central compartment (C.C.) in both the control (1.25 unit) and chromium treatment (1.86 unit), i.e. the chromium treatment further decreased the pH (0.61 unit) within a range of 2 mm from the rhizoplane. Phosphomonoesterase, phosphodiesterase, exocellulase and β-glucosidase activities were much higher in the C.C. with a negligible or no rhizospheric effect in other compartments both in the control and chromium treatment. However, the chromium treatment enhanced the activities of exocellulase and β-glucosidase, but decreased the activities of phosphomonoesterase and phosphodiesterase in the C.C. The findings obtained in the current studies was analyzed in terms of possible application to the development of phytoremediation technology.
5. **Ganesh, K.S., L. Baskaran, A. Chidambaram, and P. Sundaramoorthy. 2009. Influence of chromium stress on proline accumulation in soybean (Glycine max L. Merr.) genotypes. *Global Journal of Environmental Research*, *3*(2), pp.106-108.** Abstract: Four genotypes of soybean (Glycine max L. Merr.) were taken for investigation to know their response towards chromium stress. On the basis of seedling growth vigour index and dry weight, the genotypes JS 355 and P 1 were found tolerant to chromium stress when compared to the other genotypes. The tolerant genotypes had shown higher proline contents in their shoots.
6. **Khan, M.Y., H.N. Asghar, M.U. Jamshaid, M.J. Akhtar, and Z.A. Zahir. 2013. Effect of microbial inoculation on wheat growth and phytostabilization of chromium contaminated soil. *Pak J Bot*, *45*(S1), pp.27-34**. Abstract: Higher concentration of chromium-6 in the plant root zone affects many physiological processes and inhibits plant growth. Plant growth promoting rhizobacteria (PGPR) can improve plant health in contaminated soil as well as convert chromium-6 to less toxic chromium-3. In this study, 180 chromium-6-tolerant bacteria were isolated and after screening 10 efficient bacteria capable to work under chromium stress conditions were selected. Wheat (*Triticum aestivum* L.) seeds were inoculated with selected bacterial isolates and sown in chromium-6 contaminated (20 mg kg^{-1}) pots. Results showed that chromium-6

contamination significantly suppressed the plant growth and development. However, inoculation improved plant growth parameters significantly compared to un-inoculated plants. In inoculated pots chromium-6 contents were decreased in soil up to 62% while plant analysis for chromium-6 revealed that inoculation decreased uptake and translocation of chromium-6 from soil to the aerial parts of plant. Concentration of chromium-6 was up to 36% less in roots and 60% less in shoots as compared to un-inoculated plants grown in contaminated pots.

7. **Kumar, A., S. Joseph, L. Tsechansky, I.J. Schreiter, C. Schüth, S. Taherysoosavi, D.R. Mitchell, and E.R. Graber. 2020. Mechanistic evaluation of biochar potential for plant growth promotion and alleviation of chromium-induced phytotoxicity in Ficus elastica. *Chemosphere*, *243*, p.125332**. Abstract: The potential of biochar to enhance phytorestoration of hexavalent chromium [chromium-6]-contaminated soils was investigated. Rooted cuttings of *Ficus elastica* Roxb. Ex Hornem were transplanted to soil treated with 0 or 25 mg kg^{-1} chromium-6, –Cr and +Cr designations respectively, and amended with cattle manure-derived biochar at 0, 10 and 50 g kg^{-1}. Plants were grown for 180 d in a temperature-controlled greenhouse. In the –Cr treatment, biochar addition enhanced plant growth without affecting plant water status, leaf nutrient levels, photochemical efficiency, or hormone levels. In the absence of biochar, *Ficus* growth in the +Cr treatment was stunted, exhibiting decreased leaf and root relative water content and photochemical efficiency. Adding biochar to +Cr soil resulted in decreased Cr uptake into plant tissues and alleviated the toxic effects of soil chromium-6 on plant growth and physiology, including decreased leaf lipid peroxidation. High-resolution electron microscopy and spectroscopy elucidated the biochar role in decreasing chromium mobility, bioavailability, and phytotoxicity. Spectroscopic evidence is suggestive that biochar mediated the reduction of chromium-6 to chromium-3, which was subsequently incorporated into organomineral agglomerates formed at biochar surfaces. The dual function of biochar in improving *F. elastica* performance and detoxifying chromium-6 demonstrates that biochar holds much potential for enhancing phytorestoration of chromium-6-contaminated soils.
8. **Lopez-Bucio, J, F. Hernández-Madrigal, C. Cervantes, R. Ortiz-Castro, Y. Carreón-Abud, and M. Martínez-Trujillo. 2014. Phosphate relieves chromium toxicity in *Arabidopsis thaliana* plants by interfering with chromate uptake. Biometals : an international journal on the role of metal ions in biology, biochemistry, and medicine. 27. 10.1007/s10534-014-9718-7.** Abstract: Soil contamination by hexavalent chromium [chromium-6 or chromate] due to anthropogenic activities has become an increasingly important environmental problem. Mineral nutrients such as phosphate (Pi), sulfate and nitrate have been reported to attenuate chromium-6 toxicity, but the underlying mechanisms remain to be clarified. Here, we show that chromate activates the expression of low-Pi inducible reporter genes AtPT1 and AtPT2 in Arabidopsis thaliana transgenic seedlings. Primary-root growth was inhibited by 60 % in AtPT2::uidA-expressing seedlings upon exposure to 140-μM chromium-6. However, increasing the Pi and sulfate supply to the seedlings that were experiencing chromium-6 toxicity completely and partially restored the root growth, respectively. This effect correlated with the chromium-6-induced AtPT2::uidA expression being completely reversed by addition of Pi. To evaluate whether the nutrient supply may affect the endogenous level of Cr in plants grown under toxic chromium-6 levels, the contents of Cr were measured (by ICP-MS analyses) in seedlings treated with Cr and with or without Pi, sulfate or nitrate. It was found that Cr accumulation increases tenfold in plants treated with 140-μM chromium-6 without modifying the phosphorus concentration in the plant. In contrast, the supply of Pi specifically decreased the Cr content to levels similar to those found in seedlings grown in medium without chromate. Taken together, these results show that in A. thaliana seedlings the uptake of chromium-6 is reduced by Pi. Moreover, our data indicate that Pi and sulfate supplements may be useful in strategies for handling Cr-contaminated soils.
9. **Ma, Q., X. Cao, J. Ma, X. Tan, Y. Xie, H. Xiao, and L. Wu. 2017. Hexavalent chromium stress enhances the uptake of nitrate but reduces the uptake of ammonium and glycine in pak choi (Brassica chinensis L.). Ecotoxicology and environmental safety. 139. 384-393. 10.1016/j.ecoenv.2017.02.009**. Abstract: Chromium pollution affects plant growth and

biochemical processes, so, the relative uptake of glycine,nitrate, and ammonium by pak choi (Brassica *chinensis*) seedlings in treatments with 0 mg L−1and 10 mg L−1chromium-6 were detected by substrate-specific15N-labelling in a sterile environment. The short-term uptake of15N-labelled sources and15N-enriched amino acids were detected by gas chromatography mass spectrometry toexplore the mechanism by which chromium stress affects glycine uptake and metabolism, which showing that chromium stress hindered the uptake of ammonium and glycine but increased significantly the uptake of nitrate. Chromium stress did not decrease the active or passive uptake of glycine, but it inhibited the conversion of glycine to serine in pak choi roots, indicating that the metabolism of glycine to serine in roots, rather than the root uptake, was the limiting step in glycine contribution to total N uptake in pak choi. Since chromium affects the relative uptake of different N sources, a feasible way to reduce chromium-induced stress is application of selective fertilization, in particular nitrate, in pak choi cultivation on Cr-polluted soil.

10. **Molla, K., A. Dimirkou, and V. Antoniadis. 2012. Hexavalent Chromium Dynamics and Uptake in Manure-Added Soil. *Water Air Soil Pollut* 223, 6059–6067 doi: 10.1007/s11270-012-1340-0.** Abstract: The soil dynamics of hexavalent chromium (chromium-6), a particularly mobile and toxic metal, is of a great environmental concern, and its availability to plants depends on various soil properties including soil organic matter. Thus, in a pot experiment, we added 50 mg chromium-6 kg^{-1} soil and studied chromium-6 soil extractability and availability to spinach, where we applied both natural (zeolite), synthetic adsorptive materials (goethite and zeolite/goethite) and organic matter with farmyard manure. We found that, compared to the unamended control plants, dry matter weight in the chromium-6-added soil was greatly decreased to 17 % of the control, and height was decreased to 34 % of the control, an indication of chromium toxicity. Also, exchangeable chromium-6 levels in soil decreased back to the unamended control even in the first soil sampling time. This was much faster than the exchangeable chromium-6 levels in the mineral-added soil, where chromium-6 levels were decreased to the levels of the unamended control in the third sampling time. The positive effect of organic matter was also indicated in the chromium quantity soil-to-plant transfer coefficient (in grams of chromium in plant per kilogram of chromium added in soil), a phyto-extraction index, which was significantly higher in the manure-amended (1.111 g kg^{-1}) than in the mineral-added treatments (0.568 g kg^{-1}). Our findings show that organic matter eliminates the toxicity of added chromium-6 faster than the mineral phases do and enhances the ability of spinach to extract from soil greater quantities of chromium-6 compared to mineral-added soils.
11. **Shanker, A.K., C. Cervantes, H. Loza-Tavera, and S. Avudainayagam. 2005. Chromium toxicity in plants. *Environment international*, *31*(5), pp.739-753.** Abstract: Due to its wide industrial use, chromium is considered a serious environmental pollutant. Contamination of soil and water by chromium is of recent concern. Toxicity of chromium to plants depends on its valence state: chromium-6 is highly toxic and mobile whereas chromium-3 is less toxic. Since plants lack a specific transport system for chromium, it is taken up by carriers of essential ions such as sulfate or iron. Toxic effects of chromium on plant growth and development include alterations in the germination process as well as in the growth of roots, stems and leaves, which may affect total dry matter production and yield. Chromium also causes deleterious effects on plant physiological processes such as photosynthesis, water relations and mineral nutrition. Metabolic alterations by chromium exposure have also been described in plants either by a direct effect on enzymes or other metabolites or by its ability to generate reactive oxygen species which may cause oxidative stress. The potential of plants with the capacity to accumulate or to stabilize chromium compounds for bioremediation of chromium contamination has gained interest in recent years.
12. **Sun, Z.Q., Y.H. Qui, S.W. Li, X.M. Han, and H.L. Li. 2019. Comparison on the Tolerance And Accumulation of Hexavalent Chromium by Different Crops under Hydroponic Conditions. *Applied Ecology And Environmental Research*, *17*(5), pp.11249-11260**. Abstract: Seedlings of six crops including wheat, radish, cucumber, Chinese cabbage, oilseed rape, and lettuce were treated with hexavalent chromium (chromium-6) in a hydroponic system. Root

surface area, tissue biomass, the activities of superoxide dismutase (SOD) and peroxidase (POD), and chromium contents were determined to evaluate the tolerance and accumulation of chromium-6 by these crops. The results showed that the biomass reduction of wheat was the lowest, and that of lettuce was the highest. Significant decrease in SOD activity was observed in 1 mg/L chromium-6 treatment for Chinese cabbage and radish. While significant activation effect on the POD was observed in 1 mg/L or 5 mg/L chromium-6 treatment for Chinese cabbage and oilseed rape. Moreover, the activities of the two antioxidant enzymes in cucumber leaves did not change significantly at the two levels of chromium-6 concentrations. The transfer coefficient of Chinese cabbage was the highest, while that of lettuce was the lowest. In conclusion, Chinese cabbage has a certain tolerance to chromium-6 and exhibits the highest accumulation of chromium in the edible parts. Therefore, when planting crops in low and medium chromium-contaminated soil, concerns should be addressed on the food safety issues from leafy vegetables, especially Chinese cabbage.

Refined Plant Risk-Based Concentrations for Hexavalent Chromium in Soil, Topock Compressor Station, Needles, California, October 10, 2019 (Revised January 31,2020)

Document Prepared by: PG&E
Comments Submitted By: DOI
DOI Reviewer(s): P. Innis, Carrie Marr
BB&E Reviewer(s): G Long (EHS Support, LLC); D McCue (EHS Support, LLC)

Comment No.	Page No.	Sect No.	Para No.	Text in October 10, 2019 Document	Proposed Revision to Text	January 31, 2020 PG&E Response to Comment	Review of PG&E Response-to- Comment
1	NA	NA	NA		General comment: The approach for the derivation of a refined plant RBC for chromium-6 is consistent with guidance and is generally based on plant toxicity studies identified for the derivation of chromium-6 soil screening values for the protection of terrestrial plants. Further detail is requested based on the specific comments below to clarify the derivation and application of the refined plant RBC for chromium-6 at the site.	Comment noted.	No additional comment.
2					In the HHERA, Table 7-1a, plants and inverts are called out as 'risk drivers' for chromium-6 SWMU 1, AOC 9, and AOC 10. It was also noted that the USEPA didn't calculate an EcoSSL for chromium-6 for inverts either. If PG&E is going to calculate a special plant chromium-6, inverts should be considered as well. The reason that an invert chromium-6 RBRG was not calculated may be because there are only two data points for invert tox in the EcoSSL. At a minimum, they should discuss that they looked into invert chromium-6 tox too. https://www.epa.gov/sites/prod uction/files/2015-09/documents/eco- ssl_chromium.pdf	An alternate invertebrate screening level, based on the chromium-6 toxicity data presented in the EcoSSl (Van Gestel et al. 1992, 1993), was discussed in Section 6.5.1.1 of the Draft Soil HHERA (Arcadis 2018). This value, 57 mg/kg, is recommended for use as the alternate soil chromium-6 RBC for invertebrates. **Corrected Response:** The alternate soil chromium-6 RBC noted in the original response is based on total chromium, not chromium-6, and is therefore not appropriate as an alternate chromium-6 RBC for invertebrates. A literature search found that the available data are insufficient to calculate an alternate RBC using the methodology used to calculate the alternate soil chromium-6 RBC for plants (namely, using soil toxicity tests conducted with soil pH greater than 7 and reported pH/organic matter [OM]). One study was identified with relevant data. Sivakumar and Subbhurram (2005) determined 14 day LC50 values for the earthworm *Eisenia fetida* in 10 different soils spiked with chromium-6. One soil with pH > 7 and organic carbon content of 0.19% had an LC50 of 257 mg/kg, although LC50 values for all ten soils were similar (range 222-257 mg/kg). Using a uncertainty factor of 10 to adjust the LC50 to a low-effect adverse concentration results in a value of 25.7 mg/kg, which is recommended as the refined soil chromium-6 RBC for invertebrates.	

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Comment No.	Page No.	Sect No.	Para No.	Text in October 10, 2019 Document	Proposed Revision to Text	January 23 and February 14, 2020 PG&E Response to Comment	Review of PG&E Response-to- Comment
3	1		3	The floristic surveys report a diverse assemblage of plants species found in typical abundance, density, cover, and vigor of plant communities in undisturbed desert habitat. These observations are not consistent with impairment of the plant community at the Topock Site.	Similar to the comment on the EE/CA, DOI received the following input from FWS: Early in the ERA process, we discussed that while the desert has sparse vegetation, it provides an important ecosystem for its inhabitants. The desert habitat at Topock has a relatively low density, compared to other habitat types in the country, by definition*. Adverse effects to plant community composition would be difficult to detect given that the habitat is dominated by low density species like creosote bush. The lack of any noticeable impairment does not mean that plants have not been affected at the Site. Effects on germination, plant vigor, or colonization cannot be determined without species-specific toxicity studies. Additionally, the habitat at Topock is heavily disturbed by 60 years of transportation, industrial and remedial activities. Since plant community composition, distribution, and diversity is affected by human disturbance, it would be very difficult to distinguish between changes in the plant community due to human activities versus contaminant impacts. *Creosote bush density was 448 plants per hectare in the Lower Colorado River Valley subdivision of the Sonoran Desert (MacMahon 1988, Brown 1994). Relative abundance was 10.8 percent and relative plant cover was 19.6 percent in Rock Valley, Nevada (Ackerman et al. 1974) https://www.fs.fed.us/database/ feis/plants/shrub/lartri/all.html	Language provided for EE/CA in response to this comment was and approved by DOI and DTSC on January 8, 2020 was incorporated into this revised chromium-6 RBC tech memo.	

Refined Plant Risk-Based Concentrations for Hexavalent Chromium in Soil, Topock Compressor Station, Needles, California, October 10, 2019 (Revised January 31,2020)

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4	2	NA	5	Table 1 identifies NOAEC endpoints from Gunther and Pestemer (1990) of 9 mg/kg and 3 mg/kg for oats and turnip, respectively based on 5% effect concentrations (EC_5s). However, EPA identifies these endpoints as 50 percent effect concentrations (EC_{50}s) in the evaluation of chromium-6 plant toxicity endpoints (Table 3.1 in USEPA 2008).	Discuss the basis for the use of 9 mg/kg and 3 mg/kg as NOAEC endpoints for oat and turnip, respectively, in the calculation of the recommended effects levels.	In their Figure 3, Gunther and Pestemer (1990) present both EC5 (top figure) and EC50 (bottom figure) values for oats and turnip. As estimated from Figure 3, the EC50s for turnip and oats are 8.25 and 30 mg/kg, respectively, and the EC5 values are 3 and 9 mg/kg, respectively. The EC50 of 8.25 mg/kg for turnip is also presented in Table 3. It appears that USEPA mistakenly identified 3 and 9 mg/kg as EC50 values instead of EC5 values from Figure 3. EcoSSL guidance (USEPA 2008) recommends the EC20 as the preferred effect level and is associated with effects approximating a LOAEL. Therefore, the EC5 values of 3 and 9 mg/kg associated with a 5% decrease in plant growth were considered NOAEL- equivalent values for the purpose of this evaluation.	Response confirmed. The 9 mg/kg and 3 mg/kg NOAEC endpoints for oat and turnip, respectively, were confirmed in Figure 3 of Gunther and Pestemer (1990).

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BB&E Reviewer(s): G Long (EHS Support, LLC); D McCue (EHS Support, LLC)

Comment No.	Page No.	Sect No.	Para No.	Text in October 10, 2019 Document	Proposed Revision to Text	January 23 and February 14, 2020 PG&E Response to Comment	Review of PG&E Response-to- Comment
5	2	NA	5	The plant toxicity studies that are summarized in Table 1 were based on literature reviews conducted prior to 2008 (the date of last revision of the Eco-SSL for chromium).	Please confirm if a literature search was conducted to identify any relevant plant toxicity studies for chromium-6 that should be considered in the derivation of the refined plant RBC. If relevant studies are identified, incorporate these studies into Table 1 and include in the calculation of the refined plant RBC.	A literature search for more recent data (2006 and later) was conducted and the chromium-6 RBC memo and Table 1 were updated to incorporate the relevant information. The plant chromium-6 RBC value was updated with additional data.	Additional studies identified in the literature review were incorporated into the alternate plant RBC calculation. However, please refer to the response to Comment #6 regarding the applicability and relevance of these additional endpoints to site exposure conditions and the calculation of the alternate plant RBC.
6	3	NA	2		The text presents the range of RBCs calculated based on the toxicity endpoints compiled in Table 1. The endpoints used to calculate RBCs were derived from soil test conditions that vary by soil type, pH, and OM. Given that these soil characteristics affect the speciation and bioavailability of chromium in soil, a discussion of the representative soil characteristics at the Topock Compressor Station is warranted to evaluate the relevance of the soil test conditions to site soil conditions. Describe the representative site soil type, pH, and OM and discuss the relevance of soil test conditions summarized in Table 1 to site conditions. This discussion should evaluate the uncertainty in the refined plant RBC based on potential differences between soil test conditions and site conditions and indicate if the refined plant RBC is protective of site conditions. **Note:** The study by Turner and Rust (1971) was rejected for use in deriving plant EcoSSLs because pH and OM were not reported by the authors. A qualitative evaluation of the relevance of toxicity endpoints from this study should be included based on the description of soil characteristics (e.g., loam).	As noted in the comment, the speciation and bioavailability of chromium in soil is dependent on multiple soil factors, such as pH, soil OM, and relative abundance of a variety of essential plant nutrients. Soil pH is inversely correlated with chromium-6 reduction to chromium-3 (i.e., low pH favors chromium-6 reduction) whereas soil OM is positively correlated with chromium-6 reduction (i.e., higher reduction rates at high soil OM) (Chen et al. 2010, 2012; Zhu et al. 2019). Chromium is a non-essential element in plants and plants lack a specific uptake mechanism for Cr. Instead, Cr uptake occurs via carriers for structurally-related elements, such as sulfate, phosphorus, and nitrate, which compete with Cr for carrier binding in plant roots. Thus, the presence of these essential nutrients can reduce chromium-6 uptake and mitigate toxicity associated with chromium-6 exposure in plants (Lopez-Bucio et al. 2014). Surface soils in the upland areas of the Site are primarily Quaternary and Recent alluvial materials, consisting of unconsolidated sandy gravel and silty/clayey gravel (CH2M 2007), typical of Mojave Desert soils in the region. Soil pH is alkaline, ranging from about 7.4 to greater than 10 in areas sampled as part of the Soil HHERA. Soil OM and nutrient content are expected to be low. Based on these conditions, rates of chromium-6 reduction to chromium-3 would be expected to be relatively low in soil, and chromium-6 could be expected to persist and be available for plant uptake. As shown in the Table 1 of the tech memo, plant toxicity depends strongly on soil factors as well as species- specific sensitivity to chromium-6, as a range of effects values are observed for various species and soil types. The toxicity values measured for soils with low OM and higher pH would be most relevant to the Site. As no plant species known to be present at the Site were tested, it is uncertain whether these species would be more or less sensitive to chromium-6 than the species tested. General soil characteristics of loam, the soil type used by Turner and Rust (1971) are described in the revised memo and a qualitative discussion of the effect on the data is presented. **Updated Response:** As noted in the memo, additional studies that met USEPA's EcoSSL data selection approach (USEPA 2008), were included in the dataset for the alternate soil chromium-6 RBC for plants. However, PG&E agrees with the agencies that including only those studies with pH > 7 and low OM would make the soil chromium-6 RBC for plants more site-specific. The updated calculated geometric mean Recommended Effect Level is 8.1 mg/kg. The memo and Table 1 were revised to reflect this change.	The response to comment and associated revisions to the text provide a thorough discussion of the soil characteristics that affect the speciation and bioavailability of chromium in soil. As stated in the response, soils with low pH and high OM favor the reduction of chromium-6 to chromium-3. In addition, the presence of essential nutrients in soil, such as sulfate, phosphorus, and nitrate can reduce chromium-6 uptake and mitigate plant toxicity. However, many of the toxicity endpoints included in the calculation of the plant RBC were based on soil conditions in toxicity tests (low pH or high OM) that are not representative of soil conditions at the site (high pH and low OM) and do not favor the persistence of chromium-6. As stated in the response, the pH of site soils is alkaline, ranging from about 7.4 to greater than 10 in areas sampled as part of the Soil HHERA. Further, soil OM and nutrient content are expected to be low. Based on these conditions, rates of chromium-6 reduction to chromium-3 would be expected to be low and chromium-6 could be expected to persist and be available for plant uptake. Further justification is needed for the inclusion of toxicity endpoints from toxicity tests conducted on soil conditions that are not representative of site soil conditions and not consistent with soil pH levels at which chromium-6 is expected to persist. It is noted that several of the toxicity endpoints from studies added to Table 1 since the previous draft were based on low pH and high OM test soils (which is not representative of site soils) and resulted in the highest NOAEC and LOAEC endpoints in the dataset (e.g., Chen et al., 2012, 2010; Su et al., 2005; Han et al., 2003). The inclusion of these endpoints in the geometric mean calculation contributed to an increase in the Recommended Effect Level from 7.1 mg/kg to 19.5 mg/kg between drafts of the technical memorandum. Considering only the toxicity endpoints from Table 1 that are based on test soil conditions within the range of site soil conditions (pH > 7 and low OM), the calculated geometric mean Recommended Effect Level is 8.1 mg/kg. This value is derived from studies with test conditions that are more representative of site exposure conditions and therefore, may be more appropriate as the basis for the alternate plant RBC.

Refined Plant Risk-Based Concentrations for Hexavalent Chromium in Soil, Topock Compressor Station, Needles, California, October 10, 2019 (Revised January 31,2020)

Document Prepared by: PG&E
Comments Submitted By: DOI
DOI Reviewer(s): P. Innis, Carrie Marr
BB&E Reviewer(s): G Long (EHS Support, LLC); D McCue (EHS Support, LLC)

Comment No.	Page No.	Sect No.	Para No.	Text in October 10, 2019 Document	Proposed Revision to Text	January 23 and February 14, 2020 PG&E Response to Comment	Review of PG&E Response-to- Comment
7	3	NA	3	The text indicates that site-specific observations are considered a stronger line of evidence than exceedances of low- confidence generic plant screening levels (Page 1, Paragraph 3). However, the text describing the derivation of the refined chromium-6 RBC (Page 3, Paragraph 3) does not indicate how site-specific observations will be balanced with exceedances of the refined plant risk-based RBCs.	Provide further discussion of the application of the proposed refined plant risk-based RBCs. If other lines of evidence, including site-specific observations from floristic surveys, will be considered in soil management decision-making, these lines of evidence should be described and the weight-of-evidence approach for decision making should be discussed.	The following discussion was added to the RBC memo: The alternate RBC is expected to be used to evaluate soils generated as part of the groundwater remedy. . The alternate RBC will be applied as a threshold value below which no adverse effects on plants due to chromium-6 are expected. The information from the floristic surveys was used as a stronger line of evidence in the Draft Soil HHERA (Arcadis 2018) to assess plant community health at the Site rather than simply using the exceedances of generic and low-confidence screening levels. It is not feasible to incorporate information from floristic surveys at the Site as a line of evidence for soil management decision-making because soil samples collected as part of the groundwater remedy may be from areas or depths where plants are not currently present/exposed. Therefore, a more robust plant RBC was developed for this purpose.	The response and associated text revisions are appropriate.

Refined Plant Risk-Based Concentrations for Hexavalent Chromium in Soil, Topock Compressor Station, Needles, California, October 10, 2019 (Revised January 31,2020)

Document Prepared by: PG&E
Comments Submitted By: DOI
DOI Reviewer(s): P. Innis, Carrie Marr
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Acronyms & Abbreviations:

AOC = area of concern
Cr = chromium
chromium-3 = trivalent chromium
chromium-6 = hexavalent chromium
DOI = U.S. Department of the Interior
DTSC = Department of Toxic Substances Control
EcoSSL = ecological soil screening level
EE/CA = Engineering Evaluation/Cost Analysis
EHS = Environment, Health & Safety
ERA = Ecological Risk Assessment
HHERA = Human Health and Ecological Risk Assessment
LOAEL = lowest observed adverse effects level
mg/kg = milligram per kilogram
NOAEC = no-observed-adverse-effects concentration
NOAEL = no observed adverse effect level
OM = organic matter
PG&E = Pacific Gas and Electric Company
RBC = risk-based concentration
RBRG = risk-based remediation goal
SWMU = solid waste management unit
USEPA = U.S. Environmental Protection Agency

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ATTACHMENT Errata-2

Determination of Thallium Ambient/Background Concentration at the Pacific Gas and Electric Company Topock Compressor Station, Needles, California

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Memorandum

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Subject	**Determination of Thallium Ambient/Background Concentration at the Pacific Gas and Electric Company Topock Compressor Station, Needles, California**
Attention	Pacific Gas and Electric Company (PG&E)
From	Jacobs Engineering Group Inc. (Jacobs)
Date	August 13, 2019
Copies to	Curt Russell/PG&E Pam Innis/U.S. Department of the Interior (DOI) Aaron Yue/California Department of Toxic Substance Control (DTSC)

1. Introduction

This technical memorandum presents the approach and methodology Jacobs used to develop a soil ambient concentration for thallium at the PG&E Topock Compressor Station (TCS). PG&E is implementing the Remedy Soil Management Plan (Remedy SMP), Appendix L of the Construction/Remedial Action Work Plan (C/RAWP) (CH2M, 2015), as part of groundwater remedy construction. Table 2.4-1 of the Remedy SMP contains an interim screening level (ISL) for thallium of 0.78 milligram per kilogram (mg/kg) based on the U.S. Environmental Protection Agency (EPA) Residential Regional Screening Level (RSL), (EPA 2017). The ISL is significantly less than the concentrations of thallium found in certain soil samples collected to document baseline conditions prior to installation of remedy infrastructure in areas unimpacted by past PG&E TCS operations. Additionally, the RSL of 0.78 mg/kg is below the normal detection limit of most analytical techniques and therefore poses practicability issues. The Draft Soil Human Health and Ecological Risk Assessment Report specifies risk-based criteria used to determine the acceptability of soils for reuse at the site. Until that document is approved, compliance with the Remedy SMP would necessitate offsite disposal of soils with thallium concentrations exceeding the ISL. Therefore, PG&E calculated an ambient/background threshold value (BTV) of thallium to assist the agencies in making practical ambient/background soil management decisions.

As of June 2019, a total of 38 baseline soil samples have been collected a) outside of areas of concern (AOCs) and solid waste management units (SWMUs) associated with TCS operations and b) not in close proximity to the BNSF railroad track along National Trails Highway (Figure 1). Of these 38 samples, 4 were collected approximately 1 foot below the bottom of the pipeline and conduit trenches. The remaining samples were collected approximately 1 foot below ground surface (bgs). The samples were analyzed in accordance with the Remedy SMP.

2. Ambient/Background Threshold Value Determination

When conducting a compliance test using a BTV, two types of errors occur, namely a type-I error (a false positive) and a type-II error (a false negative). A false positive error occurs where one receives a positive result for a compliance test by incorrectly rejecting a true null hypothesis. This creates a false positive error for the compliance test, leading to an erroneous conclusion that a non-compliance has occurred. This is sometimes also called a false alarm. Similarly, a false negative error occurs when one erroneously receives a negative result for a compliance test by not rejecting a false null hypothesis, i.e. the obtained false negative result is wrong. While elimination of these errors is not possible, one seeks to minimize one or both errors. In most practical applications, a confidence coefficient (CC) of 0.95 is commonly used to provide a proper balance between false positives and false negatives. The upper limits are determined for a CC of 0.95 and a coverage probability of 0.95. Such upper limits (for example, 95 percent upper confidence limits [UCLs] of the 95th percentiles are also known as ambient/background threshold values (BTVs). It is expected that 95 percent of the observations (current and future) coming from the target ambient/background population will be less than that BTV estimate, with a specified CC of 0.95.

The BTVs are estimated using established data sets collected from ambient/background reference areas and unimpacted site-specific ambient/background areas representing the ambient/background population under consideration. The established ambient/background data set should be free from outliers and represent a single environmental ambient/background population. Based on the environmental literature review, one or more of the following statistical upper limits are used to estimate BTVs (EPA, 2015a):

- Upper percentiles (x0.95)
- Upper prediction limits (UPLs)
- Upper tolerance limits (UTLs)
- Upper simultaneous limits (USLs)

From these candidate upper limits, either the UTLs or the USLs are used to estimate BTVs. To provide a proper balance between false positives and false negatives, the ProUCL Technical Guide (EPA, 2015a) suggests using the 95th percentile upper simultaneous limits (USL95) to estimate BTVs. However, USL95 should be used only when the raw ambient/background data set represents a single environmental population without outliers, as inclusion of multiple populations and outliers tends to yield elevated values of USLs, which can result in undesirable false negatives. Therefore, the following stepwise procedure is used to estimate BTV values for a given ambient/background data set:

1) If the raw ambient/background data set is free from outliers, USL95 is used to determine BTV values. Otherwise, UTL95-95 representing a 95th percentile UCL of the 95th percentile of the ambient/background population data is used to estimate BTV values.

2) Further, based upon the distributional characteristics of the given ambient/background data set, two approaches, namely parametric and nonparametric procedures, are used to determine BTV values. If the ambient/background data can be characterized by a well-known distribution (for example, a normal, a lognormal, or a gamma), the parametric method is used to estimate BTVs; otherwise, a nonparametric method is used.

2.1 Parametric Upper Tolerance Limit

Parametric tolerance limits assume normality of the sample ambient/background data used to construct the limit. Validity of this assumption is essential to the applicability of the method, since a tolerance limit with high coverage can be viewed as an estimate of a quantile or percentile associated with the tail probability of the underlying distribution. If the ambient/background sample data do not fit a normal distribution, data are transformed using an appropriate transformation so that the transformed data fit a normal distribution. If a suitable transformation is found, the UTL is calculated using the transformed measurements and then back-transformed to the raw concentration scale.

2.1.1 Normal Upper Tolerance Limit

If sample ambient/background data are normally distributed or can be transformed to fit a normal distribution, then the normal UTL is calculated using the following equation (EPA, 2009, 2015a):

$$UTL = \overline{x} + K(n, \gamma, 1 - \alpha)s \tag{1}$$

Where:

$\overline{x}$	=	The sample mean
K(n, γ, 1−α)	=	The one-sided normal tolerance factor associated with a sample size of n, coverage coefficient of γ, and confidence level of (1−α)
s	=	The sample standard deviation (SD)

2.1.2 Lognormal Upper Tolerance Limit

The procedure to compute UTLs for lognormally distributed data sets is similar to that for normally distributed data sets. In this case, the sample mean, $\overline{y}$, and SD, s_y, of the log-transformed data are computed, then the lognormal UTL is calculated using the following equation EPA (2009, 2015a):

$$UTL = \exp[\overline{y} + K(n, \gamma, 1-\alpha)s] \tag{2}$$

The K factor in Equation (2) is the same as the one used to compute the normal UTL.

2.1.3 Gamma Distribution Upper Tolerance Limit

The gamma distribution UTLs are estimated using the normal approximation to the gamma distributed data. There are two approximations that are used to transform gamma distributed data into approximate normally distributed data (EPA, 2009, 2015a):

- Wilson-Hilferty (WH) transformation: Wilson-Hilferty (EPA, 2015a) suggested that if a ambient/background data set fits the gamma distribution, then the transformation, Y = $X^{1/3}$ follows an approximate normal distribution. Using the WH approximation, the gamma UTL (in original scale, X), is given by:

$$UTL = max\left[0, \left(\overline{y} + K(n, \gamma, 1-\alpha)s_y\right)^3\right] \tag{3}$$

- Hawkins-Wixley (H-W) transformation: Hawkins-Wixley (EPA, 2015a) suggested that if a ambient/background data set fits the gamma distribution, then the transformation, Y = $X^{1/4}$ follows an approximate normal distribution.

$$UTL = \left(\overline{y} + K(n, \gamma, 1-\alpha)s_y\right)^4 \tag{4}$$

The K factor in Equations (3) and (4) is the same as the one used to compute the normal UTL.

2.2 Nonparametric Upper Tolerance Limit

If a suitable transformation is not found, then a nonparametric tolerance limit is considered. Unfortunately, nonparametric tolerance limits generally require a much larger number of observations to provide the same levels of coverage and confidence as a parametric limit. EPA guidance (2009) recommends that a parametric model be fit to the data if possible.

Unlike parametric tolerance intervals, the desired coverage (γ) or confidence level (1–α) cannot be pre-specified using a nonparametric limit. Instead, the achieved coverage and confidence level depends entirely on the ambient/background sample size (n) and the order statistic chosen as the UTL. For a nonparametric procedure, no distribution needs to be fitted to the ambient/background measurements. According to Guttman (EPA, 2009), the number of ambient/background samples should be chosen such that:

$$\sum_{i=m}^{n} \binom{n}{i} (1-\gamma)^i \gamma^{n-i} \geq 1-\propto \tag{5}$$

If the ambient/background maximum is selected as the UTL, the nonparametric UTL is defined in terms of the number of measurements, n as:

$$\gamma^n \leq \propto \quad \textbf{(6)}$$

Equation (6) can be written as:

$$n = \frac{\ln(\propto)}{\ln(\gamma)} \quad \textbf{(7)}$$

For a 95 percent confidence level and 95 percent coverage, n = 59 ambient/background measurements are required according to Equation (7). A nonparametric UTL is computed by first ranking the ambient/background data in ascending order and then choosing the lowest-ranked detected concentration that defines the 95th percentile with 95 percent confidence, such as the largest, the second largest, the third largest, and so on. The order, r of the statistic, x(r), used to compute a nonparametric UTL depends upon the sample size, n, coverage probability, γ, and the desired CC, (1 - α). Data sets with less than 59 observations, the definition of the 95 percentile, is not statistically possible with 95 percent confidence, even when the maximum concentration is assigned as the UTL. In this situation, the value of the lowest achievable coverage is reported.

For a given data set of size n, coverage probability γ, and CC $(1 - \alpha)$, the r^{th} order statistic can be determined using the normal approximation of the binomial distribution as (EPA, 2015a):

$$CC_{Achieved} = Probability\left\{F_{[2(n-r+1),2r]} \leq \frac{r(1-\gamma)}{(n-r+1)\gamma}\right\} \quad \textbf{(8)}$$

After determining the r^{th} order, the corresponding value of r^{th} order statistic x(r) is determined from the ranked data. As mentioned previously, for a given data set of size n, the r^{th} order statistic may or may not achieve the specified CC, (1 - α). ProUCL Guide (EPA, 2015a) suggests using the F-distribution ($F_{df1,df2}$) to compute the CC achieved by the UTL determined by the r^{th} order statistic as (EPA, 2015a):

$$CC_{Achieved} = Probability\left\{F_{[2(n-r+1),2r]} \leq \frac{r(1-\gamma)}{(n-r+1)\gamma}\right\} \quad \textbf{(9)}$$

As a cautionary note, outliers, when present, distort BTVs, which, in turn, may lead to incorrect remediation decisions that may not be cost-effective or protective of human health and the environment. Thus, the BTVs should be estimated by statistics representing the dominant ambient/background population represented by most of the data set. Upper limits computed by including a few low-probability high outliers (for example, coming from the far tails of data distribution) tend to represent locations with elevated concentrations rather than representing the main dominant ambient/background population. The minimum sample size needed to achieve a coverage probability γ, and CC (1 - α), can be calculated using the following equation suggested by Scheffe and Tukey (EPA, 2015a):

$$n_{needed} = 0.25\chi^2_{2m,(1-\alpha)}\left[\frac{(1+\gamma)}{(1-\gamma)} + \frac{(m-1)}{2}\right] \quad \textbf{(10)}$$

In Equation (10), m should follow the constraint:

$$1 \leq m \leq n$$

Where:

m = 1 when the largest value, x(n), is used to compute the UTL.

m = 2 when the second largest value, x(n-1) is used to compute a UTL.

m = n-r+1 when the r^{th} order statistic, x(r), is used to compute a UTL.

By construction, outliers in ambient/background can be a problem for nonparametric tolerance limits, especially if the ambient/background maximum is chosen as the upper limit. A limit based on a large, extreme outlier will result in a test having little power to detect increases in compliance samples. Consequently, the ambient/background sample should be screened ahead of time for possible outliers. Confirmed outliers should be removed from the data set before setting the tolerance limit (EPA, 2009).

An important caveat to this advice is that almost all statistical outlier tests depend crucially on the ability to fit the remaining data (minus the suspected outliers) to a known statistical distribution. In those cases where a nonparametric tolerance limit is selected because of a large fraction of nondetects (NDs), fitting the data to a distributional model may be difficult or impossible, negating formal outlier tests. As an alternative, the nonparametric UTL could be set to a different order statistic in ambient/background (that is, other than the maximum) to provide some insurance against possible large outliers. This strategy will work, provided there are enough ambient/background measurements to allow for adequately high coverage and confidence in the resulting limit.

2.3 Parametric Upper Simultaneous Limit

An (1 – α) * 100 percent USL based upon an established ambient/background data set provides coverage for all observations simultaneously in the ambient/background data set. It is implicitly assumed that the data set comes from a single ambient/background population and is free of outliers (so is the established ambient/background data set). It is expected that observations coming from the ambient/background population will be less than or equal to the USL95 with a 95 percent CC.

2.3.1 Normal Upper Simultaneous Limit

If sample ambient/background data is normally distributed, then the normal USL providing coverage for 100 percent of the sample observations is given as follows:

$$USL = \bar{x} + d_{2\alpha}^{b} s \tag{11}$$

Where:

$\bar{x}$ = The sample mean

$d_{2\alpha}^{b}$ = The critical value of the maximum Mahalanobis distance, Max (MDs), for a 2α level of significance (EPA, 2015a)

s = The sample SD

2.3.2 Lognormal Upper Simultaneous Limit

The procedure to compute USLs for lognormally distributed data sets is similar to that for normally distributed data sets. In this case, the sample mean, $\bar{y}$, and SD, s_y, of the log-transformed data are computed, then the lognormal USL is calculated using the following equation:

$$USL = max\left[0, \left(\bar{y} + d_{2\alpha}^{b} s_y\right)^3\right] \tag{12}$$

2.3.3 Gamma Distribution Upper Simultaneous Limit

The gamma distribution USLs are estimated using the normal approximation to the gamma distributed data. There are two approximations that are used to transform a gamma distributed data into an approximate normally distributed data (EPA, 2015a):

- WH transformation: Transform the ambient/background data using the transformation, $Y = X^{1/3}$, then the gamma USL in original scale is given as:

$$USL = max\left[0, \left(\overline{y} + d_{2\alpha}^{b} s_y\right)^3\right] \tag{13}$$

- H-W transformation: Transform the ambient/background data using the transformation, $Y = X^{1/4}$, then the gamma USL in original scale is given as:

$$USL = \left(\overline{y} + d_{2\alpha}^{b} s_y\right)^4 \tag{14}$$

2.4 Nonparametric Upper Simultaneous Limit

When an assumption of normality cannot be justified, USL is determined using the nonparametric method. According to this method, the largest value, x(n), is used as the nonparametric USL. Just like a nonparametric UTL, a nonparametric USL may fail to provide the specified coverage, especially when the sample size is small (for example, less than 60). The confidence actually achieved by a USL can be computed using the same process as used for a nonparametric UTL described in the preceding section. Specifically, by substituting r = n in Equation (6), the confidence coefficient achieved by a USL can be computed, and by substituting m =1 in Equation (7), one can compute the sample size needed to achieve the desired confidence.

2.5 Ambient/background Threshold Value Estimation for Nondetect Data

NDs are inevitable in most environmental data sets. The following procedure is used to manage ND data:

1) For constituents composed of 100 percent NDs, the Double Quantification Rule (EPA, 2009) is used. According to this rule: “A confirmed exceedance is registered if a constituent exhibits quantified measurements (i.e., at or above the reporting limit).” Thus, for 100 percent NDs data, the reporting limit was used as the BTV.
2) For constituents exhibiting an ND frequency greater than 50 percent, a nonparametric BTV was computed.
3) For constituents exhibiting an ND frequency less than or equal to 50 percent, the Kaplan-Meier (KM) censored estimation technique was used to estimate the ambient/background mean and SD to determine the parametric BTV.

2.6 Assumptions

To estimate appropriate BTVs, the following assumptions must be satisfied by the ambient/background data:

- Parametric BTVs assume that the data follow a normal distribution. If a data set does not fit a normal distribution, then a suitable transformation is needed to normalize the measurements. The BTV should be computed using the transformed values and then back-transformation should be used to determine the final limit in the original scale.
- Nonparametric BTVs do not assume normality or any particular type of distributional form.
- The ambient/background data must be stationary. Thus, the temporal ambient/background data collected over a period of time must be free from any obvious trends or temporal patterns.

- The ambient/background data should be statistically independent i.e., it should have no auto-correlation. Thus, ambient/background samples collected over time should have enough temporal spacing between consecutive observations so that temporal independence can be assumed.
- Although nonparametric BTVs do not require an assumption of normality, other assumptions of BTVs apply equally to parametric and nonparametric methods. Specifically, the ambient/background data should be statistically independent and show no evidence of autocorrelation, trends, or seasonal effects.
- If a USL is used as the BTV, the original ambient/background data set should be free from outliers and represent a single environmental ambient/background population.
- If a UTL is used as the BTV, the confirmed outliers should be removed from the data set before estimating values of UTLs.

2.7 Preliminary Data Analysis

Table 1 presents basic statistics of the thallium ambient/background data.

Table 1. Basic Statistics of Thallium Ambient/background Data

Determination of Thallium Ambient/background Concentration at the Topock Compressor Station, Needles, California

General Statistics for Raw Dataset using Detected Data Only								
NumObs	**Min**	**Max**	**Mean**	**Median**	**Var**	**SD**	**Skewness**	**CV**
11	2.6	4.2	3.545	3.6	0.223	0.472	-0.635	0.133
General Statistics for Censored Datasets (with NDs) using KM Method								
NumObs	**NumDs**	**NumNDs**	**% NDs**	**Min ND**	**Max ND**	**KM Mean**	**KM SD**	**KM CV**
38	11	27	71.05	2	2.5	2.447	0.742	0.303

Notes:

% = percent

CV = coefficient of variation

Max = maximum

Min = minimum

NumDs = number of detects

NumNDs = number of nondetects

NumObs = number of observations

Based on these statistics, the following points are noted:

- The ambient/background data set consists of 38 observations. Among these observations 11 observations are detects and 27 observations are nondetects (NDs). Thus, there are about 71 percent NDs in the ambient/background data.
- The mean, SD, and CV values of the detected data are 3.545 milligrams per kilogram (mg/kg), 0.472 mg/kg, and 0.133, respectively.
- The mean, SD, and CV values of the censored data sets using the KM method are 2.447 mg/kg, 0.742 mg/kg, and 0.303, respectively.

To further investigate whether the ambient/background data complies with the required assumptions for estimating BTVs and selecting the most appropriate method, statistical independence, spatial stationarity, outliers, and normality characteristics are examined.

2.7.1 Identification of Outliers

Outliers are data that appear anomalous or outside the range of expected values. Outliers may indicate errors, may indicate data unrelated to the rest of the data set, or may be perfectly valid data that indicate contamination or unusual geochemical conditions. The goal of outlier identification is to properly analyze the data to determine which outliers are representative of valid data points and should be kept, and which outliers likely represent anomalous situations and should be removed from the data set. Data should not be ignored simply because they are identified as outliers. After identifying data points as potential outliers, further evaluation is conducted to determine the reason for their existence. Outliers should generally be kept as part of the data set unless there is reasonable evidence that they are the result of an error. Many statistical tests require that outliers resulting from an error be removed; some statistical tests may also require removal of valid but extreme outliers that are not representative of the general population. The presence of outliers may preclude the use of some statistical methods altogether, requiring, for example, a nonparametric alternative.

The box-whisker plot is a good tool for screening the data to identify possible outliers. Figure 1 presents time-series and box-whisker plots for observed thallium concentrations. The time-series plot shows the thallium concentrations with respect to sampling time. It shows two types of points: hollow and solid circles. The hollow circles are NDs; whereas, the solid circles are the detected observations. In the box-whisker plot, an outlier is defined as a value falling outside the first quartile (Q1) and the third quartile (Q3) range by more than 1.5 times the interquartile range (IQR = Q3-Q1). Based on the developed box-whisker and time-series plots (Figure 1), it appears that there are no outliers in the ambient/background data set.

For formal outlier assessment, the ND observations were replaced with half of their reporting limits. The obtained data was tested for normality and found that it does not comply with the normality assumption. Thus, the Rosner's test cannot be applied to test outliers. The nonparametric tests (for example, the IQR and median of absolute deviations [MAD] tests) were used instead. These tests are particularly useful for data sets that do not comply with normality assumptions.

Reviewing outlier results, the following points are noted:

- The IQR value is 1.825, indicating no outliers in the ambient/background data.
- The MAD value is 0.074, indicating no outliers in the ambient/background data.

2.7.2 Testing Normality

A normality assumption is not only needed for establishing a BTV (that is, a UTL or USL), but it is also needed for evaluating the ambient/background data for outliers using the parametric methods, as described. Therefore, data need to be examined for normality prior to performing the outlier tests. In most situations, probability plots are used as a screening tool for checking a data set's conformance to a normal distribution, and the Shapiro-Wilk test is used as a formal test of normality. To verify the normality of the raw data, histograms and Q-Q plots were developed, as shown on Figure 2.

Looking at the histogram and Q-Q plot of thallium raw ambient/background data, it is clear that the thallium concentration does not fit a normal distribution. Based on further analysis, it was observed that the thallium ambient/background data does not fit any well-known distribution (for example, lognormal, gamma,). However, using the detected data only, the Shapiro-Wilk normality test gives a p-value of 0.138, indicating that the detected data fits a normal distribution.

3. Ambient/Background Threshold Value Determination

After establishing the ambient/background data based on conducting various data exploratory analyses using R (R Core Team, 2016), the following step-by-step procedure was used by applying the ProUCL Statistical Software (EPA, 2015b) for determining ambient/background limits:

1) Both UTL95-95 and USL95 were computed as a candidate for BTV using the established ambient/background data set.

2) For constituents exhibiting an ND frequency greater than 50 percent, nonparametric UTL95-95 and USL95 were computed. Based on this guideline, the following UTL and USL values are obtained:

   – 95 percent UTL with 95 percent coverage = 4.2 mg/kg. The approximate actual confidence coefficient achieved by UTL is about 87 percent

   – 95 percent USL = 4.2 mg/kg

3) Based on the Unified Guidance (EPA, 2009) for constituents exhibiting an ND frequency less than or equal to 50 percent, the KM censored estimation technique is used to estimate the ambient/background mean and SD to estimate the parametric UTL95-95 and USL95. As the current ND frequency is 71 percent, the KM censored technique is not applicable in this particular case. This technique is still applied to determine the BTV value corresponding to 95 percent confidence, as applying the nonparametric method, only 86 percent confidence could be achieved. At least 59 observations are needed to achieve 95 percent confidence. Thus, using the KM censored technique, the following results are obtained:

   – 95 percent UTL with 95 percent coverage = 4.03 mg/kg
   – 95 percent USL = 4.56 mg/kg

4) Based on EPA (2015a) recommendations, if the raw ambient/background data set is free from outliers, USL95 must be selected as the BTV value. Otherwise, UTL95-95 representing a 95 percent UCL of the 95th percentile of the ambient/background population data is selected as the BTV value. Thus, the BTV values are given as:

   – Based on the nonparametric method = 4.2 mg/kg
   – Based on the parametric method = 4.56 mg/kg

4. References

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LEGEND

Soil Sample Location

Baseline and Opportunistic Soil Sampling Locations

Monthly Progress Report

Groundwater Remedy Phase 1 Construction

PG&E Topock Compressor Station, Needles, California

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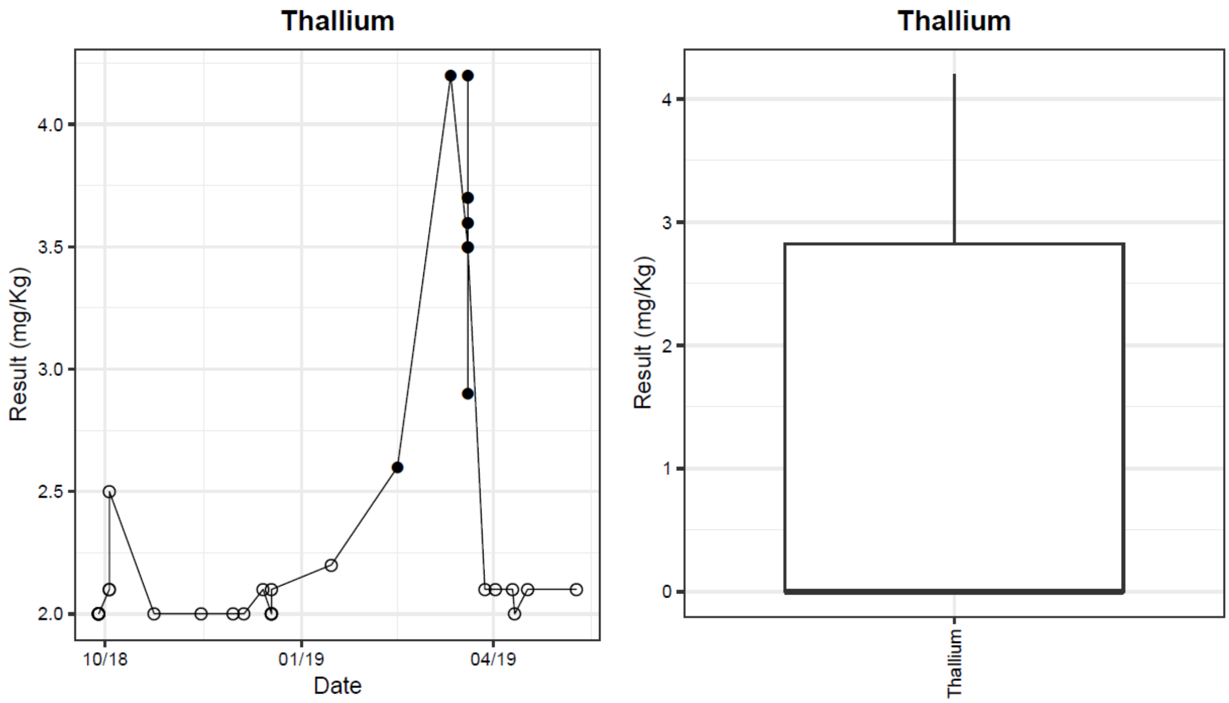

Figure 1. Time Series and Box-Whisker Plots for Thallium Concentration
Determination of Thallium Ambient/background Concentration at the Topock Compressor Station, Needles, California

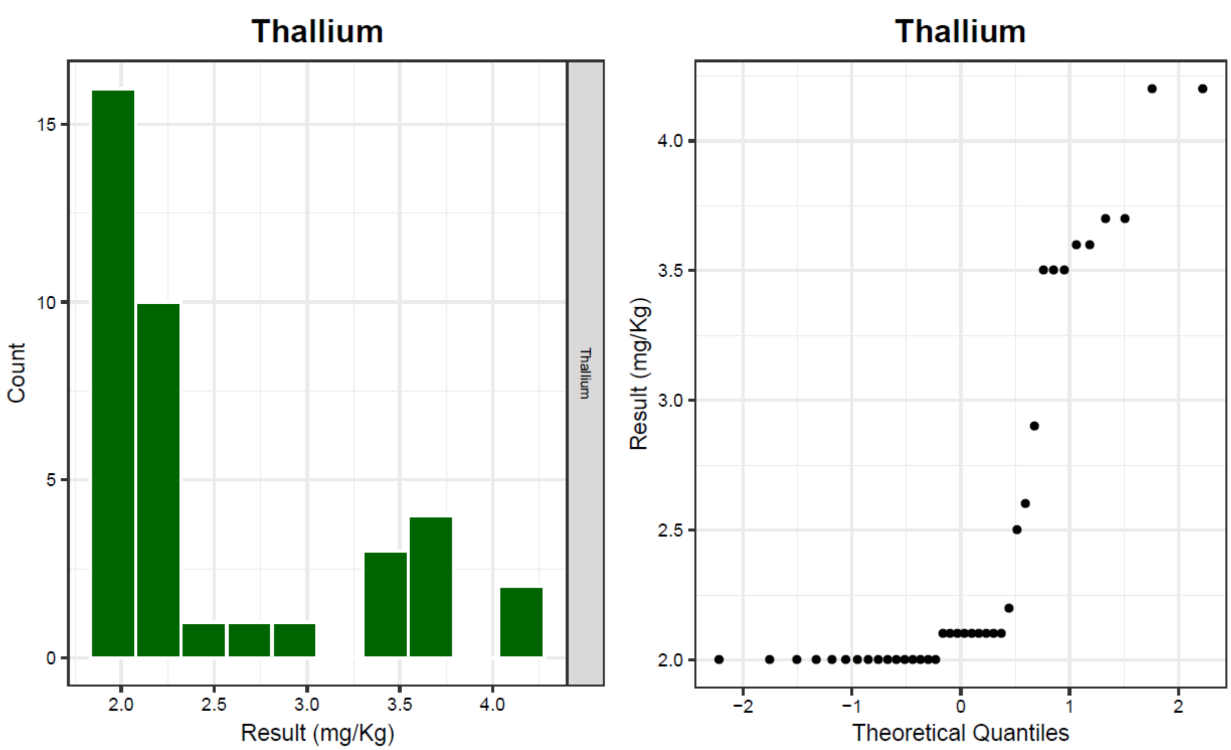

Figure 2. Histogram and Q-Q Normal Probability Plots for Thallium Concentration
Determination of Thallium Ambient/background Concentration at the Topock Compressor Station, Needles, California

ATTACHMENT Errata-3

Rationale for Not Recommending the Plant-Based Ecological RBC of 1 mg/kg for Thallium, Pacific Gas and Electric Company Topock Compressor Station, Needles, California

MEMO

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Date:

July 12, 2019

Subject:

Rationale for not recommending the plant-based ecological RBC of 1 mg/kg for thallium

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The U.S. Department of Interior (DOI) recently expressed concerns related to managing soil with concentrations of thallium above the lowest receptor-specific ecological risk-based concentration (RBC) of 1 milligram per kilogram (mg/kg). This thallium RBC is based on a generic plant screening level, as described in the Draft Soil Human Health and Ecological Risk Assessment (HHERA). As stated in Appendix RBC of the Draft Soil HHERA report (Arcadis 2018), ecological RBCs for plants and soil invertebrates are not recommended for soil-management decisions for the Pacific Gas and Electric Company (PG&E) Topock Compressor Station in Needles, California (the site) for the reasons described in this memorandum.

Ecological RBCs were developed for ecological communities (plants and soil invertebrates) and wildlife receptors (mammals and birds) and are presented in Appendix RBC of the Draft Soil HHERA (Arcadis 2018). The ecological RBCs for plants and soil invertebrates are equivalent to the media-based screening levels for these receptors (Table RBC-3.1 of the Draft Soil HHERA). As stated in the Draft Soil HHERA (Sections 6.7.5 and 8.2 of main report and Appendix RBC), these screening levels are generic and often below background threshold values, and their ability to predict risk to communities of plants and soil invertebrates is poor. Ecological RBCs were derived for wildlife populations following U.S. Environmental Protection Agency guidance (USEPA 1997, 2008) using the dietary dose model integrating site-specific parameters and population-level assessment endpoints (described in Sections 6.2 and 6.3 of the main report).

The scientific community, including Efroymson et al. (1997) who developed the plant screening levels used in the Draft Soil HHERA, has low confidence in the plant-based screening level of 1 mg/kg for thallium. PG&E does not recommend the use of this plant RBC for managing soils for the following reasons:

- **Basis of the Tl toxicity value**—The plant screening level of 1 mg/kg for thallium (Tl) was obtained from Efroymson et al. (1997) and was not based on toxicity studies. Efroymson et al. (1997) state:

  > There are no primary reference data showing toxicity of Tl to plants grown in soil. Confidence in the benchmark is low because it based on a report of unspecified toxic effects on plants grown in a surface soil with the addition of 1 part per million (ppm) Tl (Kabata-Pendias and Pendias 1984).

- Kabata-Pendias and Pendias (4th edition; 2011) reported toxic effects of Tl in plants including impairment of chlorophyll synthesis, mild chlorosis and slight cupping of leaves, and reduced germination of seeds and growth of plants; however, no toxicity studies were reported. A concentration of 1 ppm was based on a maximum allowable concentration that was unrelated to plant toxicity. Efroymson et al. (1997) state that:

  > These benchmarks are to serve primarily for contaminant screening. An assessor must realize that the soil and plant characteristics…play a large part in plant toxicity and incorporate these site-specific considerations in the evaluation of the potential hazards of a chemical. If chemical concentrations reported in field soils that support vigorous and diverse plant communities exceed one or more of the benchmarks presented in this report or if a benchmark is exceeded by background soil concentrations, it is generally safe to assume that the benchmark is a poor measure of risk to the plant community at that site.

- **Health of Plant Communities at the Site**—Vegetation communities observed at the site during the floristic surveys conducted in 2013 (GANDA and CH2M 2013) and in 2017 (CH2M 2017) are typical of Mojave Desert plant communities. More than a hundred different vascular plant species have been observed at the site. The floristic surveys report a diverse assemblage of plants species found in typical abundance, density, cover, and vigor of plant communities in undisturbed desert habitat. These observations are not consistent with impairment of the plant community at the site. The floristic surveys provide site-specific observations that support the health of plant communities at the site. They are considered a stronger line of evidence than the exceedances of low-confidence generic plant screening values, including Tl, which are widely acknowledged to have low ability to predict toxicity in plants.

- **Source of Tl**—Tl is naturally present in the environment and usually at low concentrations (USEPA 2009; Kabata-Pendias and Pendias 2011; Karbowska 2016). In terrestrial environments, Tl is bound to soils and transport is limited (Karbowska 2016). Concentrations of Tl in the lithosphere range from 0.3 to 0.6 mg/kg but can range widely depending on lithology. Karbowska 2016 reports: 0.05 to 1.7 mg/kg in igneous rocks; 1.7 to 55 mg/kg in limestone, marl, and granite; up to 1,000 mg/kg in organic slates originating from the Jurassic period; and even higher in other parts of the world (e.g., Silesian-Cracow region of Poland, Lanmuchang area in Guizhou Province in China). Background studies conducted for California Air Force Bases (Hunter et al. 2005) indicate Tl is largely undetected, however the 95th percentile background concentration is 25 mg/kg and the 99th percentile background concentration is 173 mg/kg.

  Anthropogenic activities contribute to increased concentrations of Tl in the environment (Kabata-Pendias and Pendias 2011; Karbowska 2016). These activities primarily include thallium ash from industrial coal combustion, refinement of oil fractions, smelting of ferrous and non-ferrous ores, and other industrial operations such as cement production and brickworks (USEPA 2009). In the past, Tl was used as a rodenticide/pesticide for controlling rodents and insects, but has been banned for this use in the U.S. since 1972 (USEPA 2009). Association of Tl with herbicides was not found in literature.

Industrial activities associated with thallium releases have not been conducted at the site. Use of thallium-containing pesticides is not known at the site and is considered unlikely, especially in areas outside the Compressor Station where pest control is not needed. As a result, detections of thallium are considered most likely related to background conditions, to which plants are adapted.

- **Site Tl Data**—The concentrations of Tl detected in soil evaluated in the Draft Soil HHERA are considered low and there is a low frequency of detection. For soils evaluated in the Draft Soil HHERA outside the Compressor Station, the frequency of detection was only 1% and detected concentrations ranged from 2.1 to 6.1 mg/kg (non-detects [NDs] have reporting limits ranging from 1 to 10 mg/kg). For soils evaluated in the Draft Soil HHERA inside the Compressor Station, Tl was detected in one sample at 2.4 mg/kg out of 265 samples analyzed (reporting limits ranging from 1 to 2.8 mg/kg). Concentrations in baseline soils collected during the installation of remedy wells and pipelines/conduits range from 2.5 to 3.5 mg/kg (reporting limit of 2.1 mg/kg). In the site background data set, Tl was not detected in all 55 background samples, however reporting limits ranged from 2 to 10 mg/kg (similar to the site concentrations). The detected concentrations and reporting limits for thallium in site soils (Draft Soil HHERA data set, baseline soils, and background data set) are all greater than the Tl plant screening level of 1 mg/kg.

  The generally even distribution of Tl across the site (and even at depth) indicates Tl data are part of the same population and likely all related to background. If the source of Tl is suspected to be anthropogenic, then the concentrations trends would suggest otherwise (i.e., higher concentrations in in suspected source areas).

Conclusions

The scientific community has low confidence in the plant-based screening level of 1 mg/kg for thallium as previously discussed. A historical anthropogenic source of thallium was not identified and concentrations detected in site soils are believed to be associated with background conditions. Observations of healthy plant communities onsite indicate that concentrations of thallium present onsite are not causing adverse effects to plants. For these reasons, PG&E does not recommend the use of the plant-based RBC of 1 mg/kg for thallium to manage soils.

Ecological RBCs developed for wildlife populations (mammals and birds) were based on dietary models and site-specific parameters. They are generally better suited for making decisions for the handling, management, and storage of potentially contaminated and displaced soil at the site. For thallium, as reported in Table RBC-3.1, the wildlife ecological RBCs range from 12 mg/kg (based on the shrew) to 845 mg/kg (based on the quail).

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