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7 May 2014

Mr. Aaron Yue
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Pamela S. Innis
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U.S. Department of Interior
P.O. Box 25007 (D-108)
Denver, CO 80225-0007

Subject: ***Human Health and Ecological Risk Assessment Work Plan Addendum 2***
Pacific Gas and Electric Company
Topock Compressor Station
Needles, California

Dear Mr. Yue and Ms. Innis:

This letter transmits the *Human Health and Ecological Risk Assessment Work Plan Addendum 2* Pacific Gas and Electric Company (PG&E), Topock Compressor Station, Needles, California. **This Second Addendum supplements the Human Health and Ecological Risk Assessment Work Plan (RAWP; submitted August 2008) and the RAWP Addendum (submitted February 2009), and presents additional information and activities required to complete the soil risk assessment for both human and ecological populations.**

This RAWP Addendum 2 was prepared by PG&E and its consultants (ARCADIS) based on Final RAWP Addendum 2 Scope memorandum (submitted January 2013), and the agreements reached both during and after the Soil Risk Assessment Workshop conducted in Henderson, Nevada on September 19-20, 2013. This is not a comprehensive risk assessment work plan and is intended to supplement, not replace, the RAWP, the RAWP Addendum and other risk assessment related documents. The RAWP Addendum 2 describes changes and clarifications to the approaches presented in the RAWP and related documents.

We note that this document is being submitted one day ahead of its due date of May 8, 2014 and we thank you for your effort in moving this task forward. If you have any questions regarding this letter, please call me at (805) 234-2257.

Sincerely,

Yvonne Meeks

Yvonne Meeks
Topock Project Manager

Enclosure
Human Health and Ecological Risk Assessment Work Plan Addendum 2

cc:

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Pacific Gas and Electric Company

Human Health and Ecological Risk Assessment Work Plan
Addendum 2

PG&E Topock Compressor Station
Needles, California

May 2014

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Human Health and Ecological Risk Assessment Work Plan Addendum 2

PG&E Topock Compressor Station
Needles, California

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Tables

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Appendices

Acronyms and Abbreviations

AOC	area of concern
APE	Area of Potential Effects
ARCADIS	ARCADIS U.S., Inc.
ATV	all-terrain vehicle
BCW	Bat Cave Wash
bgs	below ground surface
BLM	Bureau of Land Management
BMP	best management practice
CalEPA	California Environmental Protection Agency
CFR	code of federal regulations
CHHSL	California Human Health Screening Level
cm^2/day	square centimeters per day
CNRA	California’s Natural Resources Agency’s
COPEC	constituent of potential ecological concern
Cr(III)	trivalent chromium
Cr(VI)	hexavalent chromium
CSM	conceptual site model
DOI	Department of Interior
DQO	data quality objective
DTSC	California Department of Toxic Substances Control
ECV	ecological comparison value
EPC	exposure point concentration
ERA	ecological risk assessment
FMIT	Fort Mojave Indian Tribe
ft	feet
GWRA	Groundwater Risk Assessment
HAZWOPER	Hazardous Waste Operations and Emergency Response
HNWR	Havasu National Wildlife Refuge
HHRA	human health risk assessment
kg	kilogram
m^3/hour	cubic meters per hour
m^3/kg	cubic meters per kilogram
$\mu g/m^3$	micrograms per cubic meter

mg/cm^2	milligrams per square centimeter
OHV	off-highway vehicles
OSHA	Occupational Safety and Health Administration
PEF	particulate emission factor
PG&E	Pacific Gas and Electric Company
PPE	personal protective equipment
project	PG&E Topock Compressor Station
property	PG&E Topock Compressor Station
RAWP	Risk Assessment Work Plan
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
RI	remedial investigation
RSL	Regional Screening Level
RTC	response to comments
site	Topock Compressor Station, Needles, California
SWMU	Solid Waste Management Unit
TCS	Topock Compressor Station
UA	Undesignated Area
UCL	upper confidence limit
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service

1. Introduction

Pacific Gas and Electric Company (PG&E) is performing a Resource Conservation and Recovery Act (RCRA) facility investigation/remedial investigation (RFI/RI) for soil at the Topock Compressor Station in Needles, California (the site; Figure 1-1). Data collected during the soil RFI/RI will be evaluated in a human health and ecological risk assessment. Site background and history, as well as a description of the Solid Waste Management Units (SWMUs), Areas of Concern (AOCs), and other areas being investigated at the site, are provided in the Revised Final RFI/RI Volume 1 (CH2M HILL 2007) and Soil RFI/RI Work Plan (CH2M HILL 2013).

This document, along with other documents and activities identified in Section 1.2 below, supplements the Human Health and Ecological Risk Assessment Work Plan (RAWP; ARCADIS 2008) and the RAWP Addendum (ARCADIS 2009a), which addressed proposed approaches to both soil and groundwater risk assessment activities for human and ecological populations at the identified SWMUs and AOCs at the site. This document presents updated information relevant to the upcoming soil risk assessment activities. The Groundwater Risk Assessment (GWRA) was completed previously (ARCADIS 2009b). An addendum to the GWRA will be submitted to agencies (California Department of Toxic Substances Control [DTSC] and United States Department of Interior [DOI]) and the stakeholders in mid-2014 to address monitoring data collected since the completion of the GWRA.

1.1 Purpose of This Document

As indicated in the memorandum describing the Final RAWP Addendum 2 Scope (ARCADIS 2013a), the purpose of this document is to describe additional information and activities required to complete the soil risk assessment for both human and ecological populations. This is not a comprehensive risk assessment work plan and is intended to supplement, not replace, the RAWP (ARCADIS 2008), the RAWP Addendum (ARCADIS 2009a), and other documents identified below in Section 1.2. This RAWP Addendum 2 describes changes and clarifications to the approaches presented in the RAWP and related documents. This document also describes additional approaches and supplemental details that have been brought up during the review of subsequent PG&E Topock Compressor Station (TCS) project documents, and discussions of exposure scenarios and datasets with the stakeholders.

1.2 Summary of Soil RAWP Documents and Activities

The documents that describe the approach for conducting the soil risk assessment currently consist of the following:

- Technical Memorandum: Topock Compressor Station – Ecological Conceptual Site Models, Assessment Endpoints, and Receptors of Concern (ARCADIS BBL 2007a);
- Technical Memorandum: Topock Compressor Station – Ecological Exposure Parameters, Bioaccumulation Factors, and Toxicity Reference Values (ARCADIS BBL 2007b);
- Risk Assessment Work Plan (RAWP; ARCADIS 2008);
- RAWP Addendum (ARCADIS 2009a).

In addition to the documents listed above, the ARCADIS risk assessment team provided input to the Phase 1 Soil Sampling Results (CH2M HILL 2010) and data gaps evaluation that was conducted in accordance with the data usability criteria described in the RAWP, as well as the Soil Part A Data Quality Objectives (DQO) Part 1 through 5 (referred to as the Soil Part A DQO Tech Memo; CH2M HILL 2010). The data were deemed adequate for risk assessment and no additional soil data collection (beyond that required to identify the nature and extent of contamination) was required to support the human or ecological risk assessment. However, the response to comments (RTCs) process for the Soil Part A DQO Tech Memo, as well as for the Soil RFI/RI Workplan (CH2M HILL 2013), did identify some exposure and data handling issues that are addressed in this RAWP Addendum 2.

On September 19-20, 2013, a soil risk assessment workshop (RA Workshop) was conducted in Henderson, Nevada, with participation by the Tribes, the agencies (DTSC and DOI), and stakeholders. The purpose of this RA Workshop was to discuss soil risk assessment approaches and to resolve issues and questions raised since the submittal of the RAWP (ARCADIS 2008) and the RAWP Addendum (ARCADIS 2009a). Following the RA Workshop, Fort Mojave Indian Tribe (FMIT) provided additional input in a letter to DTSC and DOI, dated November 26, 2013 (FMIT 2013). DOI responded to FMIT’s concerns in a subsequent letter dated March 26, 2014 (DOI 2014a). Both of these letters are included in Appendix A. This RAWP Addendum 2 describes the resolutions, agreements, and resulting changes in the soil risk assessment approaches after the submittal of the RAWP (ARCADIS 2008) and RAWP Addendum (ARCADIS 2009a), and takes into consideration communications with the Tribes, agencies, and stakeholders.

1.3 Document Organization

This document is organized into sections according to the flow and structure of a typical risk assessment document and is consistent with the RAWP organizational structure for the soil sections. Only the sections and topics where a change, addition, or clarification in the soil risk assessment approach is being proposed are presented here. Appendices have been prepared for some topics to document activities and research conducted as requested by Tribes, agencies, and stakeholders and in support of the proposed changes.

The remainder of this work plan is organized as follows:

- **Section 2: Land Use** – Describes Tribal land use and DOI-reported recreational uses of the site.
- **Section 3: Data Evaluation for Soil** –Provides supplemental information on the approach that will be used in evaluating site data for use in the soil risk assessment.
- **Section 4: Human Health Risk Assessment for Soil** – Provides updates to the human health exposure assessment, toxicity assessment, and risk characterization portions of the RAWP (ARCADIS 2008) and the RAWP Addendum (2009a).
- **Section 5: Ecological Risk Assessment for Soil** - Describes updates to the ecological exposure assessment portion of the RAWP (ARCADIS 2008) and the RAWP Addendum (2009a).
- **Section 6: References** – Lists the references for documents relied upon in the preparation of this work plan.

2. Land Use

As stated in the approved RAWP Addendum 2 Scope (ARCADIS 2013a), land uses at the site that warrant additional discussion include Tribal land use and recreational use. These land uses are discussed below.

2.1 Tribal Land Use

During the September 2013 RA Workshop, the Tribes requested that land use for the site be clarified and requested that the following information be presented on figures:

- Property boundaries for different land owners;
- Receptors and activities to be evaluated in each area in the risk assessment.

As requested, Figure 2-1 presents property boundaries and land ownership. This figure also shows the receptors to be evaluated in each exposure area, based on information provided by DOI, Bureau of Land Management (BLM), United States Fish and Wildlife Service (USFWS), the Tribes, and PG&E. This figure and the following information will be incorporated into the soil risk assessment.

The Tribes indicated in their exposure scenario memorandum (FMIT 2012; provided in Appendix F), during the RA Workshop, and in the follow-up letter from FMIT (FMIT 2013) that the tribal use of the land in the area of the site is limited to the following:

- Tribal Group Activities - Several times during the year. Tribal members may meet at the site for group prayer and reflection.
- Tribal Education Activities - As part of the education of Tribal students and young people, school classes or other youth classes may come to the area to learn about its importance and spiritual significance. These visits may last for up to 2 hours and could occur several times during an individual's time as a student.
- Tribal Member Individual Visits - Individual Tribal members may go to various specific locations (e.g., the Topock Maze) within the Mojave Valley on a regular but infrequent basis for quiet time and reflection. These activities are part of the practice of their religion and culture, to pay homage to the area, and to honor their ancestors.

2.2 Recreational Land Use

Following the September 2013 RA Workshop, DOI provided information about recreational land use in the area surrounding TCS (DOI 2014b, presented in Appendix B). Figure 1 in Appendix B shows the various federal land areas discussed below. In summary, federal lands include the Havasu National Wildlife Refuge (HNWR), which is managed by USFWS, and BLM-managed lands under the jurisdiction of BLM and/or Bureau of Reclamation (collectively, “the federal land”). The federal land is managed pursuant to a number of land use objectives.

Much of the federal land in the Area of Potential Effects (APE) is undeveloped or minimally developed, notwithstanding the presence of TCS, Interim Measure-3 (IM-3), the Burlington Northern Santa Fe Railroad, Park Moabi, Pirate’s Cove Resort, and Interstate 40 (I-40). Due to the openness of the federal land and limited restrictions to site access, recreational access is potentially present across much of the APE. As indicated by DOI (DOI 2014a), recreational land use can encompass a variety of activities, including (but not limited to) hiking, camping, hunting, visiting historic Route 66, and riding off-highway vehicles (OHVs, also known as all-terrain vehicles [ATVs]). Exposure assumptions for these activities, as provided by DOI (2014b in Appendix B) are summarized in Section 4.1.3.2.

HNWR, managed by the USFWS, provides recreation opportunities for the public. Near the site, HNWR is underdeveloped in regards to general public access. Most of HNWR is outside of the area impacted by operations at TCS. There are six main activities that have been determined to be compatible with the refuge's purpose: hunting, fishing, wildlife observation, photography, environmental education, and interpretation (61 FR 13647, 1996). Camping (land or water) is prohibited on HNWR per regulation (USFWS 2013). There are no established hiking trails but most areas of the refuge are open to hiking. Near the Topock site, the most common recreational activities are hiking and boating/fishing.

Park Moabi is leased by San Bernardino County and comprises BLM and state land within the APE. The park provides seasonal residential use to the public and year-round residential use for a limited number of San Bernardino County staff. The Pirate’s Cove is a concessionaire on BLM-leased land to the east of Park Moabi; it has boat docks, a restaurant, and cabins to rent.

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3. Data Evaluation for Soil

This section describes supplemental information on the approach that will be used for evaluating site data as part of the soil risk assessment. To prepare a dataset suitable for quantitative risk assessment purposes, data will first be evaluated for usability and then processed through several steps discussed in Section 3.2 of the RAWP (ARCADIS 2008). Discussed in this section are clarifications and/or supplemental information regarding the handling of duplicate samples, unequal datasets, and perimeter area data, as well as methods for identifying hot spots and calculating spatially explicit exposure point concentrations (EPCs).

In response to agency comments on Decision 2 (data sufficiency to estimate EPCs) of the DQO process[1], in Section 4.1 of Appendix A of the Soil RFI/RI Work Plan (CH2M HILL 2013), PG&E acknowledges that DOI, DTSC, and stakeholders will need to work through a process regarding the grouping of data, data comparability, and representativeness for the risk assessment. The process will also address different analytical profiles, spatial interpretation, and EPC computations. The September 2013 RA Workshop presented an overview of the data grouping and data adequacy assessment (i.e., demonstrating data comparability and representativeness based on current data, as presented in the data usability matrix). Computing EPCs using ProUCL software was also demonstrated in the RA Workshop. Additionally, the identification of hot spots and spatially weighted approaches for calculating EPCs, along with examples, were presented at the RA Workshop and are presented in Appendix C. Additional discussion regarding unbalanced or unequal datasets is provided below in Section 3.2.

As mentioned in Section 1.2, based on the data gaps evaluation after Phase 1 sampling was completed (CH2M HILL 2010), data were deemed adequate for risk assessment and no additional soil data collection was required to support the human or ecological risk assessment. However, the characterization method used to determine nature and extent of contamination at this site, also referred to as “adaptive cluster” method, where step-out samples are collected around high concentrations of constituents, could bias the exposure concentrations as high. The impact of this biased sampling on the estimated EPCs and risks will be included in the soil risk assessment as part of the uncertainties discussion.

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[1] See Absolute Comment 74 in Appendix I of the Soil RFI/RI Work Plan (CH2M Hill 2013).

3.1 Handling Duplicate Samples

At the September 2013 RA Workshop and in FMIT's letter (2013) to DOI and DTSC, the Tribes raised a concern regarding bias related to the use of the maximum detected concentration as representative of a data pair when data from duplicate samples are available. The agencies acknowledge this approach as conservative. In their response letter to FMIT (DOI 2014a), DOI and DTSC stated that although the approach is conservative, it is not unreasonable and is consistent with United States Environmental Protection Agency (USEPA) recommendations (Appendix A). Therefore, as directed by DTSC and DOI, PG&E will manage field duplicate data and data from multiple analytical methods in accordance with the stated approach set forth in Section 3.2.8 of the RAWP (ARCADIS 2008). If the detected concentration in one sample is significantly higher than the other, it will be identified as an uncertainty and its impact will be discussed in the uncertainty analysis of the soil risk assessment.

3.2 Consideration of Unequal Datasets

At facilities where extensive sampling programs have been conducted for a variety of purposes, it is not uncommon for the site to contain unequal or unbalanced representations of different locations (i.e., co-located samples collected over multiple core depths and segment thicknesses). To develop an estimate of the mean concentration of a constituent in soil that is representative of a receptor's exposure, some consideration is required in the treatment of unequal datasets. USEPA (1996) guidance recommends collecting soil samples from the surface to one of the following depths: 1) the depth of no contamination, 2) the water table, or 3) a depth that accommodates site-specific information (such as geological conditions). USEPA (1996) guidance also recommends that if samples are collected at equal depth intervals, the arithmetic mean concentration from the surface to the maximum sampled core depth can be used to estimate the average concentration for that location. However, when samples have unequal core-segment thicknesses (e.g., some are collected over a span of 6 inches while others are collected over a span of 2 feet), the average calculation must account for the different segment lengths.

At the site, soil samples have been collected for multiple objectives over a period of several decades, resulting in unequal sampling depths and segment thicknesses. Most of the AOCs have had soil samples collected from the same location, but with variable depth profiles (i.e., co-located samples). An example of the variability in co-located samples from the site is provided in Figure 3-1. The figure illustrates variability in both the maximum soil sample depths and segment thicknesses. Despite the variability in segment thicknesses, most of the co-located soil samples were collected within the exposure depth intervals defined for the risk assessment, which allows for a straightforward depth-weighting process to be implemented.

A simple decision tree is proposed to address the calculation of average concentration for co-located samples in a manner which reflects USEPA recommendations (Figure 3-2). Data will be queried by depth for each relevant exposure depth for the risk assessment. If only a single sample is available at a particular location, that value will be used to represent the concentration for the entire exposure depth. For example, for location 42 where there is only one sample, the concentration for the 0 to 10 feet (ft) below ground surface (bgs) interval will be represented by the single sample value (Figure 3-3).

For locations with co-located samples, each sample will be weighted to account for the different lengths of the segments in the manner described by USEPA (1996). Each sample's weight will be the proportional contribution of its length to the maximum core depth. The length of each sampled segment will be calculated as the difference from the end depth of the overlying core-segment to the end depth of the subject core-segment.

An example of the depth weighting for an exposure interval of 0 to 10 ft bgs is provided on Figure 3-3. The figure illustrates the actual segment interval recorded in the database (blue symbols) and the proposed segment interval assignment for depth weighting. For example, at location 1, samples were collected from 0 to 10 ft bgs of variable segment thickness. Therefore, segment weights at location 1 would be calculated as follows:

- 0 to 0.5 ft bgs segment: The sample is reported as 0 to 0.5 foot in the database. Because this is a surface sample with no overlying sample, the segment thickness is 0.5 foot as reported. Therefore, this segment would contribute 5% toward the mean concentration, or a weighting factor of 0.05 (0.5 foot / 10 feet).

- 2 to 3 ft bgs segment: The second reported sample in the core was recorded as 2 to 3 ft in the database. As per the depth weighting rule, the segment thickness for this segment is from the end of the overlying sample (0.5 foot) to the end of the current segment (3 ft), equal to 2.5 ft. Therefore, this segment would contribute 25% toward the mean concentration, or a weighting factor of 0.25 (2.5 ft / 10 ft).

- 5 to 6 ft bgs segment: The third reported sample in the core was recorded as 5 to 6 ft in the database. As per the depth weighting rule, the segment thickness for this segment is from the end of the overlying sample (3 ft) to the end of the current segment (6 ft), equal to 3.0 ft. Therefore, this segment would contribute 30% toward the mean concentration, or a weighting factor of 0.30 (3.0 ft / 10 ft).

- 9 to 10 ft bgs segment: The fourth and final reported sample in the core was recorded as 9 to 10 ft in the database. As per the depth weighting rule, the segment thickness for this segment is from the end of the overlying sample (6 ft) to the end of the current segment (10 ft), equal to 4.0 ft. Therefore, this segment would contribute 40% toward the mean concentration, or a weighting factor of 0.40 (4.0 ft / 10 ft).

For each soil sample, the concentration will be multiplied by its segment weighting factor, and the products summed, to calculate an average 10-foot (or another relevant exposure interval) depth-weighted concentration at each location for the calculation of an area-wide EPC.

3.3 Perimeter Area Data

In FMIT's letter (2013), the Tribes raised concern regarding the inclusion of data from samples collected inside the property fence line or from fence line samples collected from along the perimeter area in the datasets that will be used to assess down gradient SWMUs/AOCs. The Tribes recommend accounting for the dilution in concentrations of constituents that may occur due to migration from the perimeter area to down gradient AOCs/SWMUs. Data collected as part of the perimeter area investigation, and the approach that will be used to evaluate those data, are discussed in detail in Appendix C of the RFI/RI Soil Work Plan (CH2M HILL 2013). As directed by DTSC and DOI (during a RCRA/ Comprehensive Environmental Response, Compensation, and Liability Act telephone meeting on March 5, 2014), PG&E will use the approach discussed in the RFI/RI Soil Work Plan (CH2M HILL 2013) to evaluate these data.

3.4 Hot Spot and Spatial Evaluation

Per the RTCs for the Soil RFI/RI Work Plan (Appendix I of the Work Plan; CH2M HILL 2013), the identification of hot spots and spatially weighted approaches for computing EPCs, along with examples, were presented at the September 2013 RA Workshop (Appendix C).The upper confidence limit (UCL) for the population mean is the typical estimate used to represent the EPC in risk assessments. However, available literature has shown that for datasets that over-sample hot spots (i.e., collect more samples in areas of higher concentration), the simple, non-weighted UCLs can be biased (Burmaster and Thompson 1996; USEPA 2001, 2006; Thayer et al. 2003; Kern 2012).

In contrast, spatially weighted UCL methods can appropriately address datasets based on biased sampling strategies and, therefore, better characterize potential exposure (Burmaster and Thompson 1996; USEPA 2001, 2006; Thayer et al. 2003; Kern 2012).

This section describes the proposed approach and application for “hot spot” detection, and the calculation of spatially explicit UCLs. The methods and their application are described further in Appendix D. The intent of the approach described herein is to: 1) direct the hot spot analyses in a productive way and 2) control the effects of biased sampling on the UCLs, thereby providing accurate expressions of potential risks.

The data will first be analyzed to determine if calculating a spatially weighted UCL is warranted. Data will be evaluated to determine if a hotspot is likely present and if sampling locations are biased toward the hot spot. Hot spots may be detected using a one or more means, including spatial mapping, exploratory graphical methods, or analytical outlier tests. Spatially explicit (geostatistical) methods may also be used to identify hot spots.

If spatial weighting of the EPC is warranted, the analyst will select an appropriate method to calculate the UCL. For extensively left-censored datasets (i.e., datasets with low concentration values that represent a detection limit or reporting limit and not an estimate of the sample concentration), Thiessen polygons are generally used to calculate the UCL. This method is most appropriate in this situation because there is a one-to-one relationship between sample points and polygons, the polygons can be flagged as detect or non-detect, and the Kaplan-Meier statistics can be used to generate spatially weighted UCLs that do not require substitution for non-detect samples (e.g., one-half the reporting limit). In some cases, the underlying spatial structure of concentrations at the site may be modeled with more complex techniques (e.g., Kriging, inverse distance weighting) to estimate concentrations by interpolating between samples based on the weighted average concentration of neighboring sampling locations. These methods, in addition to the increased complexity required in their application, require more stringent a priori assumptions regarding the nature of the data and their spatial distribution.

In summary, spatially weighted UCLs will be considered at the site when the data indicate the presence of a hot spot(s) and sampling bias toward the hot spot(s), and when the uncertainty this biased sampling introduces is likely to materially change the results of the risk assessment.

4. Human Health Risk Assessment for Soil

This section describes updates to the approaches for the human health risk assessment (HHRA), including human health exposure assessment, toxicity assessment, and risk characterization portions of the RAWP (ARCADIS 2008, 2009a).

4.1 Exposure Assessment

For the human health exposure assessment, updates provided in this RAWP Addendum 2 include changes to the conceptual site models (CSMs), inclusion of the evaluation of potential for hexavalent and/or trivalent chromium uptake into plants (particularly arrowweed), clarification of exposure assumptions for potential receptors, and clarification of exposure areas for human receptors.

4.1.1 Conceptual Site Models

The September 2013 RA Workshop presented updates to the CSMs for the human health risk assessment, and these updates were discussed by those in attendance. The CSM for Bat Cave Wash (BCW; which includes AOC 1 and SWMU 1) for the recreational user, Tribal user, maintenance worker, and construction worker has been updated to include AOC 28d, as this is an AOC in BCW that was not identified at the time the RAWP was developed (ARCADIS 2008). This updated CSM is shown on Figure 4-1. In addition, and at the request of the Tribes, Tribal user exposure to surface soil (0 to 0.5 ft bgs) and shallow soil (0 to 3 ft bgs) has been updated to show that these are incomplete exposure pathways, as exposures to the Tribal user are limited to exposures resulting from the inhalation of particulates. This is described further in Section 4.1.3.1.

In FMIT's letter (2013), the Tribes raised concern regarding the evaluation of the Tribal Land Use scenario in the area north of the railroad in BCW along with the residential/gardener scenario as not realistic and would overestimate the risk and drive unnecessary cleanup. However, as directed by DTSC and DOI (2014a), the area north of the railroad in BCW (excluding FMIT land) will be evaluated for the hypothetical future resident scenario. In DOI's letter (DOI 2014a), it is stated that for the purposes of ongoing soil investigations and baseline risk assessment, DOI maintains that the future land use assumptions for BLM-managed land should remain conservative and reflect a residential scenario while future land use assumptions on the HNWR will be limited to recreational and tribal uses.

The CSM for the hypothetical future resident in BCW north of the railroad (excluding FMIT land) is presented on Figure 4-2. The CSM shows the addition of the insignificant but potentially complete pathway for the contribution of groundwater use for irrigation. The irrigation pathway is insignificant relative to the other exposure pathways for the future hypothetical resident north of the railroad. As discussed at the RA Workshop, potential secondary groundwater exposure pathways to humans, such as ingestion of plants and animals exposed to contaminated groundwater, were evaluated in the GWRA (Appendix K of ARCADIS 2009b). As presented in Appendix K of the GWRA, human exposure to contaminated groundwater is dominated by the direct exposure routes that are commonly included in groundwater risk assessments such as the GWRA: ingestion of and direct dermal exposure to contaminated groundwater. Accordingly, although the RAWP (ARCADIS 2008) identified the use of groundwater for irrigation purposes as a potentially complete exposure pathway, the quantitative analysis presented in the GWRA supports that this pathway is insignificant. Thus, the CSM that was originally presented in the RAWP has been modified to reflect this more recent conclusion and is shown on Figure 4-2.

All of the AOCs outside BCW comprise one exposure area for human health, as indicated in the RAWP (ARCADIS 2008). The CSM shown in Figure 4-3 for areas outside BCW has been updated to include the evaluation of additional AOCs that were not identified in the RAWP (ARCADIS 2008). New AOCs considered for this exposure area are: AOC 27 – MW-24 Bench, AOC 28 – Pipeline Drip Legs, and AOC 31 – Former Teapot Dome Oil Pit. These AOCs are described in Section 4.1.4. Additionally, as described above, as the Tribal user is assumed to only be exposed through the inhalation of particulates, the Tribal user exposure to surface and shallow soil has been updated to show that these are incomplete exposure pathways.

In addition, the Tribes made clear at the RA Workshop that plant harvesting from the upland portions of the site does not occur. This was emphasized again in a letter from Mr. Sullivan, on behalf of FMIT, to DOI and DTSC that was received on November 26, 2013 (FMIT 2013; Appendix A). In accordance with the request by the Tribes, the pathway for plant contact for the Tribal user is shown as incomplete on the CSMs where the Tribal user is listed as a potential receptor (Figures 4-1 and 4-3; further discussion on this topic is provided in Section 4.1.2).

The area inside TCS is being evaluated as one exposure area, as stated in the RAWP (ARCADIS 2008). Although additional SWMUs/AOCs have been identified within the fence line at TCS that were not identified in the RAWP, the CSM for worker exposures inside the fence line still applies. A description of the additional SWMUs/AOCs that have been identified within the fence line is summarized in Section 4.1.4.

4.1.2 Potential for Hexavalent and/or Trivalent Chromium Uptake into Plants

In response to agency direction resulting from stakeholder comments, a literature search was conducted to understand the potential for hexavalent and/or trivalent chromium to be taken up into plant tissue (referred to as the “Arrowweed Memo”; ARCADIS 2013b). As requested, the literature search focused on arrowweed, but also summarized findings for other potentially relevant plant species. Additionally, the Arrowweed Memo presented a preliminary pathway analysis to understand whether, based on current site conditions, arrowweed has the potential to take up trivalent chromium or hexavalent chromium that may be present in either soil or groundwater.

A complete copy of the Arrowweed Memo is presented as Appendix E. In summary, the Arrowweed Memo concluded the following:

- The literature review revealed that plants have the ability to take up trivalent chromium (Cr(III)) and hexavalent chromium (Cr(VI)) from the soil, but that most Cr(VI) is converted to Cr(III) post-uptake (and most of the Cr(III) is retained in roots).

- Arrowweed was not observed in areas with detectable Cr(VI) in soil or groundwater above background.

- Based on soil and groundwater data collected to date, the human and ecological exposure pathway to Cr(VI) in soil, groundwater and sediments via arrowweed uptake is insignificant.

- Additional soil, sediment, pore water, and groundwater results will be evaluated to confirm current conclusions. These additional evaluations will be incorporated into the upcoming Risk Assessment.

As mentioned in Section 4.1.1, the Tribes emphasized at the September 2013 RA Workshop that plants, including arrowweed, are not harvested in the area of TCS and will not be harvested as long as the area is contaminated. This was reiterated in Mr. Sullivan’s letter, on behalf of FMIT, to DTSC and DOI (FMIT 2013; Appendix A). Any plants that may be used at the site for ceremonial or cultural purposes would be collected from other areas. The agencies agreed that exposure to arrowweed should not be included in the Tribal Land Use assessment and should be removed from the CSM as an exposure route (DOI 2014a). As stated in Section 4.1.1, the CSM has been updated to show this pathway as incomplete.

Since the completion of the Arrowweed Memo in 2013, CH2M HILL prepared a technical memorandum, “Supplemental Ethnobotanical Plant Surveys for the Pacific Gas and Electric Company’s Topock Compressor Station,” (CH2M HILL 2014) which includes a vegetation map showing additional arrowweed locations that were not identified at the time the Arrowweed Memo was prepared. However, the identification of these additional arrowweed locations would not change the approach of the upcoming soil risk assessment with regards to human health; as noted above, exposure to arrowweed is considered an incomplete exposure pathway for the Tribal Land Use assessment.

4.1.3 Potential Receptors and Exposure Assumptions

Per the exposure assessment approach provided in Section 4.4.3 of the RAWP (ARCADIS 2008), with input from the Tribes, agencies (BLM and DOI), and PG&E, site-specific exposure scenarios have been developed for the HHRA for soil contact for the Tribal user, recreational user, and maintenance worker. Described below are the specific exposure parameters that were selected for each scenario along with the rationale for the selection to be implemented in the HHRA.

4.1.3.1 *Tribal User*

In the memorandum provided by the Tribes regarding potential Tribal exposure at the site (FMIT 2012; provided in Appendix F), the following exposure assumptions were recommended to be used in the Tribal Land Use risk assessment:

Table 4-1. Exposure Parameters for the Tribal Land Use Scenario

Exposure Parameter	Values and Units
Duration in years:	60 years
Duration in visits/year:	12 visits per year
Duration in hours/visit:	2 hours per visit
Route of exposure:	Inhalation of dust derived from contaminated soil
Inhalation rate:	0.83 cubic meters per hour (m^3/hour)
Body weight:	70 kilograms (kg)
Averaging time:	25,550 days (carcinogens) 21,900 days (non-carcinogens)

These assumptions are deemed by the Tribes to adequately address the protection of the health of Tribal members engaged in the following: Tribal Group Activities, Tribal

Education Activities, and Tribal Member Individual Visits (see Section 2.1 for descriptions). None of these activities include intrusive soil activities or direct contact with soil. It was agreed at the September 2013 RA Workshop that these exposure assumptions would be used in the Tribal Land Use risk assessment to estimate potential exposure and associated risks and hazards for contact with the soil at the site via dust inhalation.

4.1.3.2 Recreational User

The lands managed by the federal agencies in the vicinity of the Topock site are largely undeveloped, but there are several recreational opportunities available. DOI has provided information to PG&E about the types of recreational activities that could occur at the site and the corresponding exposure scenarios and exposure assumptions that should be incorporated into the HHRA. This section summarizes the information provided by DOI regarding recreational users. Appendix B presents the technical memorandum provided by DOI, which was received on April 21, 2014.

Figure 2 in Appendix B presents the CSM diagram provided by DOI that connects the contaminant source with exposure to potential recreational visitors on federal land. As recommended by DOI, it is assumed that each of the recreational activities could take place at any location on federal land. In reality, specific locations may be preferred for certain activities, while other locations may be less attractive or may have limited recreational options (e.g., HNWR). As stated by DOI, the most probable recreational land use activities on federal land include hiking, camping, hunting, and OHV riding (also referred to as ATVs).

As summarized by DOI, generic, or default, exposure factors are generally not available for recreational land use (except for some specific scenarios, such as fishing and fish ingestion rates). USEPA’s 2011 Exposure Factors Handbook Update does not present exposure factors for any recreational scenarios other than fishermen (USEPA 2011). Rather, informed professional judgment is necessary to select factors that best represent the types of recreational activities that may be conducted at the site of interest.

Basis for Estimation of Exposure Assumptions for Recreational Users at the Site

In order to estimate exposure assumptions that correspond to the land uses described above, it is necessary to develop estimates of the frequency a person may be engaged in this activity (exposure frequency [EF] in days/year) and the length of time spent doing this activity (exposure duration [ED] in years). The routes of exposure, such as inhalation of dust, incidental ingestion of soil, and dermal contact with soil, are important factors in determining how much of a contaminant may enter the body during these activities. The inhalation of airborne dust associated with OHV riding is also a major exposure parameter and is discussed in further detail below.

Recreational use of federal land at the site is expected to vary during the course of a year due to a variety of factors, including weather (especially hot, cold, or rainy periods), seasonality of hunting, and time of year. In general, recreational activities at the site are expected to be limited in frequency and duration during the hottest summer months. Hunting would only occur during those months that are legally permitted; the exposure potential could vary based on game species being hunted. The exposure frequency is expected to be limited to a few weeks for the species of interest (e.g., game birds).

The exposure parameters presented below have been proposed by DOI for recreational visitors on federal land in the vicinity of the site, based on site-specific considerations and information provided from nearby sites and relevant sources. The EF parameters have been informed by information presented in State of California's Natural Resources Agency's (CNRA) document "Complete Findings: Survey on Public Opinions and Attitudes on Outdoor Recreation in California, 2009" (CNRA 2009), particularly Table 25 (Recreation Activity Participation of Respondents During the Past 12 Months). The use rates provided by CNRA are mean values; for risk assessment purposes, an upper bound measure of exposure (e.g., the 95% upper confidence limit on the mean) is generally preferred. To protect human health, it is assumed herein that a participant's entire annual recreational activity is conducted on federal land at the site rather than spread out at various sites across the state. Exposure duration values (ED, in years) below are consistent with those used in the Clear Creek Management Area HHRA (USEPA 2008a) for similar activities.

Estimation of Dust Inhalation Parameter for OHV Riding

A primary exposure concern associated with riding OHVs is the generation and subsequent inhalation of airborne particulate matter. With their large wheels, ATVs can release relatively large amounts of surface soil into the ambient air when they are ridden. For the ATV rider population, it is necessary to identify an appropriate particulate emission factor (PEF, in cubic meters per kilogram [m^3/kg]) that provides an estimate of the airborne level of respirable dust resulting from riding ATVs. A generic PEF has been developed by USEPA for evaluation of windblown fugitive dust from surface contamination sites (USEPA 1991), but that scenario does not agitate the soil as aggressively as the tires of an ATV.

DOI reviewed available and relevant studies to come up with a recommendation for the PEF that should be used at the site to represent inhalation exposures to the ATV riders. The individual studies reviewed by DOI are summarized in Appendix B. Based on the studies reviewed, DOI is recommending the use of a PEF derived for the Standard Mine Site in Colorado.

As described in Appendix B, USEPA derived a PEF for riding OHVs at the Standard Mine Site in Gunnison County, Co (USEPA 2008b; USEPA 2009). This PEF was calculated from empirical data collected by measuring airborne dust generated during activity simulations using two OHVs at the Quincy Smelter site (California) in 2004. (A reference for the Quincy Smelter project was not provided in the Standard Mine risk assessment; only a personal communication from B. Brass, USEPA/Environmental Response Team-West was cited.)

As reported in the Standard Mine Baseline Human Health Risk Assessment (USEPA 2008b), a dust collector was attached to the front rack of the second (trailing) OHV and measurements were taken over a 6-hour period. The concentrations of dust varied considerably during the measurement period, from a minimum concentration of 18.7 microgram per cubic meters (μg/m^3) to a maximum of 23,539 μg/m^3. The investigators took this to be due primarily to variations in speed and the positions of the OHVs relative to each other. From the collected air data, USEPA generated a PEF for OHV riding by "taking the mean concentration of dust in air generated during OHV use (3,400 μg/m^3) and multiplying it by the fraction of total dust that is respirable to estimate the PM10 fraction" (35%; USEPA 2009). A PEF of 1.18E-06 kilograms per cubic meter (equivalent to 8.47E+5 m^3/kg) was calculated from these data.

Because the PEF for OHV riding at the Standard Mine Site was based on actual measurements collected during OHV riding, DOI considers the PEF from the Standard Mine Site, **8.47E+05 m^3/kg,** to be the most accurate value for estimating airborne respirable dust levels from OHV riding at the TCS site (DOI 2014b). Accordingly, DOI recommends that this value be used as the PEF for estimating inhalation risks from OHV riding at the TCS site.

Summary of Exposure Parameters for Recreational Users

Table 4-2 below summarizes the DOI-recommended exposure assumptions for recreational users based on the detailed use information provided in Appendix B.

Table 4-2. Exposure Parameters for the Recreational Use Scenario

Exposure Parameters	Exposure Scenarios							Units
	Camper		Hiker		Hunter	OHV Rider		
	Child	Adult	Child	Adult	Adult	Child	Adult	
Inhalation of Soil Particulates								
Inhalation Rate	0.417	0.833	0.417	0.833	0.833	1.55	2.4	m^3/hour
Particulate Emission Factor	1.316E+09	1.316E+09	1.316E+09	1.316E+09	1.316E+09	8.47E+05	8.47E+05	m^3/kg
Ingestion of Soil								
Ingestion Rate	200	100	200	100	100	330	330	mg/day
Dermal Contact with Soil								
Skin surface area	2,900	5,700	2,900	5,700	5,700	2,900	5,700	cm^2/day
Soil adherence factor	0.2	0.07	0.2	0.07	0.07	0.8	0.8	mg/cm^2
Population-Specific Intake Parameters								
Exposure Time	24	24	24	24	24	1.5	1.5	hours/day
Exposure Frequency	8	8	16	16	8	16	16	days
Exposure Duration	6	24	6	24	30	6	24	years
Body Weight	15	70	15	70	70	33	70	kg

4.1.3.3 *Maintenance Worker*

As stated in the RAWP (ARCADIS 2008), the maintenance worker will be evaluated as a potential receptor involved in routine maintenance and/or repair of the compressor station equipment. As described in the RAWP, maintenance activities occur both inside and outside TCS. This scenario captures the upper bound potential for intermittent but repeated short-term, as well as long-term, exposure to compounds in shallow (0 to 3 ft bgs) and subsurface soil (0 to 10 ft bgs) for the maintenance worker conducting activities both inside and outside the fence line. There are substantial pipelines on PG&E property, along I-40, and along the railroad that periodically require maintenance. Exposure may result from excavation and grading activities associated with utility work or equipment maintenance/repair. This work may require intrusive activity and direct contact with shallow and subsurface soil. The soil exposure pathways include ingestion and dermal contact with soil, as well as inhalation of particulates from ambient air.

Based on information provided by PG&E, excavation work at TCS is generally conducted by three types of maintenance workers: a) local PG&E employees who could work at TCS for approximately 30 years; b) periodic PG&E employees who could work at TCS for approximately 1 to 2 years; and c) contractors who could work at TCS for less than 1 year. These categories of maintenance workers can conduct several types of subsurface/intrusive work, both inside and outside the compressor station. These include:

- Small-sized event
  - Short duration, hand digging work.
  - Occurs approximately 20 times per year, average of 4 hours per event
  - Mostly conducted by local PG&E employees
- Medium-sized event
  - Larger excavation, combination of hand digging and some backhoe work
  - Occurs approximately 5 times per year, average of 15 hours per event
  - 50% hours conducted by local PG&E employees, 25% hours conducted by periodic PG&E employees, 25% hours conducted by contractors
- Large-sized event
  - Likely involves mechanical soil removal by hydro vacuum, and possibly mechanical digging devices
  - Occurs approximately 1 to 2 times per year, average of 200 hours per event
  - 10% hours conducted by local PG&E employees, 10% hours conducted by periodic PG&E employees, 80% hours conducted by contractors
- Linear event
  - Likely uses excavators, and mostly occurs outside of TCS
  - Occurs approximately 1 time per year, average of 200 hours per event
  - 10% hours conducted by periodic PG&E employees, 90% hours conducted by contractors

Based on the exposure information above, two types of worker exposure scenarios were derived for protection of maintenance workers at the site. The two types of workers include short-term workers, primarily contractors, and long-term workers, primarily PG&E employees. A short-term worker (i.e., a contractor, as described above, who is assumed to only be present at the site for one year and does not come back, repeatedly, year after year) may be present during the various types of events as described above. The highest exposure for a short-term worker would most likely occur during a large-sized event, where the worker could potentially be exposed for 8 hours per day, for 40 days per year for a period of 1 year. Thus, these exposure parameters were selected to represent a short-term worker scenario.

A maintenance worker present at the site for longer periods (i.e., a local PG&E employee) will also be evaluated. A long-term worker may be present during various types of activities as described above. The highest exposure for a long-term worker would most likely occur during a small-sized event, where the worker could potentially be exposed for 4 hours per day, 20 days per year for a 30-year period. Thus, these exposure parameters were selected to represent a long-term scenario.

In addition to the exposure time, frequency, and duration information provided above by PG&E, the following table also summarizes DTSC (2011) default exposure assumptions for dermal contact, ingestion of soil, and inhalation of soil particulates for a construction worker that will also be used to quantify exposures and risks to short-term and long-term maintenance workers:

Table 4-3. Exposure Parameters for the Maintenance Worker Scenario

	Exposure Scenarios			
Exposure Parameters	**Short-Term Maintenance Worker**	**Long-Term Maintenance Worker**	**Units**	**Source**
Inhalation of Soil Particulates				
Particulate Emission Factor	1.00E+06	1.00E+06	m^3/kg	DTSC 2011
Dermal Contact with Soil				
Exposed Skin Surface Area	5,700	5,700	cm^2/day	DTSC 2011
Soil Adherence Factor	0.8	0.8	mg/cm^2	DTSC 2011
Absorption Factor	Chemical-specific	Chemical-specific	unitless	DTSC 2011
Ingestion of Soil				
Ingestion Rate	330	330	mg/day	DTSC 2011
Population-Specific Intake Parameters				
Exposure Time	8	4	hours/day	PG&E-specific
Exposure Frequency	40	20	days	PG&E-specific
Exposure Duration	1	30	years	PG&E-specific
Body Weight	70	70	kg	DTSC 2011

We note that none of the maintenance worker scenarios described above refer to workers involved in site characterization activities (e.g., soil and groundwater sampling), nor workers who will be involved in the implementation of the remedy for either soil or groundwater. Workers involved in either sampling or remedy implementation are required to be appropriately trained, in accordance with the Occupational Safety and Health Administration's (OSHA's) Hazardous Waste Operations and Emergency Response (HAZWOPER) standard, Title 29 Code of Federal Regulations (CFR), Part 1910.120. The objective of the HAZWOPER standard is to protect people working at hazardous waste sites and to train them to handle hazardous substances safely and effectively. As one example, HAZWOPER requires the use of appropriate personal protective equipment (PPE) in order to minimize the potential for direct contact with substances in either soil or groundwater. As workers who may be involved in either sampling or remedy implementation at the site are required by federal law to be HAZWOPER trained, they will not be included in the quantitative human health risk assessment.

4.1.3.4 *Hypothetical Unrestricted Future Use*

As stated in the RAWP (ARCADIS 2008), residential uses of DOI land managed by BLM located north of the railroad are to be evaluated in the HHRA, even though future unrestricted use is unlikely (DOI 2014b). As requested, the future unrestricted land use scenario is to consider the hypothetical future resident as a rural resident who obtains a significant portion of his/her diet from onsite produced food including vegetables, fruits, and poultry. Chemicals in soil could partition into these foods, as described in the RAWP (ARCADIS 2008). In agreement with DOI for evaluation of the BLM managed land, the uptake into homegrown produce/animal products will be evaluated using the uptake model from the Office of Environmental Health Hazard Assessment Toxic Hot Spots Program (Office of Environmental Health Hazard Assessment 2012). This model assumes uptake of compounds into different plants via deposition onto surfaces, and uptake from roots. Then, the model assumes uptake into meat, eggs, and dairy products, and uses the National Health and Nutrition Examination Survey data from 1999 to 2004 to generate per capita consumption distributions for produce (exposed, leafy, protected, and root categories), meat (beef, chicken, and pork), dairy products, and eggs.

As stated in Section 4.4.3 of the RAWP (ARCADIS 2008), default residential exposure parameters will be used to evaluate other potentially complete exposure pathways for this receptor.

4.1.4 Exposure Areas

The SWMUs and AOCs that will be evaluated as exposure areas in the HHRA are shown on Figure 2-1. Soil data from the site will be grouped into exposure areas for the HHRA. As outlined in Section 3.1.1.1 of the RAWP (ARCADIS 2008), three main exposure areas were identified for the site:

- Inside the Compressor Station
- BCW (including AOC 1 and SWMU 1)
- Outside the Compressor Station (excluding BCW).

Since the submittal of the RAWP (ARCADIS 2008), additional areas/AOCs inside and outside of the compressor station requiring investigation have been identified at the site. For the Inside the Compressor Station exposure area, these new areas/AOCs include:

- SWMU 11 – Sulfuric Acid Tanks;
- AOC 21 – Round Depression Near Sludge Drying Bed;
- AOC 22 – Three-Sided Structure in Upper Yard;
- AOC 23 – Former Water Conditioning Building;
- AOC 24 – Stained Area Associated with Former Potential API Oil/Water Separator;
- AOC 25 – Station Compressor and Generator Engine Basements;
- AOC 26 - Former Scrubber Oil Sump;
- AOC 32 – Oil Storage Tank Farm and Waste Oil Sump; and
- AOC 33 – Burn Area near AOC 17.

For the BCW exposure area, the following new area will be included:

- AOC 28d – Pipeline Drip Legs.

For the Outside the Compressor Station (excluding BCW) exposure area, these new areas/AOCs include:

- AOC 27 - MW-24 Bench;
- AOC 28 (a, b and c)- Pipeline Drip Legs;
- AOC 29 – IM 3 Treatment Plant;
- AOC 30 – MW 20 Bench;
- AOC 31 – Former Teapot Dome Oil Pit; and
- The East Ravine area (as part of AOC 10 is still being investigated).

On Figure 2-1, AOC 29 - IM 3 Treatment Plant and AOC 30 - MW 20 Bench are shown as part of the Outside the Compressor Station (excluding BCW) exposure area; however, because the investigation of these areas will be conducted as part of the decommissioning and removal activities for these areas (CH2M HILL 2013), data from AOC 29 and 30 will not be available for inclusion in the HHRA.

A description of these areas/AOCs is provided in detail in the Soil RFI/RI Work Plan (CH2M HILL 2013).

In the RAWP (ARCADIS 2008), Figure 2-28 was used to depict land use for purposes of the HHRA. The RAWP identified the area north of the railroad in BCW as a human health exposure area for hypothetical future residential users. However, land ownership of portions of the area north of the railroad in BCW was transferred to the Tribes after the submittal of the RAWP, and the Tribes stated clearly during the September 2013 RA Workshop, that the land owned by the tribes north of the railroad and adjacent to DOI/BLM land should not be evaluated for future residential use and should be excluded from this land use category. Figure 2-1 has been revised in accordance with this change.

4.2 Toxicity Assessment

The relationship between the magnitude of exposure to a constituent and the potential for adverse effects is characterized in the toxicity assessment portion of the HHRA. The approach for the toxicity assessment is provided in Section 4.5 of the RAWP (ARCADIS 2008). Updating of toxicity criteria was not part of the RAWP Addendum 2 Scope (ARCADIS 2013b); however, it was a topic discussed at the September 2013 RA Workshop and therefore, clarification about updates to the toxicity values is provided below.

As stated in Section 4.5 of the RAWP (ARCADIS 2008), the hierarchy of sources for the toxicity criteria to be used in the risk assessment generally corresponds to the state’s guidance (California Environmental Protection Agency [CalEPA] 1994). As discussed with the agencies and other stakeholders at the September 2013 RA Workshop, the toxicity criteria to be used in the upcoming risk assessment will incorporate the toxicity criteria that are current at the time of implementation and consistent with agency guidance and recommendations.

4.3 Risk Characterization

Risk characterization is the combination of the results of the exposure assessment and toxicity assessment to yield a quantitative expression of risk. The approach for the risk characterization is provided in Section 4.6 of the RAWP (ARCADIS 2008). For this addendum, the approach of the screening evaluation of pore water and sediment data, as well as of evaluation of data inside the fence line of TCS, is provided below, as these were topics that were not part of the RAWP.

4.3.1 Pore Water and Sediment Contact

Pore Water Screening
As requested by DOI during the preparation of the final RAWP Addendum 2 Scope, surface water criteria will be used to screen pore water data. If human contact with pore water were to occur at the site, dermal exposure to hands and feet is the likely potential exposure pathway. Surface water quality criteria to be used for this screening are consistent with the criteria presented in Section 5.3.1.2.1 of the RAWP and include consideration of drinking water criteria and human consumption of aquatic organisms. These criteria are considered conservative as a screening approach for potential pore water dermal contact with hands and feet. Because pore water is not a drinking water source, in the event that drinking water criteria are exceeded, a supplemental pathway specific evaluation process may be required. Development of such additional screening criteria will be discussed with the agencies, in the event it is needed. The most current surface water quality criteria for the protection of human health will be used at the time the risk assessment is conducted.

Sediments Screening
As agreed during a phone conference with DTSC and DOI on April 27, 2012 and in the responses to agency comments on the draft Soil RFI/RI Work Plan (CH2M HILL 2011) while discussing sediment sampling for the East Ravine, commercial/industrial soil screening levels (California Human Health Screening Levels [CHHSLs] or USEPA Regional Screening Levels [RSLs]) will initially be used to screen sediment data for human contact. Available soil screening values for commercial/industrial workers are likely protective of recreators and tribal users. Commercial/industrial workers are likely exposed for longer periods of time (i.e., 8 hours per day, 250 days per year for 25 years), compared to a recreator (2 to 8 days per months, 8 months per year, for 30 years) or tribal user’s exposure assumptions which are much lower (i.e., 1 to 2 hours per day, 12 days per year, for 60 years). Further, CHHSLs and RSLs for commercial/industrial workers are based on dermal contact, incidental ingestion, and dust inhalation pathways. Thus the screening levels are conservative, given that sediments are unlikely to release particulate matter that could be inhaled.

If the concentrations of chemicals in sediment exceed the commercial/industrial CHHSLs/RSLs for soil, then further evaluation can be considered such as developing site-specific sediment screening levels protective of recreators and tribal users.

4.3.2 Inside the Fence Line for Commercial Worker

The area inside the fence line of TCS is an active industrial site. Thus, not all areas inside the fence line are accessible for additional data collection for full characterization of the current soil conditions within this area. This area will be accessible for additional soil data collection when the facility is shut down and demolition occurs. Therefore, as discussed with stakeholders and as described in the RAWP Addendum 2 Scope (ARCADIS 2013a), the approach to estimating risk and hazard for the Commercial Worker inside the fence line is revised to reflect the limitations associated with the upcoming soil sampling activities. Specifically, as there will be limited data, and thus limited ability to calculate representative exposure concentrations for soils to a depth of 10 feet (as originally anticipated in the RAWP [ARCADIS 2008]), the original approach is amended from a forward quantitative risk assessment to a screening evaluation.

After the implementation of additional planned sampling activities inside TCS, the available soil data from within TCS will be screened by comparing the data to standard default soil screening levels for commercial/Industrial workers (i.e., USEPA commercial RSLs). The Exposure Assumptions in the RAWP (Section 4.4.3 page 4-20), states that the standard default assumptions developed by USEPA (1997) and adopted by CalEPA (2005) will be used for evaluating exposures to the Commercial Worker. The soil screening values (i.e., RSLs) are developed using those same exposure assumptions and are, therefore, appropriate for this screening analysis. The purpose of the screening is to identify those areas inside the fence line that could be subject to soil management guidelines prior to TCS closure. Even though some areas inside the fence line are paved, maintenance activities could include subsurface intrusive work where direct contact with the soil below pavement and deeper could occur.

Although PG&E follows all relevant and appropriate worker health and safety protocols and is in compliance with worker health and safety measures set forth by the Occupational Health and Safety Administration, as required by state and federal law, the results of the screening evaluation could provide additional information useful in identifying chemical hazards and appropriate controls.

5. Ecological Risk Assessment for Soil

This section describes updates to the approach that will be used in completing the exposure assessment for the ecological risk assessment (ERA) for the site, as outlined in the RAWP Addendum 2 Scope (ARCADIS 2013a) and as discussed during the September 2013 RA Workshop. Approaches to remaining components of the ERA (i.e., effects assessment and risk characterization) have not been updated since the submittal of the RAWP (ARCADIS 2008) and RAWP Addendum (ARCADIS 2009a) and therefore, are not discussed in this RAWP Addendum 2.

Selection of a sediment ecological comparison value (ECV) for hexavalent chromium was part of the RAWP Addendum 2 scope (ARCADIS 2013a) and will be submitted separately as a technical memorandum (similar to previous ECV technical memoranda).

5.1 Exposure Assessment

The elements of the exposure assessment for the ERA that were identified as new or updated since the submittal of the RAWP (ARCADIS 2008) and the RAWP Addendum (ARCADIS 2009a) are the ecological CSM, the inclusion of the desert bighorn sheep (*Ovis canadensis nelsoni)* as a potential receptor exposed to site media, and the process for identifying ecological exposure areas for new AOCs.

5.1.1 Conceptual Site Model

An ecological CSM was developed for the RAWP (ARCADIS 2008) and RAWP Addendum (ARCADIS 2009a), and was updated in the GWRA (ARCADIS, 2009b) and the Soil RFI/RI Work Plan (CH2M HILL 2013). The CSM was updated to include the new investigation units, new primary sources, and exposure pathways, as necessary. No updates have been warranted since the Soil RFI/RI Work Plan (CH2M HILL, 2013) was approved by the agencies. However, for the purpose of completeness of this RAWP Addendum 2, the ecological CSM is included as Figure 5-1.

5.1.2 Additional Representative Receptor: Desert Bighorn Sheep

To be consistent with the GWRA (ARCADIS 2009b) and observations made by PG&E employees at the site, Nelson’s desert bighorn sheep (*Ovis Canadensis nelsoni*) is included as a representative large home range herbivorous mammal for the ERA. Site specific information on the Nelson’s desert bighorn sheep provided by PG&E employees and CH2M HILL is summarized below.

Nelson’s desert bighorn sheep are a Fully Protected Species according to California Department of Fish and Wildlife. The site is located within the known range of Nelson’s desert bighorn sheep, in San Bernardino County at the northern terminus of the Chemehuevi Mountains, and the nearest occurrence of this species to the site according to the California Natural Diversity Database (California Natural Diversity Database 2014) is in the Chemehuevi Mountains. Although desert bighorn sheep in this area are fully protected in the State of California, the site is outside the range of the federally endangered distinct population segment of Nelson’s desert bighorn sheep, known as Peninsular Range Bighorn Sheep.

At the site, there are perennial water sources available and suitable forage plant species have been observed. During recent floristic surveys (Garcia and Associates and CH2M HILL 2013, 2014; CH2M HILL 2014) in the immediate area of TCS and within the larger vicinity east/northeast to the Colorado River and north to areas adjacent to Pirate Cove, forage plants for desert bighorn sheep were likely identified. Desert bighorn sheep tend to avoid areas with dense tamarisk cover as it outcompetes the more desirable forage of herbaceous vegetation, increases the risk of predation, and may decrease available water and access to water. However, there have been observations of Nelson’s desert bighorn sheep near BCW and game trails have been observed indicating that the desert bighorn sheep are using these areas to some extent.

While desert bighorn sheep have been observed at the site, three main factors likely limit their presence at the site. These factors are human activity (e.g., operation of the TCS, tourism, and traffic on I-40), large thickets of tamarisk, and I-40 to the north of the site which limits dispersal. However, the area east/southeast of the site and along the Colorado River offers higher quality habitat and is likely to attract desert bighorn sheep during the summer or drought months.

5.1.2.1 Assessment and Measurement Endpoints

The assessment endpoint and measurement endpoints for desert bighorn sheep are the same as those for other mammalian populations potentially present onsite, as presented in Table 6-2, discussed in Section 6.3.2 of the RAWP (ARCADIS 2008) and summarized on the following page:

Table 5-1. Assessment and Measurement Endpoints for the Desert Bighorn Sheep

Assessment Endpoint	Measurement Endpoint
Sufficient rates of survival, growth, and reproduction to sustain mammalian populations	Calculated hazard quotients for selected indicator receptors; hazard quotients will be based on estimated exposure doses compared with toxicity reference values

5.1.2.2 Exposure Parameters for the Desert Bighorn Sheep

The exposure parameters for the desert bighorn sheep are presented in Table 5-2. The body weight of the desert bighorn sheep was based on an average of male and female weights (Ballenger 1999). The desert bighorn sheep is assumed to have a 100% plant diet and an incidental ingestion consisting of 30% soil (based on the diet for the domestic sheep [Thornton and Abrahams 1983]). The food ingestion rate is based on the allometric equation for herbivores from Nagy (2001), and drinking water is based on the allometric equation for all mammals from USEPA's Wildlife Exposure Factor Handbook (USEPA 1993). Desert bighorn sheep have large home ranges (4,200 acres based on information obtained from Canadian Geographic, 2002). Following the approach in the RAWP (ARCADIS 2008), for the initial phases of the ERA, a site use factor of one will be assumed for the desert bighorn sheep and Site- or area-specific site use factors may be used in latter phases of the ERA to reduce uncertainties, if needed. These parameters were presented at the September 2013 RA Workshop.

5.1.2.3 Exposure Dose for the Desert Bighorn Sheep

Consistent with methodology described in Section 6.3.3 of the RAWP (ARCADIS 2008) and following DTSC guidance (CalEPA 1996), modeled exposure to the desert bighorn sheep will be estimated using both the maximum detected concentration and the UCL for each constituent of potential ecological concern (COPEC) in soil. The following EPCs will be estimated for each COPEC:

- Incidental ingestion of soil based on the highest maximum detected concentration from 0 to 0.5 foot bgs, 0 to 3 ft bgs, and 0 to 6 ft bgs; plant tissue concentration modeled based on the highest maximum detected concentration from 0 to 0.5 foot bgs, 0 to 3 ft bgs, and 0 to 6 ft bgs; and

- Incidental ingestion of soil based on the highest UCL from 0 to 0.5 foot bgs, 0 to 3 ft bgs, and 0 to 6 ft bgs; plant tissue concentration modeled based on the highest UCL from 0 to 0.5 foot bgs, 0 to 3 ft bgs, and 0 to 6 ft bgs.

Following the approach in the RAWP Addendum (ARCADIS 2009a) for large home range receptors, only a current condition scenario will be evaluated for the desert bighorn sheep (i.e., a scouring scenario will not be evaluated). The exposure depths that will be evaluated for the desert bighorn sheep are presented in Figure 5-2 (updated Figure 3-1 from the RAWP Addendum [ARCADIS 2009a]) and Table 5-3 provides an evaluation of exposure depth intervals and estimation of EPCs (updated Table 6-3 from the RAWP [ARCADIS 2008]).

Other components of the exposure dose model such as bioaccumulation factors will be the same as those presented in the RAWP (ARCADIS 2008) and the RAWP Addendum (ARCADIS 2009a).

5.1.3 Exposure Areas

As discussed in Section 3.1.1 of the RAWP (ARCADIS 2008), in accordance with DTSC and DOI’s requirement, each AOC outside the compressor station will be evaluated as a separate exposure area for ecological risks to small home range receptors. Exposure areas for small home range receptors are presented in Figure 5-3.

In the RAWP (ARCADIS 2008), the main exposure areas for the small home range receptors identified for the ERA included the following:

- BCW (AOC 1)
- AOC 4: Debris Ravine
- AOC 9: Southeast Fence Line combined with AOC 10a
- AOC 10: East Ravine (10b, c, and d)
- AOC 11: Topographic Low Areas

- AOC 12: Fill Area
- AOC 14: Railroad Debris Site
- Undesignated Area-2 (UA-2)/Former 300B Liquids Tank Area

For large home range receptors, two exposure areas were identified in the RAWP (ARCADIS 2008), as listed below. Exposure areas for large home range receptors are presented on Figure 5-4:

- BCW and AOC 4 (including AOC 1)
- Outside the Compressor station (including all other AOCs [9, 10, 11, 12, 14, and UA-2/300B])

Since the submittal of the RAWP (ARCADIS 2008), and as mentioned above in Section 4.1.4, additional areas and AOCs outside the compressor station requiring investigation have been identified at the site, specifically:

- AOC 27 - MW-24 Bench
- AOC 28 a, b, c and d – Pipeline Drip Legs
- AOC 29 - IM 3 Treatment Plant
- AOC30 - MW 20 Bench
- AOC 31 - Former Teapot Dome Oil Pit.

Following the approach in the RAWP (ARCADIS 2008), AOCs 27, 28 (a, b and c) and 31 will be evaluated as individual exposure areas for the small home range receptors (Figure 5-3). AOC 28d is located within BCW and therefore, will be evaluated as part of the BCW exposure area for small home range receptors. As described in Section 4.1.4, data for AOCs 29 and 30 will not be available prior to the implementation of the soil risk assessment; thus, these areas will not be evaluated in the ERA.

The new AOCs outside TCS will be combined with AOCs 9, 10, 11, 12, 14, and UA-2/300B and evaluated as one exposure area for large home range receptors (Figure 5-

4). AOC 28d is located within BCW and therefore, will be evaluated as part of the BCW and AOC 4 exposure area for large home receptors.

Once data are available from the upcoming soil sampling activities, additional refinements to the exposure areas may be necessary. The ERA will rely on the findings of the nature and extent of soil contamination both laterally and vertically as expressed in the upcoming RFI/RI Volume 3. For example, if the RFI/RI identifies the perimeter of an impacted area to be adequately defined to background conditions, the risk assessment will assume that areas beyond that boundary are not impacted by historical site operations. For the approach on evaluating perimeter area data, please see Appendix C of the RFI/RI Soil Work Plan (CH2M HILL 2013).

Furthermore, there have been significant additional soil investigations conducted and planned in the East Ravine area since the approval of the RAWP (ARCADIS 2008). Site media analytical data collected as part of the additional investigation in the East Ravine area may be included as part of the East Ravine exposure area (which currently includes AOCs 10b, c, and d).

Additional sampling is also planned in the tamarisk thicket north of the railroad near the mouth of BCW. The tamarisk thicket is a sub area of AOC 1 – Upland BCW. These data are currently described as a separate area because part of the sampling objective is to determine whether this area has served as a sediment sink, and may comprise a hot spot. In the event the data do not indicate that this is a hot spot, these data will likely be incorporated into either the Riparian area or the upland BCW area, as appropriate for their location and the soil/sediment conditions.

Ecological exposure areas for both small home range and large home range receptors are presented as Figures 5-3 and 5-4, and were previously presented at the September 2013 RA Workshop.

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Tables

TABLE 5-2
EXPOSURE PARAMETERS FOR DESERT BIGHORN SHEEP

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA
HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

Parameter	**Terrestrial mammalian herbivore** **Nelson's Desert Bighorn Sheep** ***Ovis canadensis nelsoni***	
Diet (fraction)	1	Vegetation
Body Weight (kg)	97.5	Dewey and Ballenger, 1999; Average of the following ranges: males 119-127 kg; females 53-91 kg.
Total Food Ingestion Rate (kg/day dry weight)	1.17	Nagy, 2001; Calculated using the allometric DMI equation for herbivores.
Total Food Ingestion Rate (kg/kg bw-day dry weight)	0.0120	Calculated based on body weight.
Soil Ingestion Rate (kg/kg bw-day dry weight)	0.00359	Calculated based on 30% soil in diet for the domestic sheep (Thornton and Abrahams, 1983).
Plant Ingestion Rate (kg/kg bw-day dry weight)	0.0120	Calculated based on 100% diet of plants.
Water Ingestion Rate (L/kg bw-day)	0.063	USEPA, 1993; allometric equation for all mammals.
Home Range (acres)	4,200	Canadian Geographic, 2002; Based on 17 km^2.
AUF (unitless) - conservative	TBD	Will be calculated per AOC and for combined AOCs as presented in the Work Plan
AUF (unitless) - site specific	TBD	Will be calculated if needed, based on site observations

Notes:
AUF = area use factor.
kg/day = kilogram per day.
kg/kg bw-day = kilograms per kilogram body weight per day.
L/kg bw-day = liters per kilogram body weight per day.
TBD = to be determined.

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TABLE 5-3
EXPOSURE DEPTH INTERVALS FOR CALCULATING EXPOSURE POINT CONCENTRATIONS

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA
HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

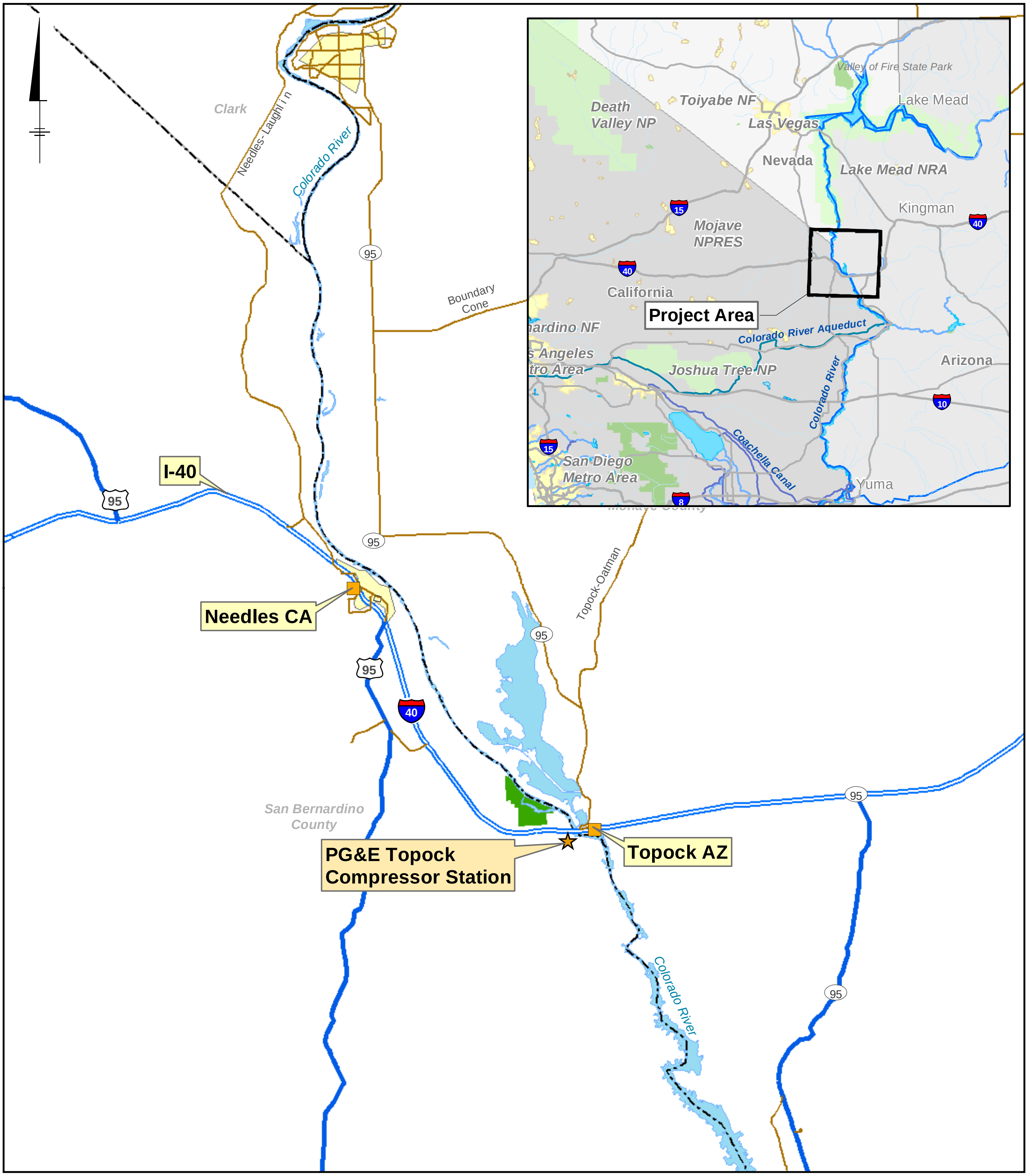
				Exposure Depth Intervals for Calculation of EPCs[a]			
		Food Source		**Soil EPCs for Uptake/Incidental Ingestion of Soil**		**Biota Tissue EPCs (modeled from soil EPCs)**	
Ecological Receptor	**Plant/Burrowing Receptor?**	**All AOCs except BCW**	**BCW**	**All AOCs except BCW**	**BCW**	**All AOCs except BCW**	**BCW**
Plants	Yes	NA	NA	Highest EPCs from the three depth intervals[b]	Highest EPCs from the three depth intervals[b]	NA	NA
Soil Invertebrates	No	NA	NA	EPCs from 0-0.5 feet bgs	Highest EPCs from 0-0.5 feet bgs and 0-3 feet bgs	NA	NA
Granivorous bird (Gambel's quail)	No	Plants (with roots in all 3 depth intervals)	Plants (with roots in all 3 depth intervals)	EPCs from 0-0.5 feet bgs	Highest EPCs from 0-0.5 feet bgs and 0-3 feet bgs	Highest EPCs from the three depth intervals[b]	Highest EPCs from 0-0.5 feet bgs and 0-3 feet bgs
Herbivorous large mammal (desert bighorn sheep)	No	Plants (with roots in all 3 depth intervals)	Plants (with roots in all 3 depth intervals)	EPCs from 0-0.5 feet bgs	Highest EPCs from the three depth intervals[b]	Highest EPCs from the three depth intervals[b]	Highest EPCs from the three depth intervals[b]

Notes:
EPCs: expousure point concentrations.

a. Exposure point concentrations for ecological receptors will be represented by both the maximum detected concentation and the 95 percent upper confidence limit on the mean.
b. Depth intervals for ecological receptors include:
  Surface Soil = 0 - 0.5 feet below ground surface (bgs).
  Shallow Soil = 0 - 3 feet bgs.
  Subsurface Soil I = 0 - 6 feet bgs.

AOC = includes areas of concern and undesignated areas outside the compressor station
BCW = Bat Cave Wash
bgs = below ground surface
EPC = exposure point concentration
NA = not applicable

Figures



0 5 10 Miles

GRAPHIC SCALE

NOTES:

Map Source: CH2M HILL (2005-2008)

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

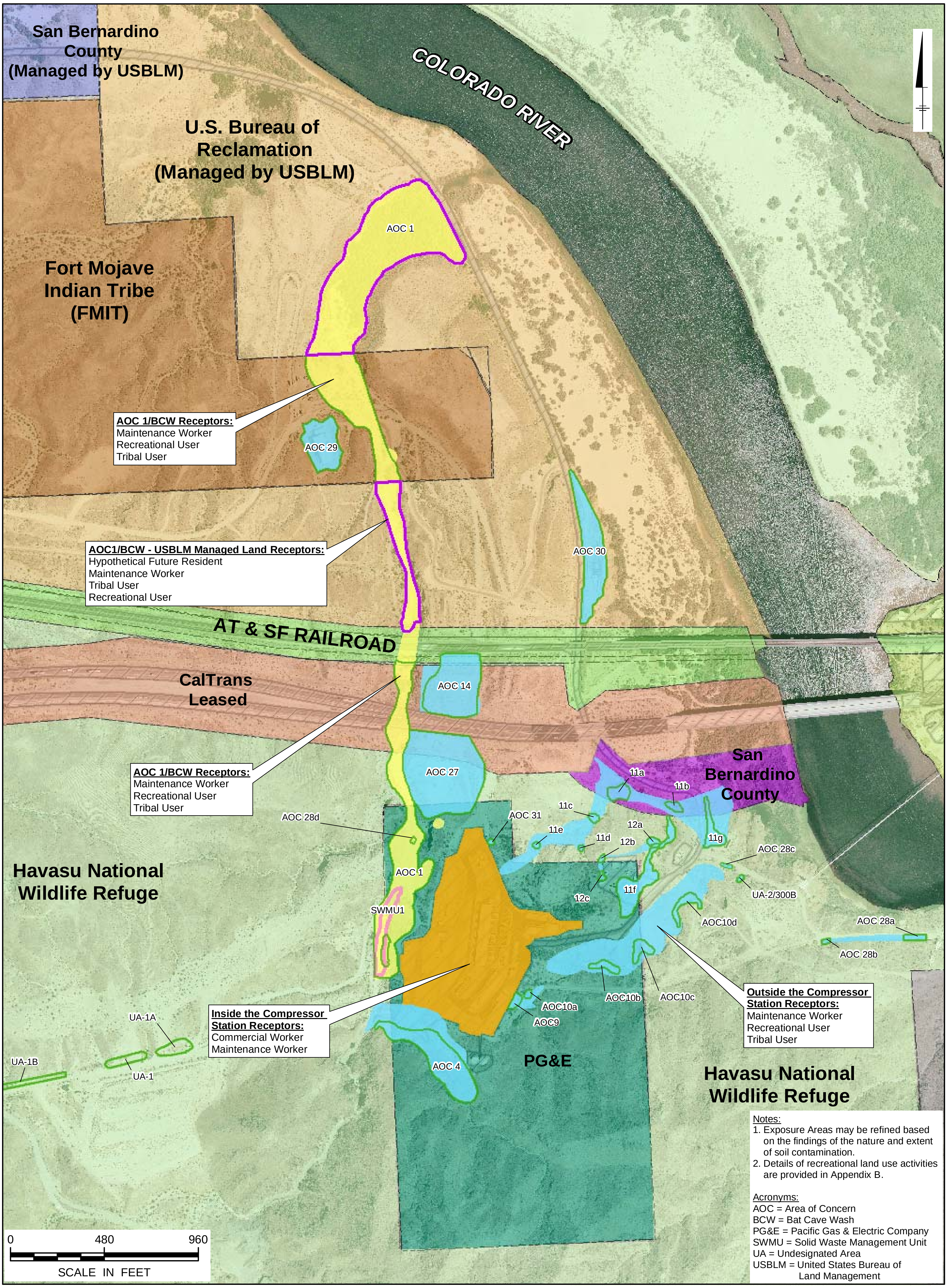
HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

SITE LOCATION MAP

ARCADIS

FIGURE
1-1

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: TR:
Project (Project #)
Q:\PGE\Topock\Soil_EPC_Workshop\mxd\Fig_1-1_Site_Location_Map.mxd: 4/11/2014: 10:02:13 AM



Notes:
1. Exposure Areas may be refined based on the findings of the nature and extent of soil contamination.
2. Details of recreational land use activities are provided in Appendix B.

Acronyms:
AOC = Area of Concern
BCW = Bat Cave Wash
PG&E = Pacific Gas & Electric Company
SWMU = Solid Waste Management Unit
UA = Undesignated Area
USBLM = United States Bureau of Land Management

Legend:

- 🟨 AOC 1/Bat Cave Wash Exposure Area
- 🟦 Outside the Compressor Station Exposure Area
- 🟧 Inside the Compressor Station Exposure Area
- ☐ AOC 1/BCW - USBLM Managed Land Exposure Area
- ☐ Preliminary AOC Boundary as per the Soil Work Plan
- ☐ SWMU 1 Boundary
- ☐ Property Boundaries

Property Owners
- 🟩 AT & SF Railroad
- 🟨 Bureau of Reclamation (Managed by USBLM)
- 🟧 Caltrans Leased
- 🟫 Fort Mojave Indian Tribe
- 🟩 Havasu National Wildlife Refuge (HNWR)
- 🟩 PG&E
- 🟪 San Bernardino County
- 🟦 San Bernardino County (Managed by USBLM)

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA
HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

PROPERTY BOUNDARIES AND PROPOSED HUMAN HEALTH EXPOSURE AREAS

ARCADIS

FIGURE
2-1

Loc Num	Loc ID	Loc Num	Loc ID
1	AOC1-BCW1	44	SSB-2
2	AOC1-BCW2	45	SSB-3
3	AOC1-BCW3	46	SSB-4
4	AOC1-BCW4	47	SSB-5
5	AOC1-BCW5	48	SWMU1-1
6	AOC1-BCW6	49	SWMU1-10
7	AOC1-T1a	50	SWMU1-11
8	AOC1-T1b	51	SWMU1-12
9	AOC1-T1c	52	SWMU1-13
10	AOC1-T2a	53	SWMU1-14
11	AOC1-T2b	54	SWMU1-15
12	AOC1-T2c	55	SWMU1-16
13	AOC1-T2d	56	SWMU1-17
14	AOC1-T2e	57	SWMU1-2
15	AOC1-T3a	58	SWMU1-3
16	AOC1-T3b	59	SWMU1-4
17	AOC1-T3c	60	SWMU1-5
18	AOC1-T4a	61	SWMU1-6
19	AOC1-T4b	62	SWMU1-7
20	AOC1-T4c	63	SWMU1-8
21	AOC1-T5a	64	SWMU1-9
22	AOC1-T5b	65	SWMU1-WP-10
23	AOC1-T5c	66	SWMU1-WP-1h
24	AOC1-T6a	67	SWMU1-WP-3a
25	AOC1-T6b	68	SWMU1-WP-3h
26	AOC1-T6c	69	SWMU1-WP-5a
27	AOC4-1	70	SWMU1-WP-5h
28	AOC4-GB10	71	SWMU1-WP-6a
29	AOC4-GB11	72	SWMU1-WP-6h
30	AOC4-GB12	73	SWMU1-WP-7
31	MW-10	74	SWMU1-WP-8
32	MW-11	75	SWMU1-WP-9
33	MW-13	76	SWMU1-WP-T3a
34	SS-1	77	T-3-B
35	SS-2	78	WP-1
36	SSB-1	79	WP-2
37	SSB-6	80	WP-3
38	SSB-7	81	WP-4
39	SSB-8	82	WP-5
40	SSB-9	83	WP-6
41	XMW-9	84	WP-BANK 1
42	MW-9	85	WP-BANK 2
43	P-2Soil		

surface samples only

point samples only

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN
ADDENDUM 2

VARIABILITY IN SEGMENT THICKNESS OF CO-LOCATED SAMPLES IN AOC 1/SWMU 1

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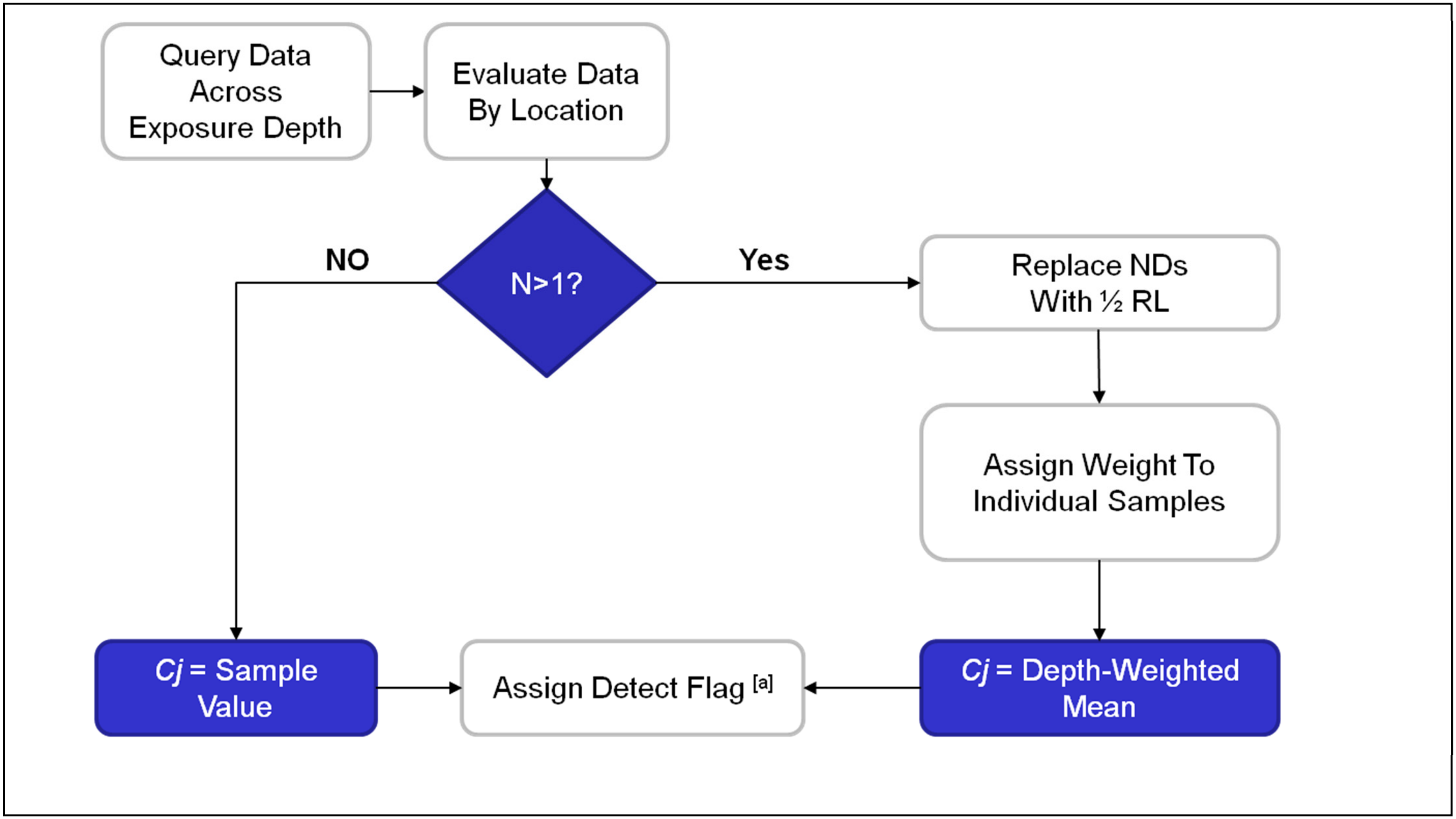
Infrastructure · Water · Environment · Buildings

FIGURE
3-1



NOTES:

Cj = Concentration at location *j* for EPC calculation.

[a] If all samples at a location are non-detect treat *Cj* as a non-detect, otherwise treat *Cj* as a detected observation.

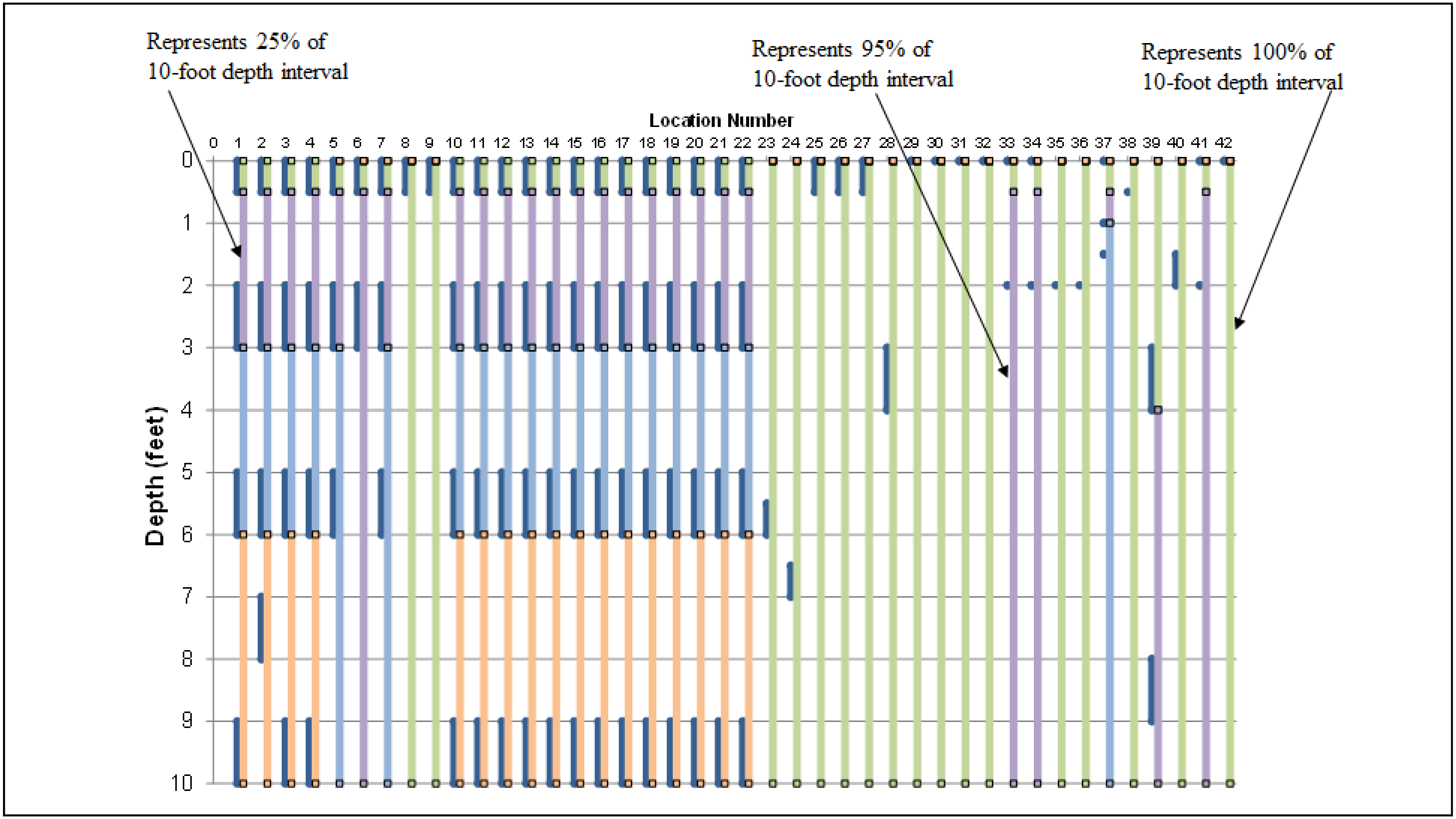
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

PROCESS FOR CALCULATING DEPTH-WEIGHTED MEAN CONCENTRATIONS OF CO-LOCATED SAMPLES

ARCADIS
Infrastructure · Water · Environment · Buildings

FIGURE
3-2



NOTES:

▬●	Actual Sampled Depth
🟩	1st Weighted Interval
🟪	2nd Weighted Interval
🟦	3rd Weighted Interval
🟧	4th Weighted Interval

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

EXAMPLE DEPTH-WEIGHTING FOR THE 0 to 10 FOOT INTERVAL IN AOC 10

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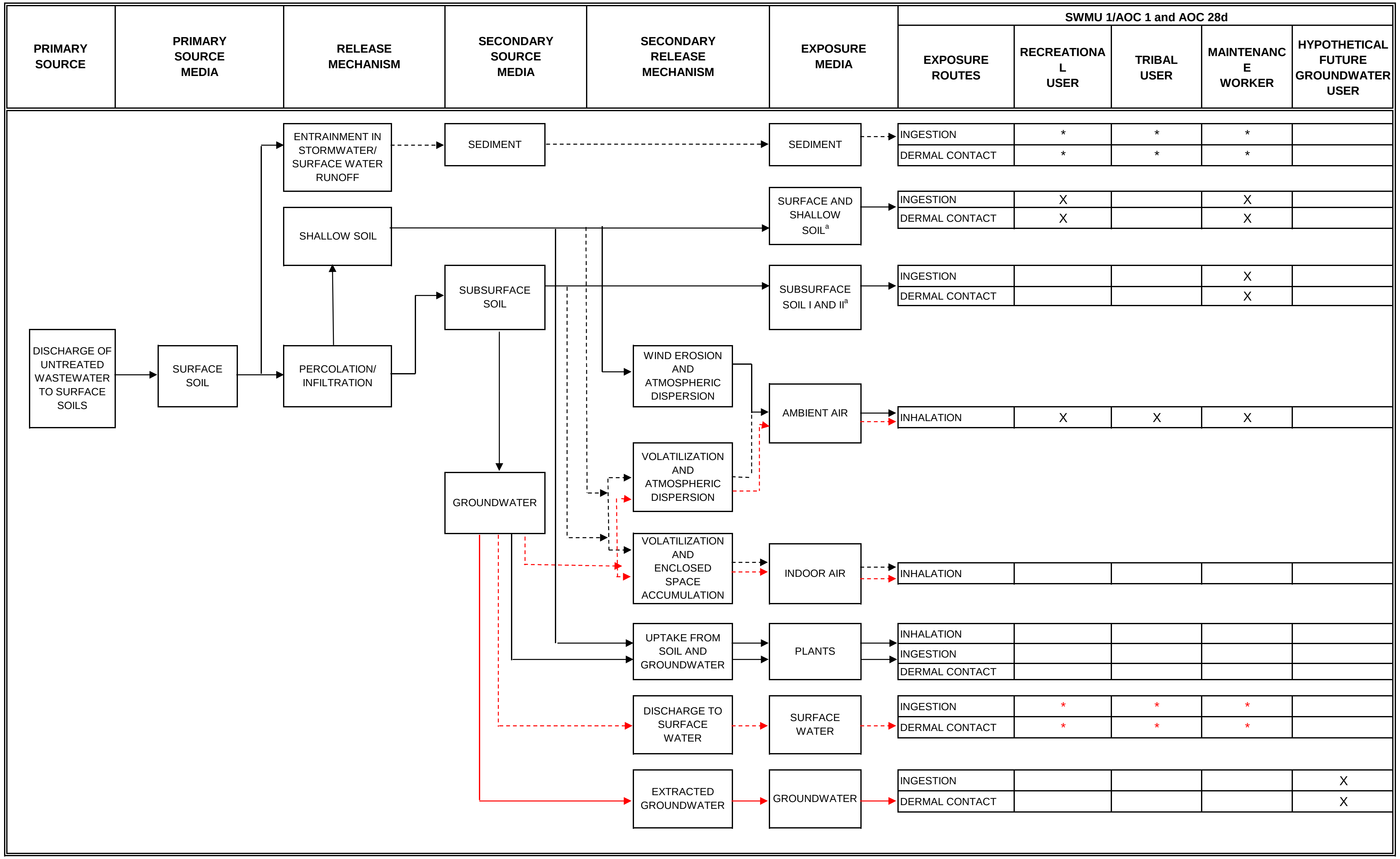
Infrastructure · Water · Environment · Buildings

FIGURE
3-3

FIGURE 4-1
UPDATED[1] PRELIMINARY HUMAN HEALTH CSM FOR BAT CAVE WASH: RECREATIONAL, TRIBAL, AND WORKER USERS

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA
HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2



EXPOSURE MEDIA	EXPOSURE ROUTES	SWMU 1/AOC 1 and AOC 28d			
		RECREATIONAL USER	TRIBAL USER	MAINTENANCE WORKER	HYPOTHETICAL FUTURE GROUNDWATER USER
SEDIMENT	INGESTION	*	*	*	
	DERMAL CONTACT	*	*	*	
SURFACE AND SHALLOW SOIL[a]	INGESTION	X		X	
	DERMAL CONTACT	X		X	
SUBSURFACE SOIL I AND II[a]	INGESTION			X	
	DERMAL CONTACT			X	
AMBIENT AIR	INHALATION	X	X	X	
INDOOR AIR	INHALATION				
PLANTS	INHALATION				
	INGESTION				
	DERMAL CONTACT				
SURFACE WATER	INGESTION	*	*	*	
	DERMAL CONTACT	*	*	*	
GROUNDWATER	INGESTION				X
	DERMAL CONTACT				X

NOTES:

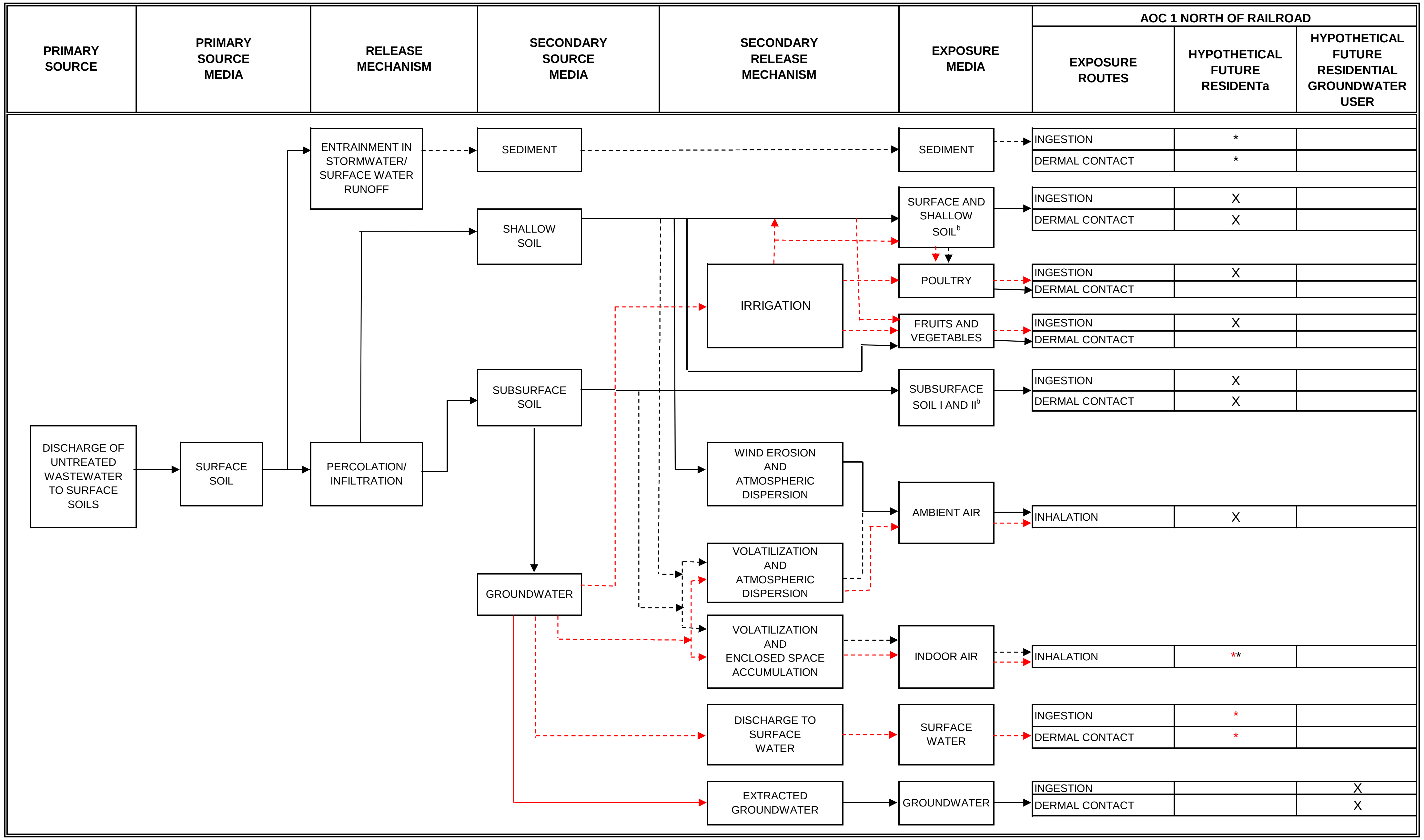
[1] Conceptual site model (CSM) from the Topock Final Human Health and Ecological Risk Assessment Work Plan (RAWP; ARCADIS, 2008), updated with information based on the Topock Groundwater Risk Assessment (GWRA; ARCADIS, 2009), the September 2013 Soil Risk Assessment Workshop and recent soil investigations.

[a] For applicable soil exposure depth, please see Fig 3-1 in the RAWP (ARCADIS, 2008).

——→	Potentially complete transport pathway to be included in the quantitative soil risk assessment.
- - - →	Potentially complete transport pathway to be further evaluated in the soil risk assessment.
——→	Quantitative evaluation of the groundwater pathway completed in the GWRA (ARCADIS, 2009a); Part A Phase I data will be reviewed in the data gaps assessment to evaluate potential future impacts or current localized impacts to groundwater from soil.
- - - →	Insignificant transport pathway as evaluated in the GWRA (ARCADIS, 2009a).
X	Potentially complete exposure route to be included in the quantitative soil risk assessment; quantitative evaluation of groundwater exposure route completed in the GWRA (ARCADIS, 2009a).
*	Potentially complete exposure route to be further evaluated in the soil risk assessment.
*	Insignificant exposure route as evaluated in the GWRA (ARCADIS, 2009a).

FIGURE 4-2
UPDATED[1] PRELIMINARY HUMAN HEALTH CSM FOR BAT CAVE WASH: HYPOTHETICAL FUTURE RESIDENTIAL USE NORTH OF RAILROAD

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA
HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2



EXPOSURE MEDIA	EXPOSURE ROUTES	AOC 1 NORTH OF RAILROAD	
		HYPOTHETICAL FUTURE RESIDENTa	HYPOTHETICAL FUTURE RESIDENTIAL GROUNDWATER USER
SEDIMENT	INGESTION	*	
	DERMAL CONTACT	*	
SURFACE AND SHALLOW SOIL[b]	INGESTION	X	
	DERMAL CONTACT	X	
POULTRY	INGESTION	X	
	DERMAL CONTACT		
FRUITS AND VEGETABLES	INGESTION	X	
	DERMAL CONTACT		
SUBSURFACE SOIL I AND II[b]	INGESTION	X	
	DERMAL CONTACT	X	
AMBIENT AIR	INHALATION	X	
INDOOR AIR	INHALATION	**	
SURFACE WATER	INGESTION	*	
	DERMAL CONTACT	*	
GROUNDWATER	INGESTION		X
	DERMAL CONTACT		X

NOTES:

[1] Conceptual site model (CSM) from the Topock Final Human Health and Ecological Risk Assessment Work Plan (RAWP; ARCADIS, 2008), updated with information based on the Topock Groundwater Risk Assessment (GWRA; ARCADIS 2009), the September 2013 Soil Risk Assessment Workshop and recent soil investigations.

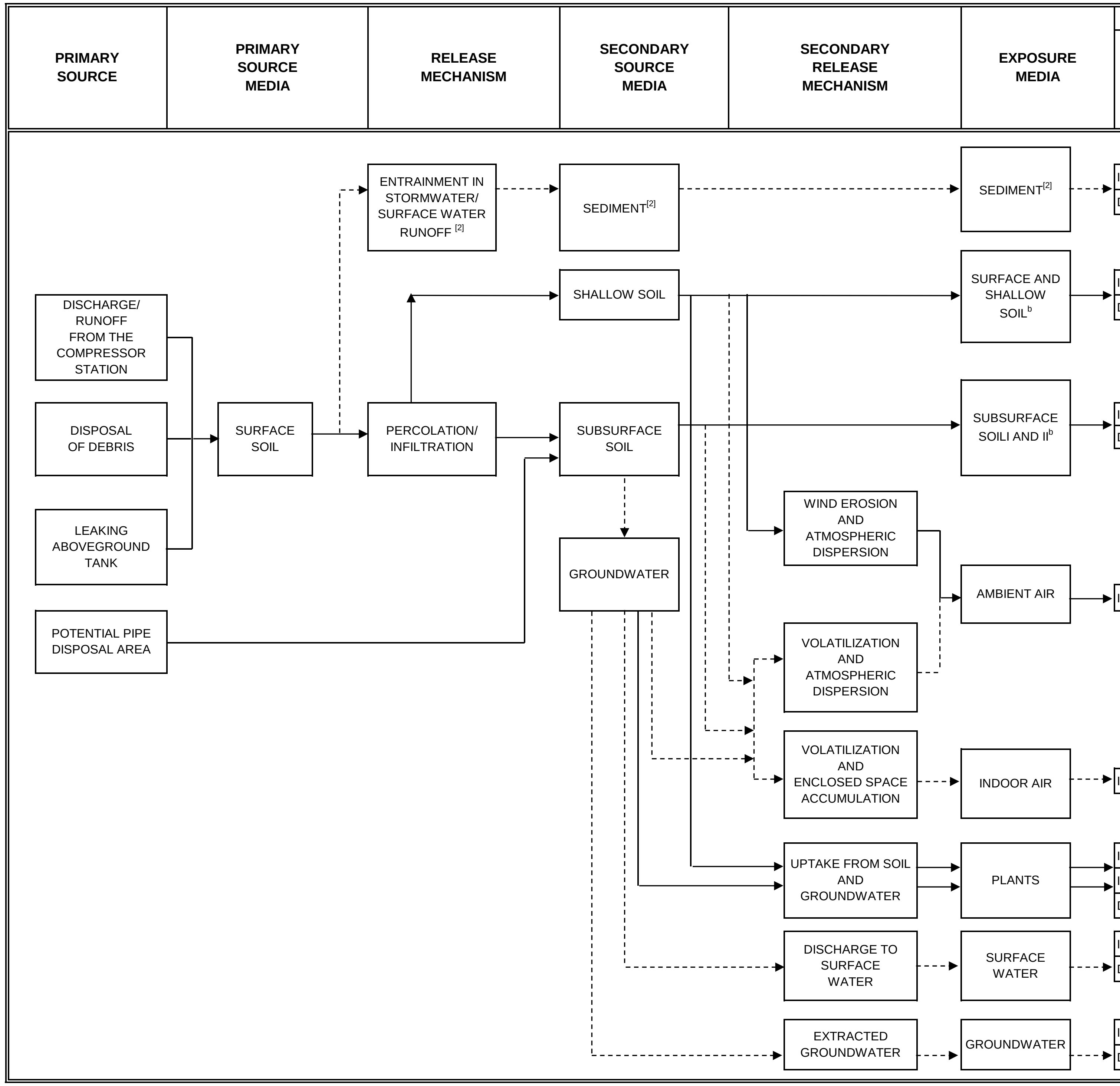
[a] As described in the text, the U.S. Bureau of Land Management (USBLM) has requested that the risk assessment assume future unrestricted use of their property. Accordingly, a future hypothetical residential scenario for contact with soils will be evaluated for property owned by USBLM.

[b] For applicable soil exposure depth, please see Fig 3-1 in the RAWP (ARCADIS, 2008).

——▶ Potentially complete transport pathway to be included in the quantitative soil risk assessment.
- - -▶ Potentially complete transport pathway to be evaluated qualitatively in the soil risk assessment.
——▶ Quantitative evaluation of the groundwater pathway completed in the GWRA (ARCADIS, 2009a); Part A Phase I data will be reviewed in the data gaps assessment to evaluate potential future impacts or current localized impacts to groundwater from soil.
- - -▶ Insignificant transport pathway as evaluated in the GWRA (ARCADIS, 2009a).
X Potentially complete exposure route to be included in the quantitative soil risk assessment; quantitative evaluation of the groundwater pathway completed in the GWRA (ARCADIS, 2009a).
* Potentially complete exposure route to be further evaluated in the soil risk assessment.
* Insignificant exposure route as evaluated in the GWRA (ARCADIS, 2009a).

FIGURE 4-3
UPDATED[1] PRELIMINARY HUMAN HEALTH CSM FOR AOCS 4, 9, 10, 11, 12, 14, 27, 28 (a, b and c), 31 and POTENTIAL PIPELINE DISPOSAL AREA (OUTSIDE THE COMPRESSOR STATION) [a]

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA
HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2



EXPOSURE MEDIA	AOCs 4, 9, 10, 11, 12, 14, 27, 28 (a, b and c), 31 AND POTENTIAL PIPE DISPOSAL AREA[a]				
	EXPOSURE ROUTES	RECREATIONAL USER	TRIBAL USER	MAINTENANCE WORKER	HYPOTHETICAL FUTURE GROUNDWATER USER
SEDIMENT[2]	INGESTION	*	*	*	
	DERMAL CONTACT	*	*	*	
SURFACE AND SHALLOW SOIL[b]	INGESTION	X		X	
	DERMAL CONTACT	X		X	
SUBSURFACE SOILI AND II[b]	INGESTION			X	
	DERMAL CONTACT			X	
AMBIENT AIR	INHALATION	X	X	X	
INDOOR AIR	INHALATION				
PLANTS	INHALATION				
	INGESTION				
	DERMAL CONTACT				
SURFACE WATER	INGESTION	*	*	*	
	DERMAL CONTACT	*	*	*	
GROUNDWATER	INGESTION				*
	DERMAL CONTACT				*

NOTES:

[1] Conceptual site model (CSM) from the Topock Final Human Health and Ecological Risk Assessment Work Plan (RAWP; ARCADIS, 2008) updated with information based on the Topock Groundwater Risk Assessment (GWRA; ARCADIS, 2009), the September 2013 Soil Risk Assessment Workshop and recent soil investigations.

[2] Applicable to AOC 10 only.

[a] The Former 300B Pipeline Liquids Tank Area outside the compressor station has already been closed (CH2M HILL, 2007), but DTSC has requested additional investigation (CalEPA, 2007). If complete pathways are identified based on the results, the Former 300B Pipeline Liquids Tank Area will also be included in the Human Health Risk Assessment (HHRA).

[b] For applicable soil exposure depth, please see Fig 3-1 in the RAWP (ARCADIS, 2008).

——▶	Potentially complete transport pathway to be included in the quantitative risk assessment.
- - -▶	Potentially complete transport pathway to be further evaluated in the risk assessment; Part A Phase I data will be reviewed in the data gaps assessment to evaluate potential future impacts or current localized impacts to groundwater from soil.
X	Potentially complete exposure route to be included in the quantitative risk assessment.
*	Potentially complete exposure route to be further evaluated in the risk assessment.

FIGURE 5-1
UPDATED[1] ECOLOGICAL CONCEPTUAL SITE MODEL

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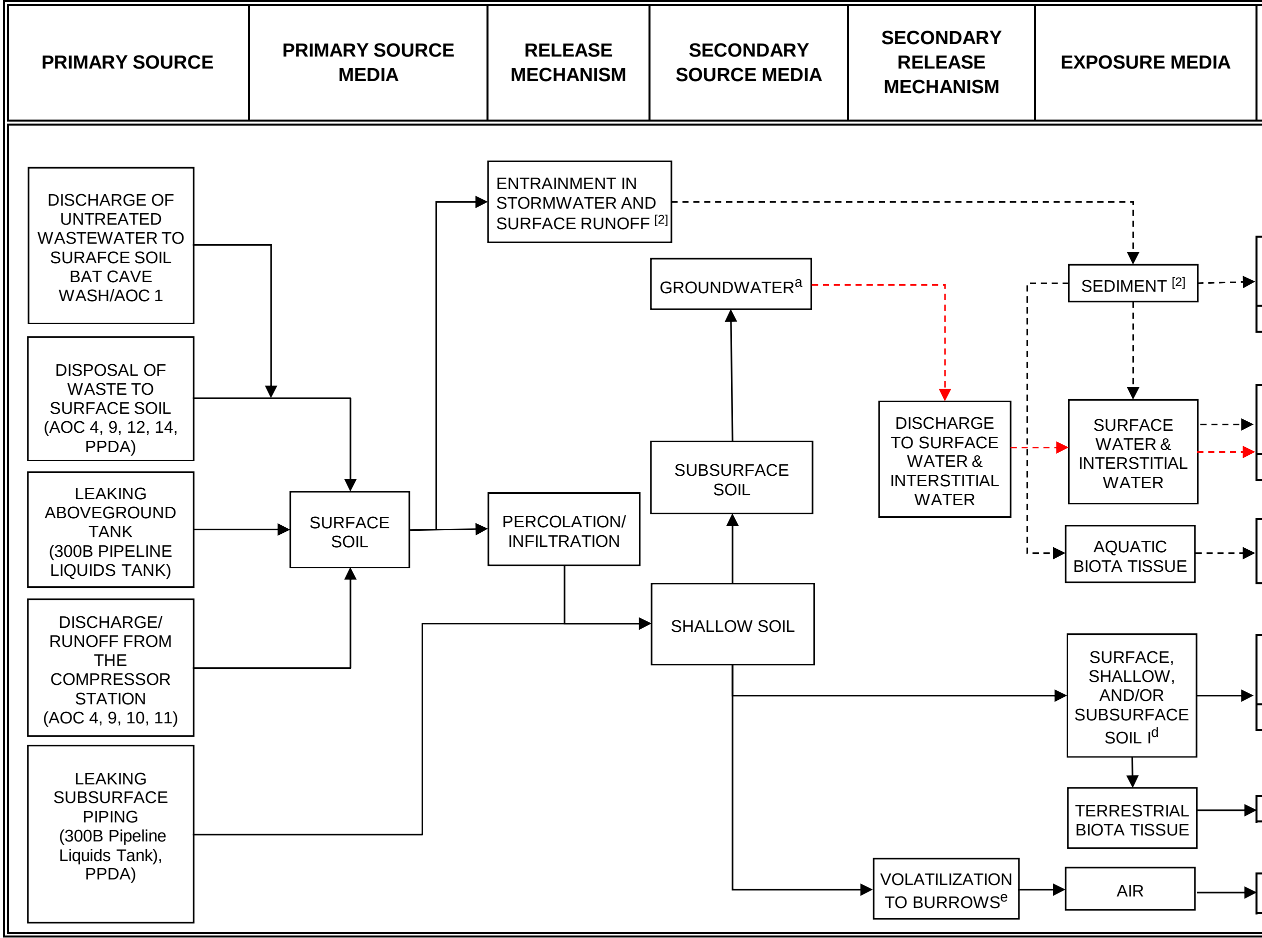

EXPOSURE MEDIA	EXPOSURE ROUTES	AOCs 1, 4, 9, 10, 11, 12, 14, 27, 28, 31 AND POTENTIAL PIPE DISPOSAL AREA[a,b]					
		PLANTS	INVERTEBRATES	FISH	REPTILES/ AMPHIBIANS	BIRDS	MAMMALS
SEDIMENT [2]	DERMAL ABSORPTION, DIRECT CONTACT, ROOT UPTAKE	*	*	*	*	*	*
	INGESTION		*	*	*	*	*
SURFACE WATER & INTERSTITIAL WATER	DERMAL ABSORPTION, DIRECT CONTACT, ROOT UPTAKE	**	**	**	**	**	**
	INGESTION		**	**	**	**	**
AQUATIC BIOTA TISSUE	INGESTION			*	*	*	*
SURFACE, SHALLOW, AND/OR SUBSURFACE SOIL I[d]	DERMAL ABSORPTION, DIRECT CONTACT, ROOT UPTAKE	X	X		O	O	O
	INGESTION		X		O	X	X
TERRESTRIAL BIOTA TISSUE	INGESTION				O	X	X
AIR	INHALATION				O[c]		O[c]

NOTES:

[1] Conceptual site model (CSM) from the Topock Final Human Health and Ecological Risk Assessment Work Plan (RAWP; ARCADIS, 2008) updated with information based on the Topock Groundwater Risk Assessment (GWRA; ARCADIS, 2009), the September 2013 Soil Risk Assessment Workshop and recent soil investigations.

[2] Applicable to AOC 1 and AOC 10 only.

a As requested by California's Department of Toxic Substances Control (DTSC), the groundwater-to-phreatophytes pathway and consumption of phreatophytes by herbivores were evaluated in the GWRA (ARCADIS, 2009a) and exposure and risk were found to be insignificant.

———▶	Potentially complete exposure pathway
- - - - ▶	Soil/sediment potential pathway under evaluation (separate assessment)
- - - - ▶	Insignificant transport pathway as evaluated in the GWRA (ARCADIS, 2009a). Part A Phase I data will be reviewed in the data gaps assessment to evaluate potential future impacts or current localized impacts to groundwater from soil.
*	Soil/sediment exposure route under evaluation (separate assessment)
*	Insignificant exposure route as evaluated in the GWRA (ARCADIS, 2009a).
X	Potentially complete exposure route
O	Potentially complete exposure route not significant or not directly assessed
AOC	Area of concern
PPDA	Potential Pipeline Disposal Area

a. The Former 300B Pipeline Liquids Tank area has already been closed (CH2M HILL, 2007), but DTSC has requested additional investigation (CalEPA, 2007). If complete pathways are identified based on the results, the Former 300B Pipeline Liquids Tank area will be included in the Ecological Risk Assessment (ERA).

b. For the large home range ecological receptors, two exposure areas will be evaluated: (i) BCW (AOC 1) and AOC 4 and (ii) all other remaining AOCs outside the compressor station (AOCs 9, 10, 11, 12, 14, Potential Pipeline Disposal Area).
For small home range ecological receptors, the Potential Pipeline Disposal Area and each AOC outside the compressor station (AOCs 4, 9, 10, 11, 12, 14) will be evaluated as separate exposure areas (See Section 3 of the RAWP; ARCADIS, 2008).
All exposure pathways inside the compressor station are considered incomplete and will not be evaluated for ecological receptors.

c. Potential inhalation exposure in burrows was included for the Former 300B Pipeline Liquids Tank area only based on the potential presence of volatile organic compounds (VOCs).

d. For applicable soil exposure depth, please see Fig 3-1 in the RAWP Addendum (ARCADIS, 2009b).

e. Applicable soil depth is 0-6 feet below ground surface (bgs) for volatilization to burrow air.

FIGURE 5-2
SAMPLING AND EXPOSURE DEPTH INTERVALS FOR SOIL TO EVALUATE EXPOSURE OF DESERT BIGHORN SHEEP

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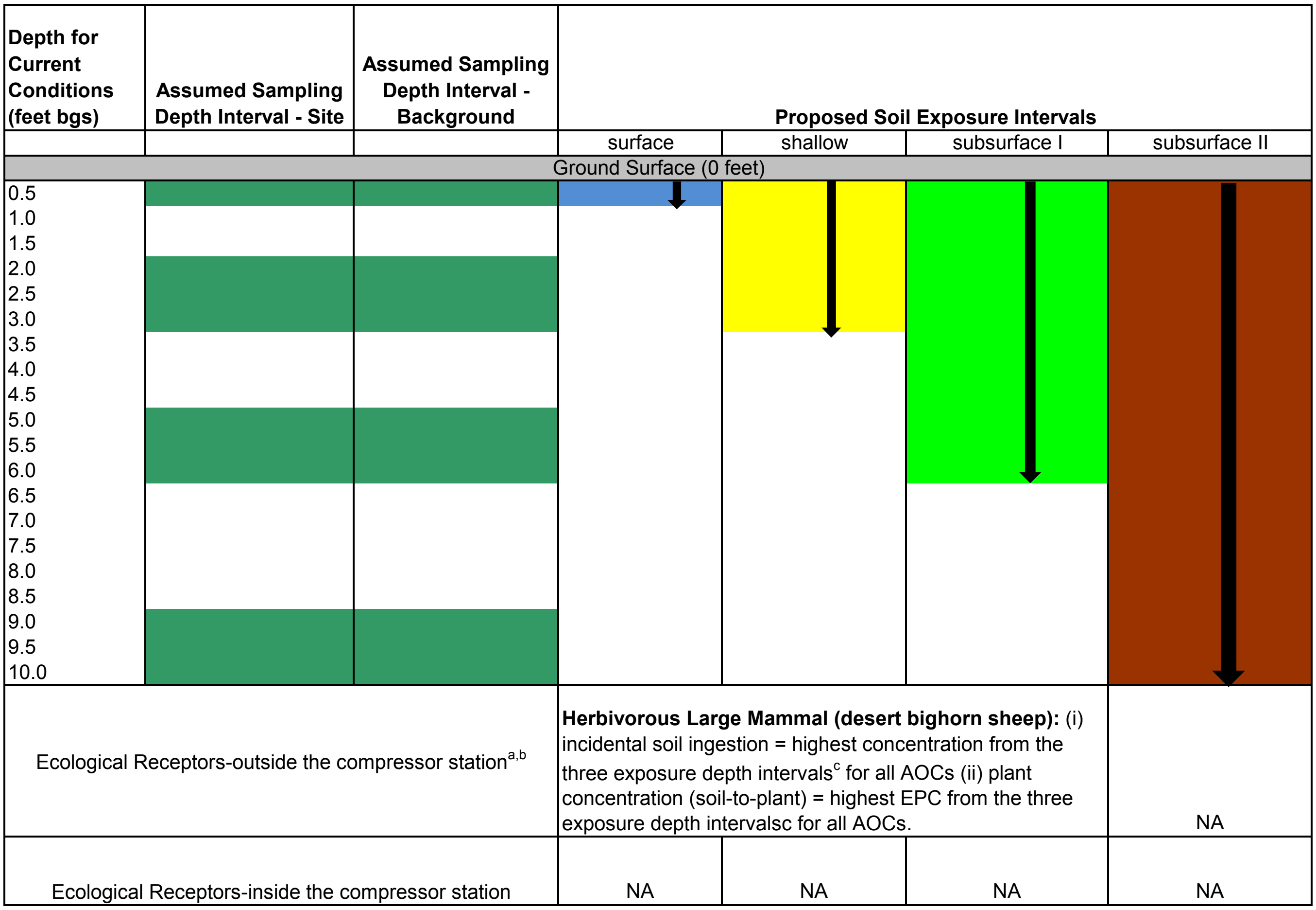
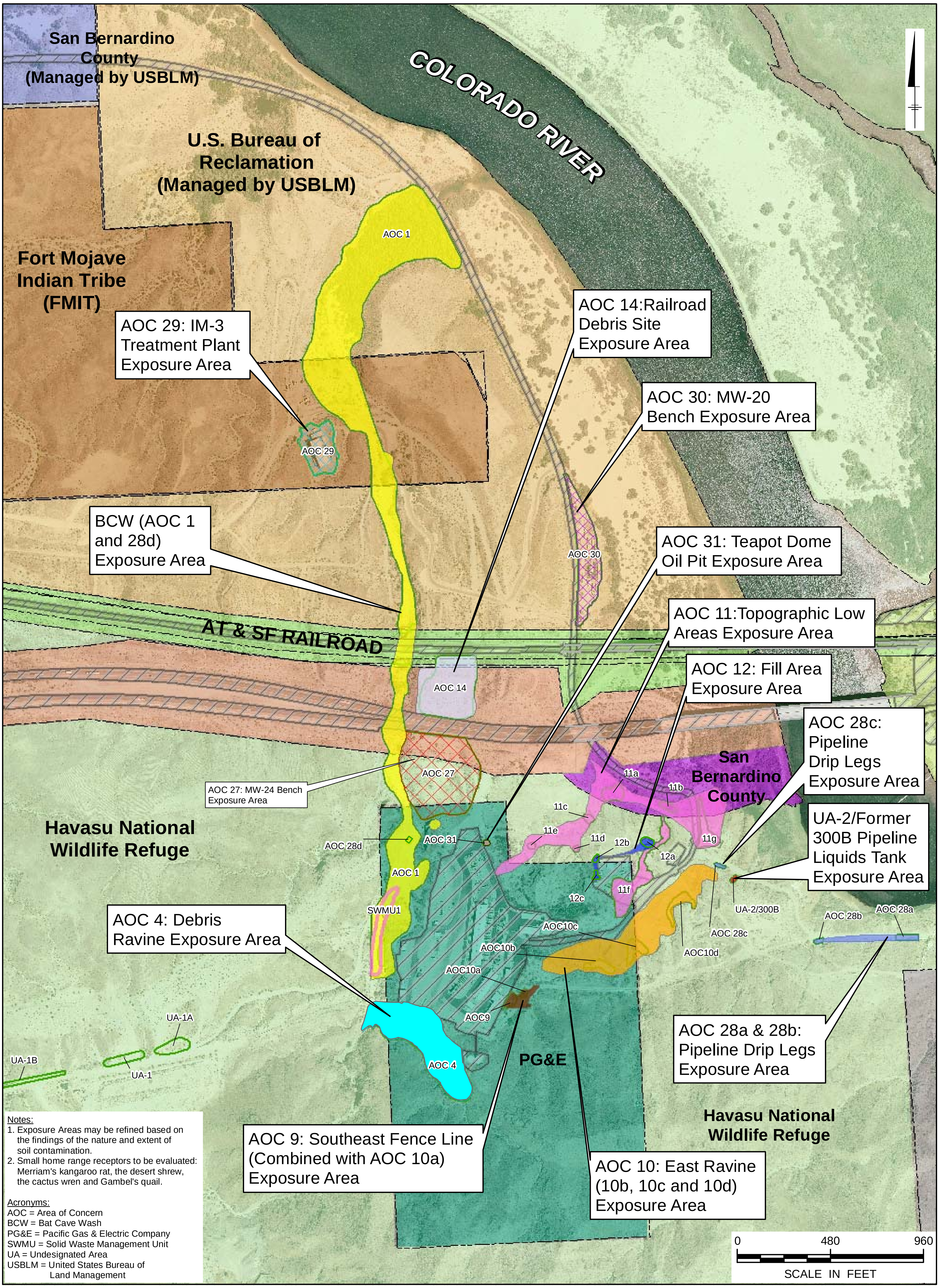


Depth for Current Conditions (feet bgs)	**Assumed Sampling Depth Interval - Site**	**Assumed Sampling Depth Interval - Background**	**Proposed Soil Exposure Intervals**			
			surface	shallow	subsurface I	subsurface II
Ground Surface (0 feet)						
0.5	🟩	🟩	🟦 ↓	🟨	🟩	🟫
1.0				🟨	🟩	🟫
1.5				🟨	🟩	🟫
2.0	🟩	🟩		🟨	🟩	🟫
2.5	🟩	🟩		🟨	🟩	🟫
3.0	🟩	🟩		🟨 ↓	🟩	🟫
3.5					🟩	🟫
4.0					🟩	🟫
4.5					🟩	🟫
5.0	🟩	🟩			🟩	🟫
5.5	🟩	🟩			🟩	🟫
6.0	🟩	🟩			🟩 ↓	🟫
6.5						🟫
7.0						🟫
7.5						🟫
8.0						🟫
8.5						🟫
9.0	🟩	🟩				🟫
9.5	🟩	🟩				🟫
10.0	🟩	🟩				🟫 ↓
Ecological Receptors-outside the compressor station[a,b]			**Herbivorous Large Mammal (desert bighorn sheep):** (i) incidental soil ingestion = highest concentration from the three exposure depth intervals[c] for all AOCs (ii) plant concentration (soil-to-plant) = highest EPC from the three exposure depth intervalsc for all AOCs.			NA
Ecological Receptors-inside the compressor station			NA	NA	NA	NA

Notes:
a. See Table 5-3 for additional details.
b. Exposure point concentrations for ecological receptors will be represented by both the maximum detected concentation and the 95 percent upper confidence limit on the mean.
c. The 3 exposure depth intervals for ecological receptors for the current conditions include:
Surface Soil = 0 - 0.5 feet below ground surface (bgs).
Shallow Soil = 0 - 3 feet bgs.
Subsurface Soil I = 0 - 6 feet bgs.

AOC = includes areas of concern and undesignated areas
bgs = below ground surface
BCW = Bat Cave Wash
NA = not applicable



Notes:
1. Exposure Areas may be refined based on the findings of the nature and extent of soil contamination.
2. Small home range receptors to be evaluated: Merriam's kangaroo rat, the desert shrew, the cactus wren and Gambel's quail.

Acronyms:
AOC = Area of Concern
BCW = Bat Cave Wash
PG&E = Pacific Gas & Electric Company
SWMU = Solid Waste Management Unit
UA = Undesignated Area
USBLM = United States Bureau of Land Management

Legend:

☐	Preliminary AOC Boundary as per the Soil Work Plan
☐	SWMU 1 Boundary
☐	Property Boundaries

Exposure Areas

🟨	BCW (AOC 1) and AOC 28d Exposure Area
🟦	AOC 4: Debris Ravine Exposure Area
🟫	AOC 9: Southeast Fence Line (Combined with AOC 10a) Exposure Area
🟧	AOC 10: East Ravine (10b, 10c and 10d) Exposure Area
🟪	AOC 11:Topographic Low Areas Exposure Area
🟦	AOC 12: Fill Area Exposure Area
⬜	AOC 14:Railroad Debris Site Exposure Area
▨	AOC 27: MW-24 Bench Exposure Area
🟦	AOC 28a, 28b & 28c: Pipeline Drip Legs Exposure Area
▨	AOC 29: IM-3 Treatment Plant Exposure Area
▨	AOC 30: MW-20 Bench Exposure Area
🟥	AOC 31: Teapot Dome Oil Pit Exposure Area
🟥	UA-2/Former 300B Pipeline Liquids Tank Exposure Area

Property Owners

🟩	AT & SF Railroad
🟨	Bureau of Reclamation (Managed by USBLM)
🟧	Caltrans Leased
🟫	Fort Mojave Indian Tribe
🟩	Havasu National Wildlife Refuge (HNWR)
🟩	PG&E
🟪	San Bernardino County
🟦	San Bernardino County (Managed by USBLM)

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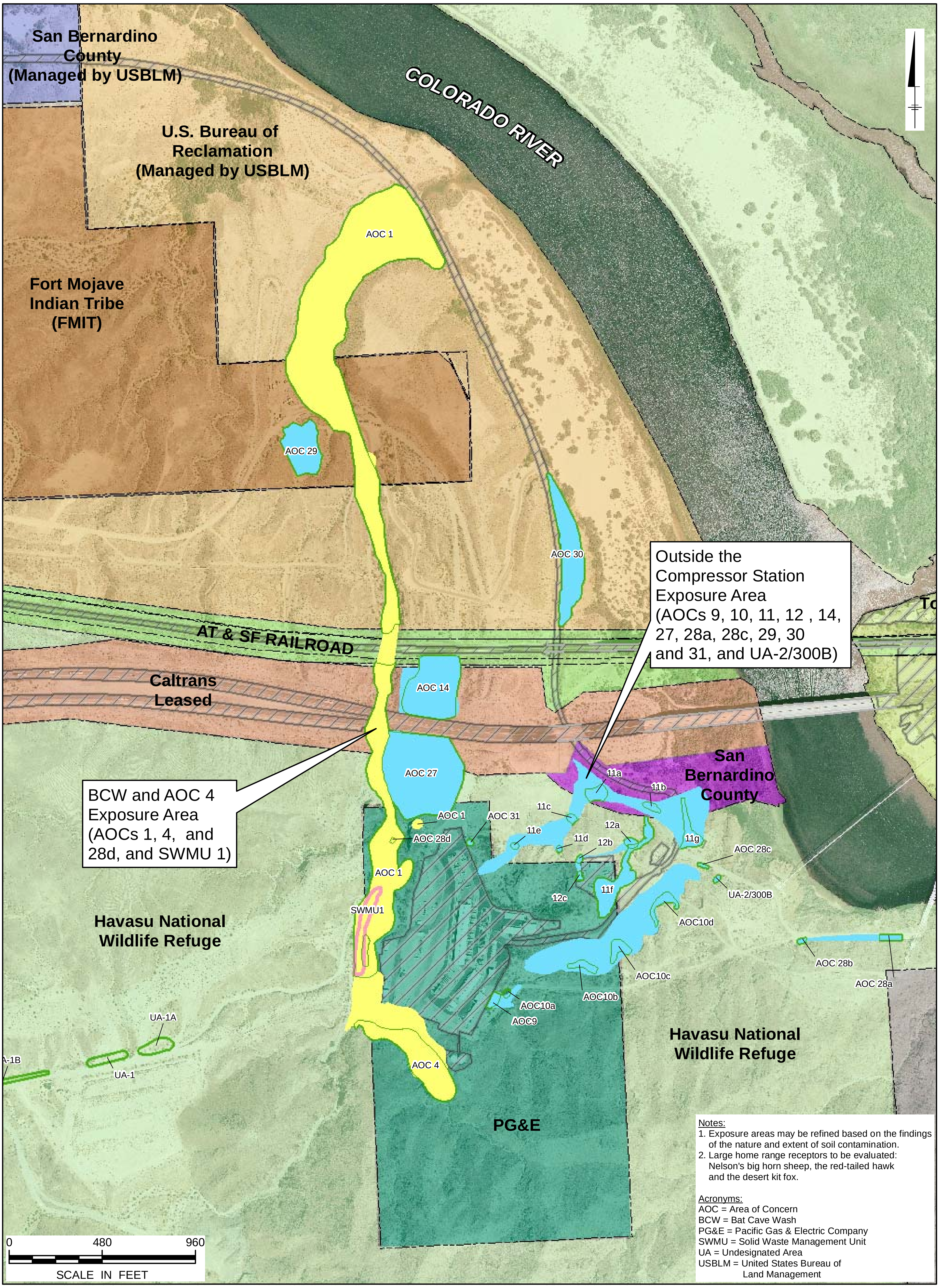
PRELIMINARY ECOLOGICAL SMALL HOME RANGE RECEPTOR EXPOSURE AREAS

ARCADIS

FIGURE
5-3

CITY: SF DIV/GROUP: ENV/IM DB: MESTIFANOS LD: PIC: PM: TM: TR:
PROJECT: (PROJECT #)
PATH: Q:\PGE\Topock\Soil_EPC_Workshop\mxd\ELHRREA.mxd 4/11/2014 9:43:02 AM



Notes:
1. Exposure areas may be refined based on the findings of the nature and extent of soil contamination.
2. Large home range receptors to be evaluated: Nelson's big horn sheep, the red-tailed hawk and the desert kit fox.

Acronyms:
AOC = Area of Concern
BCW = Bat Cave Wash
PG&E = Pacific Gas & Electric Company
SWMU = Solid Waste Management Unit
UA = Undesignated Area
USBLM = United States Bureau of Land Management

Legend:

- 🟨 BCW and AOC 4 Exposure Area
- 🟦 Outside the Compressor Station Exposure Area
- ▢ Preliminary AOC Boundary as per the Soil Work Plan
- ▢ SWMU 1 Boundary
- ⬚ Property Boundaries

Property Owners
- 🟩 AT & SF Railroad
- 🟨 Bureau of Reclamation (Managed by USBLM)
- 🟧 Caltrans Leased
- 🟫 Fort Mojave Indian Tribe
- 🟩 Havasu National Wildlife Refuge (HNWR)
- 🟩 PG&E
- 🟪 San Bernardino County
- 🟦 San Bernardino County (Managed by USBLM)

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NEEDLES, CALIFORNIA
HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

PRELIMINARY ECOLOGICAL LARGE HOME RANGE RECEPTOR EXPOSURE AREAS

ARCADIS

FIGURE
5-4

Appendix A

Letters from Tribes and Agencies pertaining to the RAWP Addendum 2

November 26, 2013

Mr. Aaron Yue, Project Manager
DEPARTMENT OF TOXIC SUBSTANCES CONTROL
5796 Corporate Avenue
Cypress, California 90630

Ms. Pamela S. Innis
Topock Remedial Project Manager
Office of Environmental Policy and Compliance
U.S. DEPARTMENT OF THE INTERIOR
P.O. Box 25007 (D-108)
Denver, Colorado 80225-007

SUBJECT: Follow-up to Soil Risk Assessment Work Plan Meeting, September 19-20, 2013

Dear Mr. Yue and Ms. Innis:

On September 19 and 20, 2012, representatives of the Fort Mojave Indian Tribe (Tribe) and their consultants attended a meeting with DTSC and DOI to discuss proposed amendments to the risk Assessment Work Plan (RAWP) for soil. That 2-day meeting was focused both on proposed updates to the RAWP as well as presentations on certain procedures contained in the current version of the RAWP. At that meeting the Tribe presented many suggestions related to how the risk assessment for soil will be performed. These suggestions mainly focus on assumptions and procedures that result in increasing calculated risks and hazards. This letter memorializes the Tribe's views.

While the Tribe does want the site contamination addressed in an appropriate manner, the inclusion of several assumptions and procedures results in the following outcomes which are unacceptable to the Tribe:

1. Increased disturbance of the site due to an increased and unnecessary amount of soil sampling,
2. Increased calculated risk and hazard in the risk assessments that will be produced for the site which could be used as justification for unneeded cleanup, and
3. An increased likelihood of an incorrect and negative perception about the Topock area, the River and potentially down-River areas.

Those assumptions and procedures that contribute to the above-listed, unacceptable consequences are outlined in the following bullets:

- The Tribe supports the use of the non-residential receptors in the risk assessments. Our understanding is that with the exception of the northern and southern portions of Bat Cave Wash (BCW) (on either side of Tribal land) where the residential scenario will be applied, the Tribal land-use scenario will be applied. Further compounding the issue, the future residential receptor is also assumed to be a subsistence farmer/gardener. This is not a realistic assumption for the Topock area and only serves to increase the human risk estimates in the risk assessments which could impact cleanup decisions. As stated above, these inflated risk estimates are not reliable risk estimates and have the potential to create a negative perception of the Topock site and surrounding area. Unreliable and inflated risk estimates could cause a belief that the Topock site, the River and even down-River areas are not safe. This negative perception results in impacts to the sacred status that the Tribe holds for this area which has been determined by your agencies to be the Topock Cultural Area and a TCP, respectively.

- The issue of arrowweed harvesting was discussed. The Tribe reiterates that arrowweed is not harvested in the Topock area and will not be harvested as long as the area is contaminated. The agencies agreed that arrowweed should not be included in the Tribal Land Use assessment and should be removed from the conceptual site models as an exposure route.

- The issue of plant harvesting and use of plants from upland areas of the site was discussed. The Tribe reiterates that plant harvesting from the upland portions of the site does not occur. Any plants that may be used at the site for ceremonial or cultural purposes would be collected in other areas. The agencies agreed that plant use should not be included in the TLU assessment and should be removed from the conceptual site models.

- DTSC eco-risk assessor Dr. Eichelberger mentioned that there may be hyper-accumulative plants at the Topock site. The plants mentioned included tumbleweed and Mesquite. The Tribe requests more specific information on the identification of these plants, the portions of the plants that may hyper-accumulate metals and which ecological receptors, if any, might be exposed through these plants. The Tribe requests to be able to review this information and discuss it with DTSC and DOI prior to its possible inclusion in the RAWP for ecological receptors.

- The issue of what type of Tribal activities should be included in the Tribal Land Use assessment was discussed. It was concluded that the tribal activity of site visits would be the most representative of the various activities and be included in the TLU assessment.

- Other Tribal activities were discussed. For example, Tribal monitor activities should not be included in the TLU assessment as these exposures, if any, are addressed through other means since they represent potential exposures during project-related activities, have already been considered there and are not part of the Tribal activities at the site. These activities are more-appropriately addressed through site-safety procedures that apply to any individuals participating in or observing site project activities. Also note that in the DTSC table titled *Table 1. Action Items from the Topock Soil Risk Assessment Work Shop, September 19 and 20, 2013, Henderson, NV* Action Item #7 is incorrect. While there was some discussion of various Tribal activities at the Topock site, there was a clear conclusion and agreement by the Tribe that the Tribal Site Visit activity included in the TLU assessment would be the exposure scenario evaluated in the Soils Risk Assessment. Please update the Action Items table to reflect this conclusion.

- The issue of the home range for Bighorn Sheep was discussed. A site map was presented that showed all of the AOCs as one exposure area for the Bighorn Sheep. The proposed evaluation is to assume that as a percentage of the total home range for the Bighorn Sheep, all the outside fence-line AOCs would contribute to its exposure in the ecological risk assessment. The Tribe agrees with this evaluation.

- The topic of soil characterization data evaluation (data evaluation) was discussed. The stated goal of the data evaluation process is to have a 'representative data set' for the exposure area evaluated. Only Category 1 data (which meets QA/AC standard and is needed to define 'nature and extent') will be included in the final datasets. It is important to the Tribe that assumptions in the data evaluation process do not overestimate the soil concentrations, resulting in erroneous reporting of increased risk and potential cleanup. If over-estimating procedures are used in the risk assessment, then the impacts of these procedures on the final risk estimates must be included in the uncertainty discussion in the risk assessment report to assist in the interpretation of risks and the proposing of cleanup decisions. For example the characterization method used on this site is called by USEPA the 'adaptive cluster' method. This method focuses on the highest detected soil concentrations and then collects 'step-out' samples around this high concentration. This is a biased sampling approach and therefore must be presented as such (versus random or random-grid sampling which provided un-biased samples). A description of the 'adaptive cluster' approach and how exposure point estimates are calculated and the effect of these approaches on exposure point concentrations and risk estimates are all topics to include in this uncertainty discussion.

- A second example of the data evaluation process that adds bias to the data resulting in higher soil concentrations (and therefore higher risk, more cleanup and more soil impacts) is the inappropriate use of field duplicate samples. The Tribe notes that the purpose of QA/QC samples (e.g., the field duplicate) is solely to determine if the data meets the quality criteria set for the project. For duplicate samples, this means that the concentrations of a primary and its duplicate sample are compared and if the difference is within a stated percentage (for example 50% or 100% are typical acceptable differences) then the data is considered usable. Once the primary data are determined to be usable there is no further use of the QA/QC samples. For the Topock project, DTSC is requiring that the higher concentration of the primary and its duplicate be used in the risk assessment. This not only is a misuse of the QA/QC samples, but it results in a built-in bias that the sample location that has a duplicate sample collected now has been effectively sampled twice (versus all the other locations only once). This procedure is not consistent with regulatory guidelines on QA/QC samples in soil sampling where the use is to determine the quality and usability of the sampling results. The Tribe requests that only primary samples are included in the soils database from which exposure point concentrations will be calculated in the risk assessment and that QA/QC samples are used only to determine data quality.

- The depths of soil horizon to be evaluated in the human and ecological risk assessments were discussed. For the Tribal Land Use assessment, only the 0' to 2' below grade surface (bgs) is appropriate. Deeper depths for the other scenarios that may include digging at the site are acceptable. In addition, the scouring scenarios (2' bgs and 5'bgs) are only applicable in drainages (e.g., Bat Cave Wash). The scouring of the soil surface is not applicable to upland areas of the site where the Tribal Land Use assessment will be applied.

- The Tribe does not support the inclusion of either inside fence line or fence line samples in the datasets for down-gradient SWMUs/AOCs. If there is a current fence line concentration that might migrate to a down-gradient SWMU/AOC, then the dilution that will occur to that concentration as it migrates must be considered. The current concentrations that may migrate are not representative of exposure area concentrations and have the effect of increasing exposure point concentrations and risk estimates as discussed above.

An issue of the RAWP that was presented at the meeting, and which the Tribe supports, is the use of an area-weighted (named Thiessen polygons) to evaluate the soil data. Since any potential future exposures (both human and most ecological) would occur over large areas, this Thiessen polygon procedure is an appropriate process to estimate exposure point concentrations over large areas. The Tribe supports the use of polygon-derived exposure point concentrations in both the human health and ecological risk assessments.

The Tribe requests that the RAWP be modified to be consistent with, or incorporate to the maximum extent appropriate, the issues described in this letter. The Tribe also requests that this letter and any Response to Comments (RTC) related to these issues be permanent attachments to the final RAWP.

In addition, the schedule for finalizing the draft RAWP was not available at the September 19-20 meeting. We request an updated copy of the project schedule that shows when the draft RAWP will be circulated for comments and dates for tentative meetings and final approval of the RAWP. We also expect that additional meetings on the RAWP will occur. Tribal representatives and consultants are available to meet with DTSC, DOI, PG&E and their risk assessment consultants to further discuss these issues.

Sincerely,

Michael J. Sullivan, Ph.D., CIH
Consultant to the Fort Mojave Indian Tribe

cc: N. McDowell/FMIT
L. Leonhart/Hargis
C. Coyle/Counsel to FMIT

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
FISH AND WILDLIFE SERVICE
BUREAU OF RECLAMATION

ELECTRONIC SUBMISSION

March 26, 2014

Subject: PG&E Topock Compressor Station Remediation Site – Land Use Assumptions in Conducting the CERCLA Baseline Human Health Risk Assessment and Implementation of the Soil Investigation Work Plan.

Dear Mr. Sullivan:

The Department of the Interior (DOI) and the Department of Toxic Substances Control (DTSC) (collectively, the Agencies) are in receipt of two letters from you, on behalf of the Fort Mojave Indian Tribe (FMIT), dated November 26, 2013 regarding the Soil Risk Assessment Work Plan Meeting on September 19-20, 2013 and the Appropriateness of the Tribal Land Use Assessment. The Agencies have considered the information that you provided in your letters and would like to address the concerns you have put forth.

As you know, the Agencies are conducting response action at the PG&E Topock Compressor Station Remediation site (Site), pursuant to their respective authorities under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA). The Agencies recognize that further intrusion into the culturally sensitive areas identified around Site during response action is objectionable to the Tribes and, based on specific comments received from multiple interested Tribes, have made significant reductions in the numbers of samples required in the Soil investigation at the Site. In October and November 2010 and January 2011, a series of meetings between the Tribes, Agencies, PG&E, and stakeholders were conducted to discuss the draft Soil RCRA Facility Investigation/ CERCLA Remedial Investigation (RFI/RI) Work Plan. During these meetings, the parties discussed and agreed on revisions to the initial proposed sample locations for the various investigation areas around the Site. In response to concerns raised by the Tribes through letters provided by the FMIT consultant (Hargis & Associates, November 22, 2010) and the

Hualapai Department of Cultural Resources (December 3, 2010), and as a result of Tribal meetings held December 7, 2010 and January 13, 2011, the Agencies evaluated each sample location to determine which, if any, location could be further eliminated to reduce disturbances to sensitive cultural resources.

Based on this evaluation, the Agencies identified sample locations that we determined could be eliminated or relocated from those presented in the Data Gaps Analysis and carried forward in the development of the Soil RFI/RI Work Plan. The Agencies' correspondence to PG&E, dated February 25, 2011, provides those recommendations and PG&E developed a comprehensive draft Soil RFI/RI Work Plan that satisfies the data quality objectives (DQOs) specified in the Soil Part A and Part B DQO documents and the stipulations described in the 1996 Corrective Action Consent Agreement between DTSC and PG&E.

DTSC provided the draft Soil RFI/RI Work Plan to the Tribes and other stakeholders for comment on May 9, 2011. In addition, BLM provided letters and the draft Work Plan on May 20, 2011 and on June 11, 2011 to the nine tribes affiliated with the Topock PG&E Remediation Project initiating formal consultation. A consultation meeting was held at the BLM Lake Havasu Field Office on July 21, 2011, and the Agencies received comments from the FMIT and Hualapai Tribe. Comment resolution took place from December 14, 2011 through June 6, 2012 and included several meetings and a site walk on December 15, 2011 to review the soil sample locations.

PG&E issued the Final Soil RFI/RI Work Plan in September 2012. The Agencies believe the sampling activities as described in the current work plan are the minimal effort required to satisfy the DQOs when considering the already reduced sampling effort and taking into consideration the multiple uses of the site and the ecological setting.

In 2007, DOI established expected future land use assumptions to be applied in the ongoing soil investigation tailored to the reasonably foreseeable uses of federal lands and reflecting the presence of sensitive cultural and biological resources in the vicinity of the Topock Compressor Station. These assumptions were reiterated in a letter to the Tribes on September 28, 2011 and to Ms. Nora McDowell-Antone on February 28, 2013.

In applying land use assumptions to the Topock project and evaluating remedial alternatives pursuant to CERCLA, the analysis must consider, among other things, whether the alternatives will protect human health. This analysis is based on risk levels developed during the baseline human health risk assessment that are premised on assumptions about the potential future land uses at the site. For the purposes of the ongoing soil investigation and the baseline risk assessment, DOI maintains that the future land use assumptions for BLM-managed land should remain conservative and reflect a residential scenario while future human use assumptions on the Havasu National Wildlife Refuge will be limited to recreational and tribal uses. DOI is developing recreational assumptions for use in the risk assessment and looks forward to the opportunity to share this information with tribes and stakeholders.

Although many of the issues raised will be addressed in the risk assessment work plan addendum, below is a summary of our position regarding several of the key points:

- Human and ecological exposure to Cr (VI) via arrowweed uptake represents an insignificant exposure pathway based on available literature and the FMIT position that arrowweed will not be harvested in the area as long as contamination remains.
- Soil contamination is spatially variable. When considering this, DTSC and DOI agree that the maximum detected concentration will be used for risk assessment purposes in the event of duplicate samples. This is a conservative but not unreasonable approach and is consistent with EPA recommendations. In the event that one sample is dramatically higher than another, it will likely be identified as an uncertainty and its impact discussed in the risk assessment.
- Consistent with input from the Tribes, tribal activities that will be considered in the tribal use scenario will be the representative site visit use.

Other issues presented in your letters will be addressed in the Risk Assessment Work Plan Addendum and can be commented on during the regular comment period and discussed during comment resolution. The November 26, 2013 letters will be included in the Administrative Records for the project and included as attachments to the final Risk Assessment Work Plan Addendum.

The Agencies appreciate receiving the FMIT's comments on these issues and will continue to work with all of the Tribes and interested stakeholders as we move forward in the process of developing cleanup decisions for the contaminated soil at the site.

If you have any questions, please contact Pamela Innis at (303) 445-2502 or Aaron Yue at (714) 484-5439.

Sincerely,

Pamela S. Innis

Pamela S. Innis
DOI Topock Remedial Project Manager

Aaron Yue
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Geological Services Branch
Department of Toxic Substances Control

[illegible] on Remediation – Response to 11/26/13 letters from Michael Sullivan to Pamela Innis (DOI) and Aaron Yue (DTSC)

cc: N. McDowell/FMIT
L. Leonhart/Hargis & Associates
C. Coyle/Counsel to FMIT
Consultative Work Group
Technical Review Committee

Appendix B

Information from DOI on Recreational Users

Revised Technical Memorandum
Recreational Visitor Exposure Scenario for Federal Land
PG&E Topock Compressor Station Remediation Project, California

Introduction

The Department of the Interior (DOI), through the Bureau of Land Management (BLM), the U.S. Fish and Wildlife Service (USFWS), and the Bureau of Reclamation (BOR), manages land that has been impacted by releases of hazardous substances from the PG&E Topock Compressor Station (Topock site or Site)[1] and is the subject of response actions pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The land consists of the Havasu National Wildlife Refuge (HNWR) which is managed by USFWS and BLM-managed lands under the jurisdiction of BLM and/or BOR (collectively, "the federal land"). The federal land is managed pursuant to a number of land use objectives and is approved for specific uses, including recreation. DOI has advised PG&E and the Technical Working Group (TWG) that DOI will provide information to complete a recreational visitor risk assessment for federal land at the Site. This information includes a discussion of the different types of recreational activities that may occur and the frequencies that people may engage in these activities. The risk assessment will be integrated with the remedial investigation (RI) of the soils operable unit at the Site for decision making purposes. This technical memorandum discusses the Site background, possible recreational uses of federal land on and in the vicinity of the Site, and provides DOIs recommended exposure assumptions to support a quantitative risk assessment for recreational visitors to Topock.

Site Description

Releases at and from the Site have impacted land owned by the federal government, local tribal governments, California state and municipal governments, and private entities. **Figure 1** shows the land ownership in the vicinity of the Topock site. Much of the land is undeveloped or minimally developed, notwithstanding the presence of the PG&E Compressor Station, IM-3, the BNSF Railroad, Park Moabi, Pirate's Cove Resort, and Interstate 40. Due to the openness of the federal land and limited restrictions to site access, recreational access is potentially present across much of the area. Recreational land use can encompass a variety of activities, including (but not limited to) hiking, camping, hunting, visiting historic Route 66, and riding off-highway vehicles (OHVs, also known as all-terrain vehicles [ATVs]). These uses are influenced by a variety of issues, including site access, vegetation, natural or man-made features of interest, weather, and an interested population. The Colorado River is adjacent to the Topock site and provides recreational opportunities; access to the river may be gained across federal land, although access is easier using designated boat ramps that are available nearby at Park Moabi or the Topock Marina.

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[1] For the purposes of this document, the "Topock site" or Site is synonymous with the Area of Potential Effect (APE) as defined in the Programmatic Agreement.

Some federal land within and adjacent to the Topock site has been developed for routine recreational use. Park Moabi is leased by San Bernardino County and comprises BLM and State Land within the Site and provides seasonal residential use to the public and year-round residential use for a limited number of San Bernardino County staff. The Pirate's Cove is a concessionaire on BLM-leased land to the east of Park Moabi; it has boat docks, a restaurant, and condos to rent. The Topock Marina is a private facility in Arizona within the APE, which is adjacent to the HNWR. It provides boat docks and gasoline and soon will provide overnight rentals. The Colorado River floodplain attracts OHVs and other recreators since it has an open area of sandy beach. Parcels of federal land are near to the Colorado River and could be suitable for camping and access to the river.

The BLM Lake Havasu office, which manages land in the vicinity of the Topock site, has stated that it does not collect data regarding recreational visitation of use of BLM land (Cox, 2013). There are no sign-in logs or user fees collected at any access points on BLM land. The BLM's Needles Field Office manages the BOR lands near the Topock site and has designated many hiking trails near the site in the Bullhead Travel Management Plan (DOI/BLM 2009). These trails cross portions of the Site, although there is no organized trail network through the soil investigation area.

The Havasu National Wildlife Refuge (HNWR), managed by the USFWS, provides recreation opportunities for the public. The HNWR comprises 37,515 acres along the lower Colorado River in Arizona and California. The HNWR protects 30 river miles and encompasses 300 miles of shoreline from Needles, California, to Lake Havasu City, Arizona. The HNWR near the Topock site consists of two main areas: Topock Marsh and the wilderness area surrounding the Needles Mountains. Near the Site, the HNWR is underdeveloped in regards to general public access. Most of the HNWR is outside of the area impacted by the Topock Compressor Station.

The primary purpose of the National Wildlife Refuge System is to provide habitat for fish, wildlife, and plant resources. All activities that take place on the HNWR have to be appropriate and compatible with this main purpose. There are six main activities that have been determined to be compatible with the refuge's purpose: hunting, fishing, wildlife observation, photography, environmental education, and interpretation (61 FR 13647, 1996). Camping (land or water) is prohibited on HNWR per regulation (USFWS, 2013). There are no established hiking trails but most areas of the refuge are open to hiking. Near the Topock site, the most common recreational activities are hiking and boating/fishing. Street legal vehicles and OHVs are allowed on refuge roads, but off-roading is not allowed. Hunting is allowed on HNWR; hunting upland game would be the most likely form of hunting near the Topock site although it is rare. The HNWR has the authority to close off portions of the refuge for hunting and/or safety concerns. Closed areas are marked by regulatory signs and/or buoys (USFWS, 2013).

Recreation Exposure Information from Published Sources

As noted in the Site Description, there are a variety of recreational activities that may be conducted on federal land near the Topock site. These activities include hiking, camping, bird watching, hunting, and riding OHVs. Of primary concern for this evaluation is how often a person comes to the Site and how they may be exposed to chemicals that could be present in the soil. Several relevant documents have been identified that describe the frequency that individuals have been observed, or were assumed, to be engaged in these activities at other sites in the area and across California.

In 2008 a human health risk assessment was prepared for the **Clear Creek Management Area (CCMA),** a BLM property in Central California (USEPA, 2008a). The CCMA includes part of the New Idria Formation, a serpentinite rock body which contains a 31,000 acre outcrop of naturally occurring asbestos. The BLM has designated the New Idria portion of the CCMA as the Serpentine Area of Critical Environmental Concern (ACEC). The risk assessment evaluated a number of scenarios representative of typical recreational activities at the 75,000 acre property.

Although there are significant differences in some of the site attributes between CCMA and the Topock site (e.g., CCMA is primarily a naturally occurring asbestos site), some of the activities considered in the risk assessment at CCMA are similar to those proposed for recreational visitors at the Site. The primary concern at the CCMA was the inhalation of asbestos fibers in ambient air generated from soil-disturbing activities, particularly by motorized vehicles. The scenarios were designed to reflect the spectrum of activities an individual would participate in during a typical day, weekend, or work year visit to CCMA, e.g., driving in, riding motorcycles, camping, and driving out.

In summary, the scenarios at CCMA included:

- Weekend rider
- Day use rider
- Day use hiker
- Weekend hunter
- Combined rider/workday
- Patrol
- SUV/truck patrol

The risk assessment reported levels of airborne asbestos generated by activity based simulations of typical recreation activities at CCMA. Airborne dust levels, which are more relevant to the Topock site, were not reported (USEPA, 2008a).

The **State of California Natural Resources Agency** published a "*Survey on Public Opinions and Attitudes on Outdoor Recreation in California in 2009*" (CNRA, 2009). This report was developed in order to provide a comprehensive view of the outdoor recreation patterns and preferences of Californians, based on their opinions and attitudes about outdoor recreation and self-reported levels of physical activity in places where they recreate.

The primary goals of this survey were:

- to learn about the recreational activities Californians are engaged in and what they would like to do more;
- to learn about Californians' opinions and attitudes regarding recreation facilities, programs, services and policies;
- to learn about Californians' physical activity in parks;
- to assess changes in responses compared to prior surveys.

The California Natural Resources Agency report did not contain recreational activity data specific to the Topock area or to federal land in the area. It did, however, confirm that the recreational activities proposed for the Topock human health risk assessment are popular with Californians in many regions across the state. The “mean number of participation days” from survey respondents for off-highway vehicle use was reported to be 14.8 days in 2008; the mean number of days for other relevant activities, such as camping (at developed sites), picnicking, or RV/trailer camping, ranged from 7-9 days/year.

The **USDA Forest Service** compiled visitor use data in their “*National Visitor Use Monitoring Results, USDA Forest Service, National Summary Report*” (USDA, 2013). Although there is no Forest Service land at the Topock site, the data can give insight into land use patterns of recreational visitors to federal land. This report provides science-based estimates of the volume and characteristics of recreation visitation to the National Forest System, as well as the benefits recreation brings to the American public. Completed in 5-year cycles, the report helps the Forest Service to manage its recreation resources in such a way that best meets the needs of visitors while maintaining the quality of the natural resource base.

The most popular activity reported on Forest Service lands was hiking/walking, by 42% of respondents. Primitive camping (3%) and OHV use (3.6%) were activities also engaged in by Forest Service land visitors. Less than half of the OHV riders reported this was their primary activity, suggesting that they were using OHVs to access forest land for other activities (e.g., hunting, fishing, climbing).

Recreational Visitor Exposure Scenario for Federal Land at the Topock Site

The lands managed by the federal agencies in the vicinity of the Topock site are largely undeveloped, but opportunities for recreation are available across the Site area. The development of exposure assumptions for recreational visitors to federal land at Topock are discussed in this section of the Technical Memorandum.

Figure 2 presents a conceptual site model (CSM) diagram that links the contaminant source with exposure to potential recreational visitors on federal land. As a simplifying assumption, it is assumed that each of these recreational activities could take place at any location on federal land. In reality, specific locations may be preferred for certain activities while other locations may be less attractive or may limit recreation options (e.g., HNWR). The most probable recreational land use activity on federal land includes hiking, camping, hunting, and OHV riding.

Published default exposure factors are generally not available for recreational land use (except for some specific scenarios, such as fishing and fish ingestion rates). EPA's 2011 Exposure Factors Handbook Update does not present exposure factors for any recreational scenarios other than fishing (EPA, 2011a). Rather, informed professional judgment is necessary to select factors that best represent the types of recreational activities that may be conducted at the site of interest.

Exposure Parameters of Interest: Once a particular activity or scenario has been selected, it is necessary to develop estimates of the frequency a person may be engaged in this activity (exposure frequency, EF, in days/year) and the length of time spent doing this activity (exposure duration, ED, in years). The routes of exposure, including inhalation of dust, incidental ingestion of soil, and dermal contact with soil, are important factors in determining how much of a contaminant may enter the body during these activities.

Factors Impacting Exposure Potential: Recreational use of federal land at the site is expected to vary during the course of a year due to a variety of factors, including weather conditions (especially hot, cold, or rainy periods), seasonality of hunting, and the time of year. In general, recreational activities at the site are expected to be limited in frequency and duration during the hottest summer months. Hunting would only occur during those months that are legally permitted; the exposure potential could vary based on game species being hunted. The exposure frequency is expected to be limited to a few weeks for the species of interest (e.g., game birds).

The exposure frequency and duration parameters presented in **Table 1** are proposed for recreational visitors on federal land in the vicinity of the Topock site, based on site-specific considerations and information provided from nearby sites. The EF parameters were developed from information presented in CNRA's document "*Complete Findings: Survey on Public Opinions and Attitudes on Outdoor Recreation in California, 2009*", particularly Table 25 (Recreation Activity Participation of Respondents During the Past 12 Months). The use rates provided by CNRA are mean values; for risk assessment purposes, an upper bound measure of exposure (e.g., the 95% upper confidence limit on the mean) is generally preferred. To protect human health, it is assumed herein that a participant's entire annual recreational activity is conducted on federal land at Topock rather than spread out at various sites across the state. That is, the entire annual activity rate for day hiking on trails, 15.9 days/year, is spent at the Topock site. This approach is expected to provide a conservative upper bounds estimate of the potential exposure frequency and duration at the Site.

Particulate Emissions: A primary exposure concern associated with riding OHVs is the generation and subsequent inhalation of airborne particulate matter. With their large and heavily treaded tires, OHVs can release relatively large amounts of soil into the ambient air when they are ridden. For the recreational OHV rider population at Topock, it is necessary to identify an appropriate particulate emission factor (PEF, in m^3/kg) that provides an estimate of the airborne level of respirable dust resulting from riding OHVs. The PEF is the soil to air emission factor and provides a means for estimating the contaminant levels in air due to re-suspended soil particles (EPA, 2011b). A generic PEF has been developed by the USEPA for evaluation of windblown fugitive dust from surface contamination sites (EPA 1991), but that scenario does not agitate the soil as aggressively as the tires of an OHV and is not specifically relevant to an OHV scenario.

Airborne particulate levels generated during OHV riding at the Topock site have not been measured. PEFs derived for other sites were reviewed to determine their relevance for use at the Topock Site. The development of several site-specific PEFs for OHV riding at other sites are discussed in this Memorandum, along with a recommendation for evaluating risks to OHV riders at the Topock site.

Review of Relevant PEF Studies

The USEPA derived site-specific PEFs for OHV riding at two mine sites in Colorado. The baseline human health risk assessments (BHHRAs) for the Standard Mine Site and the Nelson Tunnel/Commodore Waste Rock Pile used the results from activity based air sampling to calculate PEFs for OHV riding. These risk assessments conducted field measurements that directly measured airborne levels of particulates generated from riding an OHV. These activity based projects were the only project examples identified in the literature where dust generation from OHV riding was quantitatively measured.

Standard Mine Site: The USEPA derived a PEF for riding OHVs at the Standard Mine Site in Gunnison County, Co (USEPA, 2008b; 2009). This PEF was calculated from empirical data collected by measuring airborne dust generated during activity simulations using two OHVs at the Quincy Smelter site (California) in 2004. (A reference for the Quincy Smelter project was not provided in the Standard Mine risk assessment; only a personal communication from B. Brass, USEPA/ERT West was cited.)

As reported in the Standard Mine BHHRA, a dust collector was attached to the front rack of the second (trailing) OHV and measurements taken over a six hour period. The concentrations of dust varied considerably during the measurement period, from a minimum concentration of 18.7 ug/m^3 to a maximum of 23,539 ug/m^3. The investigators took this to be due primarily to variations in speed and the positions of the OHVs relative to each other. From the collected air data, EPA generated a PEF for OHV riding by "taking the mean concentration of dust in air generated during OHV use (3,400 ug/m^3) and multiplying it by the fraction of total dust that is respirable to estimate the PM10 fraction" (35%; USEPA, 2009). A PEF of 1.18E-06 kg/m^3 (equivalent to 8.47E+5 m^3/kg) was calculated from this data.

Nelson Tunnel/Commodore Waste Rock Pile: The USEPA conducted site-specific activity based air sampling for the Nelson Tunnel/Commodore Waste Rock Pile BHHRA and RI in Creede, CO (USEPA, 2011b). The primary purpose of this study was to determine exposure point concentrations in air for lead, manganese and zinc. The appendix discussing the PEF derivation notes that three air samples were collected from the area traversed by the OHVs but does not describe where the air monitors were located or how long data was collected. Individual PEFs for each of the three metals were estimated from the site soil and air data. An "average PEF" of 6.08E-05 kg/m^3 (1.65E+04 m^3/kg) was calculated from the combined PEFs for the three metals.

A comprehensive description of the study design was not provided in the BHHRA for the Nelson Tunnel site. Although a limited amount of site-specific air data is presented for OHV riding, there is no substantiating information included (e.g., location of air monitors, actual dust levels). The lack of information for this project limits its usefulness, and it is not recommended as a surrogate for a PEF at the Topock Site.

Rand Historic Mining Complex: The BLM conducted an inhalation risk assessment for OHV riders as part of the RI at the Rand Historic Mining Complex in San Bernardino County, CA (DOI, 2011). In the Rand RI evaluation, airborne dust concentrations during OHV use were modeled by modifying an equation for calculating the PEF associated with construction traffic over an unpaved road (USEPA, 2002). This construction scenario is similar to OHV use, in that significant airborne soil and dust are generated by tires during repetitive driving activities. A combination of default values and activity-specific assumptions were integrated into the PEF estimation for the Rand RI. A PEF of 5.3E+03 m^3/kg was developed for the inhalation risk assessment for OHV riders at Rand.

Recommended PEFs for Topock Recreational Visitors

All of the OHV scenarios reviewed for this Technical Memorandum generated significant amounts of airborne dust. While particulate masks are often worn by riders in dusty conditions, for the purposes of this evaluation it is assumed that OHV riders are maskless and may be fully exposed to the dust generated from their activities.

The Standard Mine Site BHHRA derived a PEF for OHV riding based on airborne dust measurements collected during activity based sampling. Because it is based on actual measurements collected during OHV riding, the Standard Mine Site PEF (8.47E+05 m^3/kg) is considered to be the most accurate value for estimating airborne respirable dust levels from OHV riding at the Topock Site. It is recommended that this value be used as the PEF for estimating inhalation risks from OHV riding at the Topock Site. The recommended PEF for OHV riding is very similar to the default value recommended by DTSC (2011) for construction workers (1.0E+06 m^3/kg).

For campers, hikers, and hunters, the default residential PEF value of 1.316E+09 m^3/kg (DTSC, 2011) is recommended. This PEF represents the fugitive dust level a recreational visitor could be exposed to while present at the Site. The PEFs proposed for all recreational visitors to federal land are presented in Table1.

Table 1
Exposure Duration and Frequency for Recreational Visitors, Federal Land, Topock Site

Camper:

- EF: 1 day/month, 8 months/year
    - *(slightly greater than rate for "camping in developed sites", mean of 6.9 days/year, CNRA 2009)*
- ED: 30 years (6 as a child, 24 as an adult)*(DTSC, 2011)*
- PEF 1.316E+09 m^3/kg (DTSC, 2011)

Hunter:

- EF: 8 days, 1 month/year
    - *(4 weekends; assumes 1 month game season)*
- ED: 30 years for adult
    - (*default residential exposure assumption, USEPA, 1991*)
- PEF 1.316E+09 m^3/kg (DTSC, 2011)

Hiker:

- EF: 2 days/month, 8 months/year
    - *(corresponds to "day hiking on trails", mean of 15.9 days/year, CNRA 2009)*
- ED: 30 years (6 as a child, 24 as an adult)*(DTSC, 2011)*
- PEF 1.316E+09 m^3/kg (DTSC, 2011)

OHV Rider:

- EF: 2 days/month, 8 months/year
    - *(corresponds to "off-highway vehicle use", mean of 14.8 days/year, CNRA,2009)*

  1.5 hours/day
    - *(corresponds to time spent riding solely on the potentially contaminated area, USEPA 2008b)*
- ED: 30 years (6 as a child, 24 as an adult) *(DTSC, 2011)*
- PEF: 8.47E+05 m^3/kg *(USEPA, 2008a; 2009)*

Pathway-Specific Exposure Assumptions

Table 2 presents DOI's recommended assumptions for each exposure pathway of interest for the different recreational visitor populations. All populations are assumed to be exposed to site contaminants in soil by ingestion, dermal contact, and inhalation of particulates, but to varying degrees depending on their activities. When relevant, default exposure assumptions recommended by DTSC (2011) were used. Standard default exposure assumptions are not available for OHV riders, and a combination of site-specific information and professional judgment was used to select parameters for this population.

The default soil ingestion rate for construction workers is recommended to represent the higher rates of exposure expected from OHV activities than experienced by most recreational visitors. Similarly, the soil adherence factor for dermal exposure for construction workers is recommended for adult OHV riders. Both soil ingestion and dermal contact are considered episodic in nature, where an individual could receive the equivalent of a full day's exposure in less time during a limited number of exposure events (e.g., hand to mouth actions, dermal contact while sitting on the ground). Although OHV riders were assumed to ride on the Site for only a portion of a day, it was conservatively assumed they would incur a full day's exposure rate for the soil ingestion and dermal contact pathways.

The skin surface area values for dermal exposure assumes that the face, forearms, hands, lower legs, and feet are exposed skin. Separate default values have been provided for both children (up to age 6) and adults. As noted in Table 2, the skin surface area for adult hunters is likely overestimated, since they will probably wear shoes or boots.

Dermal absorption rates of inorganic chemicals have not been studied for recreational populations. Lacking population- or activity-specific information for skin surface area for soil contact and the soil adherence factor, default assumptions were made for this pathway. As shown in Table 2, DTSC-recommended default values for residents and construction workers were used in lieu of site-specific information for campers, hikers, hunters, or OHV riders. While this introduces some uncertainty into the analysis, it is not considered to be significant, as dermal exposure to metals is typically a low risk pathway.

The inhalation rates for all recreational populations potentially exposed to airborne particulates are also shown in Table 2. It was assumed that the populations of campers/hikers/hunters could be present at the Site all day and potentially exposed to airborne dust for the entire period. OHV riders are assumed to spend 1 ½ hours actively riding on the Site during each exposure period, although they may certainly ride for longer periods of time across a larger and non-impacted area.

It was also assumed that an individual could participate in these recreational activities for 30 years. For campers and hikers, it was assumed that 6 years of this activity would occur as a child aged 1-6 and 24 years as an adult (a standard assumption for exposure purposes) aged 7-30. Children riding OHVs were considered to be slightly older; EPA used the ages 6-12 in the

Standard Mine Site BHHRA (USEPA, 2008b; 2009). Exposure assumptions for a child ages 6-12 riding OHVs are included in Table 2. Children were not evaluated for the hunter scenario.

It is anticipated that these populations and pathways will be evaluated in the human health risk assessment for recreational visitors on federal land at the Topock site. In the event that any exposure parameters need clarification or updating, values recommended in the Topock HHRA workplan or EPA and DTSC guidance should be considered.

Table 2
Pathway-Specific Exposure Assumptions for Recreational Visitors, Federal Land, Topock Site

Parameter	Adult Value	Child Value	Reference
Body weight (kg)			
OHV Rider	70	33 (ages 6-12)	USEPA 2008b
Camper/Hiker	70	15 (ages 1-6)	DTSC 2011
Hunter	70	NA	DTSC 2011
Soil Ingestion (mg/day)			
OHV Rider	330[a]	330[a] (ages 6-12)	DTSC 2011
Camper/Hiker (resident default value)	100	200 (ages 1-6)	DTSC 2011
Hunter (resident default value)	100	NA	DTSC 2011
Dermal Contact			
Skin surface area (cm^2)			
OHV Rider	5,700	2,900 (ages 1-6)	DTSC 2011
Camper/Hiker	5,700	2,900 (ages 1-6)	DTSC 2011
Hunter	5,700[b]	NA	DTSC 2011
Soil adherence factor (mg/cm^2)			
OHV Rider	0.8[c]	0.8[c] (ages 6-12)	DTSC 2011
Camper/Hiker	0.07	0.2 (ages 1-6)	DTSC 2011
Hunter	0.07	NA	DTSC 2011
Inhalation of Particulates (m^3/hour)			
OHV Rider	2.4	1.55 (ages 6-12)	USEPA 2008b
Camper/Hiker/Hunter[d] (resident default value)	0.833[d]	0.417[d] (ages 1-6)	DTSC 2011
Averaging Time			
Carcinogens (days)	25,550 days	25,550 days	DTSC 2011
Noncarcinogens (days)	ED x 365	ED x 365	DTSC 2011

NA = Not applicable; not recommended for evaluation.

[a] the soil ingestion rate for a construction worker was used for both children and adults because OHV riding generates a large amount of dust, which can result in higher ingestion rates than more typical recreational exposures.
[b] the skin surface area for adult hunters is likely overestimated, since they will probably wear shoes or boots.
[c] the soil adherence value for a construction worker was used for both adult and children OHV riders.
[d] assumes 24 hours per day exposed to airborne particulates from the Site, equivalent to the residential default inhalation rate of 20 m^3/day for adults and 10 m^3/day for children.

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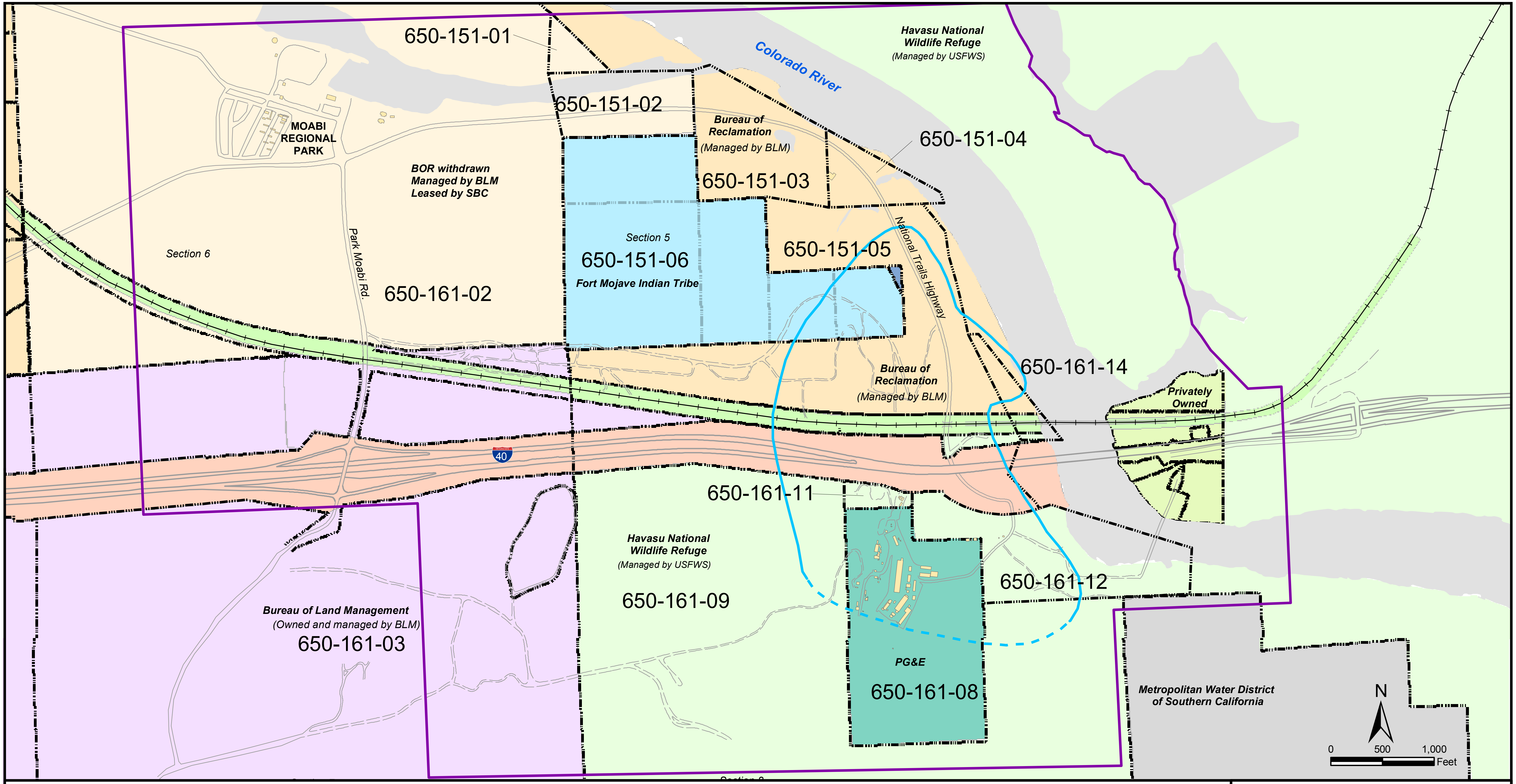


Legend

- Area of Potential Effect (APE)
- Railroad
- Parcel Boundary
- Highway
- Paved Road
- Dirt or Gravel Road
- Building

Owner

- BNSF Railroad
- Bureau of Land Management (Owned and Managed by BLM)
- Bureau of Reclamation (Managed by BLM)
- Caltrans Leased From Underlying Federal Owner
- Fort Mojave Indian Tribe owner in fee, with PG&E easement and access for remediation
- Havasu National Wildlife Refuge
- Metropolitan Water District of Southern California
- PG&E
- Privately Owned
- San Bernardino County Leased (Managed by BLM)
- State of California

Approximate extent of hexavalent chromium [Cr(VI)] concentrations exceeding 32 micrograms per liter (µg/L) at any depth in groundwater based on October 2008 and July 2009 sampling events. Dashed where based on limited data. The outline of Cr(VI) depicted as greater than 32 µg/L near or under the Colorado River is 80 feet below the bottom elevation of the Colorado River.

Note:
The boundary lines shown are approximate and for reference only.

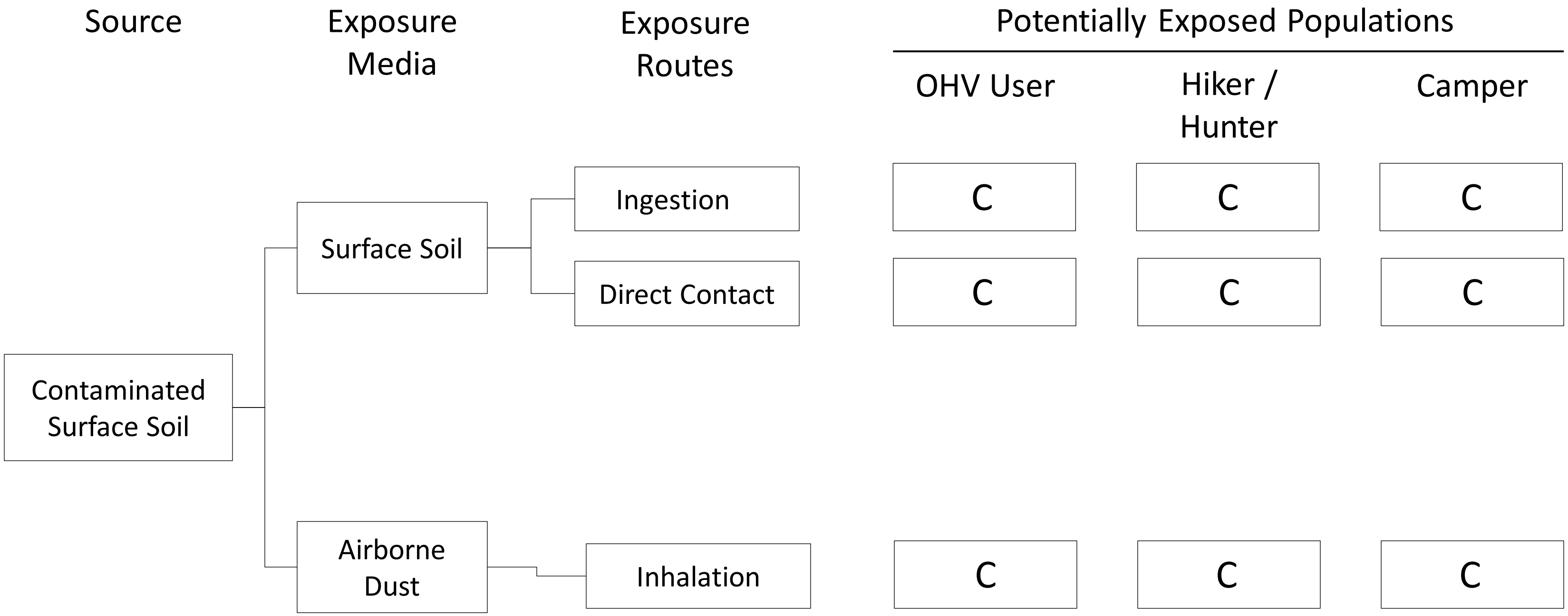
Sources:
1. San Bernardino County Assessor
2. Parcel quest
3. State Board of Equalization
4. Pacific Gas and Electric Company
5. Ecology and Environment and Plate maps provided by BLM.

FIGURE 1

Property Ownership and Managment Map (modifed from CH2M Hill)

CH2MHILL

Figure 2. Draft Human Health Conceptual Site Model (CSM): Recreational Visitors, DOI Federal Land, Topock Compressor Station



Source	Exposure Media	Exposure Routes	Potentially Exposed Populations		
			OHV User	Hiker / Hunter	Camper
Contaminated Surface Soil	Surface Soil	Ingestion	C	C	C
		Direct Contact	C	C	C
	Airborne Dust	Inhalation	C	C	C

C = Exposure Pathway Complete
N = Exposure Pathway Negligible
OHV = Off Highway Vehicle

Appendix C

Soil Risk Assessment – Slides from Day 2 of the Risk Assessment Workshop

Topock Soil Risk Assessment Workshop

Day 2 – Friday, September 20, 2013

Health & Safety Moment

Driving Safety – Not Always Safe to Go Cruising

If you set your cruise control while roads are wet or icy your car may:

- Hydro-plane
- Lose contact with the road and accelerate to a dangerous speed
- Lift off the road and fly through the air

Lessons learned:

- ALWAYS drive defensively
- Never use cruise control if roads are wet or icy
- Share this information – ***it could save a life***

Agenda for Day 2

- **Health and Safety Moment**
- **Introductions**
- **Overview and Demonstration – Data Evaluation and ProUCL**

BREAK

- **Overview – Hot Spot/Spatially-Weighted EPCs**

WRAP UP/NEXT STEPS

Introductions

Data Management

Data Evaluation Process

Acquire Database

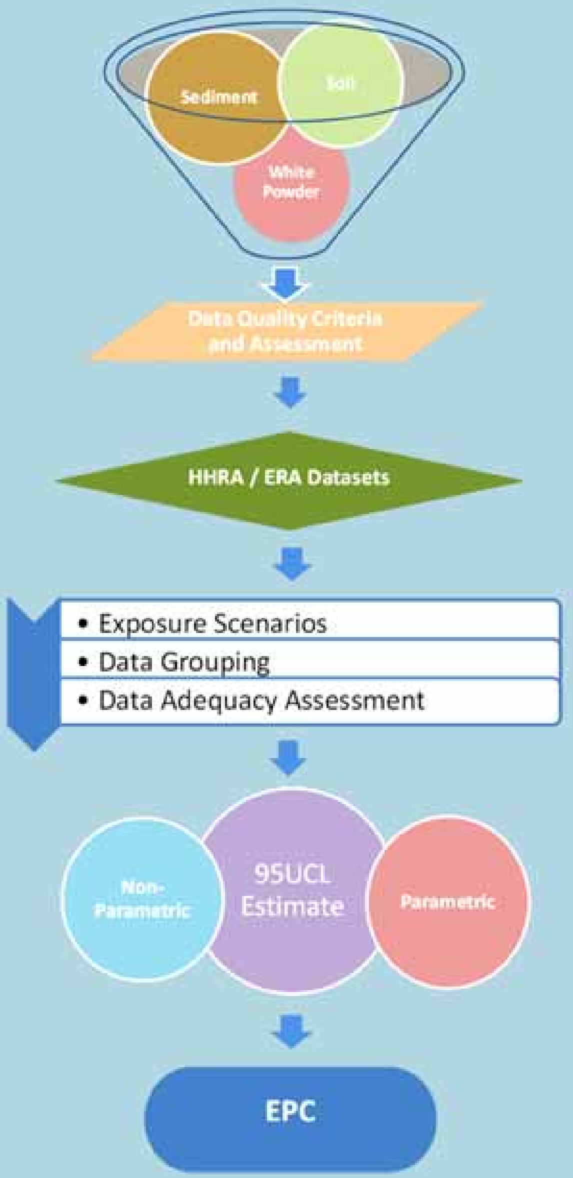
Data Quality Review

Selected Data Sets

Data Evaluation

Process for EPCs

Select EPCs



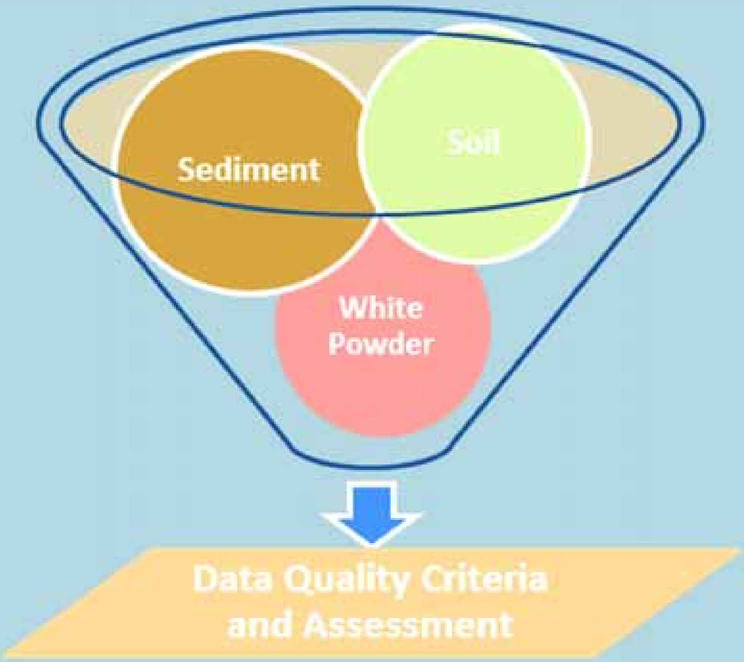
Selecting Soil Risk Assessment Data Set

Media <u>included</u>:

- Soil
- Sediment (Bat Cave Wash and East Ravine)
- Soil transitioning to Sediment
- White Powder

Media <u>excluded</u>:

- Asphalt
- Concrete
- Tar
- Debris
- Wood



Soil Risk Assessment: Data Quality

Data Quality <u>included</u>:

- Category 1: may be used with confidence for all purposes

Data Quality <u>excluded</u>:

- Category 2: Incomplete documentation available; may be used to support project objectives, including risk assessment, as long as the uncertainties are known
- Category 3: used qualitatively; not for critical decision-making

Data Consolidation/Reduction

Included Only:

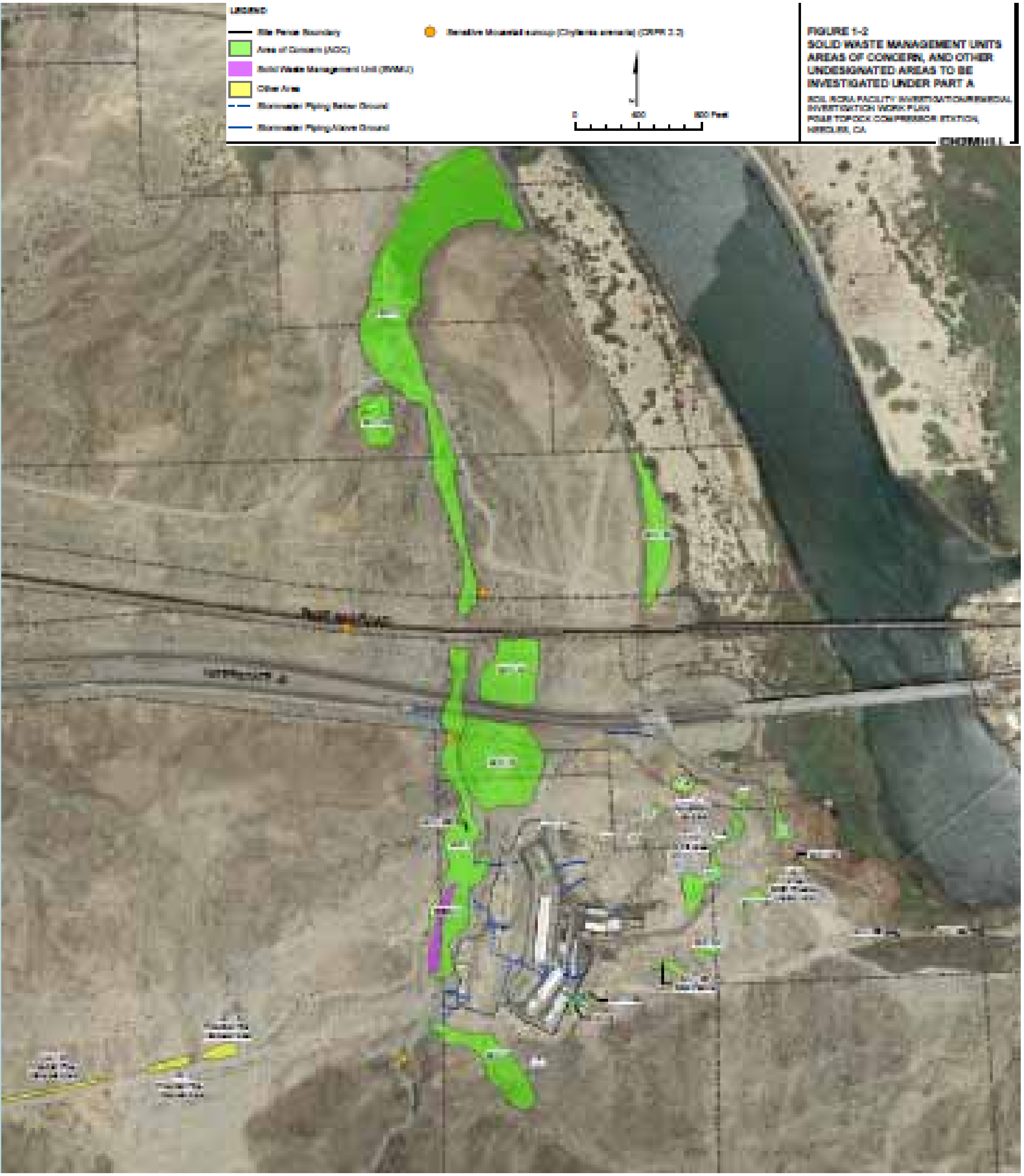
- Higher of primary or duplicate detections
- Lower of non-detected primary or duplicate reporting limit

Calculated:

- For Human Health
  - ✓ Benzo(a)pyrene Equivalent
  - ✓ Dioxin/Furan TCDD Equivalent
  - ✓ Total polychlorinated biphenyls (PCBs)
- For Ecological Risk
  - ✓ Total PCBs
  - ✓ Low Molecular Weight (LMW) polycyclic aromatic hydrocarbons (PAHs)
  - ✓ High Molecular Weight (HMW) PAHs
  - ✓ Dioxin/Furan TCDD Equivalent

Exposure Areas, Data Grouping and Data Adequacy Assessment

Investigation Area



Exposure Areas

Human Health Risk Assessment:

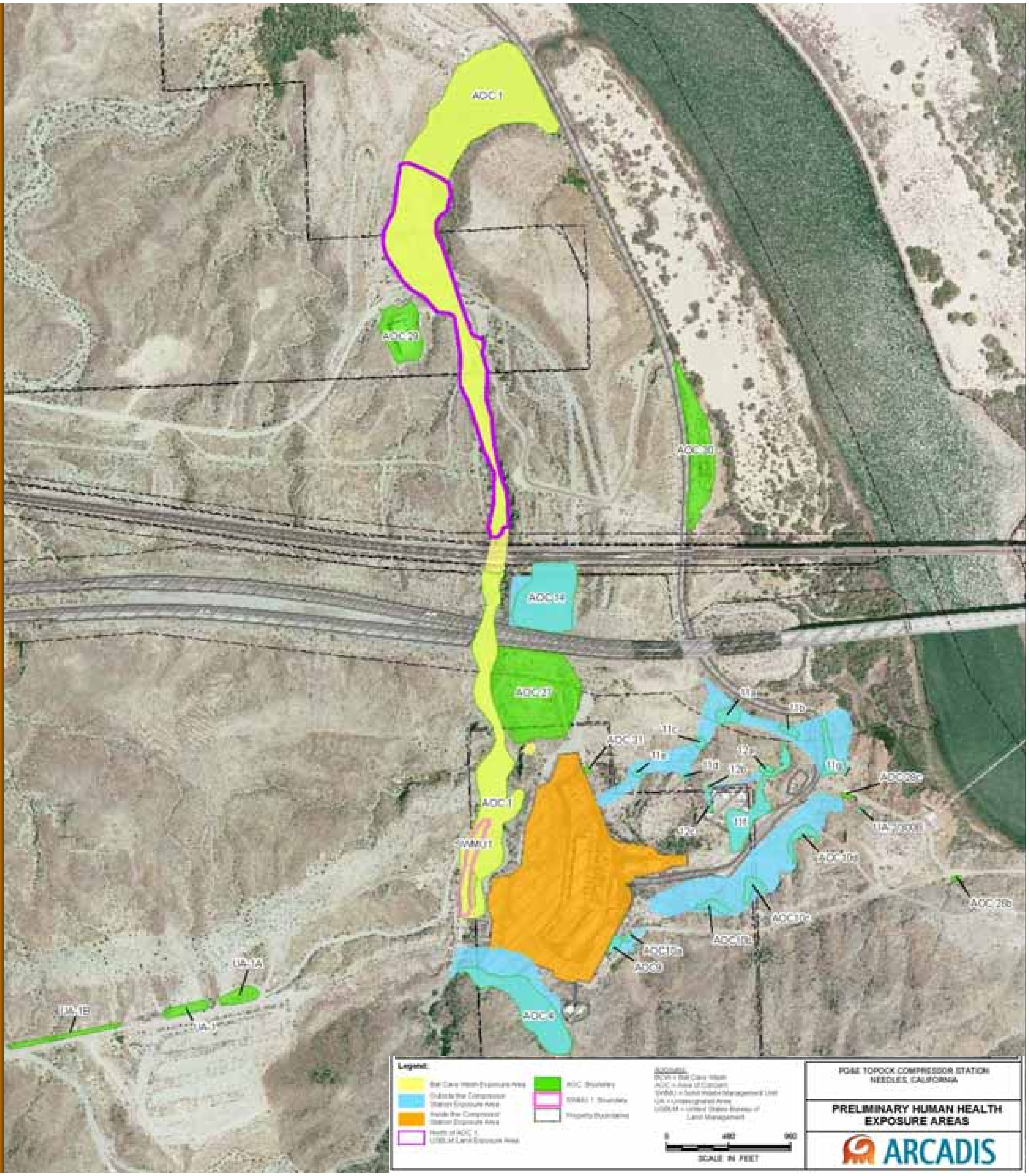
- Inside the Compressor Station
- Bat Cave Wash (BCW)
- North of the Railroad
- Outside TCS (excluding BCW)

Ecological Risk Assessment:

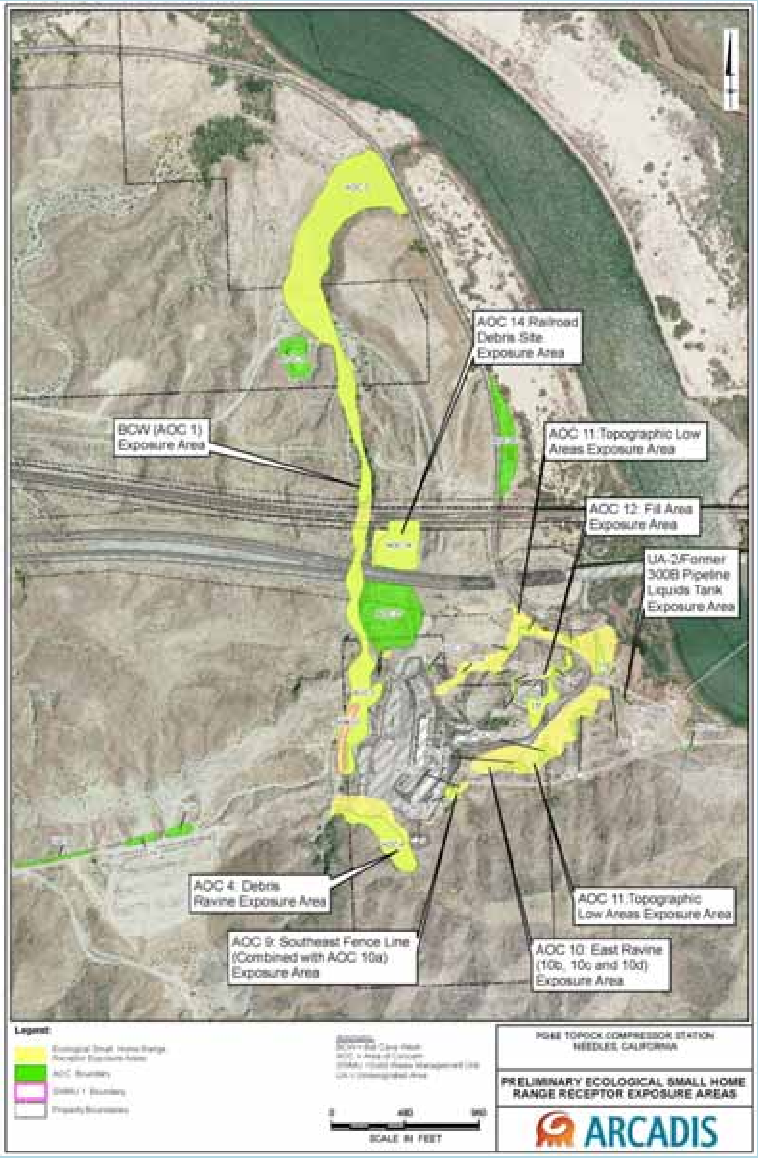
- Large home range ecological receptors, two exposure areas:
    - BCW (AOC 1) and AOC 4
    - All other AOCs outside TCS (AOCs 9, 10, 11, 12, 14, and Former 300B Pipeline Liquid Tanks Area)
- Small home range ecological receptors: Former 300B Pipeline Liquid Tanks Area and each AOC outside TCS will be separate exposure areas

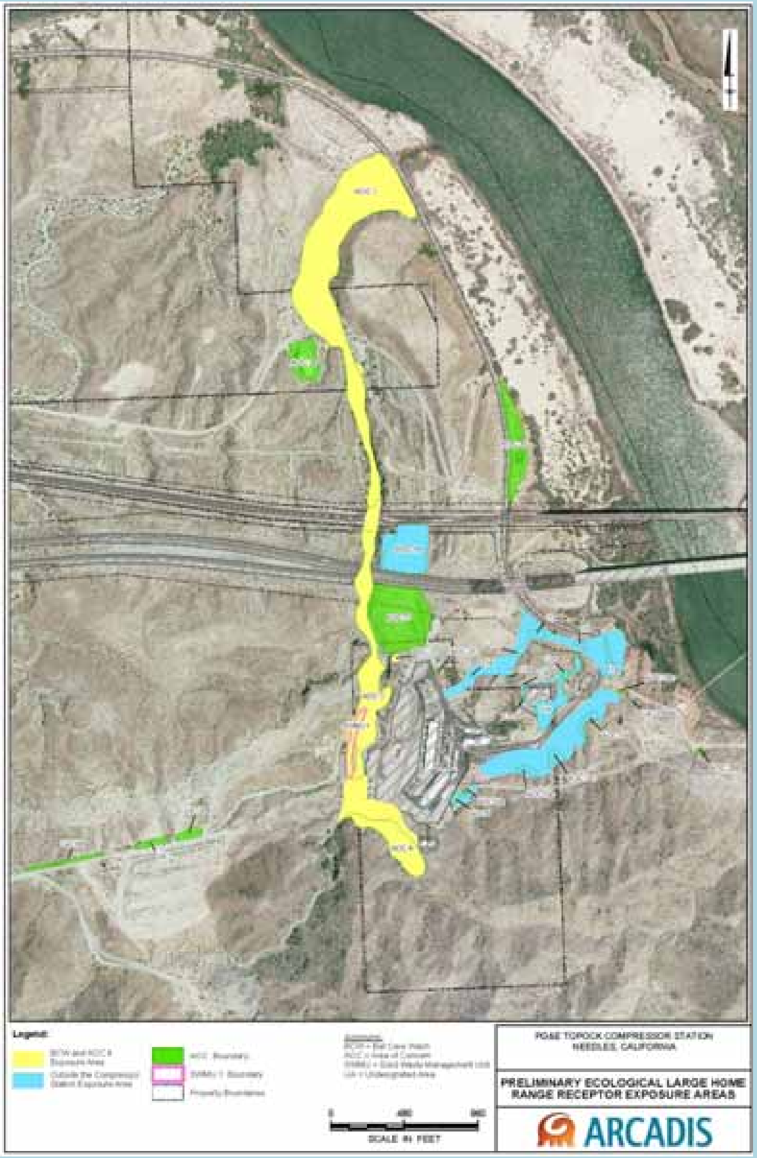
For purposes of this Workshop, 300B and AOC1/SWMU1 are treated as individual exposure areas

Exposure Areas – HHRA

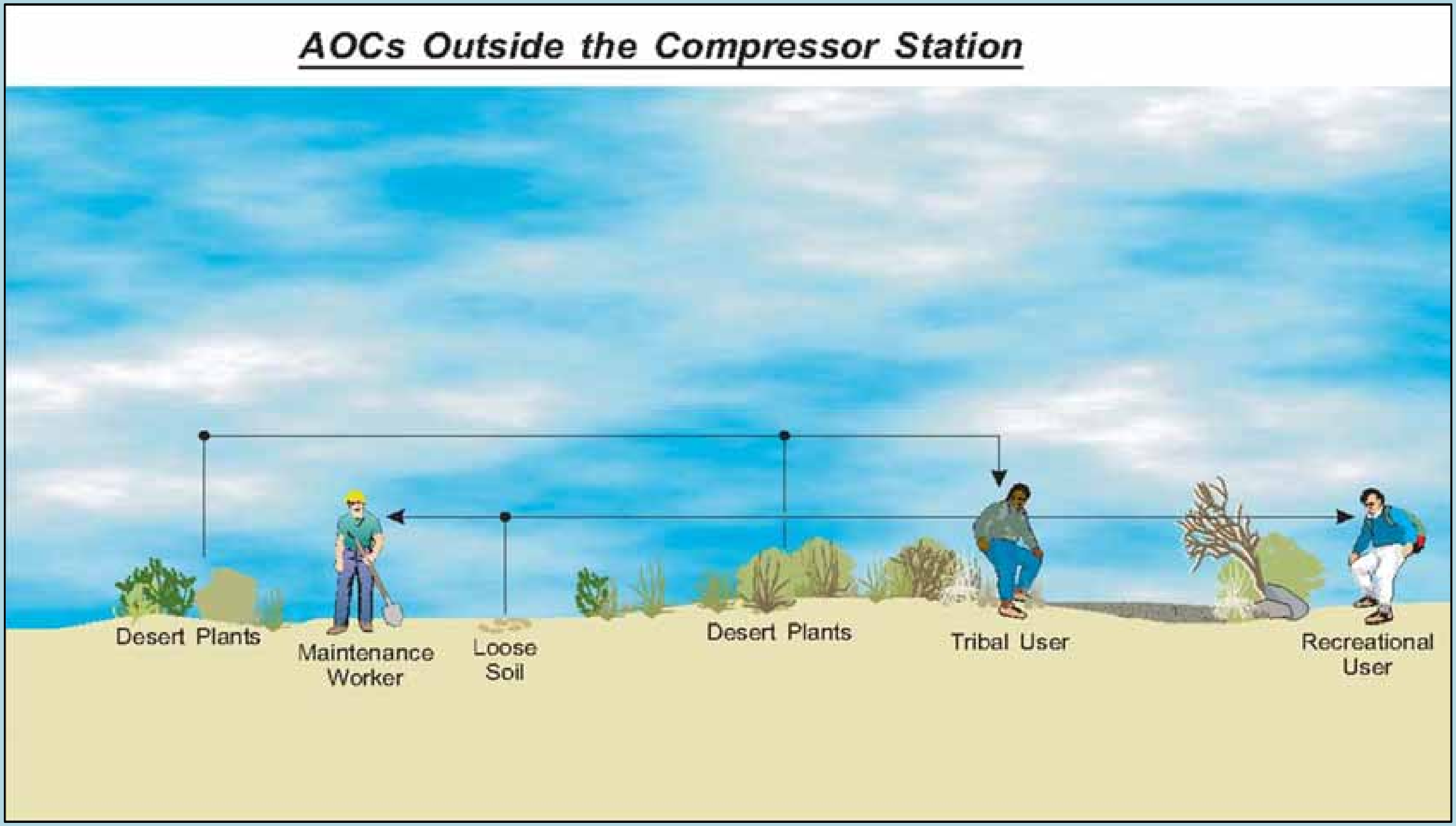


Exposure Areas – ERA

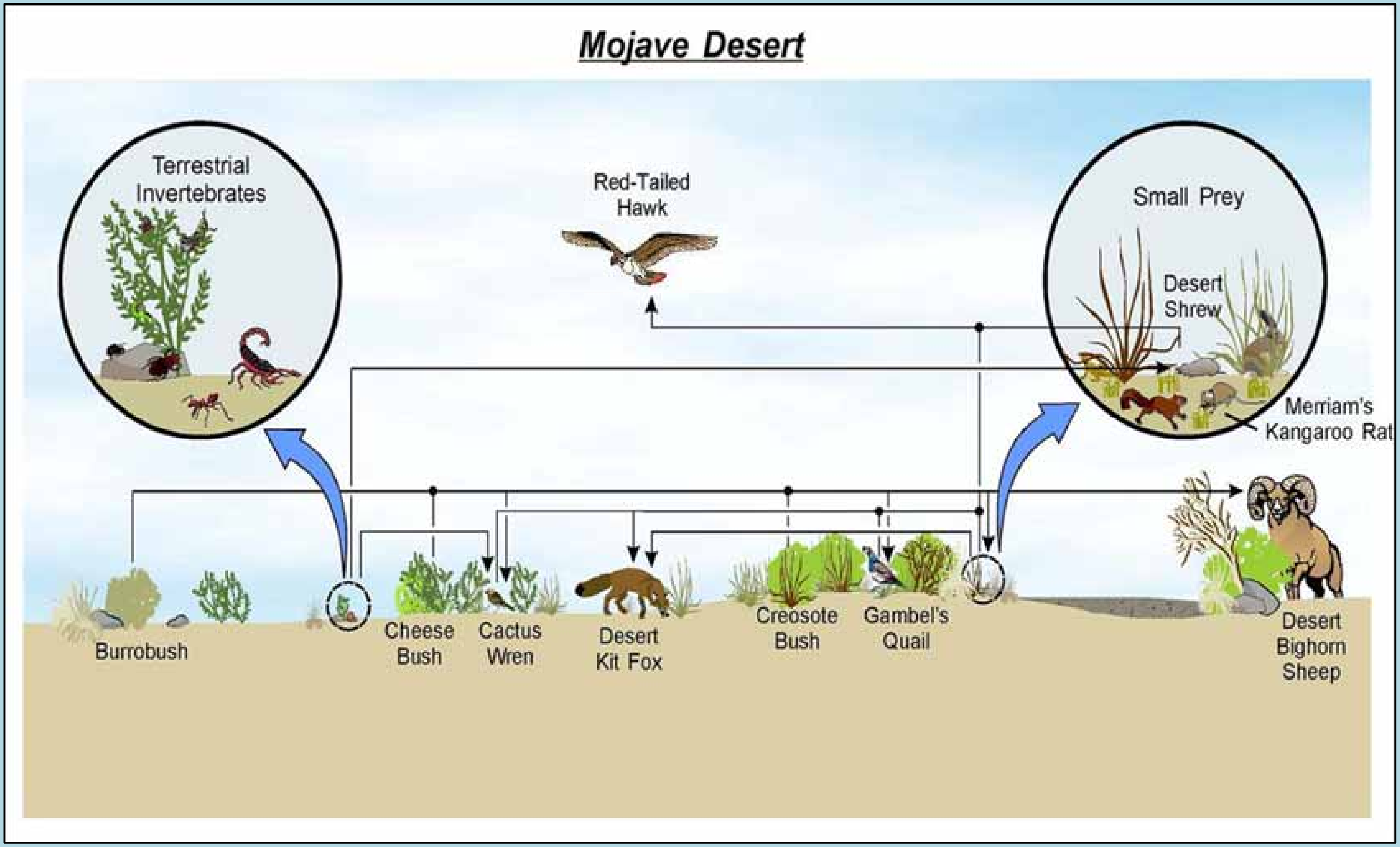




Soil Exposure Pathways - HHRA



Soil Exposure Pathways - ERA



Exposure Scenarios

Baseline:

- Current surface elevations

Scouring:

- The top 2 ft or 5 ft of soil could be scoured (AOC 1, AOC1 North of the Railroad, and AOC10)

Exposure Depths

Based on exposure scenario, exposure area data sets are separated into exposure intervals for EPC estimates

Baseline

- 0 to 0.5 ft bgs
- 0 to 3 ft bgs
- 0 to 6 ft bgs
- 0 to 10 ft bgs

Demo Example

2 ft Scouring

- 2 to 3 ft bgs
- 2 to 6 ft bgs
- 2 to 10 ft bgs
- 2 to 12 ft bgs

5 ft Scouring

- 5 to 6 ft bgs
- 5 to 10 ft bgs
- 5 to 15 ft bgs

Samples were included in interval if bottom depth of samples were within interval

Exposure Depths – Baseline

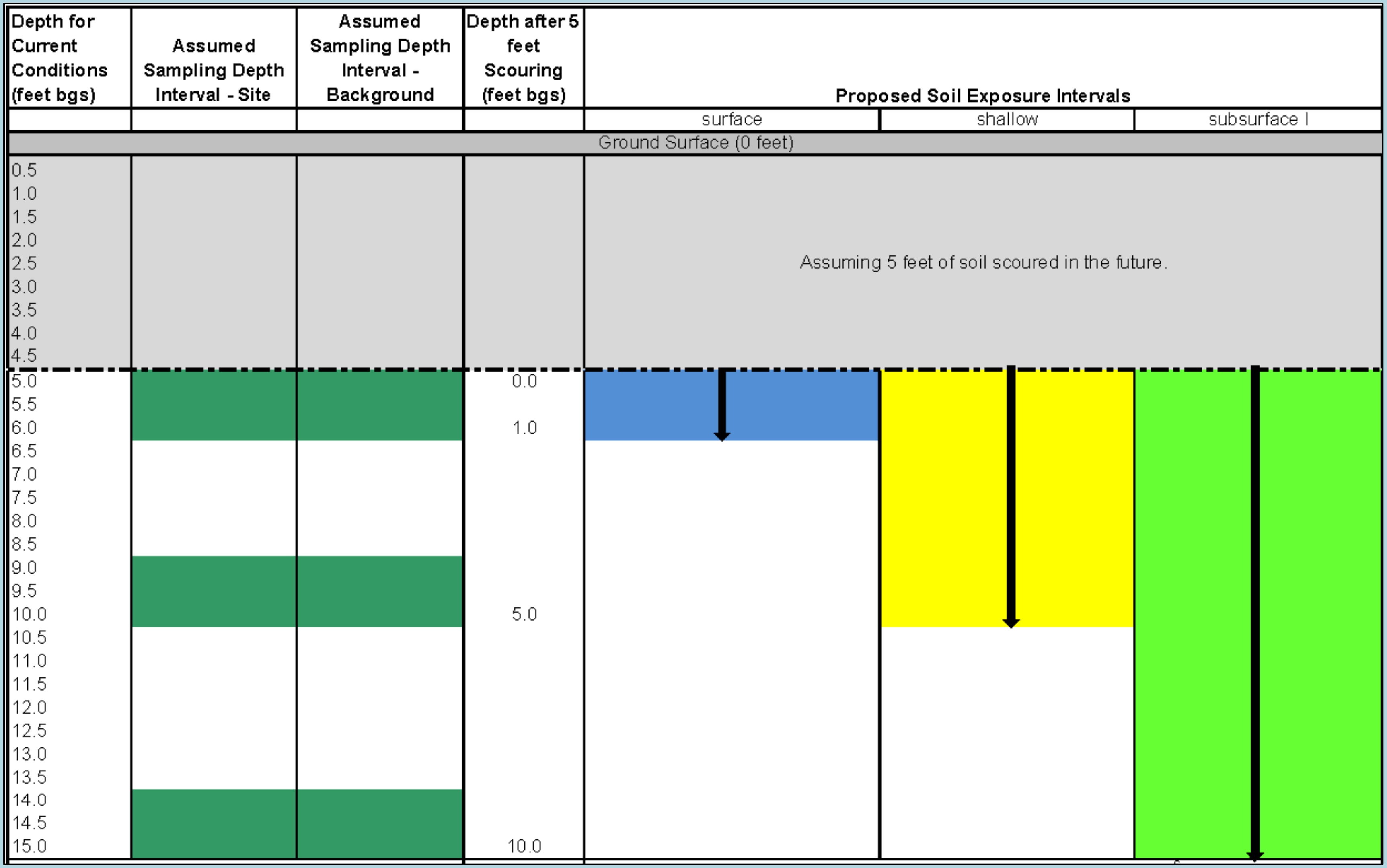
Demo Example

Depth for Current Conditions (feet bgs)	Assumed Sampling Depth Interval - Site	Assumed Sampling Depth Interval - Background	Proposed Soil Exposure Intervals			
			surface	shallow	subsurface I	subsurface II
Ground Surface (0 feet)						
0.5	🟩	🟩	🟦	🟨	🟩	🟫
1.0				🟨	🟩	🟫
1.5				🟨	🟩	🟫
2.0	🟩	🟩		🟨	🟩	🟫
2.5	🟩	🟩		🟨	🟩	🟫
3.0	🟩	🟩		🟨	🟩	🟫
3.5					🟩	🟫
4.0					🟩	🟫
4.5					🟩	🟫
5.0	🟩	🟩			🟩	🟫
5.5	🟩	🟩			🟩	🟫
6.0	🟩	🟩			🟩	🟫
6.5						🟫
7.0						🟫
7.5						🟫
8.0						🟫
8.5						🟫
9.0	🟩	🟩				🟫
9.5	🟩	🟩				🟫
10.0	🟩	🟩				🟫

Exposure Depths – 2 ft Scouring

Depth for Current Conditions (feet bgs)	Assumed Sampling Depth Interval - Site	Assumed Sampling Depth Interval - Background	Depth after 2 feet Scouring (feet bgs)	Proposed Soil Exposure Intervals for Ecological Receptors		
				surface	shallow	subsurface I
Ground Surface (0 feet)						
0.5				Assuming 2 feet of soil scoured in the future.		
1.0						
1.5						
2.0	🟩	🟩	0.0	🟦	🟨	🟩
2.5	🟩	🟩		🟦	🟨	🟩
3.0	🟩	🟩	1.0	🟦	🟨	🟩
3.5					🟨	🟩
4.0					🟨	🟩
4.5					🟨	🟩
5.0	🟩	🟩			🟨	🟩
5.5	🟩	🟩			🟨	🟩
6.0	🟩	🟩	4.0		🟨	🟩
6.5						🟩
7.0						🟩
7.5						🟩
8.0						🟩
8.5						🟩
9.0	🟩	🟩				🟩
9.5	🟩	🟩				🟩
10.0	🟩	🟩	8.0			🟩

Exposure Depths – 5 ft Scouring



Depth for Current Conditions (feet bgs)	Assumed Sampling Depth Interval - Site	Assumed Sampling Depth Interval - Background	Depth after 5 feet Scouring (feet bgs)	Proposed Soil Exposure Intervals		
				surface	shallow	subsurface I
Ground Surface (0 feet)						
0.5				Assuming 5 feet of soil scoured in the future.		
1.0						
1.5						
2.0						
2.5						
3.0						
3.5						
4.0						
4.5						
5.0	🟩	🟩	0.0	🟦	🟨	🟩
5.5	🟩	🟩		🟦	🟨	🟩
6.0	🟩	🟩	1.0	🟦	🟨	🟩
6.5					🟨	🟩
7.0					🟨	🟩
7.5					🟨	🟩
8.0					🟨	🟩
8.5					🟨	🟩
9.0	🟩	🟩			🟨	🟩
9.5	🟩	🟩			🟨	🟩
10.0	🟩	🟩	5.0		🟨	🟩
10.5						🟩
11.0						🟩
11.5						🟩
12.0						🟩
12.5						🟩
13.0						🟩
13.5						🟩
14.0	🟩	🟩				🟩
14.5	🟩	🟩				🟩
15.0	🟩	🟩	10.0			🟩

Data Usability Matrix

Demo Example

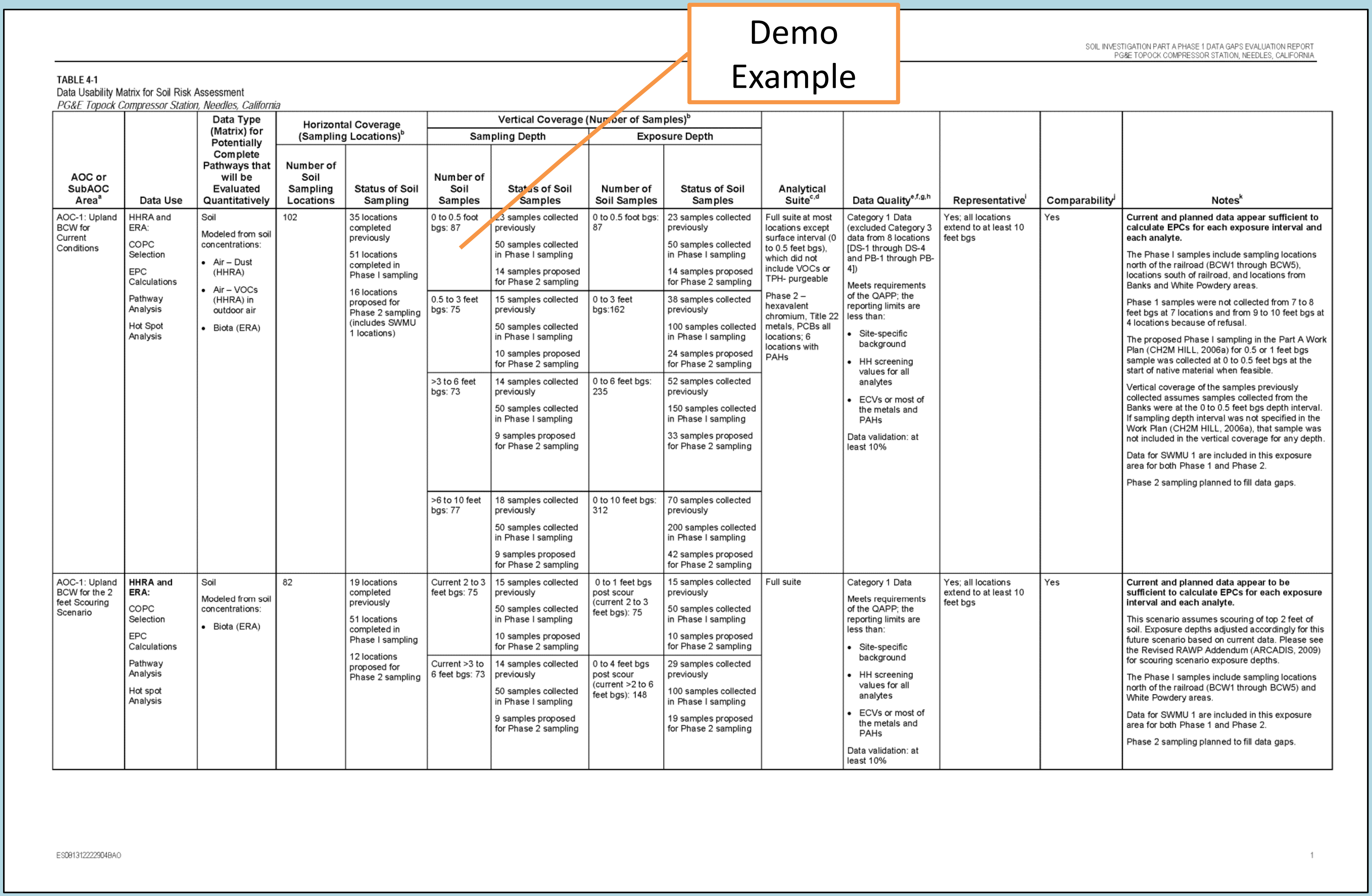


TABLE 4-1
Data Usability Matrix for Soil Risk Assessment
PG&E Topock Compressor Station, Needles, California

			Horizontal Coverage (Sampling Locations)[b]		Vertical Coverage (Number of Samples)[b]								
					Sampling Depth		Exposure Depth						
AOC or SubAOC Area[a]	Data Use	Data Type (Matrix) for Potentially Complete Pathways that will be Evaluated Quantitatively	Number of Soil Sampling Locations	Status of Soil Sampling	Number of Soil Samples	Status of Soil Samples	Number of Soil Samples	Status of Soil Samples	Analytical Suite[c,d]	Data Quality[e,f,g,h]	Representative[i]	Comparability[j]	Notes[k]
AOC-1: Upland BCW for Current Conditions	HHRA and ERA: COPC Selection EPC Calculations Pathway Analysis Hot Spot Analysis	Soil Modeled from soil concentrations: • Air – Dust (HHRA) • Air – VOCs (HHRA) in outdoor air • Biota (ERA)	102	35 locations completed previously 51 locations completed in Phase I sampling 16 locations proposed for Phase 2 sampling (includes SWMU 1 locations)	0 to 0.5 foot bgs: 87	23 samples collected previously 50 samples collected in Phase I sampling 14 samples proposed for Phase 2 sampling	0 to 0.5 foot bgs: 87	23 samples collected previously 50 samples collected in Phase I sampling 14 samples proposed for Phase 2 sampling	Full suite at most locations except surface interval (0 to 0.5 feet bgs), which did not include VOCs or TPH- purgeable Phase 2 – hexavalent chromium, Title 22 metals, PCBs all locations; 6 locations with PAHs	Category 1 Data (excluded Category 3 data from 8 locations [DS-1 through DS-4 and PB-1 through PB-4]) Meets requirements of the QAPP; the reporting limits are less than: • Site-specific background • HH screening values for all analytes • ECVs or most of the metals and PAHs Data validation: at least 10%	Yes; all locations extend to at least 10 feet bgs	Yes	**Current and planned data appear sufficient to calculate EPCs for each exposure interval and each analyte.** The Phase I samples include sampling locations north of the railroad (BCW1 through BCW5), locations south of railroad, and locations from Banks and White Powdery areas. Phase 1 samples were not collected from 7 to 8 feet bgs at 7 locations and from 9 to 10 feet bgs at 4 locations because of refusal. The proposed Phase I sampling in the Part A Work Plan (CH2M HILL, 2006a) for 0.5 or 1 feet bgs sample was collected at 0 to 0.5 feet bgs at the start of native material when feasible. Vertical coverage of the samples previously collected assumes samples collected from the Banks were at the 0 to 0.5 feet bgs depth interval. If sampling depth interval was not specified in the Work Plan (CH2M HILL, 2006a), that sample was not included in the vertical coverage for any depth. Data for SWMU 1 are included in this exposure area for both Phase 1 and Phase 2. Phase 2 sampling planned to fill data gaps.
					0.5 to 3 feet bgs: 75	15 samples collected previously 50 samples collected in Phase I sampling 10 samples proposed for Phase 2 sampling	0 to 3 feet bgs:162	38 samples collected previously 100 samples collected in Phase I sampling 24 samples proposed for Phase 2 sampling					
					>3 to 6 feet bgs: 73	14 samples collected previously 50 samples collected in Phase I sampling 9 samples proposed for Phase 2 sampling	0 to 6 feet bgs: 235	52 samples collected previously 150 samples collected in Phase I sampling 33 samples proposed for Phase 2 sampling					
					>6 to 10 feet bgs: 77	18 samples collected previously 50 samples collected in Phase I sampling 9 samples proposed for Phase 2 sampling	0 to 10 feet bgs: 312	70 samples collected previously 200 samples collected in Phase I sampling 42 samples proposed for Phase 2 sampling					
AOC-1: Upland BCW for the 2 feet Scouring Scenario	**HHRA and ERA:** COPC Selection EPC Calculations Pathway Analysis Hot spot Analysis	Soil Modeled from soil concentrations: • Biota (ERA)	82	19 locations completed previously 51 locations completed in Phase I sampling 12 locations proposed for Phase 2 sampling	Current 2 to 3 feet bgs: 75	15 samples collected previously 50 samples collected in Phase I sampling 10 samples proposed for Phase 2 sampling	0 to 1 feet bgs post scour (current 2 to 3 feet bgs): 75	15 samples collected previously 50 samples collected in Phase I sampling 10 samples proposed for Phase 2 sampling	Full suite	Category 1 Data Meets requirements of the QAPP; the reporting limits are less than: • Site-specific background • HH screening values for all analytes • ECVs or most of the metals and PAHs Data validation: at least 10%	Yes; all locations extend to at least 10 feet bgs	Yes	**Current and planned data appear to be sufficient to calculate EPCs for each exposure interval and each analyte.** This scenario assumes scouring of top 2 feet of soil. Exposure depths adjusted accordingly for this future scenario based on current data. Please see the Revised RAWP Addendum (ARCADIS, 2009) for scouring scenario exposure depths. The Phase I samples include sampling locations north of the railroad (BCW1 through BCW5) and White Powdery areas. Data for SWMU 1 are included in this exposure area for both Phase 1 and Phase 2. Phase 2 sampling planned to fill data gaps.
					Current >3 to 6 feet bgs: 73	14 samples collected previously 50 samples collected in Phase I sampling 9 samples proposed for Phase 2 sampling	0 to 4 feet bgs post scour (current >2 to 6 feet bgs): 148	29 samples collected previously 100 samples collected in Phase I sampling 19 samples proposed for Phase 2 sampling					

Data Quality Objectives – Decision 2

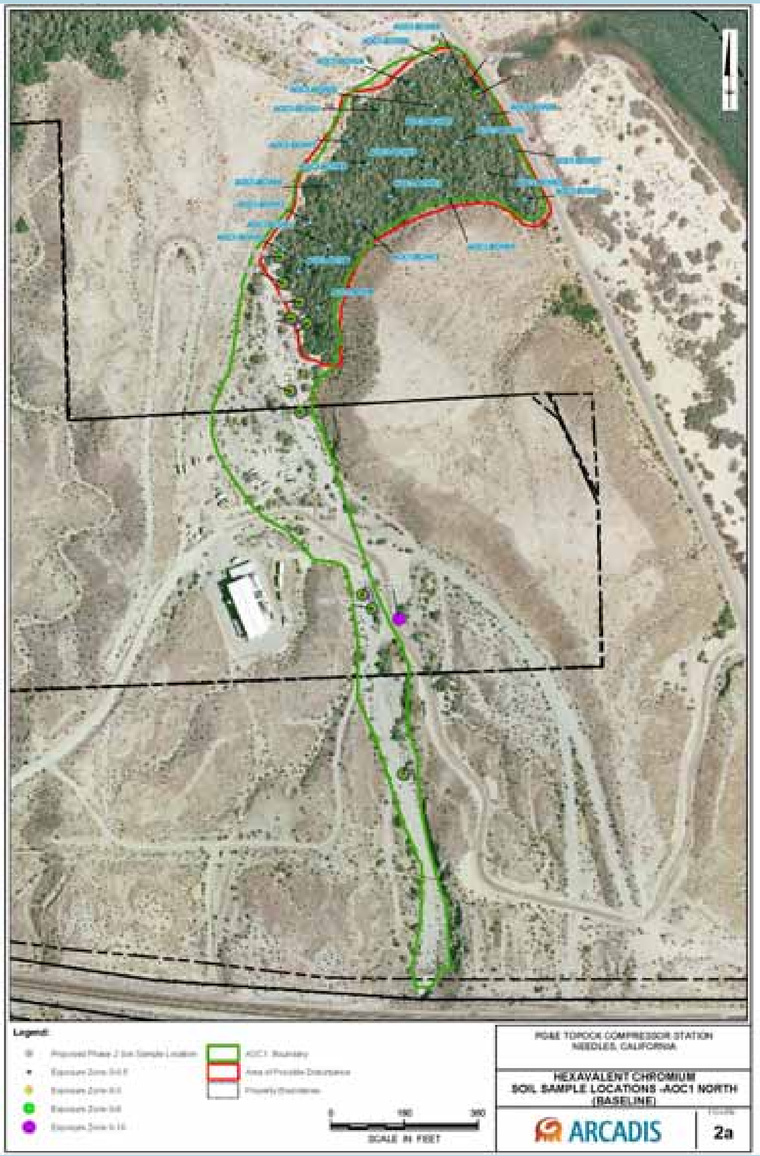
Representativeness:

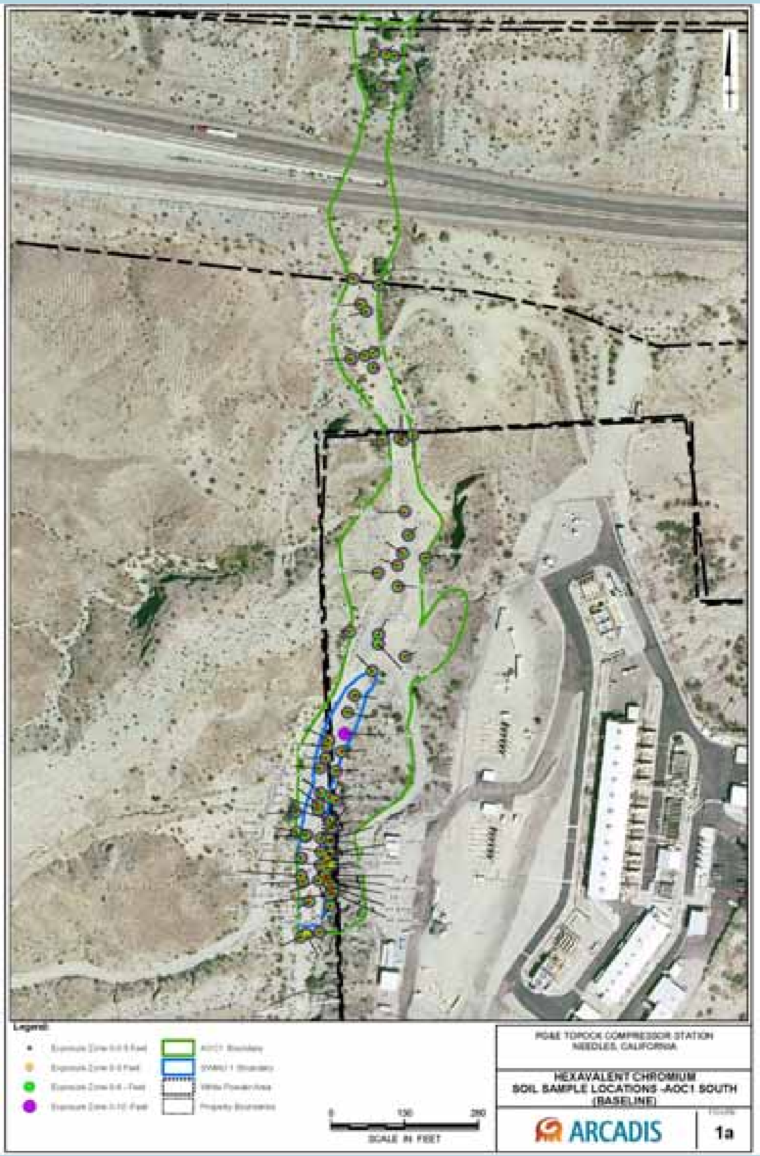
- Degree to which sample data accurately reflect characteristics of a population
- Achieved by well-designed, standardized sampling and analysis
- Optimized by the appropriate placement of sample locations in areas suspected to have been impacted by site releases
- Selection of the analyte list to capture those chemicals assumed to be associated with a potential release

Comparability:

- Confidence in which one data set can be compared to another
- Achieved by maintaining standard techniques and procedures for collecting and analyzing samples and reporting in consistent units

Spatial Coverage





Data Processing and Calculating EPCs

Exposure Point Concentrations

Exposure Point Concentration (EPC):

- Estimate of the average chemical concentration
- Constituent-specific and exposure area-specific
- Typically represented by the upper confidence limit (UCL) on the arithmetic mean
- Maximum detected concentration may be selected if the data do not support a valid UCL calculation
- Specific areas of hot spots may warrant specific assessment

ProUCL - EPC Calculations

95UCLs are calculated or COPCs with >=5 detections and >=8 sample results

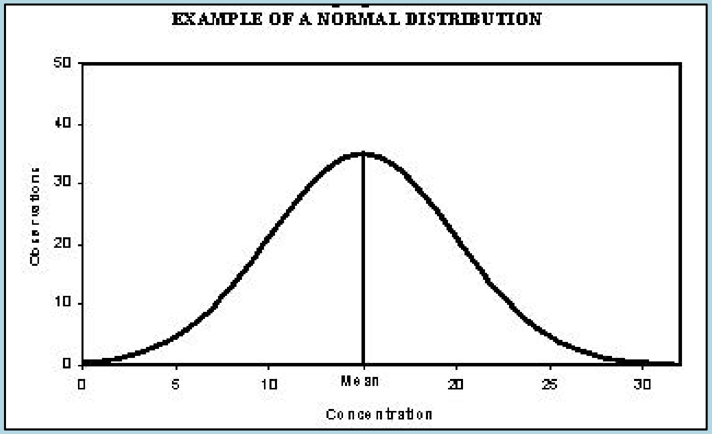
Based on the data distribution (parametric or non-parametric), the 95UCL could be estimated based on the following methods:

Parametric

- Normal Student’s t-statistics
- Lognormal Land’s H-statistics
- Chebyshev Theorem using the MVUE; assume lognormality
- Gamma distribution statistics – Approximate or Adjusted UCL

Non-Parametric

- Modified Student’s t-statistics
- Central limit theorem (CLT)
- Adjusted CLT
- Jackknife Method
- Bootstrap Methods (Standard, Percentile, Bias-corrected accelerated [BCA], Bootstrap t, and Hall’s)



ProUCL Demo

Calculation of 95UCL: Cr (VI) data sets for AOC1/SWMU1

- Load data sets into ProUCL
- Select UCL Menu Option
- Choose ‘with ND’ data set and ‘all’ distribution run
- Select variable, confidence level and number of bootstrap operations
- Review 95UCL results

Selection of EPCs

Max Concentration = EPC IF:
<5 detects and/or <8 sample results

95UCL (from ProUCL) = EPC IF:
>5 detects and >8 sample results

Exceptions:

- 2 Recommended 95UCLs
- Frequency of Detection < 30%
- Hot Spot Bias
- Spatially-Weighted EPCs

Selection of EPCs

Two or More Recommended 95UCL Estimates:

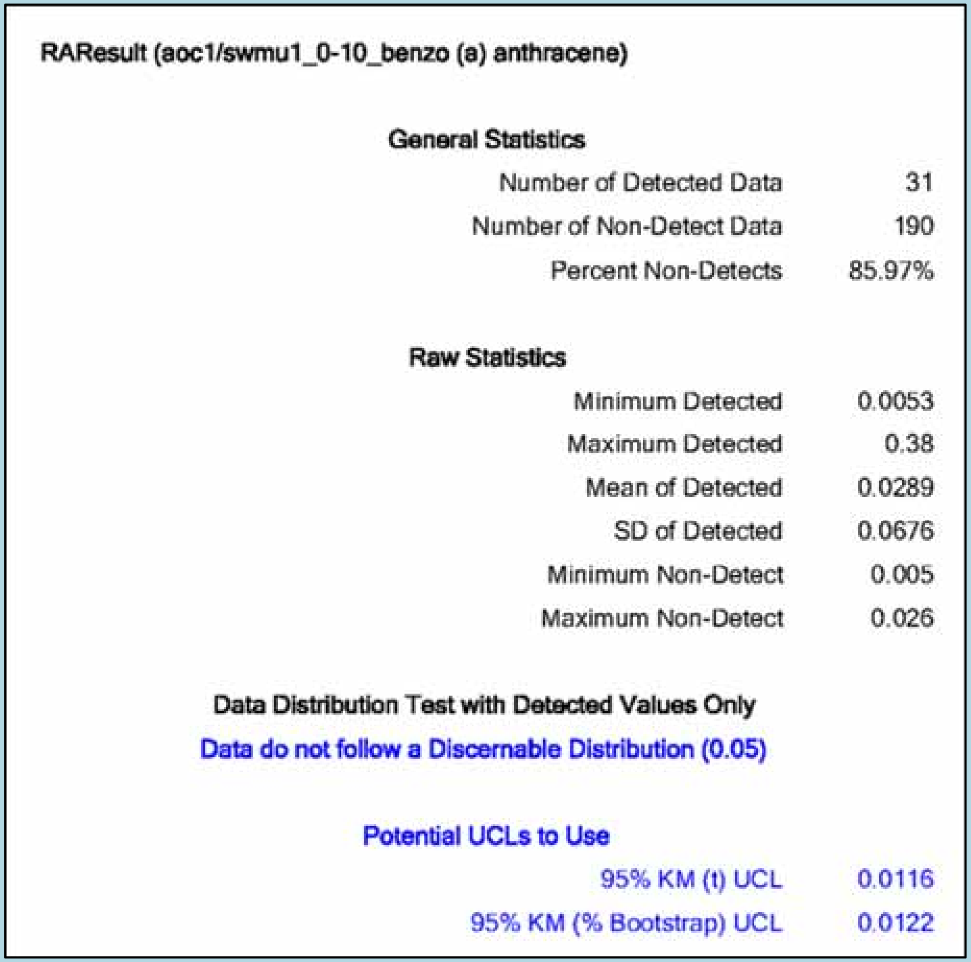
- When ProUCL recommends two or more 95UCL estimates, the estimate that best represents the data set is selected based on skewness, sample size, and percentage of non-detects in the data set (USEPA 2007):

  - If the RPD < 5%: conservatively select the max recommended UCL
  - If the RPD > 5%: use ProUCL Technical Guidance to determine the appropriate UCL based on the skewness of the data

Example of EPC Selection

Two recommended 95UCL estimates for Benzo(a)anthracene for the baseline (0-10 ft bgs) data set

- **The 95% KM (t) UCL was selected as the EPC based on:**
  - **Skewness (SD<0.5)**
  - **Sample size (8≤n)**
  - **Percentage of non-detects (0%≤FOD)**



```
RAResult (aoc1/swmu1_0-10_benzo (a) anthracene)

                         General Statistics
                              Number of Detected Data        31
                            Number of Non-Detect Data       190
                                  Percent Non-Detects    85.97%

                          Raw Statistics
                                   Minimum Detected      0.0053
                                   Maximum Detected        0.38
                                    Mean of Detected     0.0289
                                      SD of Detected     0.0676
                                 Minimum Non-Detect       0.005
                                 Maximum Non-Detect       0.026

              Data Distribution Test with Detected Values Only
            Data do not follow a Discernable Distribution (0.05)

                       Potential UCLs to Use
                                      95% KM (t) UCL     0.0116
                          95% KM (% Bootstrap) UCL       0.0122
```

Demo EPC

Summary statistics for Cr (VI) for AOC1/SWMU1

- Selection of EPC

BREAK
(15 mins)

Hot Spot Analysis and Spatially-Weighted EPCs

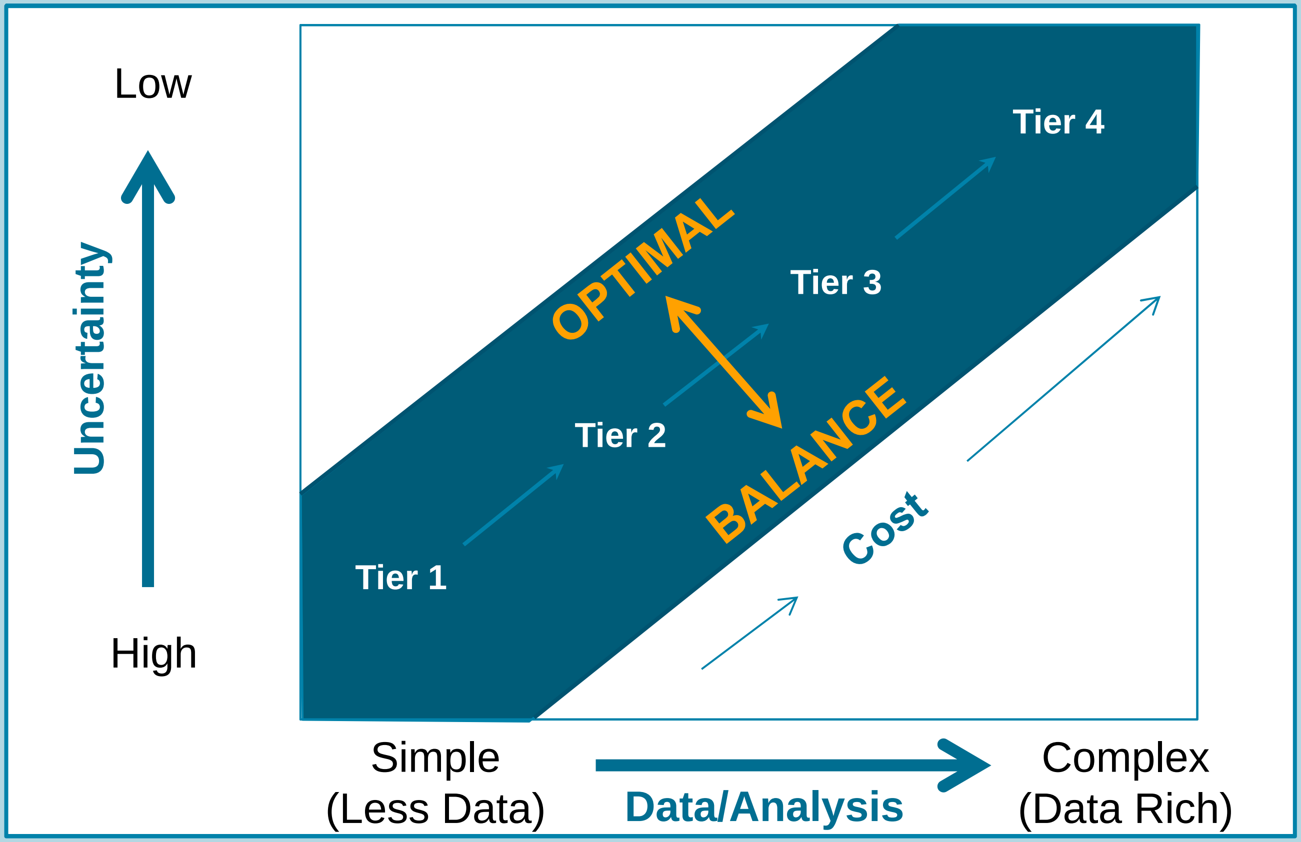
Objectives

Demonstrate spatial data analysis relevant to future risk assessment per the RAWP:

- Identify and evaluate hot spots
- Develop Thiessen polygons for spatially-weighted EPCs
- Calculate spatially-weighted EPCs

Tiered Process

- **Balance between complexity of analysis and level of conservatism required for risk management decisions**
- **Objective is to achieve the best unbiased estimate of the EPC**



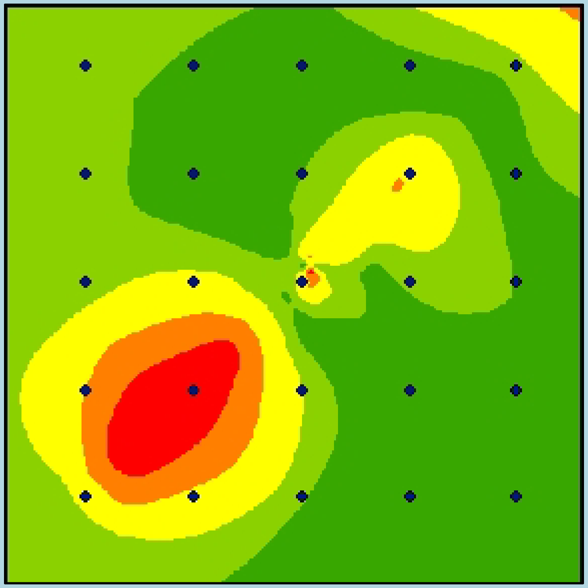
Spatial Analysis in Risk Assessment

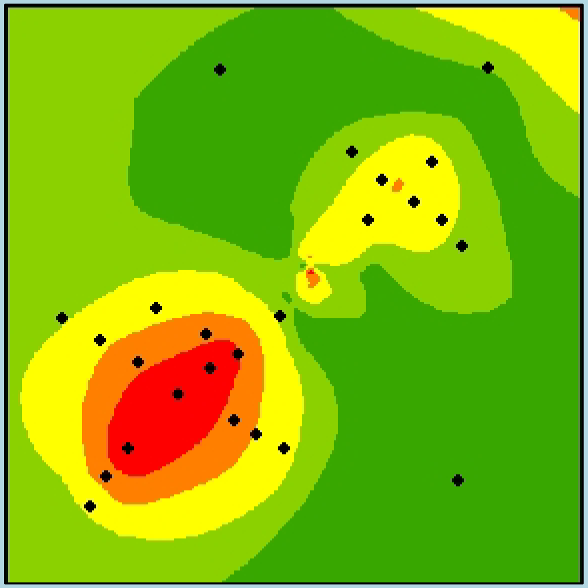
- **A higher Tier analysis (e.g., spatial weighting) can provide a better unbiased estimate of the EPC, but requires more analysis and tools**
- **Characterizing Variability and Uncertainty in the Concentration Term (USEPA, 2002):**

“**…***Often, the EPC is estimated without regard to the spatial patterns in contamination… Geostatistics (see Section C.5.2 and Appendix D) offers a wide range of techniques for incorporating spatial information into estimates of the EPC. <u>These techniques are particularly useful when there is uncertainty in the representativeness of site sampling, due to</u> a difference in scale between site sampling and the size of the EU, or <u>the use of targeted sampling designs that oversample areas within an EU believed to contain the highest levels of contamination</u>…*”

Sampling Bias

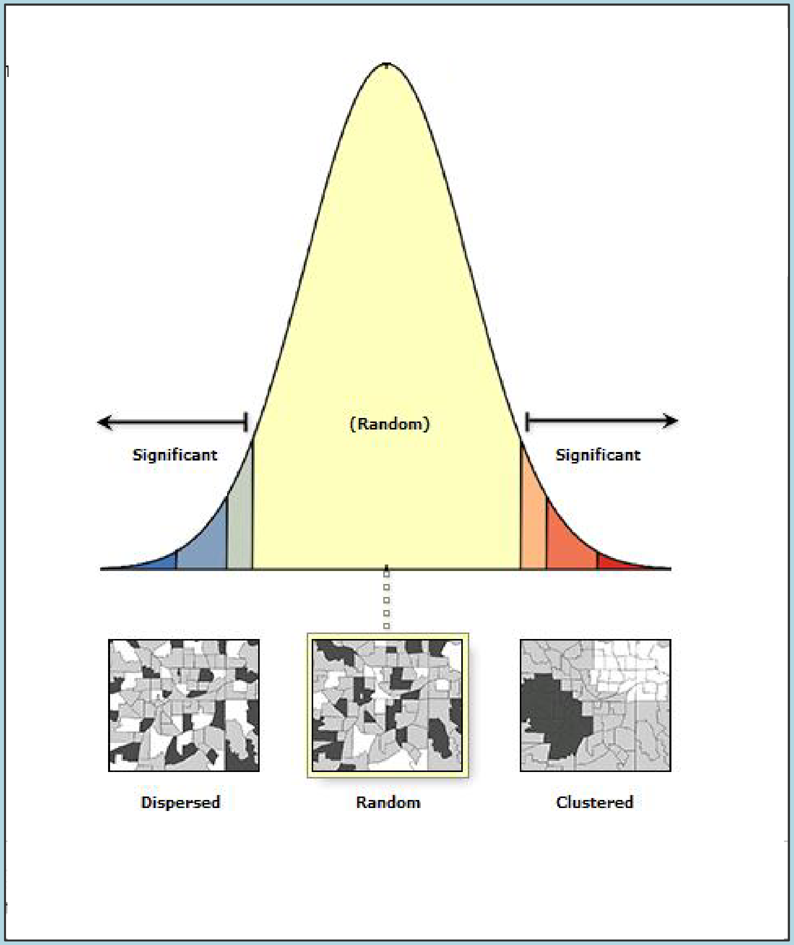
- **Non-spatial upper confidence limits (UCLs; as calculated in ProUCL, for example) assume that all samples are equal in estimating the overall exposure potential**
- **Sampling programs often collect more samples in known or suspected hot spots, thereby potentially over-estimating the exposure concentration**


Grid Sampling


Biased Sampling

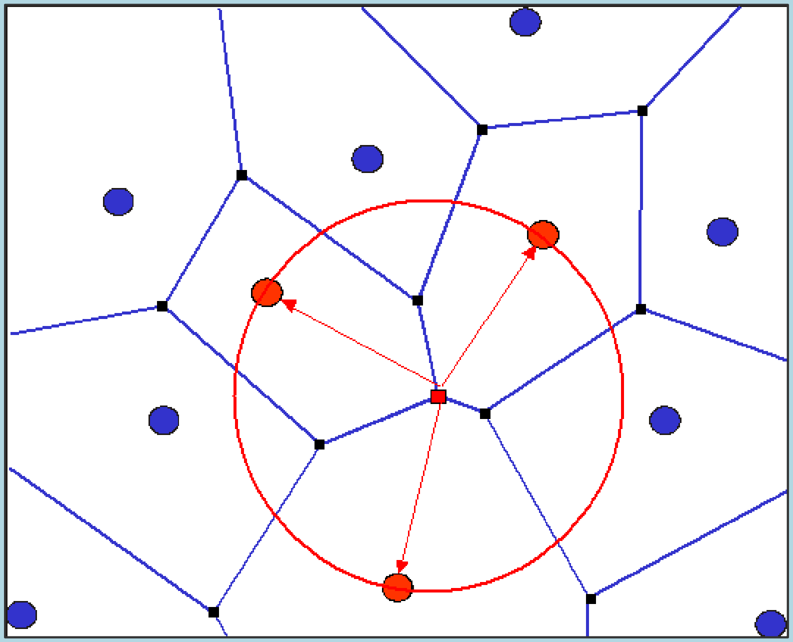
Statistical Analysis of Spatial Data

- Referred to as Geostatistics
- Used to assess uncertainty in spatial modeling/estimation (e.g., unsampled/unknown areas)
- Considers a location’s neighborhood (e.g., magnitude of values and the distance between similar and dissimilar samples)
- Often allows for a better characterization of population distributions/unknown locations
- Interpolation allows for the spatial weighting of EPCs



Spatial Weighting

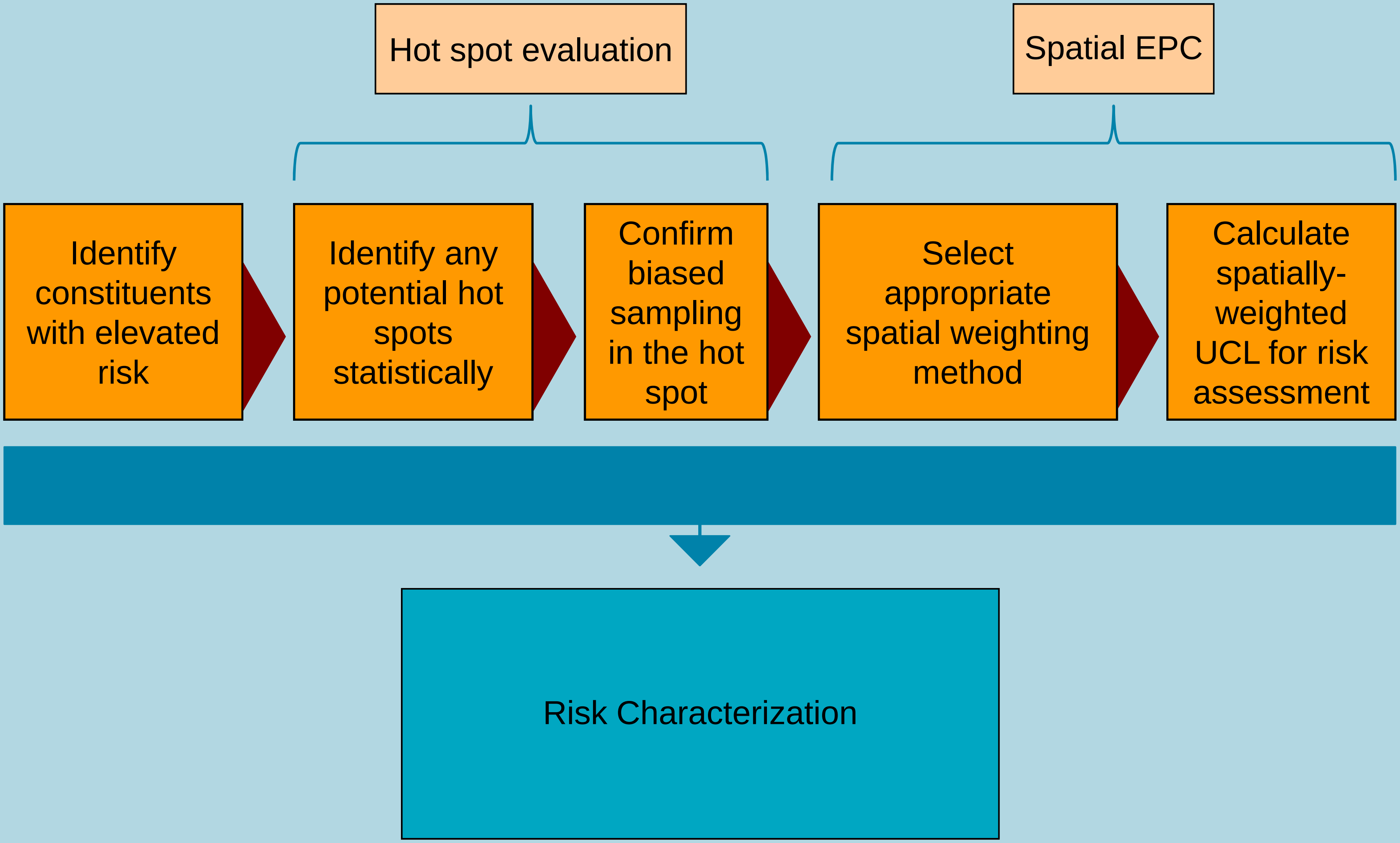
- **Traditional statistical evaluations consider each sample as equivalent weight**
  - Implicit assumption is that each sample represents an equal geographical area
  - If there are sufficient samples, randomly located, this technique will represent the population accurately
  - Biased sample locations can skew results



- **Geostatistical methods weight samples by area explicitly, rather than implicitly**
  - This can more accurately characterize areas with non-random sampling

Spatially-Weighted UCL Roadmap

Steps in the decision-making process



Hot spot evaluation

Spatial EPC

Identify constituents with elevated risk

Identify any potential hot spots statistically

Confirm biased sampling in the hot spot

Select appropriate spatial weighting method

Calculate spatially-weighted UCL for risk assessment

Risk Characterization

Potential Constituents

Step 1 – Identify Constituents

The following constituents were selected as case-studies for the Topock site AOC1/SWMU1 to demonstrate hot spot analysis and spatially-weighted EPCs

Constituent	Number Detects	Number Samples	FOD %	95UCL
Chromium, hexavalent (mg/kg)	25	81	31	3.0
Chromium, total (mg/kg)	75	75	100	380
Zinc (mg/kg)	74	74	100	65.2
Aroclor 1254 (ug/kg)	12	27	44	51.1
Total PCBs (ug/kg)	12	27	44	51.1

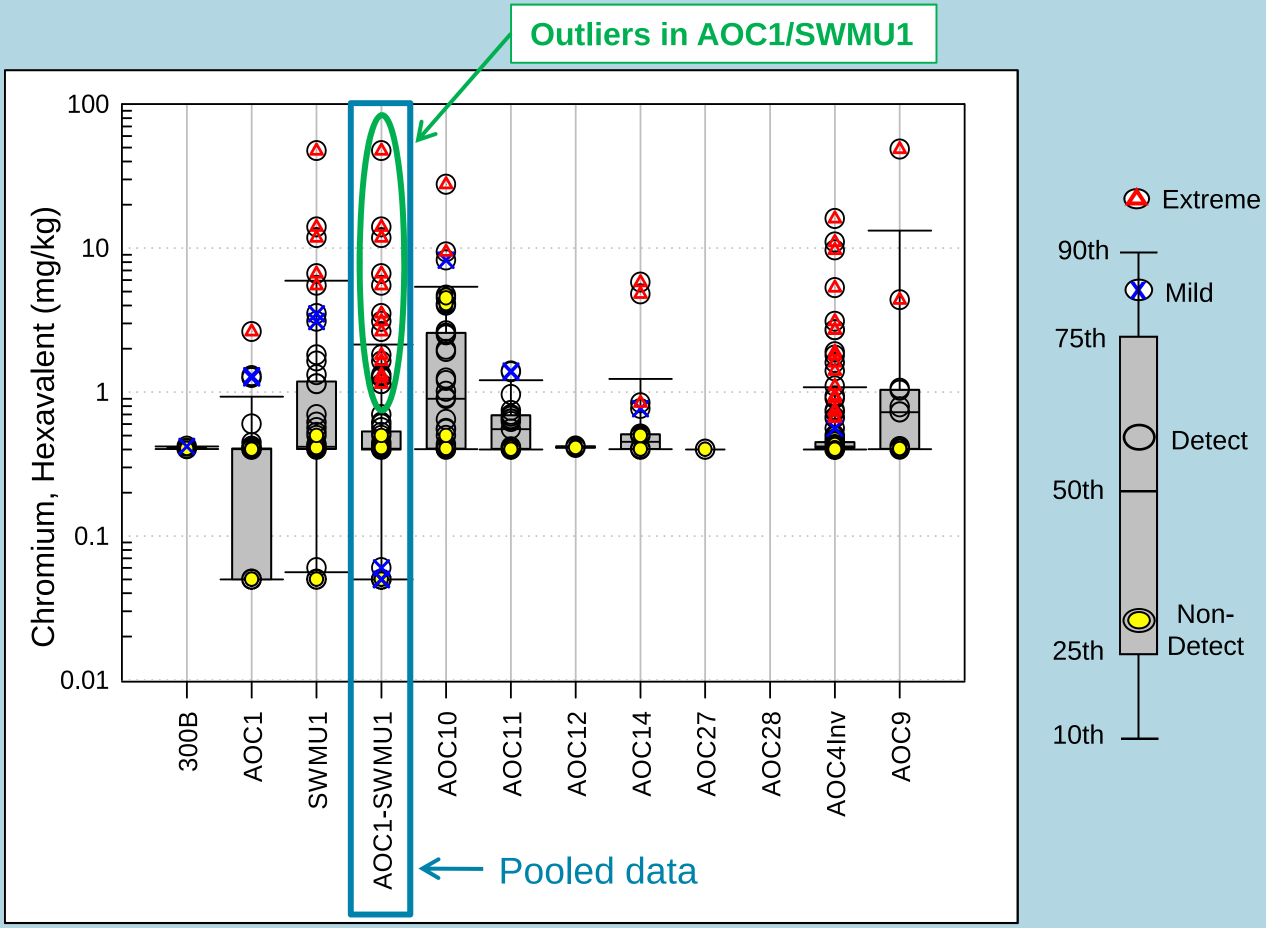
Example Hot Spot Evaluation

Cr (VI)

AOC1/SWMU1

Method 1 – Cr VI Boxplot

- **Numerous outliers in AOC1-SWMU1, suggesting potential hot spot or multiple populations**
- **Outliers in AOC1-SWMU1 largely due to SWMU1 data**
- **Outliers in AOC1 (northern and central areas) are not as high as the outliers in the southern area (SWMU1)**
- **Evaluate outliers further using probability plot**

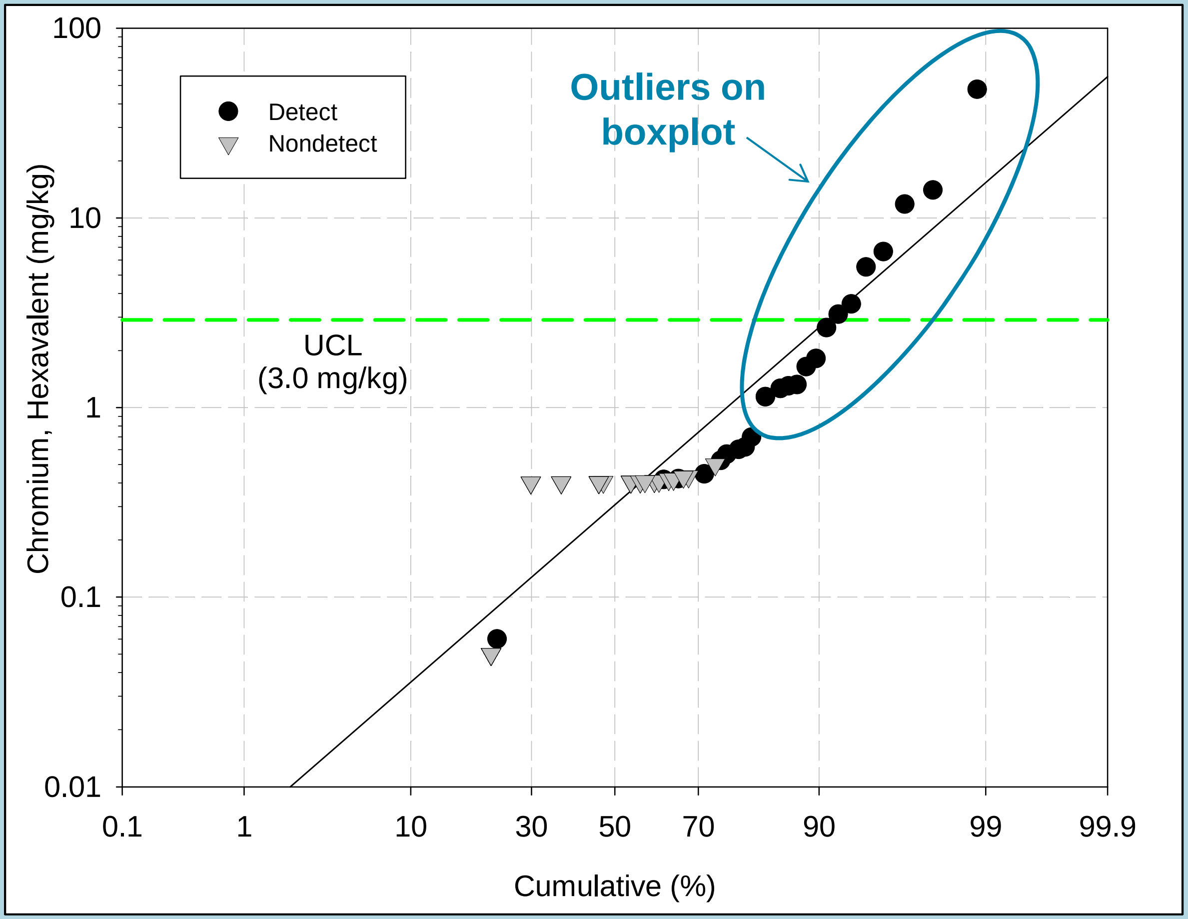


Notes:
1. Data is plotted on a logarithmic scale.
2. Box and whiskers show percentiles.
3. Interquartile range (IQR) = 75th percentile **-** 25th percentile.
4. Extreme outlier is a value **>** 75th percentile **+** 3 **x** IQR.
5. Mild outlier is a value **>** 75th percentile **+** 1.5 **x** IQR.

Method 2 – Probability Plot

- **Data set consists of 69% censored values (FOD is 25 / 81)**
- **Plot visually confirms:**
  - outliers appear to be a hot spot or separate population
  - the 16 samples in hot spot bias UCL high
- **Evaluate outliers spatially to determine if clustered**

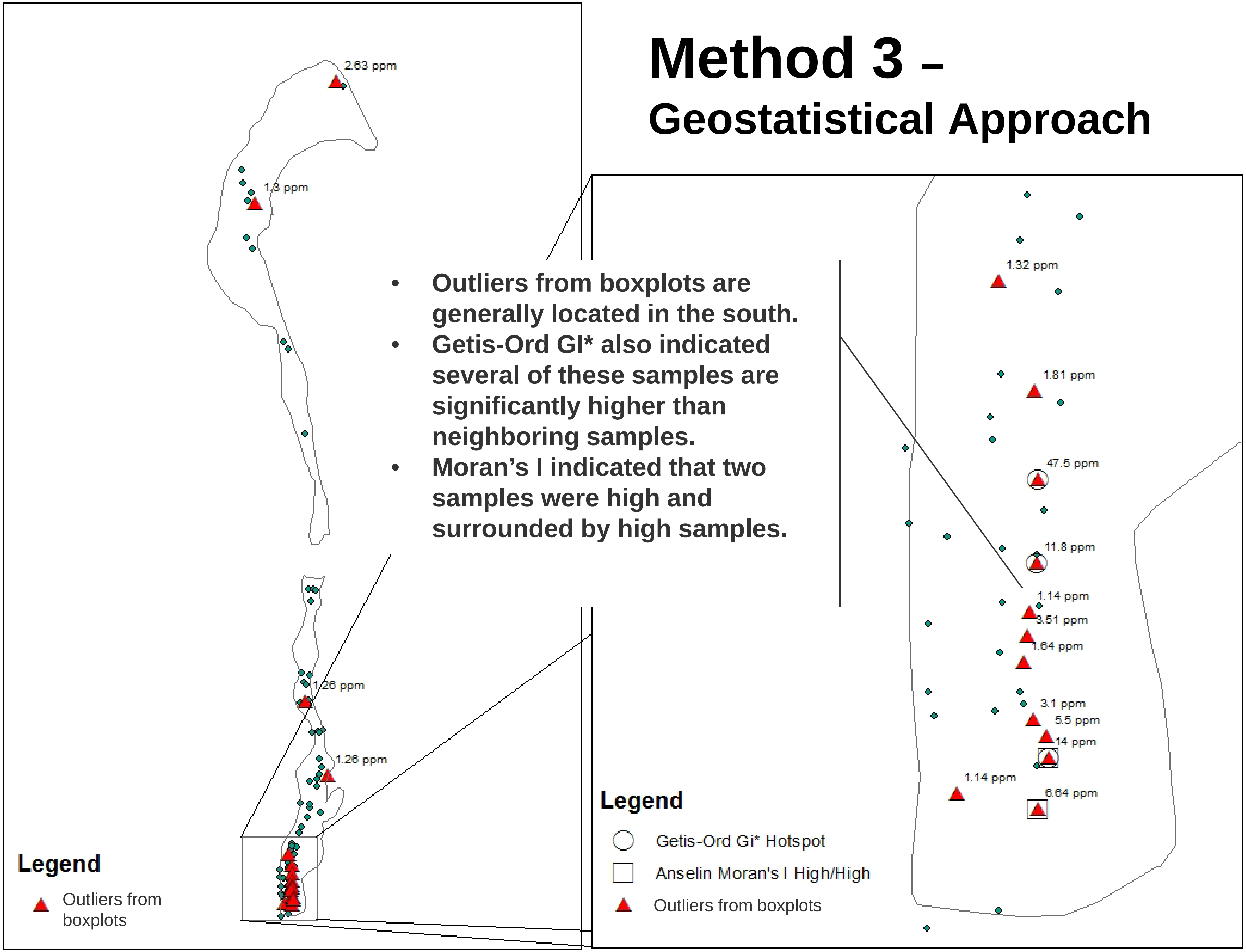
AOC1-SWMU1



Note: Data is plotted on logarithmic scale.

Method 3 –
Geostatistical Approach

- Outliers from boxplots are generally located in the south.
- Getis-Ord GI* also indicated several of these samples are significantly higher than neighboring samples.
- Moran’s I indicated that two samples were high and surrounded by high samples.

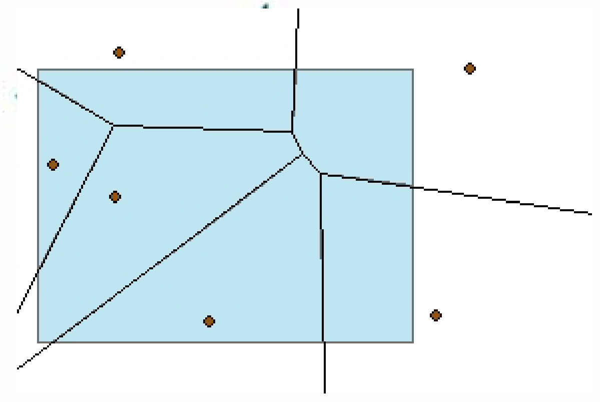


Example Spatial Weighting – Thiessen Polygons

Cr (VI)

AOC1/SWMU1

Thiessen Polygons



Exposure Unit (EU)

Weighting factor

$$w_i(\mathrm{EU}) = \frac{A_i}{\sum_{i=1}^{n} A_i}$$

w_i = weight of the i^{th} sampled location for i^{th} polygon that intersects the EU

A_i = area of portion of i^{th} polygon inside EU that is associated with i^{th} sampled location

n = number of polygons that intersect the EU

Spatially-weighted concentrations

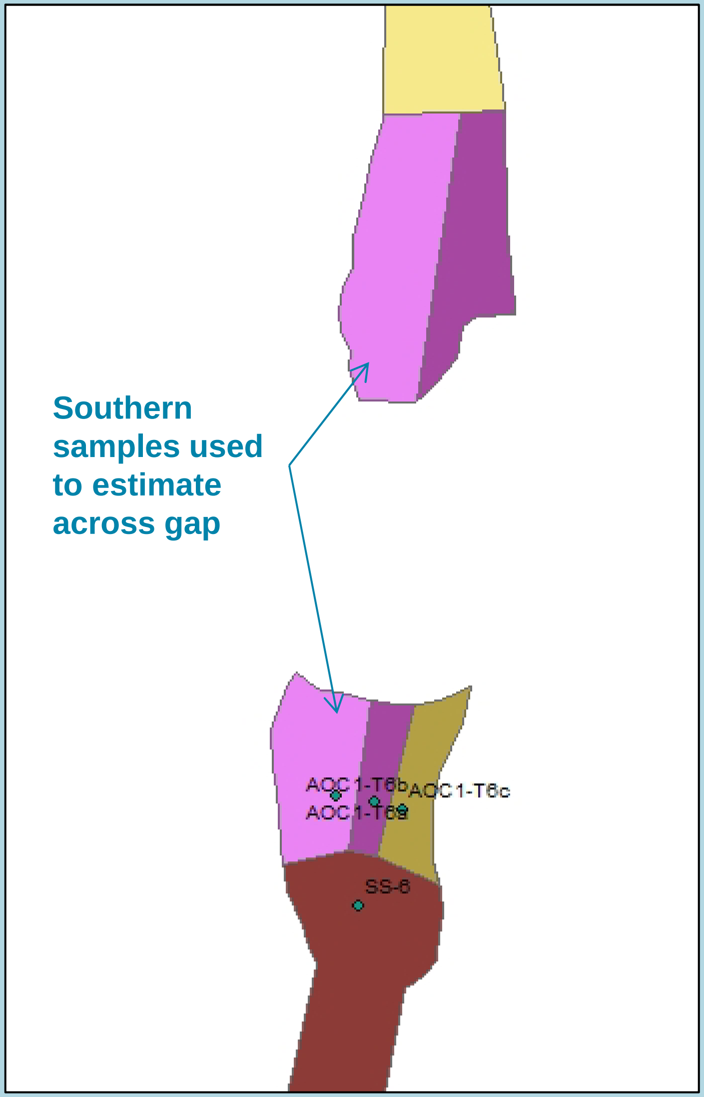
$$\overline{C}_{EU} = \sum_{i=1}^{n} w_i \times C_i \qquad \hat{\sigma}^2_{EU} = \sum_{i=1}^{n} w_i \frac{\left(C_i - \overline{C}_{EU}\right)^2}{(n-1)}$$

Thiessen Polygon Considerations

- **Care should be taken with gaps in exposure units**

- **In some cases, it is appropriate to estimate across gaps using whatever point is closest**

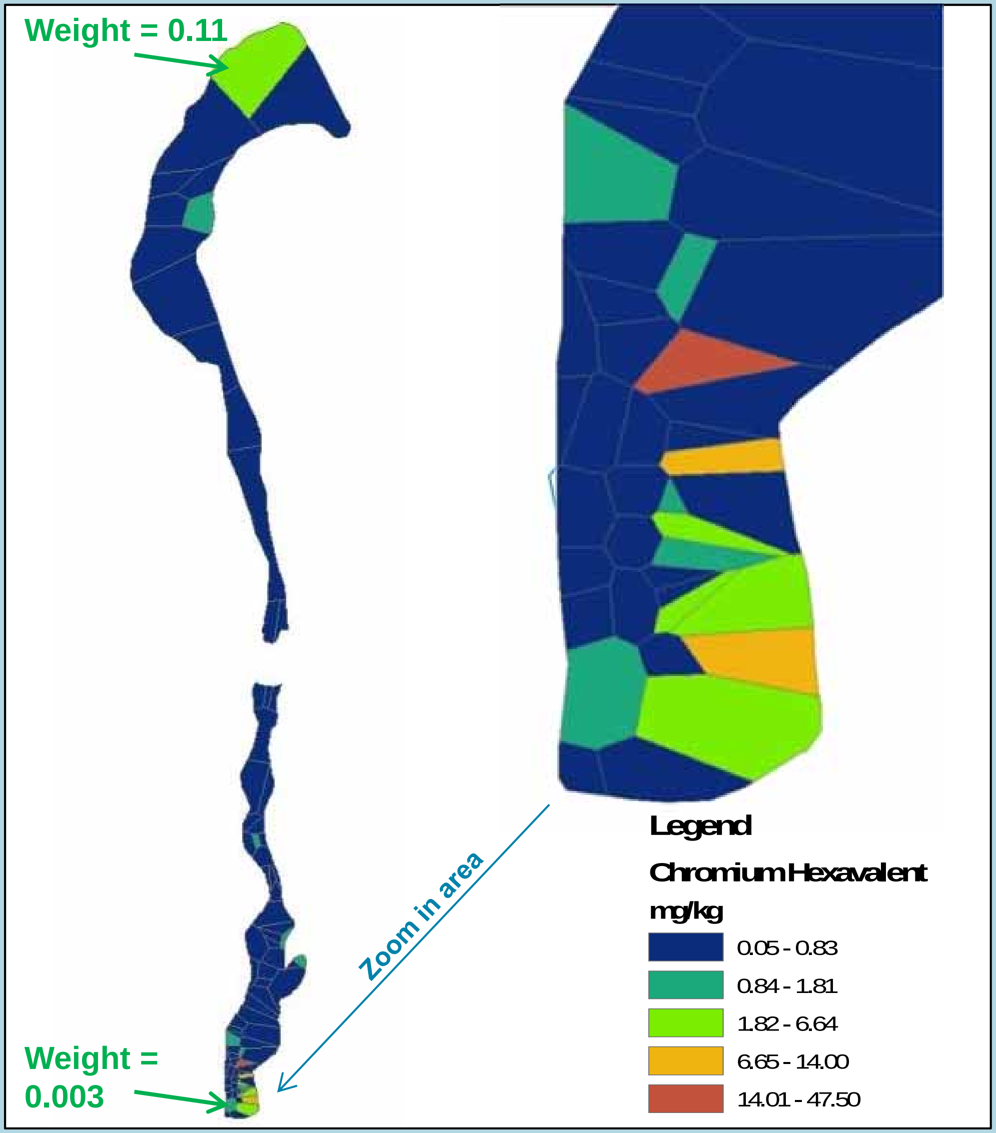
- **In other cases, it may be appropriate to treat subareas as separate populations for spatial estimation purposes**



Southern samples used to estimate across gap

Thiessen Polygons for Cr VI

- **Majority of the area does not present elevated risk**
- **Polygons with potentially elevated risk represent a small fraction of the overall area, however sample density is high in these areas, noted by many small polygons**
- **Samples in the northern area contribute more (higher weights) due to the spatial distribution of the sampling points**
- **Without spatial weighting, each sample represents 1/86th or 0.012**



Spatial vs. Non-spatial UCLs

Cr (VI)

Spatially-Weighted Percentile Bootstrap Method

Weights for each concentration are based on Thiessen polygon area within the AOC1/SWMU1

- Using weights by bootstrapping:
    - Random draw of n = 81 sample results from the population of 81 sample results
    - Random draw is weighted such that the probability of drawing a sample result is based on the spatial weighting factor
    - 1000 iterations of n = 81 data sets
    - 95% UCL is calculated for each data set of n = 81
    - The mean of 1000 95% UCLs is calculated

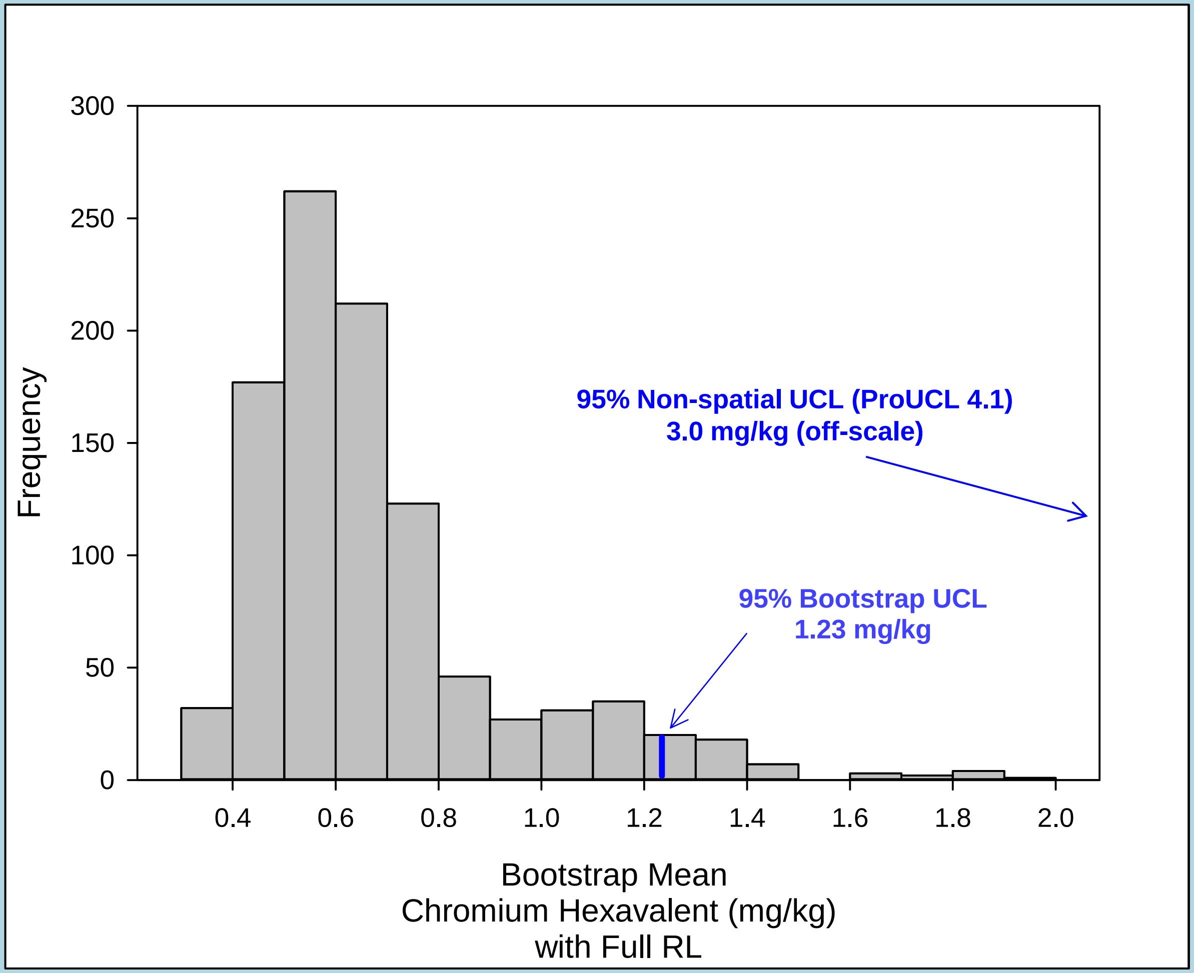
95UCL Comparison
Cr (VI) (mg/kg)

Method	Number Detects	Number Samples	FOD%	Max Detected	95UCL
Non-Spatially Weighted					
ProUCL 95UCL	25	81	31%	47.5	**3.00**
Spatially Weighted					
Percentile bootstrap (Full RL)	26.3	81	NA	47.5	**1.23**
Percentile bootstrap (DL/2)	26.3	81	32%	47.5	**1.17**
Kaplan-Meier 95UCL (generally 95% KM (t) UCL)	26.3	81	32%	47.5	**1.19**

Distribution of Bootstrap Means Cr (VI) (mg/kg)

Spatially-weighted percentile bootstrap method using full reporting limits

- 1000 Bootstrap Iterations of n = 81 weighted random draws



95% Non-spatial UCL (ProUCL 4.1)
3.0 mg/kg (off-scale)

95% Bootstrap UCL
1.23 mg/kg

Other Examples

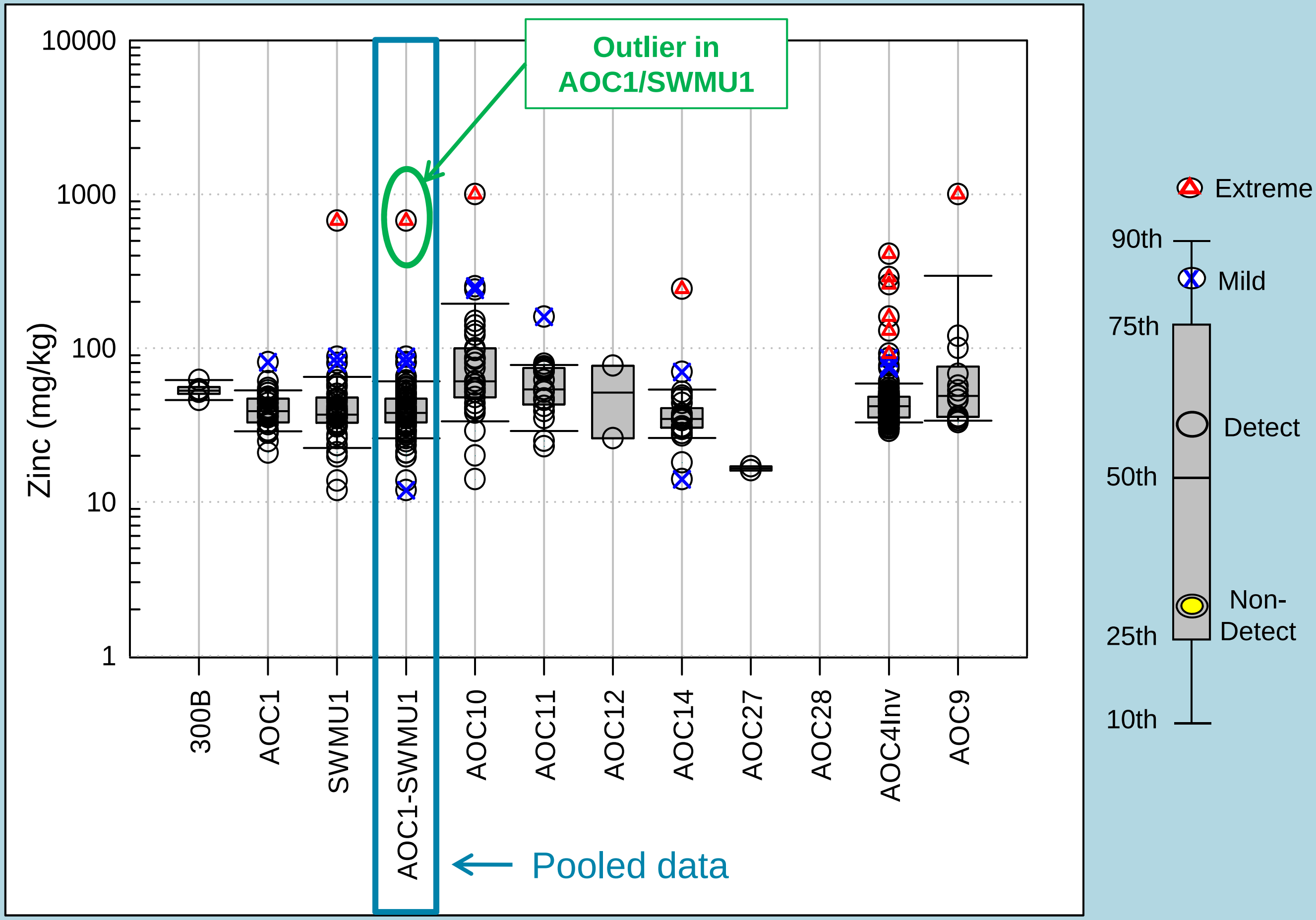
Example Hot Spot Evaluation

Zinc

AOC1/SWMU1

Zinc Boxplot

- **One outlier in AOC1-SWMU1, not necessarily suggesting potential hot spot or multiple populations**
- **Outlier in AOC1-SWMU1 due to SWMU1 data**
- **Evaluate outlier further using probability plot**



Outlier in AOC1/SWMU1

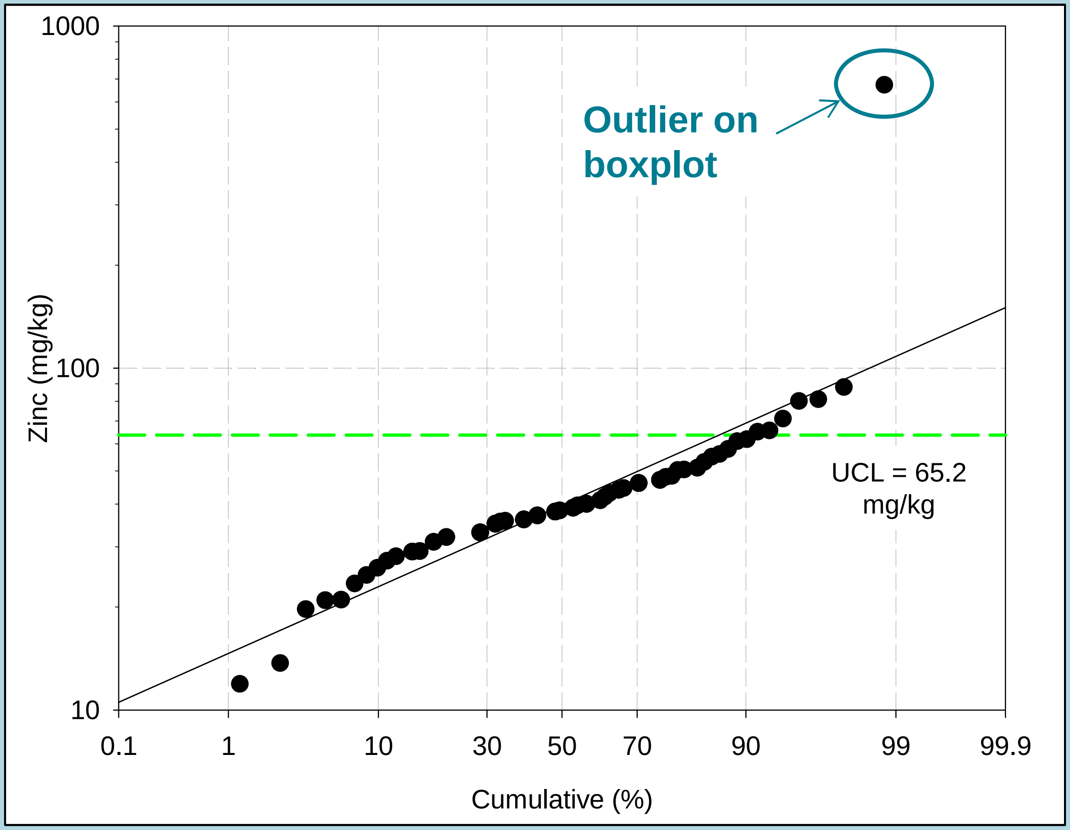
Pooled data

Notes:
1. Data is plotted on a logarithmic scale.
2. Box and whiskers show percentiles.
3. Interquartile range (IQR) = 75th percentile **-** 25th percentile
4. Extreme outlier is a value **>** 75th percentile **+** 3 **x** IQR.
5. Mild outlier is a value **>** 75th percentile **+** 1.5 **x** IQR.

Zinc Probability Plot

- **Data set consists of 100% detected values (n = 75)**
- **Plot visually confirms:**
  - One outlier may or may not be a hot spot or separate population
  - One extreme result may bias UCL high
- **Evaluate outliers spatially to determine if location is separate**

AOC1-SWMU1



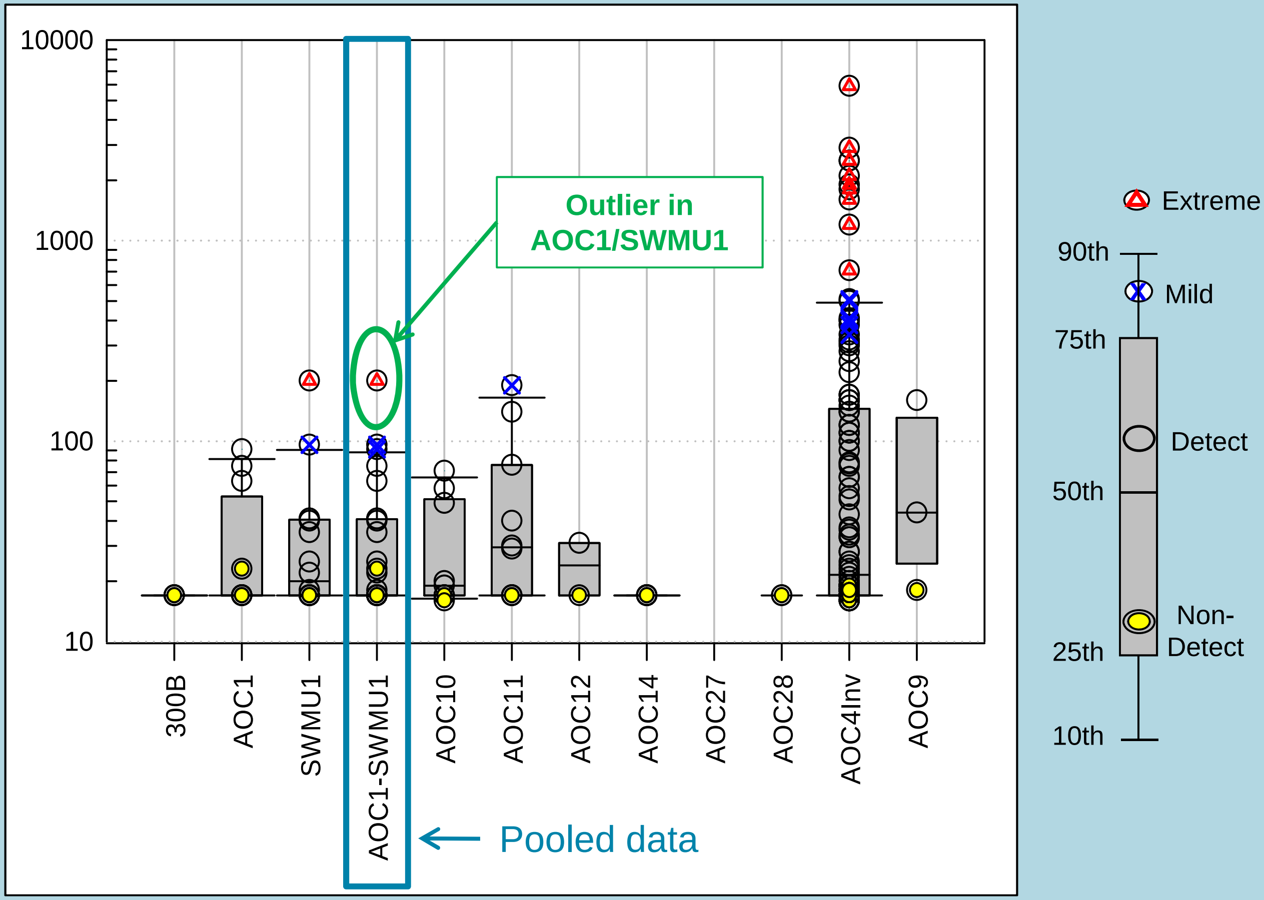
Note: Data is plotted on logarithmic scale.

95UCL Comparison
Zinc (mg/kg)

Method	Number Detects	Number Samples	FOD%	Max Detected	95UCL
Non-Spatially Weighted					
ProUCL 95UCL	74	74	100%	673	**65.2**
Spatially Weighted					
Percentile bootstrap	74	74	100%	673	**50.6**
Spatially-weighted 95UCL (generally a 95% Modified-t UCL)	74	74	100%	673	**50.8**

Aroclor 1254 Boxplot

- **Several outliers in AOC1-SWMU1, suggesting potential hot spot or multiple populations**
- **Outliers in AOC1-SWMU1 due more to AOC1 data**
- **Outliers in AOC1 (northern and central areas) are higher than the outlier in the southern area (SWMU1)**
- **Evaluate outliers further using probability plot**

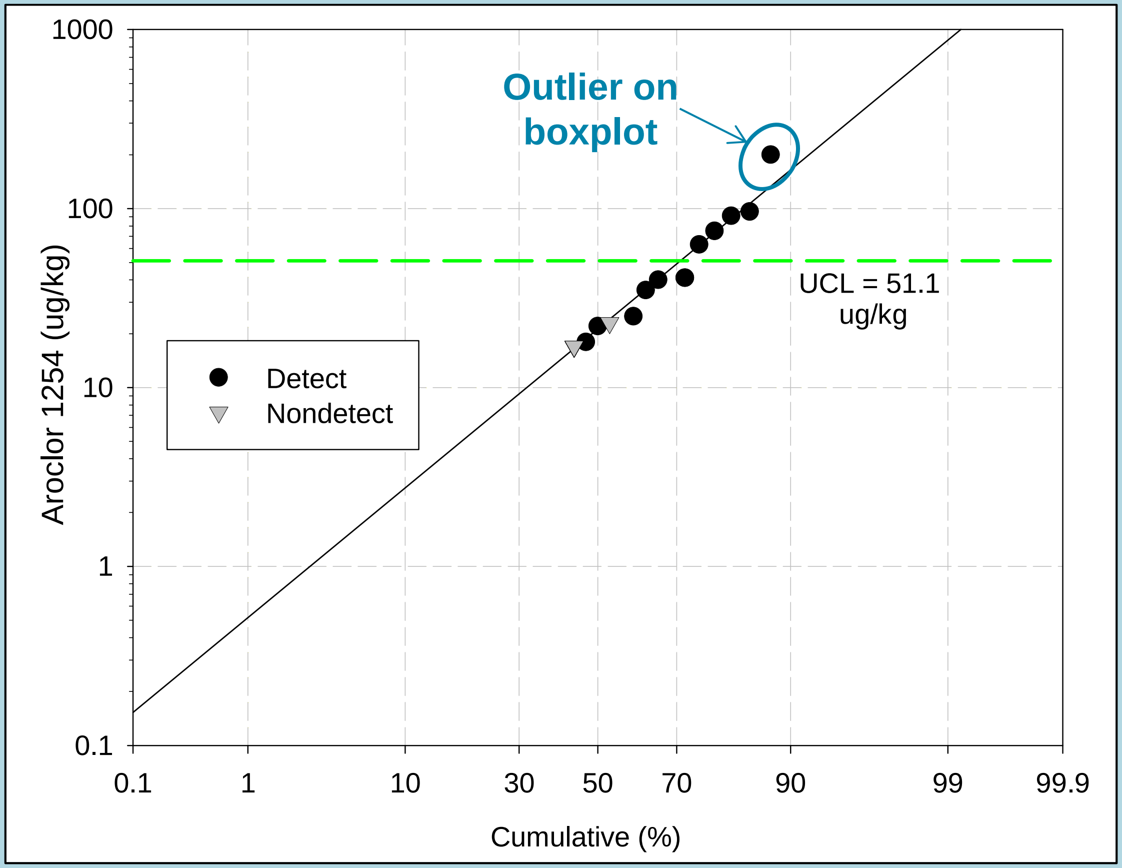


Notes:
1. Data is plotted on a logarithmic scale.
2. Box and whiskers show percentiles.
3. Interquartile range (IQR) = 75th percentile **-** 25th percentile.
4. Extreme outlier is a value **>** 75th percentile **+** 3 **x** IQR.
5. Mild outlier is a value **>** 75th percentile **+** 1.5 **x** IQR.

Aroclor 1254 Probability Plot

- **Data set consists of 52% censored values (FOD is 16 / 31)**
- **Plot visually confirms:**
  - Outliers may or may not appear to be a hot spot or separate population
  - The 4 boxplot outliers bias UCL high
- **Evaluate outliers spatially to determine if clustered**

AOC1-SWMU1



Note: Data is plotted on logarithmic scale.

95UCL Comparison
Aroclor-1254 (ug/kg)

Method	**Number Detects**	**Number Samples**	**FOD%**	**Max Detected**	**95UCL**
Non-Spatially Weighted					
Non-spatially-weighted 95UCL	12	27	44%	200	**51.1**
Spatially Weighted					
Percentile bootstrap (Full RL)	12	27	NA	200	**41.8**
Percentile bootstrap (DL/2)	12	27	44%	200	**36.1**
Kaplan-Meier 95UCL (generally a 95% KM (t) UCL)	12	27	44%	200	**52.5**

Summary

- **The purpose of the analysis was to demonstrate spatial data analysis relevant to future risk assessment as per the RAWP**

- **Sampling programs often collect more samples in known or suspected hot spots, thereby potentially over-estimating the exposure concentration**

- **Non-spatial UCLs (e.g., ProUCL) assume that all samples are equal in estimating the overall exposure potential**

- **A higher Tier analysis (e.g., spatial weighting) can provide a better unbiased estimate of the EPC, but requires more analysis and tools**

- **Examples evaluated from the Topock data set for AOC1/SWMU1 (Cr (VI), Zinc, and Aroclor) demonstrate methods to identify potential hot spots and the sensitivity of 95UCLs to biased sampling programs**

- **Data sets evaluated demonstrate that biased sampling in hot spots can increase the 95UCL by a factor of 2 over unbiased sampling**

Appendix D

Statistical Methods: Hot Spot Evaluation and Calculation of Spatially Weighted Exposure Concentrations

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Appendix D

Statistical Methods: Hot Spot Evaluation and Calculation of Spatially Weighted Exposure Concentrations

Human Health and Ecological Risk Assessment
Work Plan Addendum 2

PG&E Topock Compressor Station
Needles, California

May 2014

Figures

Appendix D – Statistical Methods: Hot Spot Evaluation and Calculation of Spatially Weighted Exposure Concentrations

PG&E Topock Compressor Station
Needles, California

1. Introduction

This appendix describes statistical methods available to identify hot spots and account for biased sampling in hot spots using spatially weighted exposure point concentrations (EPCs).

It is important that hot spots be defined in the context of human health or ecological risk assessment (United States Environmental Protection Agency [USEPA] 2002). If a hot spot evaluation is warranted (e.g., concentrations and/or non-spatial EPCs exceed a risk-based screening level), the project team may use spatially explicit (geostatistical) or non-spatial methods to treat concentration data for further evaluation. As an example, uncertainty in a risk assessment may be reduced using geospatial statistics, when “sampling tends to disproportionately represent ’hot spots’ (i.e., a relatively large portion of a dataset with a small sample size (n) tends to be concentrated at ’hot spots’)” (USEPA 2001).

This appendix contains three parts addressing the statistical methods: 1) Hot spot evaluation methods for the detection and evaluation of potential hot spots or other spatial irregularities, 2) overview of spatially weighted EPC methods for treating concentration data, and 3) decision framework for a selecting spatial weighting method. Examples of non-spatial and spatial (geostatistical) methods are provided.

2. Hot Spot Evaluation

Hot spot evaluations may be conducted using spatially explicit (geostatistical) methods such as Moran's I, Getis-Ord, or Ripley's K statistics; or non-spatial methods such as boxplots, probability and quantile plots, and statistical outlier tests. Section 2 describes both spatially explicit and non-spatial methods.

2.1 Non-Spatial Methods

Non-spatial methods to detect outliers generally focus on identifying a value or set of values that do not fit the overall distribution of the data without regard to their spatial arrangement. An outlier may represent a true extreme value from a highly variable dataset (i.e., outlier) or it may represent an erroneous measurement (USEPA 2006). When data are grouped by location and compared across constituents, differences in the distribution of one or more locations may indicate that the location is representative of a different population (e.g., hot spot). The following are examples of non-spatial methods available to identify hot spots.

- **Boxplots** – A box-and-whisker plot (boxplot) shows the 25th, 50th, and 75th percentiles, as well as the mean spread of the data, and extreme values. Boxplots can help to identify potential outliers based on the interquartile range (IQR; the IQR = 75th – 25th percentiles) multiplied by 1.5 or 3.0 added to the 75th percentile. Commonly, values that exceed the 75th percentile plus 1.5 times IQR are considered moderate outliers, whereas values that exceed the 75th percentile plus 3.0 times IQR are extreme outliers (USEPA 2010). Benefits of boxplots are that they are simple to construct, relatively easy to understand, display key descriptive statistics on one plot, can be applied to all available datasets regardless of the underlying distribution, and can be used to compare the overall distributions of the same constituent across multiple exposure units. For these reasons, boxplots are proposed as a simple method to test for hot spots in soil at the Topock Compressor Station in Needles, California (the site). An example boxplot is presented on Figure D.2-1.

- **Probability and Quantile Plots** – This family of univariate plotting methods provides a means of visual analyses of the distribution of the values of a dataset in a variety of ways: direct comparison to its quantiles (Q-plot); comparison to some theoretical distribution (i.e., normal, lognormal, or gamma) in a probability plot (P-plot); or comparison to the distribution of some other observed dataset in a quantile-quantile plot (Q-Q plot). In addition to their value in the detection of various distributional anomalies (e.g., inflection points indicating a mixture of underlying chemical populations; extreme values in the upper and/or lower tails of a distribution, which may be indicative of suspected outliers), these visual analyses are a valuable accompaniment to formalized statistical tests (e.g., tests of goodness-of-fit to theoretical distributions or outlier analyses). The benefit of probability plots is that they consider the overall distribution of the data. Because they require the data to be parametric (e.g., normal or can be transformed to a normal distribution) they are not applicable to all datasets. In addition, they are best interpreted by an experienced statistician. ***For these reasons, probability plots are proposed to be used on a case-by-case basis to supplement the boxplots for site data.*** An example quantile-quantile plot is presented on Figure D.2-2.

- **Statistical Outlier Tests** – USEPA recommends statistical outlier tests for datasets that are a normal distribution (or can be transformed to a normal distribution), or non-normal but large (n≥50). Statistical tests for outliers are also conducted to determine if there is sufficient evidence of the likelihood (probability) that one or more extreme values is inconsistent with the remainder of the data at a 95% significance level. If data excluding suspected outlier(s) are approximately normally distributed (or can be transformed to a normal distribution) and the dataset contains a low percentage of non-detect samples (<15%), Dixon's test is used if n<25, and Rosner's test is used if n≥25. For normally or lognormally distributed datasets (excluding suspected outliers) with greater than 15% non-detect samples, the IQR test is used. If the data excluding suspected outlier(s) are not approximately normally distributed (or cannot be transformed to a normal distribution), Walsh's test is used if n≥60, and the IQR test is used if n<60. Note that Walsh's test is performed at α=0.10 if n<220. Non-detect values are set to the reporting limit (e.g., practical quantitation level) for these tests. ***These parametric statistical outlier tests may be used to provide confidence that a value is a statistical outlier.***

In instances where one of these methods indicates a likely hot spot of sufficient degree to require consideration, and that hotspot is determined to have the potential to impact the overall risk conclusion, further investigation of the hot spots may be warranted. Spatially weighted EPCs may be a better representation of potential exposure, particularly in situations where data are preferentially sampled in areas of hot spots.

2.2 Spatially Explicit (Geostatistical) Methods

Hot spots may also be identified, and/or confirmed statistically using geostatistical methods to assess the applicability of various spatial models of chemical concentration (e.g., kriging versus Thiessen polygons). The ongoing advances in geographic information systems (GIS) and commercial statistical software continue to make geostatistical analysis a practical and efficient complement to classical exploratory data analysis when hot spots are suspected.

A central concept of geostatistical analysis is spatial autocorrelation. This means that the measure of correlation between observations is dependent on their spatial arrangement, whereby data that are more proximate to one another are more similar (or in the case of negative correlation, dissimilar) than data that are more distant from one another. In addition to measuring the spatial dependencies within a dataset, the methods of spatial autocorrelation can also identify data clusters, hot spots, and other spatial patterns of distribution. These spatial patterns may be observed on the global and/or local scale. The following are examples of geostatistical methods available to identify hot spots.

- **Local (Anselin) Moran's I Statistic** – The Moran's I statistic measures correlation in several dimensions and is used to analyze spatial autocorrelation (the tendency of closer samples to be more correlated in value). Global Moran's I assumes homogeneity over an area and returns one value. Local, or Anselin, Moran's I measures local clustering or dispersion, which can be used as an indicator of hot spots. A statistically significant Moran's I indicates a cluster of similar result values.

- **Getis-Ord G** – The Getis-Ord G statistic measures high/low clustering. It is a global statistic, similar to global Moran's I, but a statistically positive Z score indicates that high values are clustered, while a low Z score indicates that low values are clustered (cold spots). It can be used as an indicator of whether there are hot spots present in the dataset.

- **Getis-Ord Gi*** – The Getis-Ord Gi* is analogous to local Moran's I in that it examines local neighborhoods and indicates the locations of hot spots and cold spots, rather than returning a global indicator.

- **Ripley's K** – The Ripley's K statistic measures spatial autocorrelation on a variety of neighborhood scales. For example, data may exhibit spatial clustering over short distances and dispersion at greater distances. Because The Ripley's K statistic summarizes spatial dependence at a range of distances, it can be useful in determining parameters to use with other measures of spatial correlation and hot spots (for example, a threshold distance at which to analyze patterns).

3. Overview of Spatially Weighted EPC Methods

EPCs that may be biased by over sampling hot spots can be better represented through spatial weighting methods. This section describes common spatial weighting methods and lists key assumptions and limitations associated with each method. A formal decision framework is also provided for selecting the most appropriate method based on key statistical properties of site datasets. A bootstrap simulation procedure that incorporates the USEPA's ProUCL version 4.1 software (USEPA 2010) is also described in this section. In addition, equations for calculating spatially weighted parameter estimates and upper confidence limits (UCLs) on the mean based on these parameter estimates are given.

After describing each of the methods above, the required pre-processing of the dataset to prepare the data for these analyses is discussed (Section 3.2).

3.1 Spatial Weighting Methods

USEPA recommends considering the use of spatial weighting techniques to calculate the EPC when concentrations across the site exhibit positive spatial autocorrelation, meaning that samples located near each other have more similar concentrations than samples located further apart (USEPA 2001, 2005a). Common spatial weighting methods include Thiessen polygons, Inverse Distance Weighting (IDW), and kriging. USEPA has facilitated the application of these methods by developing public domain software including GEO-EAS (USEPA 1988), SADA (University of Tennessee 2013) and Field Environmental Decision Support Team (USEPA 2013). There are numerous examples of applications of spatial weighting methods at hazardous waste sites; sites in USEPA Regions IV, V, VII, and X are posted on the USEPA SADA website (http://www.tiem.utk.edu/~sada/applications.shtml). There are also numerous examples of applications and overviews of geostatistical methods for calculating spatially weighted UCLs available in peer-reviewed literature. As with most models, it is unreasonable to expect that one spatial weighting approach is superior for every dataset and application. USEPA has provided an overview of the benefits and limitations of spatial weighting methods and recommends a method that is "appropriate dependent upon the data, the purpose of the analysis, and the planned use of the predicted surface" (USEPA 2004).

3.1.1 Thiessen polygons

A Thiessen polygon network (or Voronoi tessellation) is perhaps the most common spatial weighting method applied to risk assessments. This may be because it is easy to understand and implement, requires few assumptions, and can yield more reliable (accurate) estimates of UCLs than non-spatial weighting methods, particularly if the sampling design is non-random. For these reasons, the Thiessen polygon is proposed as the default approach for calculating spatially weighted EPCs Examples of its application to calculating UCLs for constituents in surface soil are in provided in Clifford et al. (1995) and Burmaster and Thompson (1996).

Thiessen polygons are conceptually straightforward, and the area weighting is performed in several steps. First, an area under consideration is divided into polygons such that every polygon is associated with one and only one sample in the dataset. The unsampled area contained within each polygon is nearest to the associated sample; therefore, the concentration for the entire area contained by the polygon is assumed to be equal to that of the associated sample. A weighting factor is then applied to a sample based on the proportion of the total exposure unit that is represented by the polygon associated with the sample. Samples located within areas of dense sampling are associated with smaller polygons than samples located in less dense sampling areas. This method is sometimes considered a “de-clustering” method because it effectively associates smaller polygon areas and weighting factors to samples in clusters. The method does not require a specific assumption to model the relationship among neighboring samples in order to yield reliable summary statistics. By contrast, probability-based methods (such as kriging described below) require a set of assumptions regarding the variance in concentrations in different directions and spatial scales. One limitation of using Thiessen polygons is that they generally do not result in a smoothly contoured surface because the polygons can be large in areas of less dense sampling, and only one value contributes to the concentration for the area within each polygon. Other interpolation methods incorporate more information from neighboring samples, resulting in smoother, and often more intuitive transition in concentrations to unsampled areas. The uncertainty associated with any interpolation scheme is greatest in areas of sparse sampling.

Once a polygon network is established for a site, additional post-processing of the areas can be performed to provide improved estimates of area averages (and UCLs). For example, subareas of the polygons can be “clipped” to reflect habitat boundaries (e.g., roadways or changes in habitat type), and footprints of large structures or water bodies not included in the exposure unit (EU).

While the calculation of the spatially weighted parameters within an EU is relatively straightforward, it can be more challenging to compute the UCL because USEPA’s ProUCL software was developed to accept input files for samples with uniform (equal) weighting factors. Two methods can be implemented to generate an estimate of an EPC from spatially weighted data that is consistent with USEPA’s decision framework for selecting UCL methods: 1) numerical simulation in which ProUCL is applied to multiple bootstrapped datasets; and 2) analytical solution using a conservative UCL method with spatially weighted estimates of the mean and standard deviation. Both methods are briefly described below.

3.1.2 Numerical Simulation

The numerical simulation approach requires that a custom utility be used to sample from the original dataset (i.e., bootstrap resampling), the input file be imported into ProUCL to compute the UCL, and the summary statistics of the distribution of UCLs be calculated. This approach is reproducible by implementing the following steps:

1. Identify all polygons (or portions of polygons) that are contained within the boundaries of an EU. Note that the polygon may originate from a sample obtained outside the EU.

2. Identify the concentration associated with each polygon and calculate the corresponding weighting factor, equal to the area of the polygon divided by the area of the EU.

3. Use bootstrap resampling (i.e., resample with replacement) to generate a dataset of equal sample size to the original dataset in Step 2. Further details regarding bootstrap resampling methods are provided in USEPA guidance (USEPA 2001, 2010). Use the spatial weighting factor to determine the probability that any given sample is selected for the bootstrap sample, and retain the qualifier flag (e.g., 0 = non-detect, 1 = detect) associated with each sample.

4. Repeat Step 3 many times (i.e., 250 or more) to generate an array of bootstrapped datasets, all with sample sizes equal to the original dataset (Step 2).

5. Import the entire database of bootstrapped datasets from Step 4 into ProUCL to implement USEPA's decision rules for selecting a UCL method consistent with the statistical properties of a dataset. This is facilitated by using the "group by" run option in ProUCL 4. This step will yield as many estimates of UCLs as bootstrapped datasets (i.e., 250 or more).

6. Calculate summary statistics for the distribution of UCLs. Select the arithmetic mean of the UCLs to represent the final, spatially weighted UCL (i.e., the EPC). If the original dataset includes non-detect samples, this method can yield asymmetric (right-skewed) distributions of UCLs such that the arithmetic mean is greater than the median. Use of the arithmetic mean of the UCLs also more closely approximates the UCL for a dataset that has equal weighting factors for all samples.

In general, there is no theoretical basis to suggest that one spatial weighting method will systematically yield higher (or lower) UCLs than other methods. However, the arithmetic mean of the UCLs computed from bootstrap resampling of Thiessen polygons can sometimes be higher than one might expect, given the sample size and spatially weighted variance of the concentrations. This is particularly true for left-censored data, and reflects the fact that USEPA has adopted conservative decision rules in selecting the most robust UCL statistics. That is, the decision rules will generally result in a non-parametric statistic that yields at least 95% coverage of the mean (and often higher than 95%) depending on the degree of censoring and skewness (USEPA 2010). This pattern is less pronounced with IDW and kriging approaches that utilize ProUCL in resampling of the estimated grid concentrations because the use of substitution methods for non-detect samples results in a final dataset of estimated concentrations that are processed as all detects (i.e., "full").

3.1.3 Analytical Solution

The numerical simulation approach can be challenging to implement, even when custom utilities are created to facilitate the batch processing of input and output. The computation can be approximated with an alternative and more efficient approach. With this method, the spatially weighted sample mean and standard deviation are used directly with one of the UCL calculation methods that yields the desired coverage of the mean, even for left-censored, non-normally distributed datasets. USEPA (2010) provides guidance on the performance of a variety of UCL methods based on simulation experiments with datasets with equal sample weights. Many methods utilize bootstrap resampling procedures (e.g., Hall's Bootstrap, Bootstrap-t) which, while appropriate for certain datasets, require additional computational steps to obtain estimates of other parameters. A few of the recommended methods can be implemented in a single calculation utilizing the spatially weighted mean and standard deviation, including the parametric Student's t UCL and the Chebyshev UCL. USEPA (2010) indicates that these methods provide optimal coverage of the UCL under the following conditions:

- Student's t UCL is recommended when the data are uncensored and approximately normally distributed or non-normal but mildly skewed (i.e., standard deviation of log-transformed data ≤ 0.5). The Student's t (1-α) 100% UCL with n-1 degrees of freedom (*df*) is calculated with the following equation:

$$UCL = \bar{x}_w + t_{\alpha,n-1}\, sd_w \big/ \sqrt{n}$$

- Chebyshev UCL is one of the methods recommended when data are uncensored and either lognormally distributed with moderate skew (i.e., standard deviation of log-transformed data > 0.5) or nonparametric (i.e., data do not fit normal, lognormal, or gamma distributions). USEPA (2009) describes the Chebyshev UCL as generally more conservative (yielding a higher UCL with higher coverage of the mean) than other methods, especially when sample sizes are large (e.g., n ≥ 40). The Chebyshev (1-α) 100% UCL is calculated with following equation:

$$UCL = \bar{x}_w + \sqrt{1/\alpha - 1}\, sd_w \big/ \sqrt{n}$$

Goodness of fit may be determined for spatially weighted datasets based on visual inspection of normal and lognormal probability plots. Because ProUCL requires uniform weighting factors, these plots are generated in Excel by rank-ordering the concentrations and computing the z-score (inverse of standard normal distribution) where the cumulative distribution for x_i is defined by the sum of the weighting factors from x_1 to x_i. Either Student's t or Chebyshev can be implemented, consistent with the criteria outlined above.

3.1.4 Inverse Distance Weighting

IDW may be used to estimate concentrations by interpolating between samples based on the weighted average concentration of neighboring sampling locations. IDW differs from Thiessen polygons in that IDW uses an interpolation routine that incorporates information from multiple values, rather than simply applying the value of the nearest observation. IDW yields a grid of estimated concentrations across the EU. The interpolated value at each node in the grid represents an estimate for the concentration at that location. Concentrations at grid nodes that contain sample observations are equal to the observed concentration at that location. Collectively, the full set of concentrations across the grid represents the spatial variation of concentrations in the EU. Use of IDW requires two key assumptions: 1) definition of neighborhood or the discrete number of samples that contributes to the estimated concentration at each grid node; and 2) value of the exponent used to determine the relative weight of each sample as a function of distance. While there are general rules for these assumptions, they tend to be based on historical practice rather than a clear and transparent scientific rationale. For example, typically a “neighborhood” is defined with a fixed radius, rather than assigning a specific number of neighbors; however, the size of the radius is generally selected based on professional judgment.

With IDW, cross-validation procedures can be used to partially address these sources of uncertainty in an objective manner. Cross-validation involves the systematic evaluation of the predicted versus measured concentrations for each sample location. With this method, one sample location is temporarily removed and the same interpolation procedure is conducted with the remaining samples, thereby yielding an estimate of the concentration at the missing sample location. This process is repeated for each sample, and the prediction error (i.e., difference between measured and predicted concentrations) provides a metric for evaluating the suitability of the interpolation method and the exponent that minimizes the sum of the squared errors.

One important concept associated with the IDW approach is the need to distinguish between sample size and grid size when determining the appropriate *df* for the UCL calculation. Use of the grid size to define *df* would greatly inflate *df*, thereby yielding a UCL with much less than 95% coverage of the mean. As with the Thiessen Polygon method, there are two general approaches to estimating UCLs. A simulation method can be implemented that uses bootstrap sampling of the entire set of estimated concentrations, with the sample size for each bootstrapped dataset equal to the sample size of the original empirical data. The routine could be automated to utilize ProUCL’s decision rules for UCL calculation, similar to the method described in Section 3.1 above for Thiessen polygons. Alternatively, an analytical solution can be used by computing the spatially weighted mean and standard deviation with the full set of interpolated concentrations in the EU. In this case, the true *df* is based on the original sample size rather than the large number of estimated concentrations along the grid that comprises the interpolated surface. USEPA implemented this method to derive spatially weighted EPCs for use in a human health risk assessment addressing polychlorinated biphenyls in floodplain soils near the Housatonic River (USEPA 2005b).

The key benefit to the IDW approach is that it yields a smooth interpolated surface. Unlike Thiessen polygons, IDW uses an interpolation routine that incorporates information from multiple values, when it can be shown that there is spatial autocorrelation among neighboring samples.

3.1.5 Kriging

Like IDW, kriging methods are used to estimate concentrations in unsampled locations based on the weighted average of neighboring concentrations. The key difference between IDW and kriging is that kriged estimates require a more complex model that describes the variance, with assumptions that the variance is independent of location and direction. A semi-variogram plot is generated to represent the relationship between measured concentrations as a function of distance between sampling locations. If a reasonable fit can be achieved, the geostatistical model may provide reliable estimates of concentrations at unsampled locations. An example of a semi-variogram is presented on Figure D.3-1.

Estimates of the EPC can be obtained with sequential simulation by averaging the values of all grid points that fall within the EU. A nonparametric distribution for the UCL can then be obtained by repeating the process many times (Thayer et al. 2003). Alternatively, a bootstrap method similar to the IDW approach described above can be used to incorporate ProUCL's decision rules explicitly.

As with IDW, and in contrast to Thiessen polygons, kriging interpolates – where appropriate – across multiple values. Furthermore, the application of kriging includes certain diagnostic methods which indicate how well the model fits the observed data. However, kriging tends to smooth out the highs and lows in a data set, which may artificially constrain the variance and UCL.

3.2 Dataset Pre-processing

The following initial data processing steps are often necessary to complete prior to implementing a decision framework to select a spatial weighting method for calculating EPCs.

3.2.1 Non-detect Samples

It is well understood that UCLs and parameter estimation, in general, can be influenced by the statistical approach used to incorporate non-detect samples. Historically, substitution methods (e.g., one-half detection limits) were widely used in environmental statistics, but in the past 5 to 10 years, both the statistics literature and USEPA guidance (USEPA 2010) have reported results of simulation studies that demonstrate how substitutions can introduce bias. The options available to process non-detect samples depend on the spatial weighting method. With Thiessen polygons, interpolation between nearby samples is not required; therefore, all options are available. However, with IDW and kriging, substitution methods are generally required.

3.2.2 Exposure Boundary and Sample Coordinates

Thiessen polygons can be generated with any standard GIS software based on the spatial coordinates of each sample location. Minor post-processing of the sample coordinates and polygon boundaries may be required after viewing the original sample locations relative to exposure boundaries or aerial photographs of the site. In some analyses, polygons may be trimmed or "clipped" to reflect the site boundary, topography, or other geographic features.

4. Decision Framework for Selecting Spatial Weighting Method

While spatial weighting methods will often yield more representative estimates of UCLs than methods that do not account for spatial information, it is impractical to apply every statistical method to every dataset, especially for large sites. In addition, because each spatial weighting method can yield a different UCL, objective criteria are needed that give greater weight to the properties of the data than to the differences in the resulting UCLs. A practical decision framework can guide the selection of methods based on the value added and the statistical properties of the datasets. The purpose of establishing a process for selecting among candidate methods is to facilitate a consistent, efficient, and objective evaluation of each site area when there is reason to believe that sampling has been biased towards hot spots in the site area. The elements of the decision framework are described briefly below.

4.1 Step 1. Determine if the frequency of detects is greater than 30%

USEPA's recommended methods for calculating UCLs with left-censored data can only be implemented directly with spatial weighting by applying the bootstrap simulation method to the weighting factors determined with Thiessen polygons. The basic analytical solution does not accommodate left-censored data. With IDW and kriging, a substitution method is needed to first generate the surface of estimated concentrations. This may introduce uncertainty in the calculation of the UCL because Kaplan Meier parameter estimation is generally accepted as introducing less bias than substitution methods (USEPA, 2010). A subjective threshold of 30% for the frequency of detects is used to guide the selection of approaches. If the dataset has greater than 30% detects, initial exploratory steps are warranted to evaluate IDW and kriging options (Steps 2 and 3). If the dataset has 30% detects or fewer, IDW and kriging can be expected to be greatly influenced by the non-detect reporting limits, and the EPC can instead be determined using Thiessen polygons.

4.2 Step 2. Calculate Moran's I Statistics

Spatial weighting methods are most useful when data exhibit positive spatial autocorrelation, especially when sample collection is biased toward hot spots in the site area. A simple but informative indicator of spatial autocorrelation is the Global Moran's Index, which can be calculated in ArcGIS 10.0 (ESRI 2012). At the global scale, Moran's I tests the null hypothesis (H_0) that "there is no spatial clustering" or that the spatial pattern of the data is not substantially different than one would expect from random chance (at the desired significance level). Global Moran's I provides the index value (Moran's I) and the associated z-score. Positive values for Moran's I are indicative of clustering, whereas negative values are indicative of heterogeneity. The z-score is used to interpret the statistical significance of the result. For screening purposes, a positive Moran's I value with a z-score of at least 1.282 (corresponding to α=0.20) is used as a threshold indicator of moderate positive spatial autocorrelation. Datasets that do not exhibit spatial autocorrelation using the Moran's I criteria of 80% are less likely to yield reasonable semi-variograms or significantly different results with IDW.

4.3 Step 3. Conduct Variography

The most important indicator of the reliability of kriging methods is the semi-variogram, which shows whether a model can be used to represent the relationship between variance and distance (between sample points). Sometimes a log-transformation can be applied to yield an improved relationship. Alternative semi-variogram models, with and without anisotropy, are generated in this step to determine if kriging is likely to yield a reasonable surface of estimated concentrations. If a reasonable semi-variogram cannot be defined for the dataset, IDW can still be used. An example of a semi-variogram is presented on Figure D.3-1.

4.4 Step 4. Generate a Thiessen Polygon network and evaluate graphics showing the weighting factors versus the measured concentrations

A Thiessen Polygon network can be quickly created with most commercial geostatistics packages, including ArcGIS 10.x (ESRI 2012). For each observation, the weighting factor is calculated as the area of the polygon divided by the total area of the EU. If the sampling design is a systematic square grid, each observation would have equal weight, and there would be no need to proceed with the Thiessen Polygon approach. This type of sample would appear as a straight line on an x-y scatterplot of paired weighting factor and concentration for each observation. For all other sampling designs, the graphic will exhibit some degree of scatter. If the concentrations at either end of the distribution (high or low) have much higher weighting factors than average (i.e., they are associated with relatively large polygons), these points will have greater than average influence on the UCL. These points will appear as peaks on x-y scatterplots or bar charts and would serve as indicators that the Thiessen Polygon approach will yield a more reliable UCL than non-spatial methods.

It is important to note that when there is positive spatial autocorrelation, generally there is greater certainty in estimates at unsampled locations that are based on multiple neighbors (e.g., IDW or kriging) than with estimates based on the single closest value (Thiessen Polygon). For this reason, Steps 1, 2, and 3 verify when IDW and kriging could be used over Thiessen polygons.

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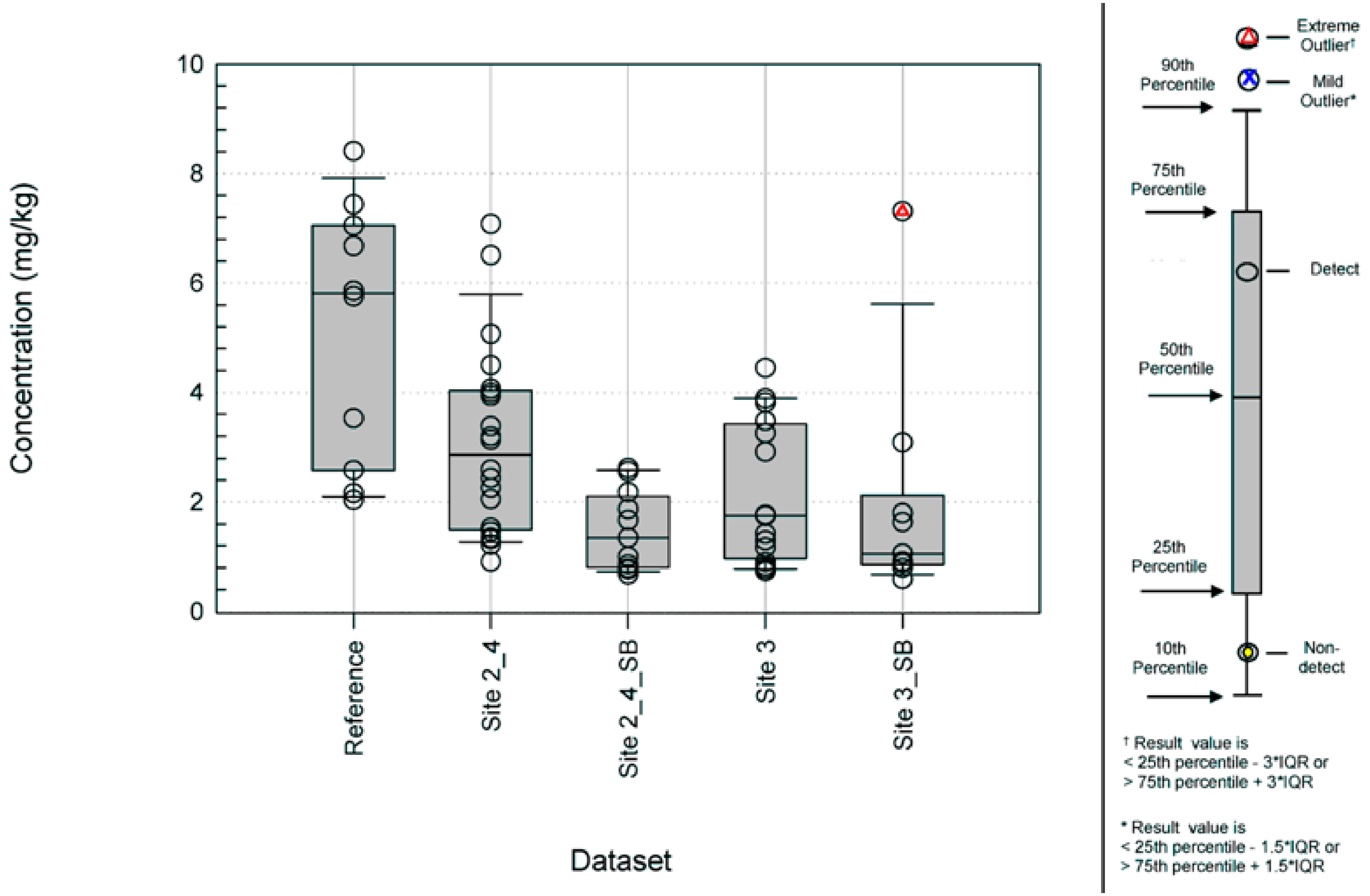


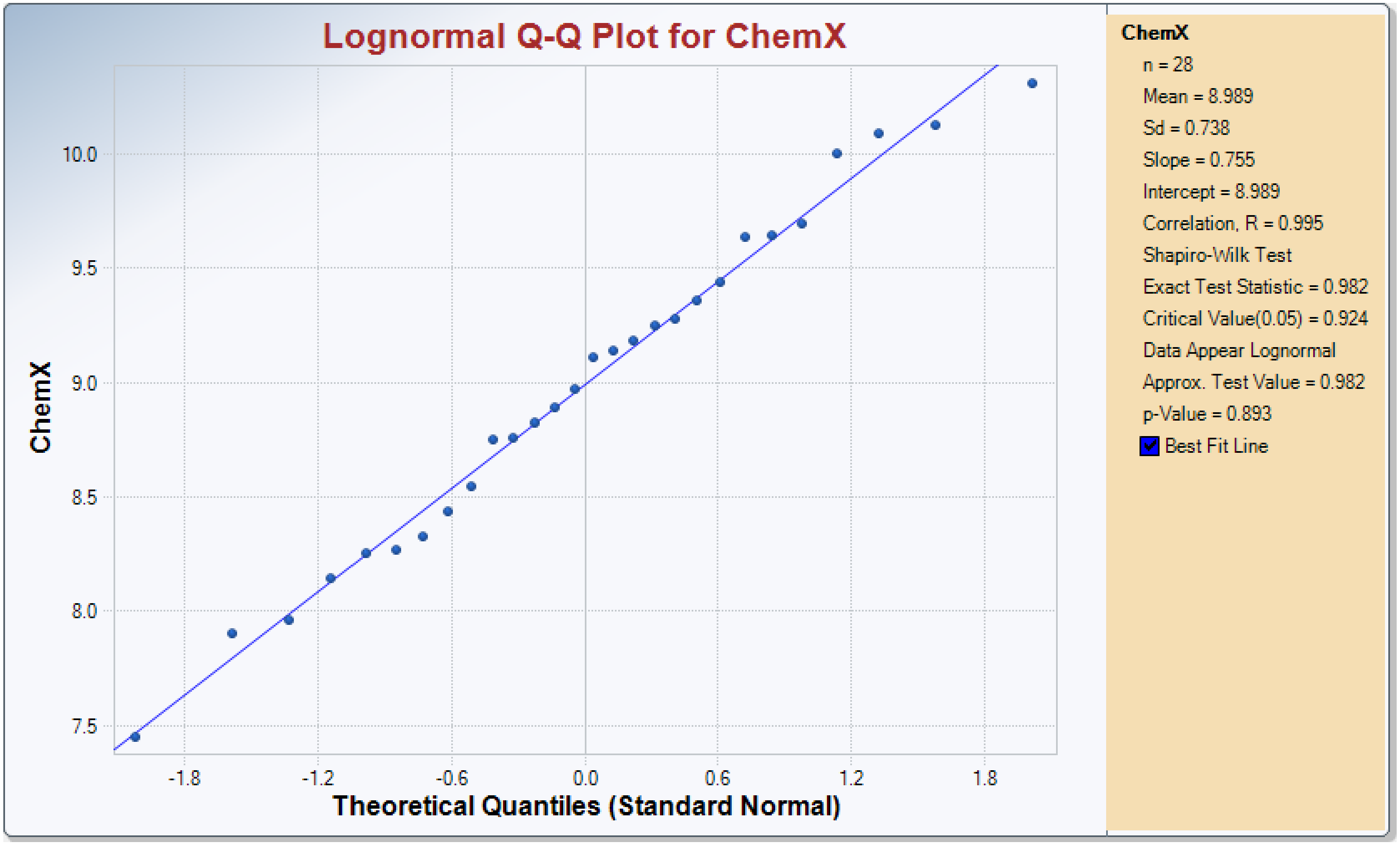
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

EXAMPLE BOX PLOT

ARCADIS
Infrastructure · Water · Environment · Buildings

FIGURE
D.2-1



ChemX

n = 28
Mean = 8.989
Sd = 0.738
Slope = 0.755
Intercept = 8.989
Correlation, R = 0.995
Shapiro-Wilk Test
Exact Test Statistic = 0.982
Critical Value(0.05) = 0.924
Data Appear Lognormal
Approx. Test Value = 0.982
p-Value = 0.893
☑ Best Fit Line

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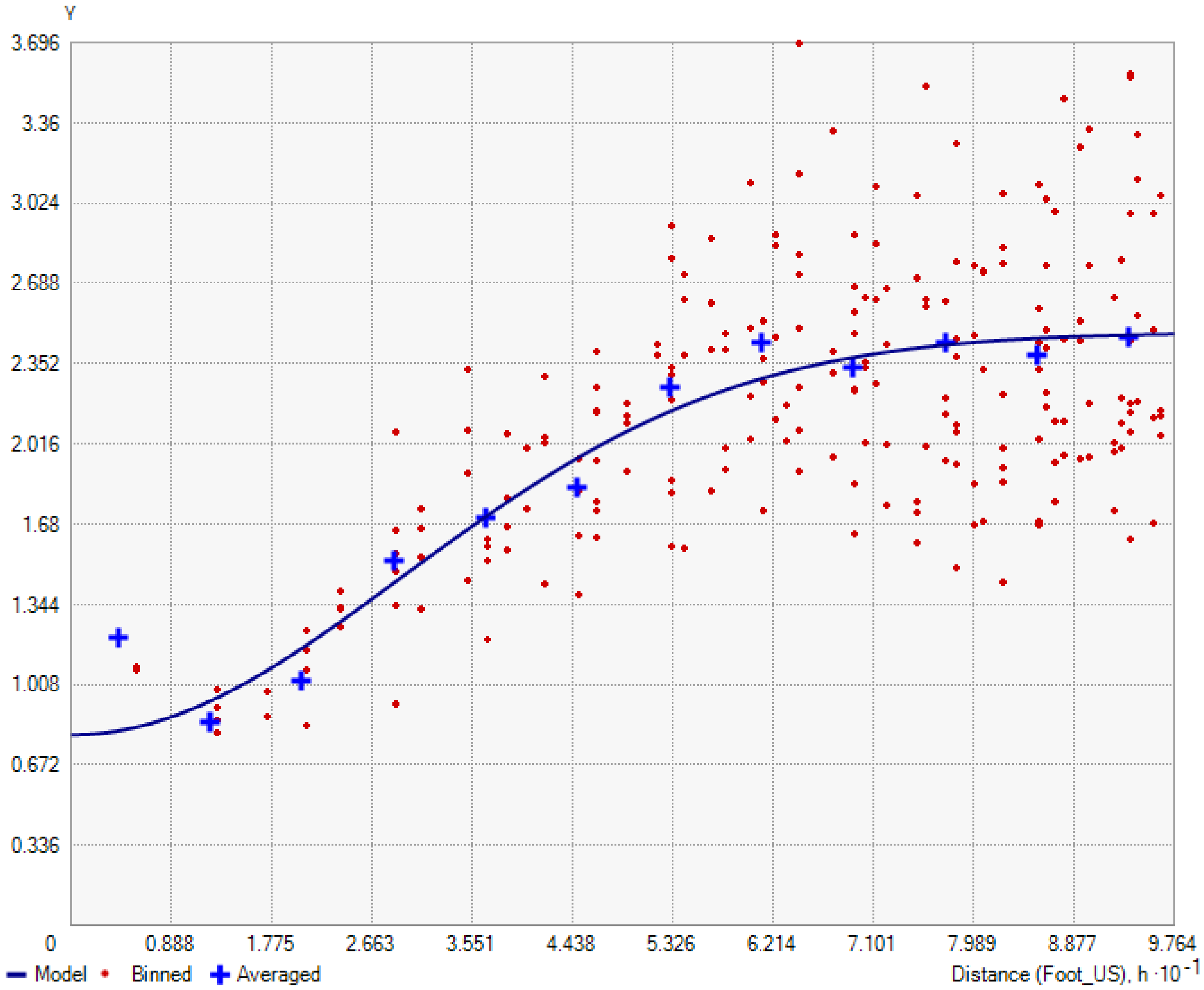
NEEDLES, CALIFORNIA

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

EXAMPLE QUANTILE-QUANTILE PLOT

ARCADIS
Infrastructure · Water · Environment · Buildings

FIGURE
D.2-2



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NEEDLES, CALIFORNIA

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT WORK PLAN ADDENDUM 2

EXAMPLE SEMI-VARIOGRAM

ARCADIS
Infrastructure · Water · Environment · Buildings

FIGURE
D.3-1

Appendix E

Arrowweed Memo

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MEMO

To:
Yvonne Meeks, PG&E

Copies:
Virginia Strohl, PG&E
Ellery Kling, PG&E
Lisa Kellogg, ARCADIS
Janis Lutrick, ARCADIS
Kelli Jo Preston, ARCADIS

From:
The ARCADIS Risk Assessment Team

Date:
January 28, 2013

ARCADIS Project No.:
RC000753.0003

Subject:
Technical Memorandum
The Potential For Chromium Uptake by Arrowweed and Potential Exposure Pathways

---

1. Introduction and Overview of Conclusions

The purpose of this technical memorandum is to provide the results of a literature review and preliminary exposure pathway analysis conducted for the Pacific Gas and Electric (PG&E) Topock Compressor Station (TCS), located in San Bernardino County, California, 12 miles southeast of Needles (the site) and the surrounding area of potential effect (APE). The literature review and pathway analysis were conducted at the request of the California Department of Toxic Substances Control and U.S. Department of the Interior in response to stakeholder questions.

The potential exposure pathway being addressed is the potential for hexavalent chromium [Cr(VI)] and/or trivalent chromium [Cr(III)] uptake by plants [specifically arrowweed (*Pluchea sericea*)] as a component of the human and ecological exposure assessment at the site. Two aspects of this pathway are evaluated in this technical memorandum:

- **Potential for Chromium Uptake by Arrowweed** – A literature search was conducted and relevant articles reviewed to evaluate the potential for Cr(VI) or

Cr(III) uptake from growth media by arrowweed and/or other relevant plants that may be used to evaluate potential arrowweed uptake.

- **Potential for Arrowweed Exposure to Chromium** – Soil and groundwater data, and arrowweed locations were reviewed to evaluate if arrowweed near the site is in contact with Cr(VI) and/or Cr(III) at concentrations greater than background. Chromium concentrations at or below background that are co-located with arrowweed would not indicate potential site-related exposure.

The conclusions of the literature review and pathway analysis are discussed in detail in the last section of this technical memorandum; a brief overview is provided below.

The literature search did not identify any published articles on chromium uptake specifically in arrowweed. The literature review indicates that plants can take up Cr(VI) and Cr(III) from soil, but much of the Cr(VI) is converted to Cr(III) in the plant. Typically, little Cr(VI) is present in above-ground plant structures relative to the exposure concentration in growth media.

The exposure pathway analysis indicates little overlap between elevated total chromium and Cr(VI) (relative to background) and arrowweed. Total chromium and Cr(VI) above background concentrations in soil does not extend to the area where the arrowweed community is located. However, arrowweed may also be present as an understory plant (i.e., plant between the canopy and ground surface) in salt cedar community, and low concentrations above background were detected at two locations in the salt cedar community near the mouth of Bat Cave Wash. Both of the locations are difficult for human receptors to access due to very steep slopes and/or very dense vegetation. Total chromium and Cr(VI) have not been identified at concentrations greater than background in groundwater underlying the arrowweed and salt cedar communities. Arrowweed plants occur at the mouth of East Ravine and are located where sediment sampling is planned but has not yet been conducted. Therefore, current soil and groundwater data indicate that contact with arrowweed by either human or ecological populations is unlikely to result in chromium exposure exceeding background conditions for the following reasons:

- Arrowweed was not observed near locations with detectable Cr(VI) in soil (Russell 2012). Therefore, based on soil data collected to date, the human and ecological exposure to hexavalent chromium in soil via arrowweed uptake is insignificant.

- No groundwater concentrations above background were co-located with arrowweed and salt cedar communities.

- The magnitude of the soil concentrations exceeding background was modest (within three times background).

- Human access is deterred in the area where chromium concentrations exceeding background were detected in soil.

Additional soil sampling will be conducted (as planned in the Combined Part A and B Work Plan) and the results of that investigation will help to determine whether ecological populations are exposed. The remainder of this technical memorandum is organized as follows:

- **Literature Review** – provides the objectives of the review, properties and uses of arrowweed, approach to the literature search, and key findings of the review. The detailed results of the literature review are provided in Attachment 1 to this technical memorandum.

- **Pathway Analysis** – provides the approach, results, and key findings of the pathway analysis, identifying the location of arrowweed in the APE and co-located chromium concentrations in soil and groundwater.

- **Conclusions** – provides conclusions regarding the potential for exposure to Cr(VI) and/or Cr(III) via contact with arrowweed under current site conditions based on the key findings from the literature review and exposure pathway analysis.

2. Literature Review

The literature review was conducted to understand the potential for Cr(VI) and/or Cr(III) uptake into plant tissue as a component of human and ecological exposure assessment. As specifically requested, the literature search focused on arrowweed. In addition, this technical memorandum summarizes findings for other potentially relevant plant species as well. A discussion of California Environmental Protection Agency's (CalEPA's) most recent relevant draft guidance regarding soil-to-plant Uptake Factors (UFs; Office of Environmental Health Hazard Assessment [OEHHA] 2012) in plants that could be consumed by humans is also included in preparation for the human health risk assessment for soil.

2.1 Objectives

The primary purpose of this literature review was to ascertain whether there is evidence in the literature that arrowweed, a plant found in the southwestern part of the United States, is able to absorb and translocate chromium in the form of Cr(VI) and/or Cr(III) from soils[1] into plant tissue. In order to gain a better understanding of whether chromium in soils at the site could be taken up by arrowweed or other potentially relevant plants, a search of the scientific literature was conducted with the goal of answering the following questions:

1. Are plants, including arrowweed, able to take up chromium from their growth media (e.g., soils, agar, or hydroponic solutions)?

2. For plants that exhibit evidence of chromium uptake, what species of chromium [i.e., Cr(VI) or Cr(III)] is found in the plant?

3. For plants that exhibit evidence of Cr(VI) or Cr(III) uptake from their growth media, what parts of the plant contain detectable chromium, and what is the ultimate form of the chromium in the various plant tissues following translocation?

Through the literature search, articles were identified that describe the uptake of chromium, both Cr(VI) and Cr(III), in plants, and the results are presented following this general outline:

1. The properties of arrowweed, including habitat, scientific classification, and potential application or use is provided. This information is useful for identifying other relevant species that could provide information about chromium uptake into arrowweed. Arrowweed properties and uses may also provide initial information that can be discussed with the stakeholders to identify relevant potential exposure pathways, if applicable.

2. The approach used to identify relevant studies identified during the literature search is described.

---

[1] In our literature search, we did not distinguish between soils and sediment as growth media.

3. The results and conclusions regarding potential uptake of Cr(VI) and Cr(III) that can be drawn from the literature search are summarized.

2.2 Properties and Uses of Arrowweed

Arrowweed (*Pluchea sericea)* is an upright shrub-like perennial plant of the sunflower family. The plant is tall (1 to 5 meters in height) with slender leafy stems (Baldwin et al. 2012). Arrowweed is an angiosperm (flowering plant), with a two-part seed (dicot). More specifically, it is classified as an asterales, which also includes other desert plants. *Pluchea*, also known as camphorweed, refers to the genus of arrowweed. The scientific classification of arrowweed is as follows:

Kingdom: Plantae – Plants
Subkingdom: Tracheobionta – Vascular plants
Superdivision: Spermatophyta – Seed plants
Division: Magnoliophyta – Angiosperms, or flowering plants
Class: Magnoliopsida – Dicots
Subclass: Asteridae – Asterid
Order: Asterales
Family: Asteraceae – Aster family
Genus: *Pluchea* – Camphorweed
Species: *Pluchea sericea* – Arrowweed

Arrowweed is commonly found in the southwestern United States desert and frequently grows between willows and mesquites along river channels (Uno 1999). The plant is a common component of streamside communities and often forms dense thickets along streams, in washes and canyons, and around springs (Uno 1999). Arrowweed is a salt-tolerant plant and typically grows in areas with low to moderate soil salinity; the soil pH requirements for arrowweed cultivation ranges from 7 to 9 (Wilson 2012). The roots of arrowweed are found most frequently in soil samples taken at depths up to about 3 feet (ft) below ground surface (bgs) (Hely and Peck 1964), but are reported to extend to up to 20 ft bgs (Alth et al. 1991).

Parts of arrowweed have been used medicinally by Native Americans. Among many medicinal treatments, the leaves may be chewed as a throat aid, the decoction of roots for antidiarrheal aid, the raw root may be chewed for gastrointestinal aid, and the roots have also been used as a wash for dermatological aid and eye medicine (UMD 2003). Other traditional uses of arrowweed include using the shaft as building material (e.g., roofing, thatching, and fences); for storage bins, animal cages, and baskets; for cradleboard beds; and for arrow making (UMD 2003). Additionally, roots may be roasted and eaten, and the leaves or the stem tips may be brewed as a tea (UMD 2003). Arrowweed is also browsed by deer and sometimes by livestock (UMD 2003).

2.3 Approach to Literature Search

The approach to the literature search is described below, including the methods for identifying relevant articles (e.g., database searched and keywords used) and compilation of the search results.

2.3.1 Identifying Relevant Articles

The first step in the literature search was to identify studies that focused on understanding the potential for total chromium and/or Cr(VI) in soil and other media to be taken up into plants. To this end, an inventory of peer-reviewed studies was assembled. The resulting inventory contains studies published between the years of 1964 and 2012.

From April 23 through May 15, 2012, the following sources were searched to identify potentially pertinent studies:

- National Library of Medicine's PubMed
- World Health Organization's AGRIS (Agricultural Sciences and Technology)
- Wiley Interscience, an online service with access to more than 3 million articles across nearly 1,500 journals and 7,000 online books and major reference works
- ScienceDirect, an online service with access to over 10 million articles across more than 2,500 journals and 11,000 books
- American Chemical Society (ACS) Publications, with access to more than 35 journals
- Google Scholar

The searches were conducted using combinations of five groups of keywords:

- **Chemical name** [i.e., hexavalent chromium, trivalent chromium, Cr(VI), Cr(III), chromium, and heavy metals]

- **Plant species** (i.e., arrowweed, plant, and *Pluchea* [same genus as arrowweed])

- **Environmental medium** (i.e., soil, groundwater, and contaminated)

- **Route of uptake** (i.e., uptake, transpiration, kinetics, fate, transport, distribution, reduction, phytoremediation, accumulation, and translocation)

- **Method analysis** (i.e., x-ray, atomic spectroscopy, x-ray absorption spectroscopy, XAS, atomic absorption, and AAS)

The search string was refined during routine database searches. Bibliographies of relevant reviews and reports were also searched to identify additional studies and references.

2.3.2 Data Compilation and Management

The results of these searches, more than 2,800 articles, were reviewed to remove duplicates and articles not pertinent to the primary study objectives. Articles from the database were removed if they did not have an abstract, and aside from reviews, articles were removed if they did not report original research results (e.g., editorials and commentaries). The results of the searches were combined into EndNote™ (version X4; Thomson Reuters, Carlsbad, CA), a reference database management software program. In addition, articles in the following categories were removed as they were deemed not of primary relevance:

- Articles on bioremediation strategies using non-plant species (e.g., bacteria, yeast, animals, or animal waste)

- Articles solely focused on methods of detecting chromium and/or speciation of chromium

- Studies that used growth media other than soils, agar, or hydroponic solutions (e.g., effluent waste and activated sludge)

- Articles from journals not related to plants (e.g., Journal of Bacteriology)

- Articles that studied binding mechanisms of chromium to plants, but did not study actual uptake of chromium into plants.

Removal of duplicate and non-relevant articles yielded approximately 300 articles. Of these articles, abstracts were reviewed and categorized into Tiers I, II, and III, in order of obvious relevancy, with Tier I being the most informative in terms of answering the question of chromium uptake, translocation, and ultimate concentration in plant tissue. The initial categorization (see results discussion below) yielded approximately 65 Tier I articles, 15 Tier II articles, and 60 Tier III articles; the remainder were classified as non-informative. The full texts of the Tier I articles were then obtained and reviewed. Following the review of Tier I articles, Tier II and Tier III articles were reviewed for additional relevant information to help answer the primary question regarding uptake of hexavalent chromium into plant tissue. If articles in Tier II or Tier III provided relevant information in terms of chromium uptake and/or speciation in plants, they were considered Tier I and summarized in the Tech Memo, Table 1 summarizes the key Tier I articles identified during the literature search. Although a full critique of each article was not conducted for the purposes of this technical memorandum, a few caveats and comments regarding study methodologies and conclusions are presented in the last column of Table 1, to aid in interpretation of results.

2.4 Key Findings from the Literature Review

The literature search did not identify any published articles on chromium uptake specifically in arrowweed. However, some of the Tier I studies were based on plants scientifically classified in the same subgroups or live in similar habitats as arrowweed, as identified in Table 2. Mesquites, tumbleweed, creosote bush, and Mexican palo verde are all desert plants (Aldrich et al. 2003; Arteaga et al. 2000; Buendía-González et al. 2010; Gardea-Torresdey et al. 2005; Zhao et al. 2009, 2011); mesquites and creosote bush are also found in some areas of the Topock site. Therefore, it is reasonable to conclude that findings from the literature search are potentially applicable to site-specific plants.

Some Tier I studies indicate concerns with the reliability and precision of the analytical methods available to measure Cr(VI) and Cr(III) in plant tissue. As indicated by OEHHA, there are methodological challenges associated with estimating the actual speciation of chromium in biological tissues during analysis (OEHHA 2012). It has been suggested that chemical extractions may induce alterations on speciation results in samples (Lytle et al. 1998). For example, Gheju et al. (2009) used a strong acid solution to extract Cr(VI) from plant tissues. Some authors have noted that a strong acid digestion could potentially alter the oxidation state of the chromium being measured (Espinoza-Quinones et al. 2009). It should be noted that due to the limitations of the types and number of studies measuring Cr(VI) in plant tissue, OEHHA, in its draft Hot Spots guidance, recommends that until the form of chromium found in edible plant portions of crops is able to be determined, the health protective assumption is that the (total) chromium found in crops due to root uptake is in the form of Cr(VI) (OEHHA 2012).

In general, the literature supports that plants have the ability to absorb both Cr(VI) and Cr(III) from soil, solution, and agar. The extent of this absorption varies due to many factors, some of which are described in more detail in the paragraphs of this section discussing study methodology and variations in findings. In summary, studies varied in their conclusions on what form of chromium is more likely to be taken up in plant roots, and the absolute quantity of Cr(VI) that is reduced to Cr(III) in plant tissue.

With a few exceptions, most notably the study by Sampanpanish et al. (2006) using *Pluchea Indica*, the Tier I studies support the finding that once absorbed by root tissues, it appears that most of the Cr(VI) is reduced to Cr(III) and retained by the roots in a tightly bound or insoluble form or in a soluble complex that is not translocated to a large degree to the above-ground plant parts (OEHHA 2012). Once Cr(VI) and Cr(III) are actually inside the plant, it is reported that Cr(VI) is more mobile while Cr(III) likely interacts with surrounding plant cells and components (Skeffington et al. 1976). A portion of absorbed chromium in the form of Cr(III) and/or Cr(VI) may migrate throughout the stem and leaves of the plant, interacting with plant biochemical species along the way, some of which may facilitate further reduction, oxidation, solubility, movement across cell membranes, or precipitation of chromium species. Buendía-González et al. (2010) concluded there was significant translocation of total chromium from roots to aerial parts, and Gardea-Torresdey et al. (2005) measured higher translocation of total chromium when Cr(VI) was supplied to plant in agar compared to Cr(III) supplied in agar. Zhao et al. (2009) also measured Cr(VI) and concluded complete reduction of Cr(VI) in all plant tissues. In a soil experiment, Zhao et al. (2011) showed that chromium supplied in either form increased translocation of total chromium over time into the stems of Mexican palo verde plants.

The study on chromium uptake in Indian camphorweed (*Pluchea indica*), which may be a useful comparison to arrowweed as they share the same genus, detected Cr(VI) in leaves after 30 and 60 days; however, Cr(VI) concentrations fell below the detection limit due to dilution by plant growth and, therefore, Cr(VI) was not detected in stems or leaves at 90 or 120 days (Sampanpanish et al. 2006). A few of the caveats related to this study's design are described on the following page, as well as in Table 1.

The growth medium (i.e., soil, solution, or agar) for the study has an important impact on potential plant uptake of Cr(VI) and Cr(III), soil being the least facilitative for uptake. Variation in transport and accumulation of chromium in plants may depend on the chemical complexes that may form in the soil prior to being absorbed, as well as those formed inside the plant after absorption (Đogo et al. 2011; Gardea-Torresdey et al. 2005; Shanker et al. 2005). Differences in uptake and translocation may be explained by pH or oxidation-reduction reactions occurring in soil, along with organic matter and other ionic elements interacting with one another in the soil (Gardea-Torresdey et al. 2005; McGrath 1982). Aldrich et al. (2003) directly measured Cr(VI) and found partial reduction of Cr(VI) in roots and stems of plants grown in solution, but the Cr(VI) was fully reduced in the leaves, as well as in all plant tissues grown in agar medium. Additionally, it is important to note that hydroponic media used in some studies may not be a realistic representation of field conditions, because more soluble chromium is present in this media as opposed to in soil, where chromium may be adsorbed, complexed, reduced, or precipitated and, therefore, less available (Zayed and Terry 2003).

Studies reviewed from the literature search demonstrated variability in results based on plant types, plant age, cultivation times, extraction methods, sample preparation, growth media, pH conditions, concentration of chromium sources, oxidation conditions, presence of other chemical species in growth medium, and the extrapolation of laboratory experiments to natural habitats. Some of these issues have been described above. Due to these complexities, it is difficult to draw a simple conclusion regarding Cr(VI) and/or Cr(III) into arrowweed based on the literature available. Notable issues regarding study methodologies and issues impacting the variability in findings are summarized below to provide some additional perspective on the conclusions drawn from this evaluation.

In general, several studies failed to mention the presence of a plant control or method limit of detection; therefore, the results from these studies may not accurately represent actual concentrations of chromium in the plant.It was noted above that the one study identified using *Pluchea indica*, or Indian Camphorweed (Sampanpanish et al. 2006) could be useful in interpreting results for arrowweed since this is the most closely related plant studied. However, there are issues with study methododologies and conditions that bring into question the relevance of this study for the Topock site. At the end of the Sampanpanish study, the resulting pH of the soils was fairly acidic.

Specifically, the starting pH of the soil was 5.2, while the pH in the soil at the end of the study was 3.8. Typical soil pH conditions at Topock range from 7.48 to 10.49 (CH2M Hill 2011). Given the sensitivity of chromium speciation to pH conditions, it is questionable how relevant the results of this study are to the soil conditions at the Topock site. This is an important distinction because this study is one of the minority that did show uptake for and the ultimate presence of Cr(VI) in leaves. Additionally, some researchers have documented challenges associated with the method for alkaline extraction of Cr(VI) used by Sampanpanish et al. (2006) from biological matrices, due to interactions between metals or anions with organic components (Buckley et al. 2009). Further, as described in Table 1, a limit of detection for Cr(VI) was not reported in this study by Sampanpanish et al. (2006),

It is also important to note that the experimental conditions in this study exposed plants to high concentrations of chromium. Sampanpanish et al. (2006) supplied plants with 100 parts per million of Cr(VI), which is above the tolerance level for some species of plants. Therefore, uptake of chromium in plants at high initial concentrations may result in different accumulation and translocation patterns when compared to Cr(VI) at lower initial concentrations more typical of Topock soil and groundwater conditions in the areas where arrowweed is found.

Cr(VI) was also detected in the leaves of crops near a tannery by Elci et al. (2010). Tomato and fig leaves collected near the tannery contained 14% and 48% of total chromium as Cr(VI), respectively, while corn leaves and cotton leaves collected far from the tannery contained around 12% of total chromium as Cr(VI), respectively. However, during sample preparation, the leaves of the plants were not rinsed as was done in many other studies to eliminate debris or contamination from surface deposition. Therefore, while it is plausible that plants near tanneries contain elevated concentrations of Cr(VI), these concentrations may not accurately reflect concentrations of chromium accumulated specifically by absorption through roots.

The amount of time a plant is exposed or grown in soil or other media containing chromium may also affect the quantity of chromium accumulated by plant tissues. For example, Zhao et al. (2011) demonstrated that translocation of total chromium into stems of the plant increased with time. In contrast, Sampanpanish et al. (2006) observed a decreasing trend of total chromium and Cr(VI) concentrations in plants over time.

Plant age was also shown to play a role in the uptake of chromium. Choo et al. (2006) reported higher uptake of Cr(VI) in nine week old plants, followed by six and three week old plants. Choo et al. (2006) also studied the effects of uptake when chromium was supplied alone in the growth media or in the presence of other metals. As a result, the presence of copper [Cu(II)] with Cr(VI) in solution resulted in decreased uptake and accumulation of Cr(VI). This presents an additional issue in generalizing results, because of the differences in solutions provided to plants.

3. Exposure Pathway Analysis – Location of Arrowweed and Chromium Concentrations in Soil and Groundwater

To assist in the evaluation of the potential for a complete human or ecological (upper trophic level) exposure pathway to chromium in arrowweed tissue, historical soil and groundwater results and the occurrence of arrowweed in the APE were reviewed. Additional soil sampling will be conducted (as planned in the Combined Part A and B Work Plan) and the results of that investigation will be used to determine whether ecological populations are exposed.

A geographic information system was used to evaluate the co-location of arrowweed and chromium in soil and groundwater. The purpose of the effort was to identify potentially complete exposure of arrowweed to chromium concentrations greater than background in either soil or groundwater, and to assess the significance of this potential exposure pathway to human and ecological receptors.

3.1 Approach to Exposure Pathway Analysis

The potential exposure area (i.e., the location of arrowweed) in the APE was identified using the Programmatic Biological Assessment (PBA) completed “to determine any potential effect on species protected under the federal Endangered Species Act (ESA) resulting from past, present, or planned remedial and investigative activities” (CH2M Hill 2007). The PBA provides data on the location of plant communities within the APE (i.e., the area surrounding the TCS that may be affected by investigation or remediation). The location of plant communities with arrowweed listed as a dominant or understory plant were selected to identify the potential exposure area.

The potential exposure depth for arrowweed was then identified to assess the likely vertical limit of exposure. The depth of arrowweed roots (up to 20 ft bgs) was previously identified in the approved *Human and Ecological Risk Assessment of Groundwater Impacted by Activities as Solid Waste Management Unit (SWMU) 1/Area of Concern (AOC) 1 and SWMU 2* (ARCADIS 2009). This depth was applied to identify representative soil and groundwater samples.

Soil samples collected in the exposure area were identified and total chromium and Cr(VI) data from the exposure area were summarized. Well locations within the area where arrowweed may occur were identified, and the screened interval of the wells was reviewed. Wells completed in the shallow zone, alluvial aquifer with screened intervals less than 20 ft bgs were identified, and recent total chromium and Cr(VI) data from these wells were summarized. Only recent groundwater data (from May 2011 to May 2012) were reviewed.

Chromium data from soil and groundwater within the exposure area were then compared with corresponding background values. Background values were obtained from the *Soil RCRA Facility Investigation/Remedial Investigation Work Plan* (CH2M Hill 2011) for soil and from the *Revised Final RCRA Facility Investigation/Remedial Investigation Report Volume 2. Hydrogeologic Characterization and Results of Groundwater and Surface Water Investigation* (CH2M Hill 2009a) for groundwater. Concentrations exceeding background were identified and the potential exposure pathway was discussed.

3.2 Results of Exposure Pathway Analysis

In the PBA, CH2M Hill reports two plant communities that include arrowweed: arrowweed and salt cedar communities (CH2M Hill 2007). Arrowweed community is located along the river, and is not located within the boundaries of site SWMUs or AOCs. Arrowweed is also reported to be present as understory in the dense monotypic stands of salt cedar (CH2M Hill 2007) that occur at the mouth of Bat Cave Wash and along the river east of National Trails Highway. During a recent reconnaissance of the occurrence of arrowweed near the mouth of Bat Cave Wash, no arrowweed was observed as understory in the tamarisk thicket southwest of National Trails Highway (Russell 2012). Figures 1 and 2 show the location of soil samples collected to date to characterize chromium concentrations as well as the occurrence of arrowweed and salt cedar communities in the APE, and the location of AOCs.

As shown on Figures 1 and 2, soil samples collected to investigate AOCs in the APE did not extend into the arrowweed community. The AOCs are not co-located with the arrowweed community. Further, additional proposed soil sampling locations identified during the data gaps evaluation, and also depicted on Figures 1 and 2, do not overlap with the arrowweed community because no source of site-related contamination has been identified or is expected in the arrowweed community. Arrowweed does occur in small stands outside the identified arrowweed community shown on Figures 1 through 4. This is confirmed by data that are now available from more current plant surveys conducted in support of the Environmental Impact Report (EIR) (AECOM, 2011) mitigation measures (floristic survey report in preparation), as well as incidental observations of arrowweed near proposed sediment sampling location(s)[2]. Although no soil data gaps were identified in the arrowweed community, sediment data gaps were identified where arrowweed occurs in small stands but is not a dominant species (Russell, 2012). Data collected during the forthcoming soil/sediment investigation will be reviewed to evaluate the potential for a complete and significant exposure pathway via arrowweed tissue. Data gaps are discussed in Appendix C Part A of the *Soil RCRA Facility Investigation/Remedial Investigation Work Plan* (CH2M Hill 2011).

Soil samples were collected in several locations in or adjacent to salt cedar community where arrowweed may occur as understory (Figures 1 and 2). Both total chromium and Cr(VI) exceeded background in one sample at one location, AOC1-BCW6, and Cr(VI) exceeded background in one sample from a second location, AOC1-BCW4 (Figure 1). Total chromium at AOC1-BCW6 (71 milligrams per kilogram [mg/kg]) was less than twice the background value (39.8 mg/kg). Cr(VI) at AOC1-BCW6 (2.63 mg/kg) was slightly greater than three times the soil background value (0.83 mg/kg) at AOC1-BCW6, and less than twice background at AOC1-BCW4 (1.3 mg/kg). Access near AOC1-BCW6 is deterred by the density of the salt cedar and steep slopes bounding the wash. The concentration of Cr(VI) at AOC1-BCW4 is lower than at AOC1-BCW6, and the area is somewhat more accessible, though still in dense vegetation. Sampling at the remaining locations in the salt cedar community did not identify total or Cr(VI) in excess of background conditions. Current human exposure to arrowweed that may be present near AOC1-BCW4 and AOC1-BCW6 is not expected, given the very few and modest detections greater than background and that arrowweed was not observed in these areas during a recent reconnaissance (Russell 2012).

Based on data collected to date and the detailed data gaps evaluation conducted with the agencies and stakeholders, no significant current exposure pathway has been

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[2] More current vegetation maps (than those presented herein) based on data from recent vegetation surveys in the project area are in preparation. Figures in the RAWP Addendum 2 will provide more current and precise information about the distribution of arrowweed communities (arrowweed thickets and salt cedar/arrowweed thickets) in the project area. The more current vegetation survey data do not change the conclusions regarding the overlap between arrowweed communities and soil and groundwater data reviewed for this memorandum.

identified for human exposure to site-related chromium in arrowweed. This conclusion will be validated through additional soil sampling already planned in the salt cedar community at the north end of Bat Cave Wash (CH2M Hill 2011). Plant identification could be performed concurrent with the soil sampling to identify the extent of arrowweed and further refine the exposure assessment. While the pathway is currently judged to be insignificant in part due to limited accessibility, it should be noted that access to the area will be temporarily improved to allow soil sampling. The co-occurrence of chromium concentrations in groundwater with the root zone of arrowweed was also reviewed. The greatest density of arrowweed roots are typically found in the top 3 ft of soil (Hely and Peck 1964), although arrowweed roots may extend to 20 ft bgs (Alth et.al. 1991).

Wells with screened intervals within 20 ft bgs (shallow zone, alluvial aquifer) were identified based on well construction data provided in Appendix A3 of the RFI Volume 2 (CH2M Hill 2009b) and locations are depicted on Figures 3 and 4. Using this 20-ft depth criterion, wells constructed within or adjacent to arrowweed were identified and associated chromium data are provided on Figures 3 and 4. Total chromium and Cr(VI) were detected in wells screened within 20 ft of ground surface only in the East Ravine. Total chromium was detected in nine of the wells (meeting the depth criterion) that were sampled between May 2011 and May 2012, while Cr(VI) was detected in five of the wells. Both Cr(VI) and total chromium detections were very low (i.e., close to the detection limit that was typically 1 microgram per liter [µg/L]). Recent (May 2011 to May 2012) chromium data was compared with background concentrations for wells within the exposure area for arrowweed. Background concentrations were site Upper Tolerance Limits of the mean (UTLs) for total chromium (34.1 µg/L) and Cr(VI) (32 µg/L). Chromium was not detected at concentrations greater than background in recent groundwater samples from wells with screened intervals within 20 ft bgs *and* within or adjacent to arrowweed at the site (see Figures 3 and 4). Therefore, chromium concentrations available for uptake by arrowweed are considered insignificant.

3.3 Key Findings from the Exposure Pathway Analysis

Soil samples collected to investigate AOCs in the APE did not extend into the arrowweed community, but did extend into the salt cedar community where arrowweed may be present in the understory. Total chromium was detected at concentrations greater than background in one soil sample co-located with arrowweed in an area where access is deterred by steep slopes and dense salt cedar. Cr(VI) was detected at concentrations greater than background at the same location, and one additional location also in dense salt cedar. During a recent site reconnaissance, arrowweed was not observed in the areas where hexavalent chromium was detected in soil, but small stands of arrowweed plants were observed at the mouth of East Ravine where sediment sampling is planned (Russell 2012). Groundwater wells were identified within the arrowweed exposure area. Chromium was not detected in recent groundwater samples (May 2011 to May 2012) from these wells at concentrations greater than background when compared with the site UTLs for total chromium and Cr(VI).

Based on review of current soil and groundwater data, and the detailed soil data gaps evaluation conducted with the agencies and stakeholders, no significant current exposure pathway has been identified for human exposure to site-related chromium in arrowweed. Additional soil data collection already planned in the salt cedar at the mouth of Bat Cave Wash and at the mouth of East Ravine will be done to validate this conclusion.

4. Summary of Conclusions

Based on the key findings presented above for the literature review and exposure pathway analysis, the conclusions regarding the potential for exposure to Cr(VI) and/or Cr(III) via contact with arrowweed under current site conditions are as follows:

- Although studies indicate that plants can absorb Cr(VI) and Cr(III) from soil, the extent of total chromium and Cr(VI) above background concentrations in site soil does not extend to the area where arrowweed community is located. In salt cedar community in Bat Cave Wash, total chromium and Cr(VI) was detected at one location at a concentration greater than background, and Cr(VI) was detected at a second distant location at a concentration greater than background. Both locations are difficult to access due to rugged terrain and/or very dense vegetation. Further, arrowweed was not observed in these areas during a recent site reconnaissance (Russell 2012). The potential exposure pathway to groundwater in AOC 11 and the mouth of the East Ravine remains to be evaluated and will be considered in the future.

- Total chromium and Cr(VI) have not been identified at concentrations greater than background in groundwater underlying the arrowweed and salt cedar communities.

- Current site data indicates that contact with arrowweed by either human or ecological populations is unlikely to result in exposure exceeding background conditions.

- Existing soil sampling data adequately define background conditions adjacent to the location of arrowweed community; therefore, additional soil sampling for Cr(VI) or Cr(III) is not needed to refine this potential exposure pathway.

- Soil sampling already proposed in the salt cedar community in Bat Cave Wash, and plant identification will validate the exposure pathway for chromium uptake by arrowweed in the understory.

- Based on the above, exposure to chromium in arrowweed does not represent a significant pathway under current conditions. However, based on the literature review, there is the potential for plant uptake of chromium. Consistent with the approved *Human Health and Ecological Risk Assessment Work Plan* (ARCADIS 2008) and subsequent discussions with the agencies and stakeholders, we will work with the stakeholders to identify appropriate modeling methods and relevant species to estimate current and future potential exposures using current and new information from pending soil sampling and porewater/sediment sampling.

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Tables

Figures

Attachments

Tables

Table 1: Summary of Articles Included in Technical Memorandum for Hexavalent Chromium Uptake in Plants

Author	Journal	Title	Year	Growth Medium (soil, solution, etc.)	Plant type(s)	Study Objective	Analytical Method and Sample Prep	Total Cr tested for?	Cr(VI) tested for?	Cr(VI) detected in plant?	Conclusions (as cited in literature)	Comments, critiques and caveats in study methodologies and conclusions
Aldrich et al.	Environ Sci Technol	Uptake and reduction of Cr(VI) to Cr(III) by mesquite (*Prosopis* spp.): chromate-plant interaction in hydroponics and solid media studied using XAS	2003	agar & hydroponics; added K2CrO7 to both agar and hydroponic	*Prosopis spp.* [mesquite]	To investigate the possibility that mesquite can remove Cr from the environment via active transport systems to the aerial portions of the plant.	XAS was used to determine the uptake and binding of Cr(VI) in live mesquite tissue	not studied	Yes	Yes in hydroponics; No in agar	The XAS results for both the hydroponic and the agar study showed some of the supplied Cr(VI) was uptaken by the mesquite roots. The data analyses of the plant tissues grown in agar demonstrated that it was FULLY reduced to Cr(III) in the roots, stems and leafs. in contrast, the plants grown in hydroponics showed a small percent of hexavalent chromium in the roots (1.2%) and stems (6.2%), but no CrVI in the leaves.	Mesquite is an indigenous desert plant; No CrVI detected in plant tissues in agar. No controls presented for speciation work, no information on instrument sensitivity. High concentrations (80ppm) may cause some Cr(VI) to be transported thru plant and also exceed biological capacity of plant's ability to reduce Cr(VI) to Cr(III).
Arias et al.	Environ Sci Technol	Plant Growth and Metal Distribution in Tissues of *Prosopis juliflora-velutina* grown on chromium contaminated soil in presence of *Glomus deserticola*	2010	Uncontaminated soil from El Paso; CrIII and CrVI soil added w/ seed	*Prosopis juliflora-velutina* seeds [mesquite]	Determine presence of Cr in mesquite; total amylase activity recorded as an indicator of stress.	ICP-OES	Yes	No	N/A	Inoculated Cr(VI) treated plants had 21% and 30% more Cr than uninoculated and EDTA treated roots, respectively, at 80 mg Cr kg 1 treatment. In the case of Cr(III), EDTA produced the highest Cr accumulation in roots. TAA was higher in inoculated plants grown with Cr(III) at 80 and 160 mg kg-1 and Cr(VI) at 40 and 160 mg kg-1.	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Arteaga et al.	Hazardous Waste Research	Spectroscopic Confirmation of Chromium Uptake by Creosote Bush (*Larrea tridentata*) Using Hydroponics	2000	hydroponic; supplied with Cr(VI) only	*Larrea tridentata* [Creosote Bush]	To gain a better understanding of the processes through which creosote bush accumulates Cr(VI) and Cr(III) ions, and ascertain the functional chemical groups responsible for Cr binding.	Plants separated into roots, stems, leaves; digested using EPA 200.3; then Total Cr analyzed by FAAS; Cr speciation also in plant by XAS	Yes	Yes	Yes	Results indicate the roots absorbed Cr(VI) from solution, but was partially reduced to Cr(III)(that is, some of the Cr in the roots remained as CrVI). Some Cr(VI) and the reduced Cr(III) were transported through the stems (and thus there was some CrVI in the stems), and finally accumulated as Cr(III) in the leaves of the plant.	Note that only Cr(VI) was supplied; but authors measured both Cr(VI) and Cr(III) in plant tissue. This study demonstrates that high concentrations (520ppm) may exceed plant's biological capacity to reduce Cr(VI) to Cr(III). Time of exposure to Cr(VI) may also be a potential factor in how much is reduced (if experiment continued past 48 hours, would plant contain Cr(VI) in roots?). No information on instrument sensitivity; oven drying/rinsing of plant may contribute to changes in Cr oxidiation.
Banerjee et al.	Environ Pollut	Uptake studies of environmentally hazardous 51Cr in Mung beans	2008	Sand; added nutrient solution containing K2 ^{51}Cr207 and ^{51}CrNO3	*V. radiata* [mung bean]	To study the accumulation behavior of a common plant, Mung bean (*Vigna radiata*) towards Cr(III) and Cr(VI) to have an insight on the migration and bio-magnification of Cr.	The amount of 51Cr(VI) and 51Cr(III) accumulated by 10 days old seedlings was determined by gamma spectroscopic techniques.	Yes	No	N/A	The transfer of Cr(VI) from sand to plant is of the order of only about 5% (4.5-7.5 mg) and transfer does not depend on the presence or absence of phosphate ion. The accumulation of 51Cr(VI) in the Mung bean seedlings has been found mainly in the root. Cr(VI) migration as total chromium is higher than that of Cr(III).	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Bonfranceschi et al.	J Hazard Mater	Study of the heavy metal phytoextraction capacity of two forage species growing in an hydroponic environment	2009	hydroponic + CrVI	*Sorghum bicolor* [Sorghum] and *Medicago sativa* [alfalfa]	To evaluate the metal extraction capacity of sorghum and alfalfa growing in hydroponic conditions, focusing the case of Cd (II), Ni(II), Cr(VI), and Cr(III), made partially soluble by complexing (simulating what occurs in nature) with EDTA.	Metal contents in plant tissues was determined after by acidic digestion with HNO3 (c)/H2SO4 (c). The measurement of the metal content in the extracts was accomplished through AAS.	Yes	No	N/A	In alfalfa, the increases in the concentration of Cr(VI), Cd(II) and Cr(III)/EDTA, favored the translocation of total chromium to the aerial parts of the plants. In sorghum, Cr(VI) increases in the metal solution concentration lead to higher translocation of this metal.	Study measures uptake of CrVI, but measures total Cr in plant tissue.
Buendia-Gonzales et al.	Bioresource Technol	*Prosopis laevigata* a potential chromium (VI) and cadmium (II) hyperaccumulator desert plant	2010	solution + CrVI	*Prosopis laevigata* [smooth mesquite]	The aim of this work was to investigate the in vitro ability of P. laevigata (mesquite), a widely distributed species in the semi-arid and arid regions in Mexico, to remove two different heavy metals in different concentrations from the culture media, and to assess the effect of these metals uptake on the growth, morphology and survival of the plant.	The metals concentration was analyzed from those samples using an Atomic Absorption Spectrometer	Yes	No	N/A	Heavy metals did not stop germination, but smaller plants with fewer leaves and secondary roots were produced. Seedlings showed an accumulation of 8176 and 21,437 mg/kg Cd and of 5461 and 8090 mg Cr/kg dry weight, in shoot and root, when cultured with 0.65 mM Cd(II) and 3.4 mM Cr(VI), respectively. These results indicated that significant translocation from the roots unto aerial parts took place. A bioaccumulation factor greater than 100 for Cd and 24 for Cr was exhibited by the seedlings.	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Cary et al.	J Agricultural and Food Chem	Control of Cr concentrations in food plants. I. Absorption and translocation of Cr by plants.	1977	Solution: added CrVI and CrIII; Soil: added K2CrO7	Wheat (*Triticum aestivum*), corn (*Zea mays*), potato (*Solanum tuberosum*), tomato (*Lycopersicon esculentum*), pea (*Pisum sativum*), red kidney bean (*Phaseolus vulgaris*), Barley (Hordeum uulgare), beet (Beta vulgaris), buckwheat (Fagopyrum esculentum), rutabaga (Brassica napus), snap beans (Phaseolus spp.), spinach (Spinacia oleracea), and Swiss chard (Beta cicla)	The primary objective was to provide a basis for designing crop production practices that might increase the Cr concentration in food and feed crops.	Used ^{51}Cr and gamma ray spectrometry	Yes	No	N/A	There was very little translocation of any 51Cr from the roots to the tops in any species treated with the nutrient solution; CrEDTA was apparently readily translocated from the roots to the tops, but the roots removed very little Cr from the nutrient solution. For the soil experiment, CrVI only was added the soil and levels of chromium were measured in the leaves and stems of a variety of plants (e.g., spinach, Swiss chard, rutabaga, buckwheat) after between 70 and 100 days after seeding. chromium was detected in leaves and stems of plants.; SOIL: Total CR was measured in all plants; leafy vegetables appear most effective at translocating Cr to aerial parts (spinach, turnip leaves), very low transport into seeds.	Document cited in 2012 Hot Spots Draft plant uptake factor derivation for Cr. The leafy UF of 0.3 was based on this study based on a sample size of 3. Hot Spots document took the leafy UF of 0.3 and multiplied it by a factor of 10 to give us the root UF of 3.

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Author	Journal	Title	Year	Growth Medium (soil, solution, etc.)	Plant type(s)	Study Objective	Analytical Method and Sample Prep	Total Cr tested for?	Cr(VI) tested for?	Cr(VI) detected in plant?	Conclusions (as cited in literature)	Comments, critiques and caveats in study methodologies and conclusions
Choo et al.	Chemosphere	Accumulation of chromium (VI) from aqueous solutions using water lilies (*Nymphaea spontanea*)	2006	aqueous solution + potassium dichromate (CrVI)	*Nymphaea spontanea* [tropical water lilies]	Investigate the effectiveness of using water lilies to remove Cr(VI) from aqueous solutions and electroplating waste and assess the effect of Cr(VI) on some of the plant biochemical processes	Samples were digested in a mixture of HNO3 and HClO4 in the ratio of 4:1 to determine metal contents (Pickford's wet ashing method)	Yes	No	N/A	Water lilies are capable of accumulating substantial amount of Cr(VI), up to 2.119 mg g 1 from a 10 mg l 1 solution. The roots of the plant accumulated the highest amount of Cr(VI) followed by leaves and petioles, indicating that roots play an important role in the bioremediation process. The maturity of the plant exerts a great effect on the removal and accumulation of Cr(VI). Plants of 9 weeks old accumulated the most Cr(VI) followed by those of 6 and 3 weeks old. The results also show that removal of Cr(VI) by water lilies is more efficient when the metal is present singly than in the presence of Cu(II) or in waste solution.	Age of plant may play role in uptake and accumulation. Researchers concluded Cr(VI) was taken up by plant but study did not measure actual Cr(VI) concentration, but just supplied the plant with Cr(VI). Concentrations reported assume that Cr(VI) accumulated.
Dogo et al.	J Serb Chem Soc	Analysis of the bioavailability of Cr(III) and Cr(VI) based on the determination of chromium in Mentha piperita by graphite furnace atomic absorption spectrometry	2011	soil + Cr(NO3) for CrIII, and Dichromate (CrVI)	*Mentha piperita (L*. Lamiaceae) [peppermint]	Plants cultivated in the presence of varying levels of Cr(III) and Cr(VI) in order to determine its capacity to control chromium uptake and its tolerance limit.	Total Cr measured by GFAAS	Yes	No	N/A	Total chromium content in plant in general increased with soil concentration of the metal. Relatively low uptakes of Cr for all soil types and at all investigated pH values. High mobility of Cr(VI) through the plants tissues, low mobility of chromium in Cr(III) contaminated plants.	Study measures uptake of CrVI, but measures total Cr in plant tissue.
Elci et al.	J Hazard Mater	Selective extraction of chromium(VI) using a leaching procedure with sodium carbonate from some plant leaves, soil and sediment samples	2010	soil + Cr(VI)	Leaves of tomato, fig, corn, and cotton plants near tannery	To speciate chromium in various environmental samples like various vegetable plants, soil and sediment near and far from a tannery in Denizli, Turkey	Total Cr in plant: acid/H2O2 digestion; CrVI species: alkaline digestion to extract CrVI (USEPA 3060A); then analyze by GFAAS	Yes	Yes	Yes	Cr(VI) is accumulated by the plants. The contents of Cr(VI) and total chromium for growing plant leaves, such as tomato and fig leaves, in soil of land close to the leather tanning industry region are highest. No more than 14% of the total Cr present in the plant leaves, except for fig sample, under examination in this study are Cr(VI) compounds.	Note that this study is a field study, not a controlled experimental study. As stated by the authors, the study shows that some plant leaves collected near the old tannery industry used for a very long time, still have elevated levels of chromium and CrVI. Results are based on assumption that analytical method accurately extracts Cr(VI); other researchers have documented difficulties with this method. Also note: researchers did not wash leaves - potential Cr on leaf surfaces
Espinoza-Quionones et al.	Water Research	Root uptake and reduction of hexavalent chromium by aquatic macrophytes as assessed by high-resolution X-ray emission	2009	hydroponic + CrVI (as CrO3) and CrIII (as CrNO3)	ROOTS: *Salvinia auriculata* [eared water moss], *Pistia stratiotes* [water lettuce], *and Eichornia crassipes* [water hyacinth]	To investigate the Cr(VI) reduced by root-based biosorption in a chromium uptake experiment, using a high-resolution XRF technique.	Used only plant roots; analytical method: X-ray spectroscopy	Yes	Yes	No	High-resolution X-ray fluorescence emission spectroscopy provided information about the bioreduction phenomenon by measuring the Cr-Kb emission lines which involve transitions from valence states. The comparison of the high-energy region of the Cr-Kb spectra of treated plants with that of Cr(VI) and Cr(III) reference compounds showed that there is no contribution of the hexavalent oxidation state in Cr(VI)-treated plants. This indicates that reduction of hexavalent chromium occurred for all the studied living aquatic macrophytes.	Roots were exposed to low (3ppm) CrVI concentrations for 27 days; may be partial reason why results showed complete reduction of Carve to CrIII. However, no LOD for Cr is listed. Authors note how often-used chemical extraction techniques introduce probable alterations on the speciation results. Thus, X-ray spectroscopy is used, which avoids this disadvantage. Also, note that it appears that only the roots were measured, not the aerial parts of the plants.
Gardea-Torresdey et al.	Arch Environ Contamin Toxicol	Differential Uptake and Transport of Trivalent and Hexavalent Chromium by Tumbleweed (*Salsola kali)*	2005	agar: added K2CrO7 and Cr(NO3)3 (both CrVI and CrIII) in a nutrient solution	*Salsola kali* [Tumbleweed] (same class as arrowweed)	To determine the differential absorption of Cr species by tumbleweed (*Salsola kali*) as well as the effect of this heavy metal on plant growth and nutrient uptake.	oven dried, then acid digestion of pure HNO3. analysis by ICP/MS	Yes	No	N/A	Uptake of Cr was affected by species of Cr and metal concentration in medium. Hexavalent Cr resulted in concentrating of total Cr in plant tissues 10 to 20 times than if CrIII was supplied. Hexavalent form moves more easily from stems to leaves than trivalent form.	Tumbleweed is the same kingdom, phylum and class as arrowweed; found in deserts. Cr uptake could potentially be compared to arrowweed. Note however the aggressive chemical digestion step which could alter speciation.
Gheju et al.	Ovidius University Annals of Chemistry	Analysis of hexavalent chromium uptake by plants in polluted soils	2009	soil: added Cr(VI) (as K2Cr2O7 solution)	*Zea mays* [corn]	Concentration levels of Cr(VI) in contaminated soil and in Zea mays (corn) plant parts were determined and Cr(VI) bioaccumulation and bioconcentration capacity of this plant were discussed.	Dried plant parts were ashed in a furnace (600 degrees) and then digested with HCL/HNO3. Total Cr in plants and soil was then measured using a spectrophotometer	Yes	No	N/A	Total Cr concentrations in plant organs decreased in the following order: roots > stems > leaves; Zea mays roots have the greatest tendency to concentrate Cr(VI), the concentration in these plant parts being 11.7 times greater than in the surrounding soil. The translocation factor (TF), bioaccumulation factor (BAF) and the bioconcentration ratio (BCR) were determined and indicate that Cr(VI) was slowly translocated within the plant from the roots to stems, and very slowly further translocated to leaves.	Note the acid digestion technique and ashing process could potentially impact speciation? Interesting that the calculated UF (or BAF) for above ground vegetation (shoot) of 0.33 is greater than the UF recommended by OEHHA of 0.07 for protected produce (which is where corn would be classified).

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Hauschild, M	Ecotoxicology and Environmental Safety	Putrescine as an indicator of Pollution-induced stress in higher plants: Barley and Rape stressed with Cr(III) or Cr(VI)	1993	Nutrient solution + CCl3 (CrIII) or CrO3 (CrVI)	*Hordeum vulgare* [Barley seeds] and *Brassica napus* [Rape seeds]	To study the behavior of putrescine under simulated soil pollution stress, and measure chromium content in the plant.	Plant leaf or stem digested in HNO3, analyzed by AAS	Yes	No	N/A	Differences between chromium concentrations were found in plants stressed with CrVI vs. CrIII. In rape plants, chromium concentrations were 10-500 times higher when exposed to Cr(VI) than Cr(III). Concentrations of chromium found in stems of CrVI stressed rape were lower or similar to concentrations found in leaves, suggesting rapid transport of chromium to the leaves. Considering large concentrations were found in leaves of CrVI exposed rape plants, it is likely that parts of this chromium has reached the leaves in the form of CrVI and that the strong chlorotic symptoms observed are caused in part by oxidative attack on the leaf cells.	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Howe et al.	Environ Sci Technol	Localization and speciation of chromium in subterranean clover using XRF, XANES, and EPR spectroscopy	2003	hydroponic + different variations of CrIII and CrVI depending on pH	Trifolium brachycalycinum *[subterranean clover]*	To localize Cr and determine the oxidation state and possible complexation mode of Cr in intact plant tissue by means of XANES, synchrotron XRF microprobe spectroscopy, and EPR spectroscopy.	XANES, synchrotron XRF microprobe spectroscopy, and EPR spectroscopy	Yes	Yes	Yes	The uptake, translocation, and form of Cr in the plant were dependent on the form and concentration of supplied Cr. Cr was found predominately in the +3 oxidation state, regardless of the Cr source supplied to the plant, though at high Cr(VI) treatment concentrations, Cr(VI) and Cr(V) were also observed (i.e., CrVI in the roots, and CrV in roots and leaves). At low Cr(VI) concentrations, the plant effectively reduced the toxic Cr(VI) to less toxic Cr(III), which was observed both as a Cr(III) hydroxide phase at the roots and as a Cr(III)- organic complex in the roots and shoots. At low Cr(VI) treatment concentrations, Cr in the leaves was observed predominately around the leaf margins, while at higher concentrations Cr was accumulated at leaf veins. The following Cr species were identified in subterranean clover following growth in Cr(VI): (i) Cr(VI) (by XANES) in the roots at high Cr(VI) concentration in solution, (ii) Cr(V) (by EPR) in the roots and leaves at high Cr(VI) concentration, and (iii) Cr(III)-organic complexes (by EPR) in roots and leaves.	Nondestructive techniques, such as EPR spectroscopy, XANES, and synchrotron X-ray fluorescence (SXRF) microprobe spectroscopy, are useful for investigation of speciation, complexation, oxidation state, and spatial distribution of Cr. These procedures eliminate possible artifacts in the oxidation state and chemical bonding that can occur as a result of homogenization or extraction procedures. Study supports that not ALL Cr (VI) is reduced in the roots; some stays as Cr(VI) in the roots. Time of exposure is a possible variable, along with exceedance of biological capacity of plant's ability to reduce Cr(VI) to Cr(III) (in this case, 0.04mMol); any CrVI leftover may contribute to plant toxicity. No LOD provided but controls were used.
Liu et al	Bioresource Technol	Hexavalent chromium uptake and its effects on mineral uptake, antioxidant defense system and photosynthesis in Amaranthus viridis L.	2008	Hydroponic solution, with other metals, EDTA, and after 2 weeks, CrVI (Dichromate) was added	*Amaranthus viridis* L (slender amaranth)	Investigate the effects of different concentrations of CrVI on mineral uptake, activities of antioxidant enzymes, and photosynthetic parameters.	Wet digestion; total chromium measured by ICP-AES	Yes	No	N/A	Chromium accumulated primarily in roots; Cr content increased in roots and shoots with increasing CrVI concentrations, and induced decrease absorption of other metals.	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Lytle, CM	Environ Sci Technol	Reduction of CrVI to CrIII by Wetland plants: potential for in situ heavy metal detoxification	1998	Solution: added CrVI (as dichromate)	*E. crassipes* [Water Hyacinth], from San Joaquin River), and other wetland plants	Can this plant or other wetland plants reduce CrVI to CrIII and accumulate detoxified Cr into leaf and roots?	Plants were grown; given nutrient solutions w/ CrVI; plant tissues analyzed with XAS	not studied	Yes	No	This plant can absorb CrVI, and reduce it to CrIII which accumulates in plant tissues, especially in roots; authors conclude very fast reduction to CrIII, because Cr(VI) was not detected in plant tissues.	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
McGrath, SP	New Phytol	The Uptake and Translocation of Tri and Hexavalent chromium and effects on the growth of oat in flowing nutrient solution and soil	1982	Solution of CrIII and CrVI with seed; Soil with CrVI and CrIII added along w/ seeds	*Avena sativa* [Oat]	Measure uptake and translocation of CrVI and III at equal concentrations and determine relative toxicities.	Harvested after 35 days; total Cr determined by AAS; CrVI in solution determined by absorptiometric method	Yes	No	N/A	Toxicity to plants occurs when CrVI is present and pH is high; or in low pH, CrVI can be reduced to CrIII which equilibrates with soil solution (implies that CrIII is also toxic)	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Micera, G	Journal of Inorganic Biochemistry	Chromium Adsorption by Plant Roots and Formation of Long-Lived CrV species - an ecological hazard?	1988	Hydroponic + CrIII nitrate or potassium dichromate (CrVI)	*Allium sativum* [garlic]	To determine mechanism of reduction in plants	Electron Spin Resonance (ESR) Spectroscopy	Yes	Yes	Yes	Plant roots absorb CrVI but then it is partially reduced in the roots to CrIII by components inside plant (sugars, phenolics, or organic acids perhaps)	Study suggests theory of exceedance in biological capacity of plant's ability to reduce Cr(VI) to Cr(III); no LOD or controls provided. ESR may not provide accurate quantitative measurements of Cr(VI). Also mentions CrV (intermediate species)
Mishra, S	Food and Chemical Toxicology	Studies on Uptake of Trivalent and Hexavalent Chromium by Maize	1995	Soil and sand, separately (added water with CrVI and CrIII)	*Zea maize* [Corn]	To quantify amount of chromium uptake by maize (zea mays) in soil and sand, to understand key elements of oxidation and reduction and mobilization of CrIII.	Pot culture: soil and seeds, irrigated with water w/ known amounts of CrVI and CrIII in water; used radiotracers (51Cr) to measure total chromium.	Yes	No	N/A	CrIII does get taken up in roots; perhaps gets oxidized to CrVI and translocated to various parts of plant and perhaps changes back into CrIII (evidence for reduction to CrIII).	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Mishra, S	Agriculture Ecosystems and Environment	A study on uptake of trivalent and hexavalent chromium by paddy (oryza sativa): possible chemical modifications in rhizosphere	1997	Quartz sand and soil each, + nutrient solution w/ CrIII and CrVI salts	*Oryza sativa* [Paddy or rice]	Study uptake of CrIII and CrVI through irrigation water in paddy	Grow plants for 120 days in soil/sand; add Cr salts, after 7 days, harvest plant; Used radiotracer tagged chromium (51Cr) and analyzed roots, shoot and grain for chromium via gamma spectrometric assay methods.	Yes	No	N/A	CrIII is taken up less than CrVI. CrVI and complexed CrIII can be translocated, but very small amounts make it to aerial parts of plant.	uptake patterns of chromium under submerged (anaerobic) conditions thought to be different than those in soil.

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Montes-Holguin et al.	Environ Toxicol Chem	Biochemical and spectroscopic studies of the response of Convolvulus arvensis L. to chromium(III) and chromium(VI) stress	2006	hydroponic: Cr(III) (as CrNO3) or Cr(VI) (as dichromate)	*Convolvulus arvensis L.* [field bindweed or morning glory]	To determine the oxidative stress caused by Cr(VI), the chromium (Cr) uptake, and the Cr speciation in plants grown in hydroponics media containing either Cr(VI) or Cr(III)	Total Cr determination by ICP/OES; Cr speciation in plant by XAS	Yes	Yes	No	Results show that the plant absorbs Cr(VI) and reduces it to a less toxic species. No Cr(VI) detected in plant tissues.	Time is potential variable - how long does it take for the plant to reduce Cr(VI) once Cr(VI) is absorbed? No LOD information, but used controls. Results suggest plants have biological capacity to reduce Cr(VI) to Cr(III), as no Cr(VI) was detected in plants, so plant may have been able to reduce all CrVI that it was exposed to in this study.
Peralta et al.	Bull Environ Contam Toxicol	Uptake and effects of five heavy metals on seed germination and plant growth in alfalfa (*Medicago sativa L*.)	2001	agar + Cr(VI)	*Medicago sativa L.* [alfalfa]	Investigate the ability of alfalfa seeds to germinate and grow in media containing Cd(III), Cr(VI), Cu(II), Ni(II), and Zn(II) ions.	heavy metal content analyzed by FAAS	Yes	No	N/A	Heavy metal content strongly correlated with the heavy metal content in the media. In general, the ratio of the amount of metal in the shoots to the amount of metal in the roots increased with the dose; the corresponding ratios for total chromium after treatment with Cr(VI) were 27.3%, 18.4%, and 43.1%, respectively.	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Sampanpanish	Water, Air, and Soil Pollution: Focus	Chromium removal from soil by phytoremediation with weed plant species in Thailand	2006	Uncontaminated soil near tannery in Thailand; added K2CrO7 at 3 concentrations	Pluchea indica (same genus as arrowweed) and other weeds	Planted seeds in pots; add CrVI water; plant harvested @ 30, 60, 90 days; alkaline digestion and Atomic absorption	FAAS for total Cr; alkaline digestion (EPA 3060A) followed by colorimetric method (EPA 7196A) for Cr(VI) measurement	Yes	Yes	Yes	Describes CrVI specifically in pluchea; CrVI and CrIII accumulation in roots at 30, 60, 90 and 120 days; provides evidence for transport in root, stem, and leaves. Accumulations of both CrVI and CrIII reached the highest values in roots on day 30 (30mg/kg and 150mg/kg, respectively), and gradually decreased on days 60, 90 and 120. Concentration of CrVI was higher in leaves than roots at day 30 and 60 (roots: ~30mg/kg; leaves: 70mg/kg for both time periods); but no CrVI was measured in leaves at 90 or 120 days.	Difficult to extract Cr(VI) using this method. Experiment ended at a low pH (around 4) which may impact speciation of chromium (CrIII is more likely to be present at lower pH). No plant controls or LODs were presented for CrVI, although total Cr LOD was reported as 30mg/kg; high concentrations were used that may be toxic to plant.
Sawalha et al.	Microchemical J	Determination of adsorption and speciation of chromium species by saltbush (*Atriplex canescens*) biomass using a combination of XAS and ICP–OES	2005	Aqueous solutions of CrIII and CrVI added to plant material	*Atriplex canescens* [saltbush]	To determine the effect of pH on chromium (Cr) binding by native, esterified, and hydrolyzed saltbush (Atriplex canescens) biomass. In addition, X-ray absorption spectroscopy studies were performed to determine the oxidation state of Cr atoms bound to the biomass.	ICP–OES was used to analyze the samples resulted from the pH and Cr binding capacity studies. XANES was used to provide information about possible changes in the oxidation of Cr atoms bound to the biomass.	Yes	Yes (see comment)	Yes (see comment)	The results of the XAS experiments showed that Cr(VI) was reduced in some extend to Cr(III) by saltbush biomass at both pH 2.0 and pH 5.0.	This was only a binding study, conducted to understand the chemical bonding mechanism of chromium atoms in plant tissue. Many factors could affect binding. This research does not study uptake of chromium into plant tissue.
Skeffington et al.	Planta	Chromium Uptake and Transport in Barley Seedlings (*Hordeum vulgate L.*)	1976	solution + radioisotope of potassium dicrohmate or CrCl3 (CrIII)	*Hordeum vulgare* [barley] seedlings	To investigate the kinetics of Cr uptake by barley seedlings, the form of chromium within the root, and discuss the apparent block in Cr transport from roots to shoots.	Plant material dried, ashed at 450C, taken up in 2N HCL; total Cr concentration measured using an atomic absorption spectrophotometer	Yes	No	N/A	Transport of Cr up the root is very slow, accounting for the low levels of Cr in the shoots. Chromate is transported better than Cr(III) though still to a very limited extent. Apparent uptake of Cr(III) was greater than that of CrO4 2- in the roots, but more Cr appeared in the shoots when the plants was fed CrO4 2-. 51CrO,~2- for 24 h, the only Cr species extractable from the roots was CrO42-. When plants were fed 51Cr(III) under the same conditions, however, CrO4 2- was again the only species detected. Further experiments showed that this effect occurred independently of Cr(III) concentration, nor was the feeding solution the source of the CrO4 2- as none could be detected in it. These results indicate that some Cr(III) can be converted to CrO4 2- after entering the tissues. However, when roots from plants not previously supplied with Cr were ground in the presence of Cr(III) and/or CrO4 2- and the aqueous ethanol fraction subjected to electrophoresis, the Cr 3+ again could not be detected, presumably as it was adsorbed onto the residue, whereas CrO4 2- was unaffected. This strongly suggests that the apparent absence of Cr 3+ in the Cr(III)	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).
Sorensen, M. A. et al.	Environmental Pollution	Effects of pollutant accumulation by invasive weed salt cedar (Tamarix ramosissima) on the biological control agent Diorhabda elongata (Coleoptera: Chrysomelidae)	2009	Solution: 2mg/L CrVI (as CrO3)	*Tamarix ramosissima* [Salt cedar]	To quantify D. elongata (beetle) larval growth while feeding on T. ramosissima plants grown in the presence of various pollutants, including CrVI.	Salt cedar grown from cuttings, in nutrient solution; treatment solution added; acid and H2O2 digestion of plant material; analyzed using GFAAS	not studied	No	N/A	Treatment of 2mg/L of CrVI resulted in 1.90 mg/kg total Cr in plant tissue.	Study was used for GWRA HRA.
Vazquez, MD	Annals of Botany Company	Chromium VI induced structural and ultrastructural changes in bush bean plants	1987	Nutrient solution with Na2CrO4 (which is CrVI)	*Phaseolus vulgaris* [Bush Bean plants]	To establish if CrVI induced changes in structure of plant organs are consistent with hypothesis of a direct toxic action of Cr on roots and indirect effect on leaves	Bean plants grown in nutrient solution, with and without Cr; plant material analyzed by Light Microscopy and TEM (transmission electron microscopy)	See comment	See comment	See comment	CrVI in direct contact with plant cells causes membrane damage; small amounts of CrVI may reach upper parts of plant/leaves, since less damage was seen there, and Cr may exist as CrIII in these parts. Evidence for reduction in plant tissue.	Indirectly measured accumulation of CrVI by observing damage to plant organs. Did not directly measure concentrations of Cr in plant; used TEM images to assess damage to organs and therefore if CrVI or CrIII was present.

Table 1: Summary of Articles Included in Technical Memorandum for Hexavalent Chromium Uptake in Plants

Author	Journal	Title	Year	Growth Medium (soil, solution, etc.)	Plant type(s)	Study Objective	Analytical Method and Sample Prep	Total Cr tested for?	Cr(VI) tested for?	Cr(VI) detected in plant?	Conclusions (as cited in literature)	Comments, critiques and caveats in study methodologies and conclusions
Zayed and Terry	Plant and Soil	Chromium in the environment: factors affecting biological remediation	2003	soil and hydroponics (review article)	Various (review article)	-- (review article)	-- (review article)	Review	N/A	N/A	Chromium may be absorbed as Cr(III) or Cr(VI) by roots. Studies have shown that after Cr is absorbed by roots from nutrient solution as Cr(III) or Cr(VI) it is poorly translocated elsewhere and largely retained in the roots. Shoot concentrations of Cr barely exceeded one-hundredth of those in roots, regardless of the Cr species supplied. The restriction in the translocation of both Cr forms in plants to the same degree, despite the differential accumulation in roots and shoots, suggests that conversion of Cr(VI) to Cr(III) is almost certain to occur in roots. Since the predominant species of Cr in roots is Cr(III), very little translocation of Cr to the shoot is expected to occur when plants are supplied with either forms of Cr.	Used for general information
Zayed et al.	Planta	Chromium accumulation, translocation an chemical speciation in vegetable crops	1998	hydroponic	beet (Beta vulgaris L. var. crassa (Alef.) J. Helm), broccoli (Brassica oleracea L. var. Italica Plenck), cantaloupe (Cucumis melo L. gp. Cantalupensis), cucumber (Cucumis sativus L.), lettuce, radish (Raphanus sativus L.), spinach, tomato (Lycopersicon lycopersicum (L.) Karsten), and turnip (Brassica rapa L. var. rapifera Bailey)	To determine the extent to which various vegetable crops absorb and accumulate Cr(III) and Cr(VI) into roots and shoots and to ascertain the different chemical forms of Cr in these tissues.	Total Cr in plant extract measured by direct aspiration into ICP; also conducted Cr speciation in plant by XAS	Yes	Yes	No	Results suggest that plant tissues are able to convert Cr(VI) species to Cr(III) species, a conversion that almost certainly occurred in the root tissues since no Cr(VI) species were observed in roots of plants that were previously supplied with Cr(VI). There is also evidence that no conversion occurs for Cr species in the nutrient solution before absorption by plant roots. Speciation analysis indicates that Cr(VI) is converted in the root to Cr(III) by all plants tested (no CrVI was detected). Translocation of both Cr forms from roots to shoots was extremely limited and accumulation of Cr by roots was 100-fold higher than that by shoots, regardless of the Cr species supplied. In studies of Cr supplied to plants in irrigation water, uptake of both Cr species increased as the concentration of Cr in irrigation water increased with a strong correlation between plant Cr concentrations and the level of Cr in irrigation water.	Study supported by grants from PG&E and the Electric Power Research Institute. No CrVI was detected in plant roots; all CrVI was reduced to CrIII.
Zhao et al.	Metallomics	Use of synchrotron-and plasma-based spectroscopic techniques to determine the uptake and biotransformation of chromium(III) and chromium(VI) by *Parkinsonia aculeata*	2009	hydroponic + CrVI and CrIII	*Parkinsonia aculeata* [Mexican Palo Verde], a desert plant	Inductively coupled plasma optical emission spectroscopy was used to determine the total amount of Cr, micro, and macro nutrients taken up; and to determine the oxidation state and coordination environment of Cr taken up by plants treated with Cr(III) and Cr(VI).	use XAS to determine the Cr oxidation state	Yes	Yes	No	XAS data showed that Cr(VI) was reduced to Cr(III) in/on the plant roots and transported as Cr(III) to the stems and leaves. The XANES spectra demonstrate that, irrespective of the supplied Cr form, Palo Verde plant samples contained Cr(III), and no CrVI was detected.	Only CrIII was detected in plant roots, stems, and leaves (no CrVI detected), indicating all was reduced.
Zhao et al.	Int J Phytoremediation	Use of plasma-based spectroscopy and infrared microspectroscopy techniques to determine the uptake and effects of chromium(III) and chromium(VI) on *Parkinsonia aculeata*	2011	soil watered with CrNO3 (CrIII) or potassium dichromate (CrVI)	*Parkinsonia aculeata* [Mexican palo verde tree]	Objectives of this study was to determine the effects of both Cr ions on the seedlings' vigor at an early critical stage in plant development and to determine Cr uptake and tolerance by Mexican palo verde.	The total Cr and macro- and micro-nutrient uptake by MPV plants at different Cr concentrations were measured by ICP-OES. In addition, infrared microspectroscopy was employed to analyze tissue changes on Cr(III) and Cr(VI) treated plants.	Yes	No	N/A	Results of this research have shown that in MPV roots, the uptake of Cr from Cr(III) did not increase after the first month of growth; however, in Cr(VI)-treated plants, Cr in roots increased for up to three months of growth. In both cases the translocation of Cr into the stems increased with time. Results have also shown that the uptake of nutrient elements varied with time and Cr ion.	Study examines uptake of CrVI, but measures only total Cr in plant tissue (i.e., no speciation to determine the form of chromium in the plant tissue).

NOTES:

ET-AAS = electrothermal atomic absorption spectrometry
FAAS = flame atomic absorption spectrometry graphite furnace atomic absorption spectrometry
GFAAS = graphite furnace atomic absorption spectrometry
ICP = inductively couple plasma
OES = optical emission spectroscopy
XANES = X-ray absorption near edge structure
ESR = Electron Spin Resonance Spectroscopy

Table 2. Scientific Classification of Arrowweed and Other Plant Species

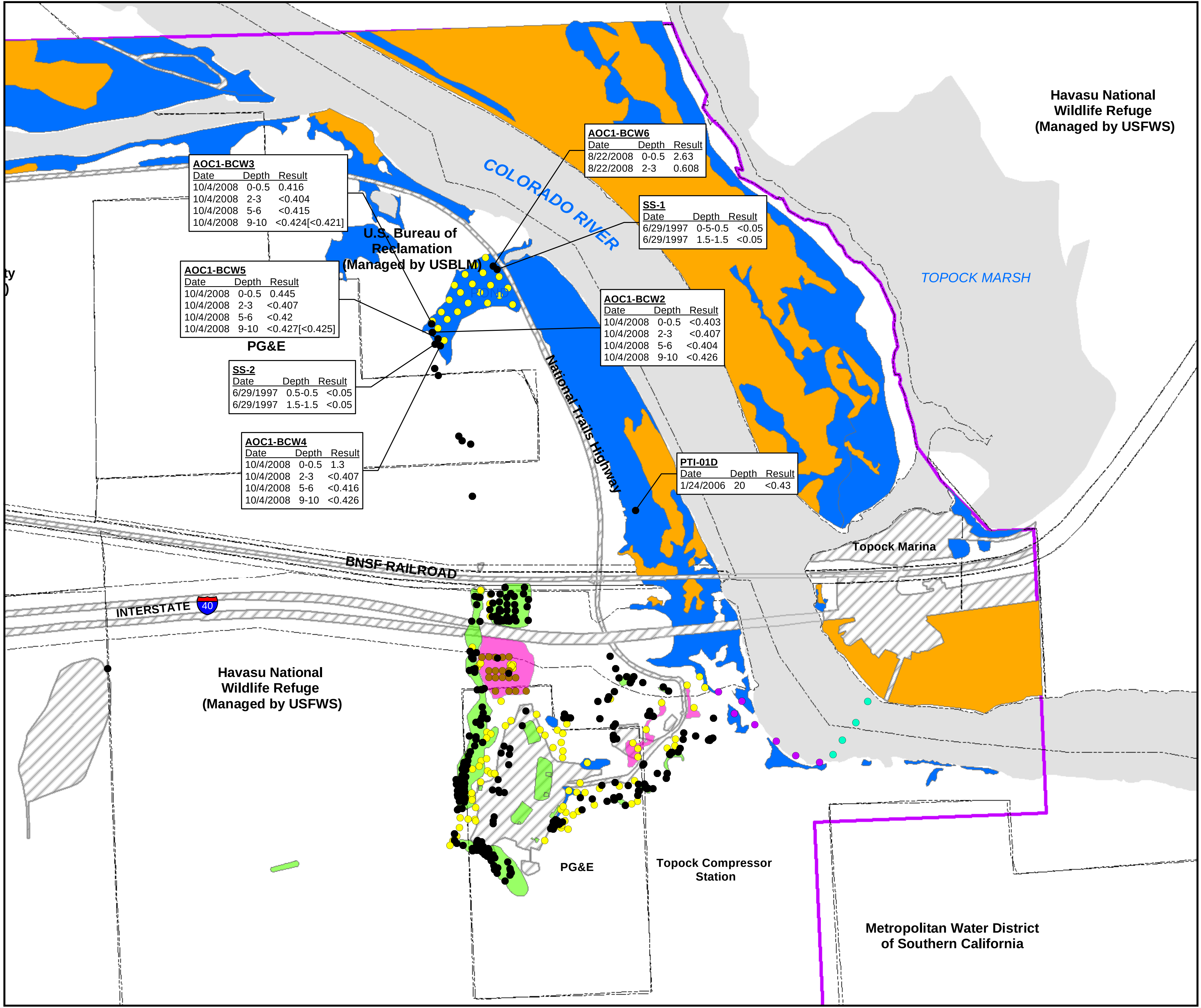
Arrowweed

Kingdom: Plante - Plants
Subkingdom: Tracheobionta - Vascular plants
Superdivision: Spermatophyta - Seed plants
Division: Magnoliophyta - Flowering plants
Class: Magnoliopsida - Dicots
Subclass: Asteridae
Order: Asterales
Family: Asteracea
Genus: Pluchea - Camphorweed
Species: Serica - Arrowweed

Other Plant Species	**Classification Group Comparison to Arrowweed**	**Source of Information**	**Authors**	**Comment**
Peppermint (*Mentha piperita*)	Subclass (Asteridae)	USDA	Dogo et al. (2011)	
Tumbleweed (*Salsola kali*)	Class (Magnoliopsida)	USDA	Gardea-Torresdey et al. (2005)	Also desert habitat. Found in most of United States (except South).
Oat (*Avena sativa*)	Division (Magnoliophyta)	USDA	McGrath (1982)	
Mung bean (*Vigna radiata*)	Class (Magnoliopsida)	USDA	Banerjee et al. (2008)	
Crops (including beets, broccoli, cucumber, radish, spinach, turnip, kidney bean, apples)	Class (Magnoliopsida)	USDA	Zayed et al. (1998), Cary et al. (1977a)	
Crops (tomatoes, potatoes)	Subclass (Asteridae)	USDA	Zayed et al. (1998), Cary et al. (1977a)	
Barley (*Hordeum vulgare*)	Division (Magnoliophyta)	USDA	Hauschild (1993)	
Rape seed (*Brassica napus*)	Class (Magnoliopsida)	USDA	Hauschild (1993)	
Slender amaranth (*Amaranthus viridis*)	Class (Magnoliopsida)	USDA	Liu et al. (2008)	
Sorghum (*Sorghum bicolor*)	Division (Magnoliophyta)	USDA	Bonfranceschi et al. (2009)	
Alfalfa (*Medicago sativa*)	Class (Magnoliopsida)	USDA	Bonfranceschi et al. (2009), Peralta et al. (2001)	
Creosote bush (*Larrea tridentata*)	Class (Magnoliopsida)	USDA	Arteaga et al. (2000)	Also desert habitat. Southwestern portion of the United States.
Paddy or rice (*Oryza sativa*)	Division (Magnoliophyta)	USDA	Mishra et al. (1997)	
Water lilies (*Nymphaea spontanea*)	Class (Magnoliopsida)	USDA	Choo et al. (2006)	
Maize or corn (*Zea maize*)	Division (Magnoliophyta)	USDA	Cary et al. (1977a), Gheju et al. (2009)	
Indian camphorweed (*Pluchea indica*)	Genus (Pluchea)	USDA	Sampanpanish et al. (2006)	
Mesquite (*Prosopis spp .*)	Class (Magnoliopsida)	USDA	Aldrich et al. (2003)	Desert habitat; indigenous desert species, found in southwestern United States.
Mesquite, smooth (*Prosopis laevigata*)	Class (Magnoliopsida)	USDA	Buendía-Gonzáles et al. (2010)	Desert hyperaccumulator plant; found in Texas.
Eared watermoss (*Salvinia auriculata*)	Subkingdom (Tracheobionta)	USDA	Espinoza-Quionones et al. (2009)	
Water lettuce (*Pistia stratiotes*)	Division (Magnoliophyta)	USDA	Espinoza-Quionones et al. (2009)	
Water hyacinth (*Eichornia crassipes*)	Division (Magnoliophyta)	USDA	Espinoza-Quionones et al. (2009), Lytle (1998)	
Subterranean clover (*Trifolium brachycalycinum*)	Class (Magnoliopsida)	USDA	Howe et al. (2003)	
Morning glory (*Convolvulus arvensis*)	Subclass (Asteridae)	USDA	Montes-Holguin et al. (2006)	
Garlic (*Allium sativum*)	Division (Magnoliophyta)	USDA	Micera and Dessì (1998)	
Saltbush (*Atriplex canescens*)	Class (Magnoliopsida)	USDA	Sawalha et al. (2005)	Desert shrub; found in western United States.
Bush bean (*Phaseolus vulgaris*)	Class (Magnoliopsida)	USDA	Vazquez et al. (1987)	
Mexican palo verde (*Parkinsonia aculeata*)	Class (Magnoliopsida)	USDA	Zhao et al. (2009, 2011)	Desert shrub/tree; found in southern United States.
Saltcedar (*Tamarix ramosissima*)	Class (Magnoliopsida)	USDA	Sorensen et al. (2009)	Desert tree; found in southwestern United States.

Note:
Plants highlighted in yellow share similar habitats to arrowweed (i.e., are found in deserts or are drought tolerant).

Figures



AOC1-BCW6

Date	Depth	Result
8/22/2008	0-0.5	2.63
8/22/2008	2-3	0.608

AOC1-BCW3

Date	Depth	Result
10/4/2008	0-0.5	0.416
10/4/2008	2-3	<0.404
10/4/2008	5-6	<0.415
10/4/2008	9-10	<0.424[<0.421]

SS-1

Date	Depth	Result
6/29/1997	0-5-0.5	<0.05
6/29/1997	1.5-1.5	<0.05

AOC1-BCW5

Date	Depth	Result
10/4/2008	0-0.5	0.445
10/4/2008	2-3	<0.407
10/4/2008	5-6	<0.42
10/4/2008	9-10	<0.427[<0.425]

AOC1-BCW2

Date	Depth	Result
10/4/2008	0-0.5	<0.403
10/4/2008	2-3	<0.407
10/4/2008	5-6	<0.404
10/4/2008	9-10	<0.426

SS-2

Date	Depth	Result
6/29/1997	0.5-0.5	<0.05
6/29/1997	1.5-1.5	<0.05

AOC1-BCW4

Date	Depth	Result
10/4/2008	0-0.5	1.3
10/4/2008	2-3	<0.407
10/4/2008	5-6	<0.416
10/4/2008	9-10	<0.426

PTI-01D

Date	Depth	Result
1/24/2006	20	<0.43

Legend:

- ● Soil Sample Location
- ● 2006 Porewater/Sediment Sample Location
- ● Contingency Sample Location
- ● Proposed Sediment and Porewater Sample Location
- ● Proposed Soil Sample Location
- 🟩 AOC/SMWU Areas
- 🟪 Other Investigation Areas
- 🟧 Arrowweed
- 🟦 Salt Cedar
- ▭ Property Boundaries
- ▭ Area of Potential Effects
- ▨ Developed Area

Notes:

1. Extent of vegetation communities from Figure 6 of the Programmatic Biological Assessment for Pacific Gas and Electric Topock Compressor Station Remedial and Investigative Actions report (CH2MHILL, 2007).
2. All hexavalent chromium concentrations are in milligrams per kilogram (mg/kg).
3. Depth of soil sample is in feet (ft).
4. Soil hexavalent chromium concentrations are only shown for samples collected from locations in or along the edge of the arrowweed or salt cedar plant communities.

[ ] - indicates duplicate sample result
< - indicates non-detect

0 730 1,460
Feet
GRAPHIC SCALE

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

HEXAVALENT CHROMIUM CONCENTRATIONS IN SOIL CO-LOCATED WITH ARROWWEED

ARCADIS

FIGURE
1

[MC-85 VJR] SANF-85 EGH
Project (RC000689.0002 Task 2)
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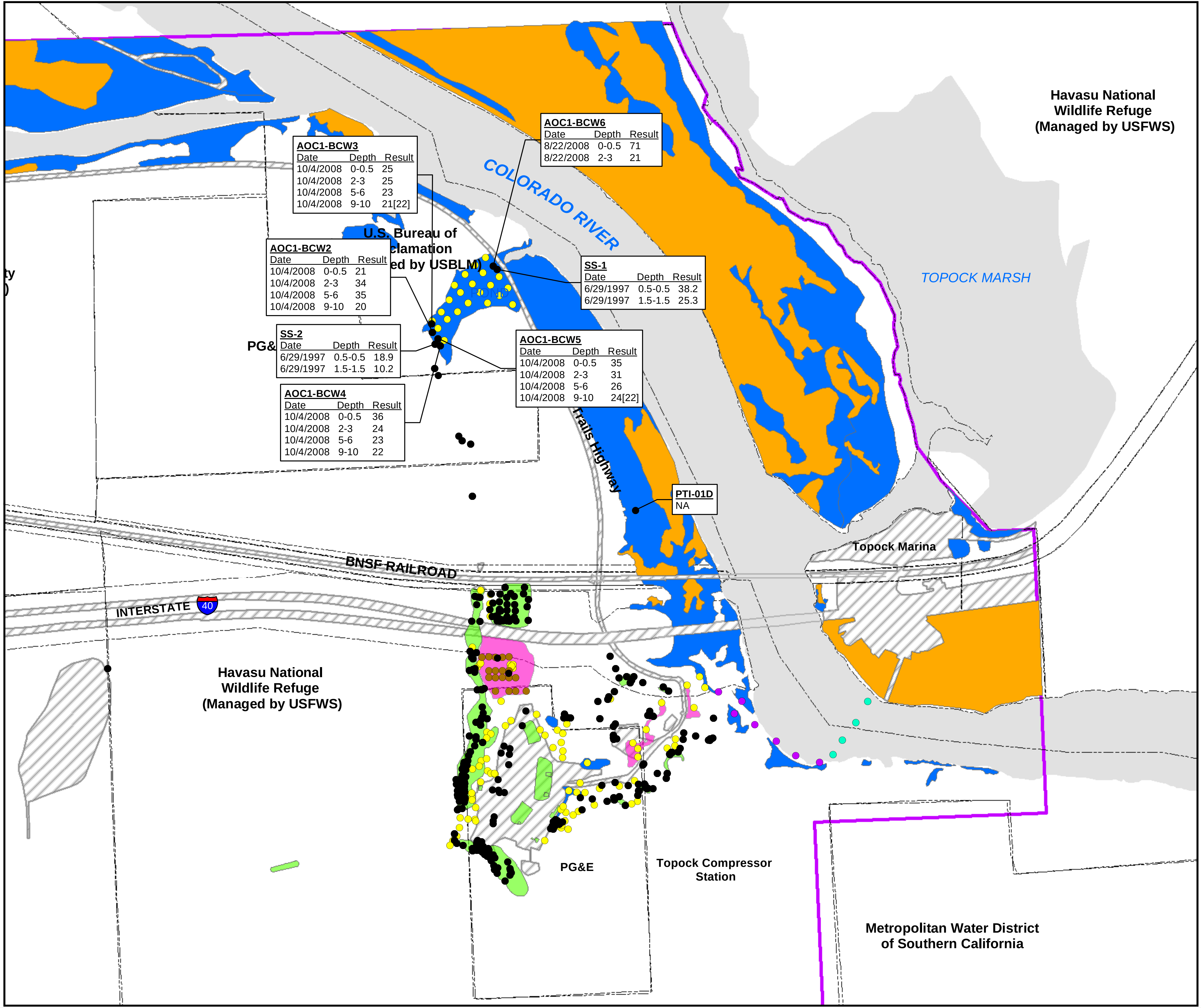

AOC1-BCW3

Date	Depth	Result
10/4/2008	0-0.5	25
10/4/2008	2-3	25
10/4/2008	5-6	23
10/4/2008	9-10	21[22]

AOC1-BCW6

Date	Depth	Result
8/22/2008	0-0.5	71
8/22/2008	2-3	21

AOC1-BCW2

Date	Depth	Result
10/4/2008	0-0.5	21
10/4/2008	2-3	34
10/4/2008	5-6	35
10/4/2008	9-10	20

SS-1

Date	Depth	Result
6/29/1997	0.5-0.5	38.2
6/29/1997	1.5-1.5	25.3

SS-2

Date	Depth	Result
6/29/1997	0.5-0.5	18.9
6/29/1997	1.5-1.5	10.2

AOC1-BCW5

Date	Depth	Result
10/4/2008	0-0.5	35
10/4/2008	2-3	31
10/4/2008	5-6	26
10/4/2008	9-10	24[22]

AOC1-BCW4

Date	Depth	Result
10/4/2008	0-0.5	36
10/4/2008	2-3	24
10/4/2008	5-6	23
10/4/2008	9-10	22

PTI-01D
NA

Legend:

- ● Soil Sample Location
- ● 2006 Porewater/Sediment Sample Location
- ● Contingency Sample Location
- ● Proposed Sediment and Porewater Sample Location
- ● Proposed Soil Sample Location
- 🟩 AOC/SMWU Areas
- 🟥 Other Investigation Areas
- 🟧 Arrowweed
- 🟦 Salt Cedar
- ☐ Property Boundaries
- ☐ Area of Potential Effects
- ▨ Developed Area

Notes:

1. Extent of vegetation communities from Figure 6 of the Programmatic Biological Assessment for Pacific Gas and Electric Topock Compressor Station Remedial and Investigative Actions report (CH2MHILL, 2007).
2. All total chromium concentrations are in milligrams per kilogram (mg/kg).
3. Depth of soil sample is in feet (ft).
4. Soil total chromium concentrations are only shown for samples collected from locations in or along the edge of the arrowweed or salt cedar plant communities.

[ ] - indicates duplicate sample result
NA - Not analyzed

0 730 1,460 Feet
GRAPHIC SCALE

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

TOTAL CHROMIUM CONCENTRATIONS IN SOIL CO-LOCATED WITH ARROWWEED

ARCADIS

FIGURE
2

[WC-85 VJR] SANF-85 EGH
Project (RC000689.0002 Task 2)
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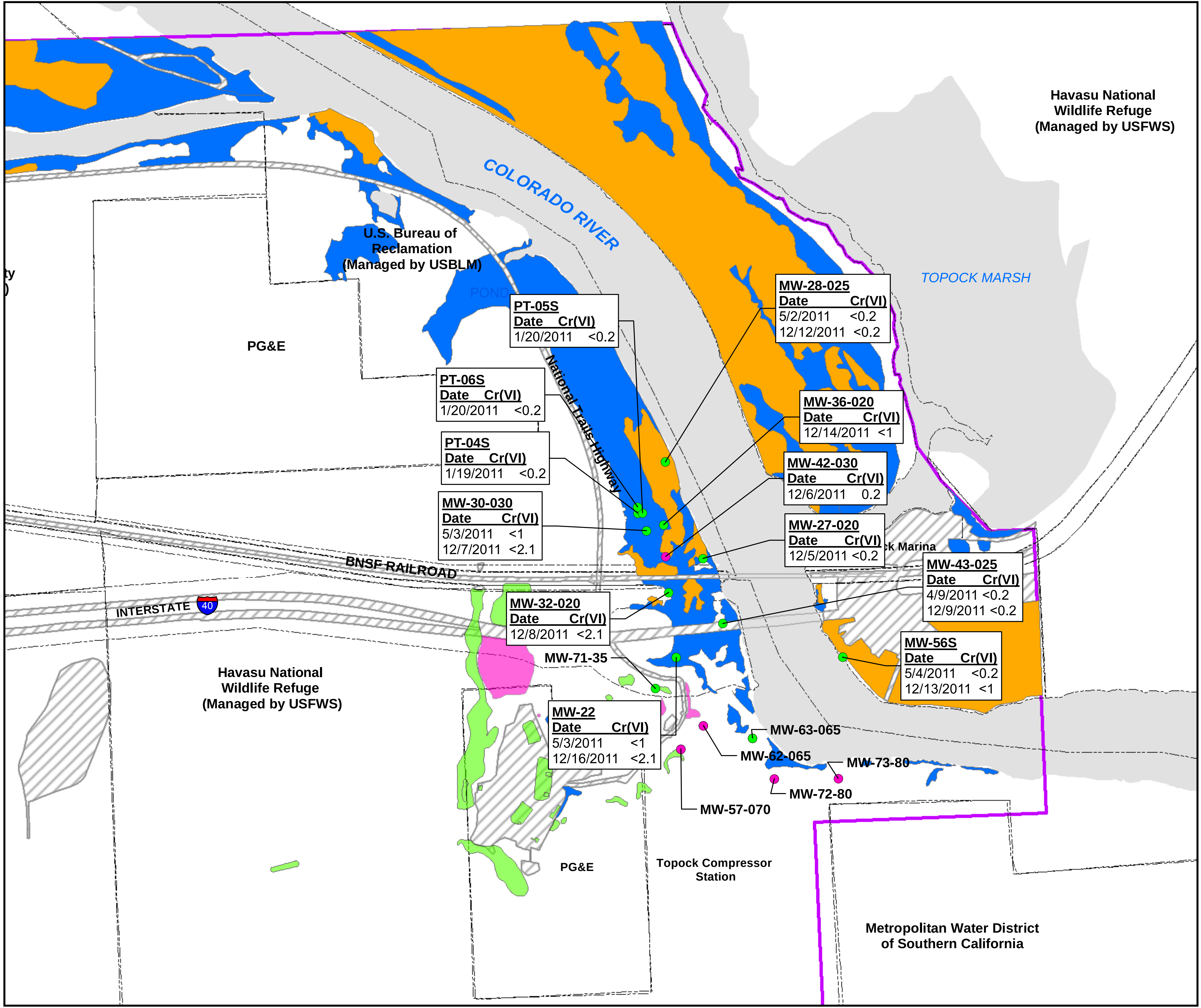


Legend:

Hexavalent Chromium Concentration (µg/L)

- ● Detected
- ● Non-Detect
- 🟩 AOC/SMWU Areas
- 🟥 Other Investigation Areas
- 🟧 Arrowweed
- 🟦 Salt Cedar
- ☐ Property Boundaries
- ☐ Area of Potential Effects
- ▨ Developed Area

Notes:

1. Extent of vegetation communities from Figure 6 of the Programmatic Biological Assessment for Pacific Gas and Electric Topock Compressor Station Remedial and Investigative Actions report (CH2MHILL, 2007).
2. Monitoring wells shown are screened at depths no greater than 20 feet below ground surface.
3. Hexavalent chromium groundwater concentrations are only shown for samples collected from wells that are located in or along the edge of the arrowweed or salt cedar plant communities.
4. The water table elevation in the flood plain is influenced by and mimics the water level in the Colorado River, which rises in the summer and falls in the winter due to Colorado River water management actions.
5. Analytical data shown are all available data from May 2011 to May 2012.

µg/L = micrograms per liter
Cr(VI) = Hexavalent Chromium
< - Indicates non-detect

0 730 1,460
Feet
GRAPHIC SCALE

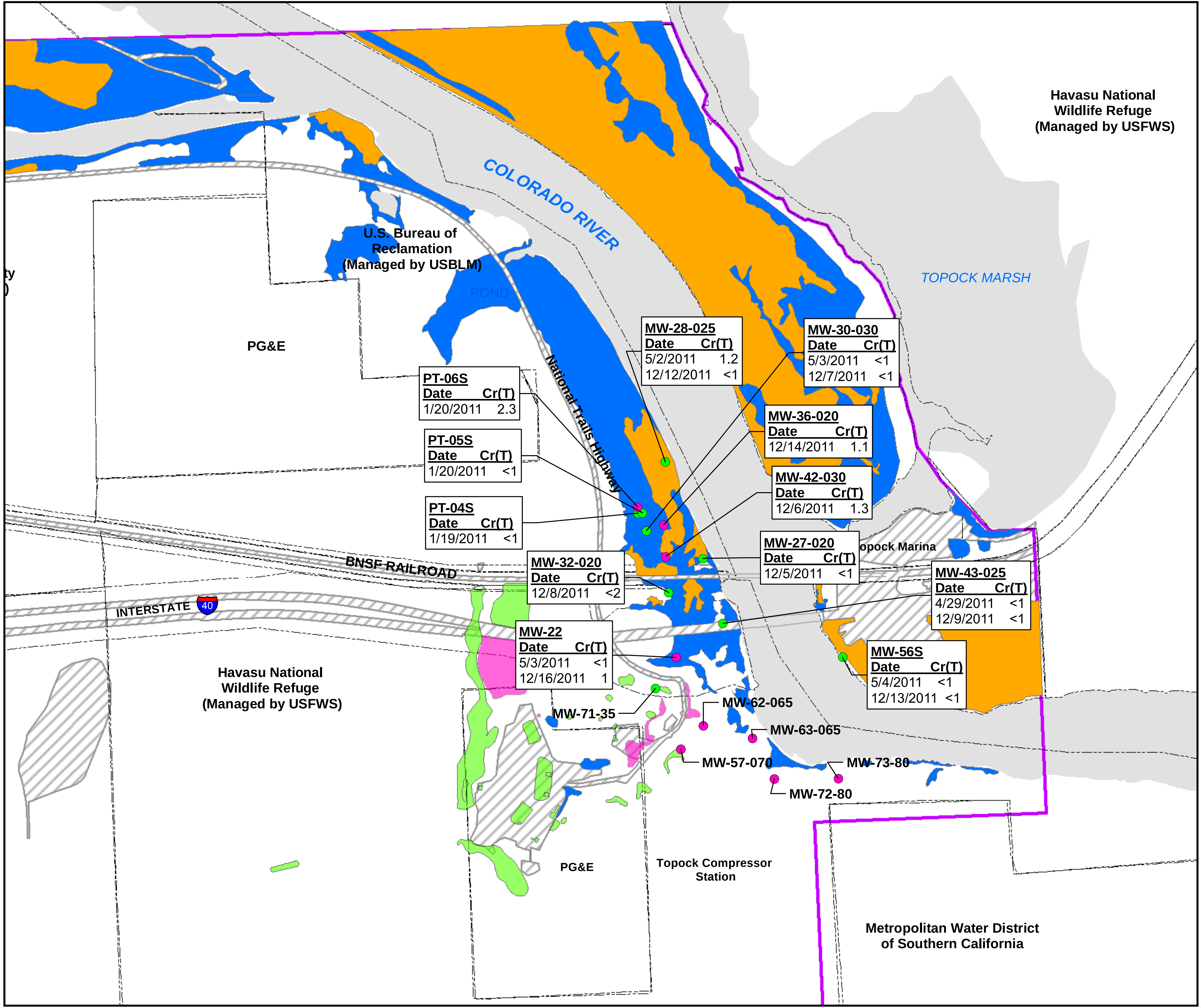
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

HEXAVALENT CHROMIUM CONCENTRATIONS IN GROUNDWATER CO-LOCATED WITH ARROWWEED

ARCADIS

FIGURE
3

[WC-85 VJR] SANF-85 EGH
Project (RC000689.0002 Task 2)
Path: Q:\PGE\Topock\ER_Evaluation\mxd\ArrowweedRiskEvaluation_CrVI_in_GW.mxd; 7/17/2012; 4:53:02 PM



Legend:

Total Chromium Concentration (µg/L)

- ● Detected
- ● Non-Detect
- 🟩 AOC/SMWU Areas
- ■ Other Investigation Areas
- 🟦 Salt Cedar
- 🟧 Arrowweed
- ▭ Property Boundaries
- ▭ Area of Potential Effects
- ▨ Developed Area

Notes:

1. Extent of vegetation communities from Figure 6 of the Programmatic Biological Assessment for Pacific Gas and Electric Topock Compressor Station Remedial and Investigative Actions report (CH2MHILL, 2007).
2. Monitoring wells shown are screened at depths no greater than 20 feet below ground surface.
3. Total chromium groundwater concentrations are only shown for samples collected from wells that are located in or along the edge of the arrowweed or salt cedar plant communities.
4. The water table elevation in the flood plain is influenced by and mimics the water level in the Colorado River, which rises in the summer and falls in the winter due to Colorado River water management actions.
5. Analytical data shown are all available data from May 2011 to May 2012.

µg/L = micrograms per liter
Cr(T) = Total Chromium
< - Indicates non-detect

0 730 1,460 Feet
GRAPHIC SCALE

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

TOTAL CHROMIUM CONCENTRATIONS IN GROUNDWATER CO-LOCATED WITH ARROWWEED

ARCADIS

FIGURE
4

[WC-85 VJR] SANF-85 EGH
Project (RC000689.0002 Task 2)
Path: Q:\PGE\Topock\ER_Evaluation\mxd\ArrowweedRiskEvaluation_CrTotal_in_GW.mxd: 7/17/2012: 4:50:40 PM

Attachment 1

Literature Review Results

1. Results of Literature Search

Relevant findings from the literature search were categorized by analytical methods used, the types of media used for plant growth, the types of plants studied, the source and type of chromium used in the study, and what type of chromium was ultimately detected in plant tissues. These findings are summarized below, including an overall discussion of the potential for chromium uptake in plants.

1.1 Analytical Methodologies

The literature search indicates that researchers used a variety of analytical methods in order to study the distribution of chromium in plants. Some analytical methods claimed that they were able to differentiate and quantify the species of chromium (hexavalent chromium [Cr(VI)] or trivalent chromium [Cr(III)]) in the plant, while other methods only quantified total chromium in plant tissues. Sample preparation also differed between research studies, including the form of chromium supplied to the plant, the growth media, cultivation time, method of extraction of chromium from the plant, and the part of the plant that was used in the analysis. Understanding these experimental components aided in interpretation of a study's results and conclusions. The following paragraphs provide an overview of analytical methods and experimental conditions reviewed during the literature search.

1.1.1 Analytical Methods for Total Chromium Determination in Plants

The methods used to determine total chromium concentration in environmental samples are atomic spectroscopic methods, such as atomic absorption (AAS), atomic emission (AES), and elemental mass spectrometry (MS). Methods commonly used in the relevant studies identified in the literature search include flame atomic absorption spectrometry (FAAS), graphite furnace atomic absorption spectrometry (GFAAS), inductively coupled plasma atomic emission spectrometry (ICP/AES), and inductively coupled plasma mass spectrometry (ICP/MS). FAAS and ICP/AES offer similar detection limits, whereas GFAAS and ICP/MS can provide a lower detection limit capability. The majority of studies identified as relevant relied on one of these types of AAS as the method for quantifying the total amount of chromium present in the plant.

Samples analyzed for total chromium generally involve an extraction step, to ensure that all chromium is separated from plant tissue before concentrations of total chromium are quantified by the analytical methods listed above. The extraction procedures vary, but usually involve acid digestion, oxidative acid digestion (i.e., hydrogen peroxide addition), and addition of heat (Peralta et al. 2001). Some researchers believe that these chemical extraction techniques may not consistently solubilize all chromium present in the sample, which may result in lower yield (Buckley et al. 2009).

Additionally, a less common technique utilized by a few authors consisted of addition of radiotracer tagged chromium (^{51}Cr) to experimental media and subsequent analysis via gamma spectrometric assay methods (Cary et al. 1977a; Mishra et al. 1995). This technique, as with those mentioned above, provides information on total chromium in the sample.

1.1.2 Analytical Methods for Chromium Speciation in Plants

In addition to total chromium determinations, speciation measurements are important to determine whether chromium exists as Cr(VI) or Cr(III) in plant tissues. Because the bioavailability and translocation of chromium is dependent on its chemical form, the development of reliable methods for identification and quantification of trace element species is critical. As indicated by the Office of Environmental Health Hazard Assessment (OEHHA), there are methodological challenges associated with estimating the actual speciation of chromium in biological tissues during analysis (OEHHA 2012). As a result, most studies only measure total chromium content of plant parts. Of the methods available, X-ray absorption spectroscopy (XAS) is a common technique for determining the speciation of chromium [e.g., Cr(VI) vs. Cr(III)] in plant tissue.

Additionally, some researchers employed other methods of speciation, which involved a Cr(VI)-specific extraction process, such as the alkaline digestion, as described in U.S. Environmental Protection Agency (USEPA) Method 3060A (Elci et al. 2010; Sampanpanish et al. 2006). According to USEPA, alkaline extraction is a procedure for extracting Cr(VI) from soluble, adsorbed, and precipitated forms of chromium compounds in solid matrices such as soils, sludges, or sediments (USEPA 1996). In this method, after Cr(VI) is separated from the sample matrix material, the concentration of Cr(VI) is determined using the analytical methods mentioned above (i.e., GFAAS or ICP/MS), or by using a colorimetric spectrophotometry method as described in USEPA Method 7196A (USEPA 1992). The concentration of Cr(III) can then calculated by subtracting Cr(VI) from total chromium concentrations (Sampanpanish et al. 2006). It has been suggested that chemical extractions may induce alterations on speciation results in samples (Lytle et al. 1998). Because of the complexity involved with chemical extraction, many authors prefer to use XAS, as this method eliminates disadvantages and potential errors induced by extraction of Cr(VI) (Espinoza-Quinones et al. 2009; Lytle et al. 1998).

1.2 Plant Species

The literature search did not identify any published articles on chromium uptake specifically in arrowweed. The strategy, therefore, was to review literature on chromium uptake in other plants, so that information on plants that may be related to arrowweed, either in terms of their scientific classification or use (e.g., desert plants and edible/medicinal plants), could be obtained and assessed for future relevancy at the site. The scientific classification of arrowweed is listed above, and Table 2 of the Technical Memorandum presents the similar scientific classifications between plant species that were used in the studies reviewed and arrowweed for contextual purposes.

Referring to the scientific classification shown above, arrowweed is an asterid, a large subgroup of flowering plants, which include many shrubs, trees, and some familiar crops. Some articles reviewed performed experiments on plants in the asterid subgroup, while other studies used plants from the broader category of *Magnoliopsida*, or dicot flowering plants. One study on chromium uptake was conducted using Indian camphorweed (*Pluchea indica*), which may be a useful comparison to arrowweed as they share the same genus and are closely related (Sampanpanish et al. 2006).

In addition, a few plants in even broader categories, such as the seed plants, shared another characteristic with arrowweed: habitat (as highlighted in Table 2 of the Technical Memorandum). For example, studies were identified and reviewed on mesquites, tumbleweed, creosote bushes, and Mexican palo verde, which are all desert/drought-tolerant plants and may share common biological mechanisms with arrowweed (Aldrich et al. 2003; Arias et al. 2010; Arteaga et al. 2000; Buendía-González et al. 2010; Gardea-Torresdey et al. 2005; Zhao et al. 2009, 2011). Further, mesquite, creosote bush, and salt cedar are plants that are found in some areas at the Topock Site along with arrowweed, and are included in the discussion below.

The findings regarding chromium uptake in various plant species provide an indication of potential uptake into arrowweed. Information on chromium uptake into produce was also noted and is presented on Table 1 (of the Technical Memorandum), as there have been questions posed by different stakeholders about uptake into homegrown produce. In addition, the U.S. Department of the Interior specifically requested that the risk assessment incorporate the assumption that their land could be used in the future for growing fruits and vegetables [and these exposure pathways were incorporated into the conceptual site model in the RAWP (ARCADIS 2008)].

Additionally, the study involving the invasive weed salt cedar (*Tamarix ramosissima*) presented in Appendix I of the *Human and Ecological Risk Assessment of Groundwater Impacted by Activities as Solid Waste Management Unit (SWMU) 1/Area of Concern (AOC) 1 and SWMU 2* (i.e., Groundwater Risk Assessment [GWRA]) (ARCADIS 2009) was reviewed for relevant content. This study was used in the GWRA as a tool for estimating uptake of Cr(VI) in groundwater into potentially relevant plant species.

1.2.1 Media for Plant Growth and Source of Chromium Used in Relevant Studies

Uptake of chromium into plant tissue is dependent on chemistry of naturally occurring chromium and various chromium compounds in soil. Chromium exists predominately in the trivalent or hexavalent form in soil. Although Cr(VI) is more soluble than Cr(III) and, therefore, more available for uptake into plants, Cr(VI) is not thermodynamically stable in soil (unless in an oxidizing environment) and is readily reduced to Cr(III) (Cary et al. 1977b). This reduction likely occurs by redox reactions with aqueous inorganic species or soil organic matter under most soil conditions (James and Bartlett 1983, as cited in Amarillo National Resource Center for Plutonium [ANRCP] 1998). Investigators have also reported that most soil systems, especially soils in high inorganic matter, can reduce Cr(VI) to Cr(III), even at pH values around and above neutrality (Bartlett and Kimble 1976; Bartlett and James 1983, as cited in Kožuh et al. 2000).

As the source of chromium (i.e., total chromium, trivalent, or hexavalent) and environmental media in which plants were grown may potentially impact results of the study, the growth media and source of chromium were identified during review of the articles. The majority of the relevant studies used soil or a hydroponic solution (see various studies in Table 1 of the Technical Memorandum) as the growth media for plants; a few studies used agar (Aldrich et al. 2003; Gardea-Torresdey et al. 2005; Peralta et al. 2001) or sand (Banerjee et al. 2008; Cary et al. 1977a, 1977b; Mishra et al. 1997).

Many of the relevant studies identified through the literature search took place in a laboratory setting, where the amount of chromium in the growth media was a known concentration or a known concentration was added to the growth media. Most relevant studies added Cr(VI) to the media in the form of potassium chromate or Cr(III) to the media, while other studies added radiolabeled ^{51}Cr to the growth media. A field study by

Elci et al. (2010) examined concentrations of chromium in plants growing in soil near a tannery, a potential source of chromium for the surrounding area (Elci et al. 2010).

1.2.2 Evidence for Chromium Uptake in Plants

From the collection of selected articles, plants were generally found to absorb chromium from the different growth media at various concentrations. Some studies specifically tested only Cr(VI) uptake and translocation, while other studies conducted experiments with Cr(VI) and Cr(III) together as total chromium, and also separately. Additionally, researchers either measured the specific form of chromium [Cr(VI) or Cr(III)] or total chromium in plant tissues, depending on their study objective and analytical method. In order to organize the information and results from the Tier I studies, these studies are categorized by the form of chromium used in the media for the plant and the form of chromium ultimately found in plant tissue. Results from the studies are presented in Table 1 of the Technical Memorandum and summarized below in two categories: 1) studies measuring only total chromium in plant tissue, and 2) studies where Cr(VI) was specifically measured in plant tissue.

1.2.3 Total Chromium in Plants Following Treatment with Cr(III) and/or Cr(VI)

Articles described in this category studied uptake of chromium [either Cr(III) or Cr(VI) or both], but ultimately measured total chromium in the plant. In other words, the results discussed below are reported as total chromium in plant tissues after uptake.

Five studies provided information regarding the relative concentration of total chromium in plant tissues depending on the form of chromium in soil, sand, agar, and solution. Đogo et al. (2011) grew peppermint plants in the presence of Cr(VI) and Cr(III) soils and found that uptake of either form of chromium was low from the soil. Results from this study also showed that plants cultivated in soil with Cr(III) had even lower concentrations of total chromium in aerial plant tissues than plants cultivated with Cr(VI) (Đogo et al. 2011). Gardea-Torresdey et al. (2005) also reported that Cr(VI) uptake by tumbleweed resulted in higher accumulation of total chromium in upper plant tissues when compared to Cr(III) uptake. Consistent with these results, an experiment on mung beans in sand by Banerjee et al. (2008) showed total chromium migration from roots to shoots was higher when plants were supplied with Cr(VI) compared to Cr(III). Hauschild et al. (1993) also detected higher total chromium concentrations in plants exposed to Cr(VI) compared with Cr(III) in an experiment with barley and rape seeds in solution;

however, McGrath (1982) reported almost equal uptake into oat plants of the two chromium species from solution.

Several studies examined the translocation of total chromium from roots to aerial plant tissues in plants exposed to either form of chromium. Results from Đogo et al. (2001) and Banerjee et al. (2008), mentioned above, observed poor translocation of total chromium from the roots to the aerial portions of the plant. Many other authors who measured total chromium in plant tissues also concluded primary accumulation of total chromium in the roots compared to aerial portions (Arteaga et al. 2000; Bonfranceschi et al. 2009; Gheju et al. 2009; Hauschild et al. 1993; Liu et al. 2008; Mishra et al. 1997; Zayed et al. 1998). Research suggests that roots of vascular plants may provide a binding mechanism for chromium absorption and adsorption, which may explain decreased concentrations of chromium in aerial portions of plants (Wallace et al. 1976). Further, consistent with results from Đogo et al. (2011), Banerjee et al. (2008) reported the amount of total chromium in the roots represented only about 5% of the Cr(III) or Cr(VI) originally supplied.

Differences in uptake based on concentrations of Cr(VI) and/or Cr(III) supplied in media were also investigated by some authors. For example, Peralta et al. (2001) and Liu et al. (2008) reported that the ratio of total chromium in shoots to chromium in roots generally increased with dose of Cr(VI) in agar and nutrient solution, respectively. Some researchers, however, reported no difference in uptake of chromium when concentrations were increased in experimental media (Buendía-González et al. 2010).

A few other researchers conducted experiments using hydroponic media and measured total chromium in plant tissues. Choo et al. (2006) found that mature water lilies take up a substantial amount of Cr(VI) from hydroponic solution, with 50 to 60% of total chromium accumulation in the roots, and the rest in leaves and petioles. These researchers also concluded that the age of the plant may play an important role in uptake of Cr(VI); three, six, and nine week old lilies were collected and exposed to a Cr(VI) solution for seven days, resulting in higher Cr(VI) concentrations in roots, petioles, and leaves of the nine week old lilies than the six and three week old plants (Choo et al. 2006).

A study by Buendía-González et al. (2010) in a desert hyperaccumulator plant (smooth mesquite) observed significant translocation of total chromium to aerial portions of the plant after treating seedlings in Cr(VI) solution for 50 days. Another hydroponic study on salt cedar conducted by Sorensen et al. (2009) found that after supplying 2 milligrams per liter of chromium trioxide solution to plants, an average concentration of 1.89 milligrams per kilogram (mg/kg) of elemental chromium was detected in plant tissue.

Cary et al. (1977a) investigated total chromium uptake from solution in a variety of food crops. These researchers found that several crops (e.g., wheat, potato, barley, spinach, and others) are able to take up both Cr(VI) and Cr(III) anywhere from 2 to 73% of the original concentration in solution, depending on the chemical complex, concentration of chromium treatment, and plant species. The ratio of total chromium detected in the tops of the plant compared to the roots, however, was very small (between 0.01 and 0.03), which is consistent with the overall conclusions from studies mentioned above. The study by Cary et al. (1977a) was used by OEHHA in developing the uptake factors presented in OEHHA's Air Toxic Hot Spots Risk Assessment Guidelines (OEHHA 2012)[3]. Additionally, OEHHA cites a study by Srivastava et al. (1994), which concluded that 10% of Cr(VI) supplied to plant roots was found in aerial portions of the plant as total chromium and, therefore, OEHHA recommends that the uptake factor (UF) for the root is 10 times that of the leafy UF (OEHHA 2012). The percentage of total chromium that exists as Cr(VI) in plant tissues is currently not accounted for in the OEHHA guidance; specifically, the recommendation in the OEHHA guidance is that the UFs that were calculated for total chromium be applied to Cr(VI).

Based on studies mentioned above, plants have the ability to absorb chromium from their growth media, perhaps at higher concentrations when supplied in the form of Cr(VI). Generally, data indicate that absorbed chromium, Cr(III) or Cr(VI), is poorly translocated to aerial portions of plants as relatively higher concentrations of total chromium were detected in roots. Although the articles discussed in this section did not determine the species of chromium in the plant tissues, it has been suggested that one reason for poor translocation is due to reduction of Cr(VI) to Cr(III), which is considered less mobile than Cr(VI) due to chemical interactions and ion exchange within the plant (Becquer et al. 2003; Elci et al. 2010; Skeffington et al. 1976; Zayed and Terry 2003).

1.2.4 Uptake, Translocation, and Ultimate Measurements of Cr(VI) in Plant Tissues

This section describes articles in which Cr(VI) was specifically measured in plant tissues. Concentrations of Cr(VI) were supplied in soil or solution, and then analytical

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[3] Note that the OEHHA (2012) Hot Spots Guidance document is still in DRAFT form.

methods were used to measure levels of Cr(VI) in plant tissues. Additionally, some of these researchers determined the concentration of Cr(III) concentrations in plant tissues, because Cr(VI) is said to reduce to Cr(III) as mentioned above.

A field study by Elci et al. (2010) using crops located near a tannery in Turkey detected concentrations of Cr(VI) in leaves of tomato and fig plants (percentages of total chromium and Cr[VI] were 14 and 48%, respectively). The same study, however, also tested cotton and corn leaves farther from the tannery, which contained much lower concentrations of Cr(VI) (Elci et al. 2010). This result may be due to the close proximity of the crops to chromium contamination from the tannery or differences in plant species.

As mentioned previously, one of the articles in the literature review includes a study conducted on *Pluchea indica*, or Indian camphorweed (Sampanpanish et al. 2006). This particular study is potentially more relevant for understanding chromium uptake in arrowweed because *Pluchea indica* shares the same genus as arrowweed (*Pluchea sericea*). Sampanpanish et al. (2006) grew *Pluchea indica* in uncontaminated soil from a Thailand tannery, added 100 parts per million Cr(VI) solution, and analyzed roots, stems, and leaves for Cr(VI) (using alkaline digestion and spectrophotometry), Cr(III), and total chromium. No initial Cr(VI) was detected in soil background before addition of Cr(VI) solution, suggesting that total chromium existed as Cr(III). Results showed total chromium accumulated in the roots, stems, and leaves at day 30 at 27%, 38%, and 35% of the total chromium mass uptake, respectively. Cr(VI) concentrations increased from roots to leaves (maximum concentration occurred at 30 days at around 30 and 73 mg/kg in roots and leaves, respectively). Over time, however, Cr(VI) concentrations fell below the detection limit due to dilution by plant growth and, therefore, Cr(VI) was not detected in stems or leaves at 90 or 120 days (Sampanpanish et al. 2006). Consistent with studies mentioned above, Cr(III) was detected at much lower concentrations in all samples of leaves than Cr(VI), indicating that the plant's ability to translocate Cr(III) is not as efficient as for Cr(VI) (Sampanpanish et al. 2006). As discussed below, it is important to note that the ultimate pH conditions of the soil in this study were fairly acidic (i.e., 3.8). Such acidic soils may not be representative of the natural soil conditions at the site which range from 7.48 to 10.49. Consequently, the applicability of this study to the site is questionable.

A few studies in the literature review included plants that share similar habitats to arrowweed (i.e., are desert habitants or drought-resistant). For example, in a hydroponic study on creosote bush (which is a plant found in some areas of the Topock site), Arteaga et al (2000) treated the plant with Cr(VI) and subsequently analyzed roots, stems, and leaves for Cr(VI) using XAS (total chromium was also measured using FAAS, mentioned previously). Data indicated that stems of the plant contained some Cr(VI) and Cr(III), but the leaves contained only Cr(III) (Arteaga et al. 2000). In another study, mesquite, an indigenous desert plant also found in some areas at the Topock site, researchers concluded that although the mesquite roots absorbed Cr(VI) from hydroponic solution, only a small percent of Cr(VI) was present in plant roots (1.2%) and stems (6.2%), and no Cr(VI) was detected in the leaves (Aldrich et al. 2003). According to several sources, a plausible explanation for this observation is that a percentage of Cr(VI) is likely reduced to Cr(III) in the roots, and Cr(III) is considered less mobile than Cr(VI) due to chemical interactions and ion exchange within the plant (Becquer et al. 2003; Elci et al. 2010; Shanker et al. 2005; Skeffington et al. 1976; Zayed and Terry 2003).

Partial reduction of Cr(VI) to Cr(III) in other plant species studied by researchers has also been documented. These observations are based on detections of both Cr(VI) and Cr(III) in subterranean clovers (Howe et al. 2003) and garlic (Micera and Dessì 1988). Vazquez et al. (1987) analyzed bush bean plant tissue using transmission electron microscopy and concluded that small amounts of Cr(VI) may reach aerial portions of the plant; however, Cr(III) was believed to be the primary form in aerial parts. This author, however, did not directly measure the concentration of chromium, but rather assessed presence of Cr(VI) in the plant by observing damage to plant tissues (Vazquez et al. 1987). Sawalha et al. (2005) conducted a binding study by adding Cr(VI) and Cr(III) to plant biomass (as opposed to cultivating plants in chromium-treated media). Analysis of plant material by XAS showed partial reduction of Cr(VI) to Cr(III). Although this study does support reduction of Cr(VI) to Cr(III) in plant tissue, the results do not consider interactions that may occur between soil and roots. Results from Micera and Dessi (1988), Howe et al. (2003), Arteaga et al. (2000), and Aldrich et al. (2003) also suggest the potential for a threshold mechanism, where plants can reduce Cr(VI) to Cr(III) up to a certain concentration.Additionally, several hydroponic studies were identified where only Cr(III) was detected in plant tissues in plants cultivated with Cr(VI) and/or Cr(III). For example, an experiment on wetland plant roots supplied with both Cr(VI) and Cr(III) in solution reported no detection of Cr(VI) in plant root tissue (Espinoza-Quinones et al. 2009). Lytle et al. (1998) studied Cr(VI) uptake and reduction in water hyacinth, another wetland plant, in solution. Data from XAS analysis indicated the presence of only Cr(III) in leaf, petiole, and root tissues. Zayed et al. (1998), in addition to measuring total chromium as mentioned above, also used XAS in hydroponic solution for various crops and concluded that all Cr(VI) was reduced to Cr(III) in the roots as no Cr(VI) was detected in the roots. Zayed et al. (1998) also reported that translocation from roots to shoots among a variety of vegetable plants was extremely low, because Cr(III) is not as mobile as Cr(VI). Similar observations were reported by Montes-Holguin et al. (2006) – no Cr(VI) was detected in morning glory plants grown in a hydroponic solution supplied with either Cr(III) and Cr(VI). Further, two studies in this category were conducted in mesquite and Mexican palo verde, which are both desert plants. Aldrich et al. (2003) analyzed uptake of Cr(VI) by mesquite in agar as well as hydroponic solution (mentioned above) by XAS. Although plants grown in the hydroponic solution contained small amounts of Cr(VI) in stems and roots, no Cr(VI) was detected in any plant tissues grown in agar. Similarly, Zhao et al. (2009) did not detect Cr(VI) in Mexican palo verde plant tissues; only Cr(III) was found in plant roots, stems, and leaves.

In summary, according to the review of the articles in this section, most of the studies support that the majority of Cr(VI) that was actually taken up by the plant did not migrate to aerial parts of the plant, but was mostly present in the roots. Further, chromium in the roots was largely present as Cr(III), and in some cases, plant tissues contained Cr(III) only. The quantity of Cr(VI) that a plant is able to reduce to Cr(III) depends on several factors including pH of medium, concentration of chromium in medium and plant, presence of enzymes and other ions, soil type, and plant type.

A few articles reviewed reported oxidation of Cr(III) to Cr(VI) in soil and possibly in plants in small amounts (Bartlett and James 1988; Mishra et al. 1995; Skeffington et al. 1976). As pointed out by Barlett and James (1988), depending on availability of organic acids from plant roots, oxidation of Cr(III) to Cr(VI) may increase absorption by plant roots, as Cr(VI) is more mobile.

1.3 Data Used in CalEPA's OEHHA Air Toxic Hot Spots Program Risk Assessment Guidelines

As mentioned above, OEHHA's draft guidance on UFs for Cr(VI) in edible plants (i.e., homegrown produce) is based on several published articles that quantify chromium uptake (OEHHA 2012). In the previous guidance document (2000), OEHHA used transfer coefficient data from Baes et al. (1984) and adjusted for the wet weight of the plant part and wet weight of soil by Clement Associates (1988) to derive plant UFs. Baes et al. (1984) estimated a soil-to-plant transfer coefficient for total chromium based principally on analysis of literature references and comparisons of observed and predicted elemental concentrations in foods. For chromium, the soil-to-plant transfer coefficients were derived from three different studies: one with pumpkins and pumpkin vines from East Tennessee; one with leaves, seeds, roots, and stems from sedge grass and nut grass; and one with sweet corn, field corn, and grain from fields where sewage sludge had been applied. The recommended root UF was 0.001, and the recommended leafy UF was 0.0008 in the previous guidance document. Although the empirical data from these studies measured only total chromium (no speciation), OEHHA recommended these values be applied to Cr(VI) as well.

In the updated February 2012 draft document, OEHHA created a database to assemble the data and calculate UFs (document does not indicate why they now created this database). The references cited in the new draft document for Cr(VI) UFs are not mentioned in the previous document. The updated leafy UF of 0.3 was based on a study by Cary et al. (1977a) based on observations using lettuce, spinach, and buckwheat that were grown for extended periods in Cr(VI)-supplemented nutrient solutions. Only total chromium was ultimately measured in the different tissues. The root UF is not based on any quantitative data; OEHHA used the leafy UF of 0.3 and multiplied it by a factor of 10 to derive a root UF of 3. OEHHA cites Srivastava et al. (1994) as the basis of the factor of 10, where it was observed that roughly 10% of the chromium added as Cr(VI) to soil was incorporated in the above-ground plant parts, with the remainder incorporated into roots and bulbs and that the difference between above-ground and root chromium was also reflected by a 10-fold greater concentration of chromium in roots compared to above-ground plant parts.

Plant Tissue	Previous OEHHA UF	New OEHHA UF
Root	0.001	3
Leafy	0.0008	0.3
Ratio Root to Leafy	1.25	10

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Appendix F

Memorandum from Mr. Sullivan on Use of Tribal Land

MEMORANDUM

DATE: March 14, 2012

TO: Pamela Innis/DOI
Aaron Yue/DTSC

FROM: Michael Sullivan/Consultant for Fort Mojave Indian Tribe
Eric Rosenblum/TRC

SUBJECT: Development of Tribal-Specific Land Use Risk Assessment

Members of the Fort Mojave, Hualapai, and Cocopah Indian Tribes met, along with consultants Leo Leonhart, Eric Rosenblum, and Michael Sullivan, to discuss the details for developing a Tribal-specific land use scenario in the soils risk assessment for the Topock Compressor Station cleanup. This memorandum summarizes the discussion and recommendations from that meeting.

Introductory Comments

The issue of the land and Tribal activities on any plot of land on or near the Topock site are sensitive in nature because they deal with spiritual issues that are at the core of Indian religious beliefs. The sensitivity of these issues not only includes the beliefs regarding the land and the actions Tribal members may undertake, but also extends to the discussion of such beliefs and actions. In order to maintain the highest level of respect for Tribal cultures and values, the discussions regarding the issue of developing a Tribal-specific land use risk assessment are general or generic in nature. However, the level of detail is sufficient to develop the needed quantitative aspects of a risk assessment.

The Topock Maze and the surrounding area is sacred to the Tribes and has been contaminated by PG&E actions. However, it is not just to this localized area that Tribal concern is focused but extends to all boundaries of the Mojave Valley. The day-to-day spiritual practices of the Tribes include reference to all lands within view of the Topock Maze and surrounding area.

It is exactly this broad view of the environment that makes the ongoing desecration of the Topock Maze and surrounding areas by PG&E, DOI and DTSC unacceptable. The mere presence of activities in this area that are not of a respectful and sacred nature constitutes a disturbance. The Tribal members do not need to be physically present at the site in order to be impacted by this desecration but may be present spiritually and be aware of, and impacted by, the contamination and these activities.

The recommendations contained in this memorandum represent the consensus of the above-mentioned Indian Tribes. With one voice we insist that Tribal-specific land use scenario become the primary consideration in any soil cleanup program.

Tribal Activities at the Topock Maze and Surrounding Area

Generic types of Tribal-use activities that could occur at the Topock Maze and surrounding area are presented. These activities are the basis for the quantitative soil risk assessment parameters proposed in the following section.

Three categories of Tribal activities are presented in the bullet list with following discussion. These three activities represent the range of reasonably anticipated Tribal uses:

- Tribal group activities
- Tribal educational activities
- Tribal member individual visits

Tribal Group Activities-Several times during the year Tribal members may meet at the site for times of group prayer and reflection. An example of this is the annual National Day of Prayer in which the Fort Mojave Indian Tribe and other tribes participate. The duration is short and formal group activities would be expected to last approximately an hour. Individuals could themselves remain for a longer time in the area (see discussion of Tribal member individual visits).

Tribal Educational Activities-As part of the education of Tribal students and young people, school or other youth classes may come to the area to learn about its importance and spiritual significance. These visits may last for up to 2 hours and could occur several times during an individual's time as a student, e.g., once in elementary school and once in high school. Individual students would only be at the site for the duration of the educational activity.

Tribal Member Individual Visits-As part of the practice of their religion and culture, to pay homage to the area and to honor their ancestors, individual Tribal members may go to specific locations within the Mojave Valley for quiet time and reflection. As there are numerous locations where these visits can take place, the Topock Maze and surrounding area would be expected to be visited on a regular but infrequent basis. In addition, as this is an individual practice, some Tribal members may choose to visit physically and others to visit spiritually. However, this practice would be expected to continue throughout the entire adult life of a Tribal member.

It is equally important to define those activities that do not occur as part of any Tribal land use of the Topock Maze and surrounding area. The confidence that these activities are not part of Tribal use is based on the knowledge that when in this area, Tribal members have entered a sacred and important religious area and therefore behave with a reverence and decorum while there. Because of this strongly-held belief Tribal members do not harvest or use any plants, do not dig into or remove any soil or rocks, and do not capture and use any animal or animal products. Therefore, these activities are excluded from the Tribal-specific land use risk assessment. The living aspects of the area remain important to the Tribes and it is expected that the ecological risk assessment will be used to ensure their appropriate protection.

An additional activity, not considered relevant to the soil risk assessment but potentially relevant to the groundwater risk assessment, is the collection of arrow-weed along the banks of the Colorado River. This activity of the Hualapai Tribe has been suspended due to the presence of the contamination. However, this concern would be related to sediment pore water concentrations, which are related to migrating groundwater, not uplands soil. If the collection of river bank plants were continued, the time spent in the area and potential soil-related exposures through dust inhalation are covered by the proposed exposure durations in the next section.

Recommended Tribal-Specific Land Use Risk Assessment Parameters

The following bullet list represents the recommended parameters to be used in the Tribal-specific land use risk assessment. These parameters quantitatively describe the Tribal member individual visits land use described above, as this represents the use with the greatest potential exposure. All other potential exposures would be lower than this use and are therefore covered by its inclusion in the risk assessment.

- Duration in years: 60
- Duration in visits/year: 12
- Duration in hours/visit: 2
- Route of exposure: Inhalation of dust derived from contaminated soil
- Inhalation rate: 0.83 m^3/hour
- Body weight: 70 kg
- Averaging Time: 25,550 days for carcinogens; 21,900 for noncarcinogens

Concluding Comments

This memorandum has presented the importance of the Tribal-specific land use risk assessment and the recommended parameters that could be used to complete the needed calculations. The discussion has been provided in as much detail as necessary while still remaining generic in nature to respect Tribal sensitivity and privacy regarding the discussion of this topic. The Tribes hope that DOI and DTSC will treat this issue in a respectful manner and instruct PG&E and its risk assessment consultants to do the same. The above-mentioned Tribes look forward to discussing this with the agencies and completing the Tribal-specific land use risk assessment in a timely manner.