Topock Project Executive Abstract

Document Title: Final Groundwater Corrective Measures Study/Feasibility Study Report for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California Submitting Agency: PG&E Final Document? ☒ Yes ☐ No	Date of Document: December 16, 2009 Who Created this Document?: (i.e. PG&E, DTSC, DOI, Other) PG&E
Priority Status: ☒ **HIGH** ☐ **MED** ☐ **LOW** Is this time critical? ☒ Yes ☐ No Type of Document: ☐ Draft ☒ Report ☐ Letter ☐ Memo ☐ Other / Explain:	Action Required: ☒ Information Only ☐ Review & Comment Return to: N/A By Date: ☐ Other / Explain:
What does this information pertain to? ☐ Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA)/Preliminary Assessment (PA) ☐ RCRA Facility Investigation (RFI)/Remedial Investigation (RI) (including Risk Assessment) ☒ Corrective Measures Study (CMS)/Feasibility Study (FS) ☐ Corrective Measures Implementation (CMI)/Remedial Action ☐ California Environmental Quality Act (CEQA)/Environmental Impact Report (EIR) ☐ Interim Measures ☐ Other / Explain:	Is this a Regulatory Requirement? ☒ Yes ☐ No If no, why is the document needed?
What is the consequence of NOT doing this item? What is the consequence of DOING this item? The CMS/FS is a step in the site cleanup process that evaluates various remedial strategies to remediate impacted groundwater. Without this step, remedial strategies either may not be implemented or may be implemented without evaluating the most beneficial options.	Other Justification/s: ☐ Permit ☐ Other / Explain:

Brief Summary of attached document:

The Final CMS/FS Report has been prepared pursuant to the requirements in Section IV.C of the RCRA Corrective Action Consent Agreement, Section 9.3 of the CERCLA Administrative Consent Agreement, and the approved CMS/FS Work Plan. The Final CMS/FS Report has been modified in response to agency and stakeholder comments on the Draft CMS/FS Report.

The CMS/FS report presents the identification and evaluation of various remedial alternatives to address the remedial action goals for groundwater contamination associated with the historic discharges to Bat Cave Wash (SWMU 1/AOC1) and within AOC 10 (East Ravine) at the PG&E Topock Compressor Station. The CMS/FS includes a description of current conditions, remedial action objectives, identification and screening of remedial technologies, and development and evaluation of remedial action alternatives.

Nine alternatives were identified:

- Alternative A - No Action

- Alternative B - Monitored Natural Attenuation
- Alternative C - High Volume *In Situ* Treatment
- Alternative D - Sequential *In Situ* Treatment
- Alternative E - *In Situ* Treatment with Fresh Water Flushing
- Alternative F - Pump and Treat
- Alternative G - Combined Floodplain *In Situ* / Pump and Treat
- Alternative H - Combined Upland *In Situ* / Pump and Treat
- Alternative I - Continued Operation of Interim Measure

The alternatives above were defined to a sufficient level of detail to develop remedial cost estimates, in accordance with USEPA guidance for feasibility studies. The alternatives are evaluated against the threshold and balancing criteria of RCRA and CERCLA.

Written by: PG&E

Recommendations:

DTSC and DOI review and provide approval.

How is this information related to the Final Remedy or Regulatory Requirements:

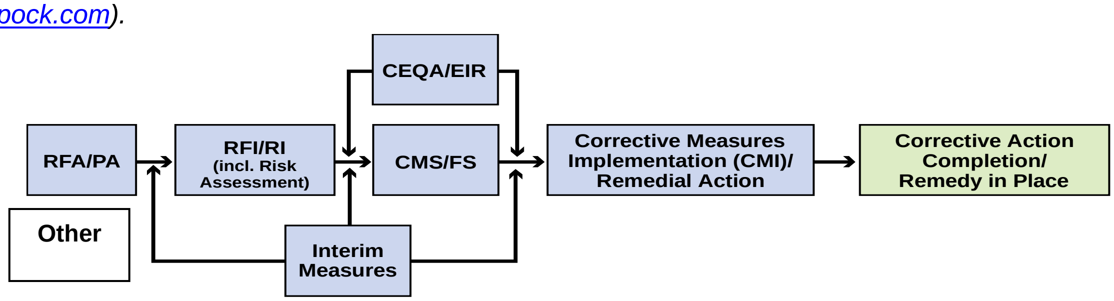
CMS/FS is a step in the site cleanup process that evaluates various remedial strategies to be used in the final remedy.

Other requirements of this information?

The CMS/FS incorporates remedy evaluation requirements of both RCRA and CERCLA.

Related Reports and Documents:

Click any boxes in the Regulatory Road Map (below) to be linked to the Documents Library on the DTSC Topock Web Site (www.dtsc-topock.com).



Legend

RFA/PA – RCRA Facility Assessment/Preliminary Assessment
RFI/RI – RCRA Facility Investigation/CERCLA Remedial Investigation (including Risk Assessment)
CMS/FS – RCRA Corrective Measure Study/CERCLA Feasibility Study
CEQA/EIR – California Environmental Quality Act/Environmental Impact Report

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December 16, 2009

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Subject: **Final Groundwater Corrective Measures Study/Feasibility Study Report for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California**

Dear Mr. Yue and Ms. Innis:

This letter transmits the *Final Groundwater Corrective Measures Study/Feasibility Study Report for SWMU 1/AOC 1 and AOC 10 at the Pacific Gas and Electric Company (PG&E), Topock Compressor Station* (Final CMS/FS Report). This final report incorporates the results of over six months of discussions between PG&E, the California Department of Toxic Substances Control (DTSC), and the Department of the Interior (DOI) to resolve more than 500 comments received from stakeholders and agencies on the January 2009 draft report and the November 2009 redline final report. The comment resolutions are memorialized in Appendix C of this report.

PG&E looks forward to receiving the agencies' approval of this Final CMS/FS Report, as this is an important milestone that enables the project to move forward towards final remedy selection and implementation.

Please do not hesitate to contact me at (805) 234-2257 with any questions or comments regarding this submittal.

Sincerely,

Yvonne Meeks

Yvonne Meeks
Topock Project Manager

c: Karen Baker, DTSC
Christopher Guerre, DTSC
Rick Newill, DOI
Laura Kaweski, DTSC
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Final Report

Groundwater Corrective Measures Study/ Feasibility Study Report for SWMU 1/AOC 1 and AOC 10

PG&E Topock Compressor Station Needles, California

Prepared for

Pacific Gas and Electric Company

December 2009

Prepared by

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Certification

Final Groundwater Corrective Measure Study/Feasibility Study Report for SWMU 1/AOC 1 and AOC 10

PG&E Topock Compressor Station Needles, California

Prepared for California Department of Toxic Substances Control and United States Department of the Interior

on behalf of Pacific Gas and Electric Company

December 2009

This report was prepared under supervision of a California Professional Engineer

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CH2M HILL Project Manager

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CH2M HILL Site Manager

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Acronyms and Abbreviations

µg/L	micrograms per liter
°F	degrees Fahrenheit
AOC	Area of Concern
APE	Area of Potential Effect
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
BLM	United States Bureau of Land Management
BOR	United States Bureau of Reclamation
CACA	Corrective Action Consent Agreement
CCR	California Code of Regulations
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
CMS/FS	corrective measures study/feasibility study
COC	constituent of concern
COPC	constituent of potential concern
Cr(III)	trivalent chromium
Cr(T)	total chromium
Cr(VI)	hexavalent chromium
DOI	United States Department of Interior
DTSC	California Environmental Protection Agency, Department of Toxic Substances Control
E&E	Ecology and Environment, Inc.
EIR	environmental impact report
gpm	gallons per minute
GWRA	groundwater human health and ecological risk assessment

HI	health index
HNWR	Havasu National Wildlife Refuge
IM	Interim Measure
IRZ	*in-situ* reactive zone
MCL	maximum contaminant level
mg/L	milligrams per liter
MNA	monitored natural attenuation
NCP	National Contingency Plan
O&M	operation and maintenance
OWS	oil/water separator
PG&E	Pacific Gas and Electric Company
POTW	publicly owned treatment works
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RFI/RI	Resource Conservation and Recovery Act facility investigation/remedial investigation
SWFL	southwestern willow flycatcher
SWMU	Solid Waste Management Unit
TDS	total dissolved solids
USC	United States Code
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
UTL	upper tolerance limit
VOC	volatile organic compound
Water Board	California Regional Water Quality Control Board

1.0 Introduction

This corrective measures study/feasibility study (CMS/FS) addresses chromium in groundwater at the Pacific Gas and Electric Company (PG&E) Topock Compressor Station. The purpose of this document is to identify and evaluate remedial alternatives and to provide the basis for the selection of a recommended alternative to address the defined objectives for this remedial action. The existing chromium contamination in groundwater near the compressor station is largely attributable to the historical wastewater discharge from compressor station operations to Bat Cave Wash, designated as Solid Waste Management Unit (SWMU) 1/Area of Concern (AOC) 1, and within the East Ravine, designated as AOC 10. Other cleanup actions at the Topock Compressor Station that may be required due to other historical operations at the compressor station are not within the scope of this document and will be addressed in subsequent documents as appropriate.

Figure 1-1 illustrates the site cleanup process. The CMS/FS is a crucial step in this process. As is shown in Figure 1-1, the step prior to the CMS/FS is the Resource Conservation and Recovery Act (RCRA) facility investigation/remedial investigation (RFI/RI). This step includes a risk assessment and characterizes the nature of and threat posed by hazardous substance releases. The CMS/FS step then identifies and evaluates remedial alternatives and allows for selection of a remedial alternative, and the corrective measures implementation/ remedial action step implements the selected remedial alternative.

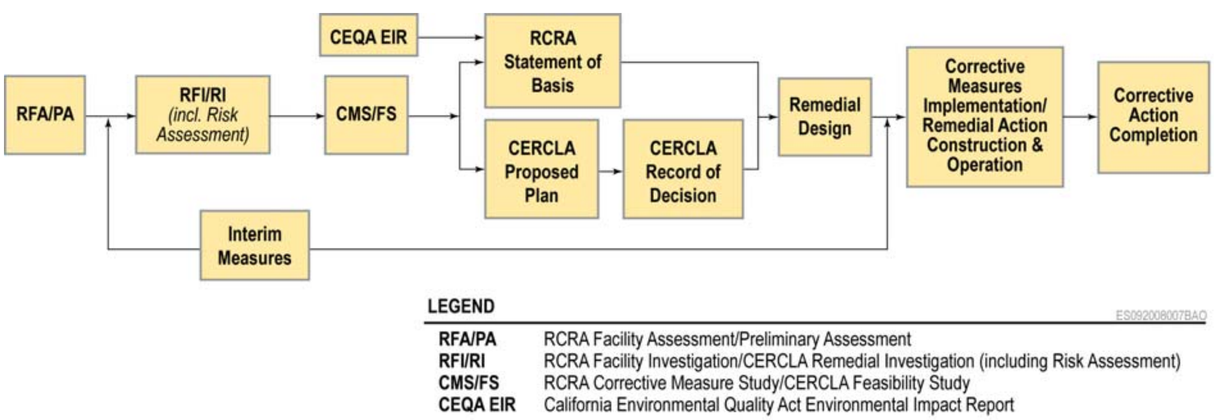

FIGURE 1-1
Site Cleanup Process
Groundwater Corrective Measures Study/Feasibility Study Report for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

The action being taken to address chromium in groundwater near the compressor station is referred to in this CMS/FS as the “remedial action,” which is intended to be equivalent to RCRA Corrective Action and Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) terminology of “corrective measure,” “corrective action,” or "response action." The remainder of this section provides project background information, project objectives, and the content and organization of this CMS/FS.

1.1 History of Investigative and Remedial Activities at the Topock Compressor Station

The California Environmental Protection Agency, Department of Toxic Substances Control (DTSC) is the state lead agency overseeing corrective actions at the compressor station in accordance with RCRA Corrective Action. The United States Department of the Interior (DOI) is the lead federal agency overseeing response actions addressing the release of hazardous substances on or from land under its jurisdiction, custody, or control near the compressor station pursuant to CERCLA.

The investigative and remedial activities at the Topock Compressor Station are being performed in accordance with a Corrective Action Consent Agreement (CACA) between PG&E and DTSC, dated February 1996 (DTSC, 1996), as well as an Administrative Consent Agreement between PG&E and DOI, the United States Bureau of Land Management (BLM), United States Fish and Wildlife Service (USFWS), and United States Bureau of Reclamation (BOR) (collectively, the "federal agencies"), dated July 2005 (DOI, 2005).

Investigative and remedial activities at the Topock Compressor Station date back to the 1980s with the identification of SWMUs through a RCRA facility assessment. Closure activities of former hazardous waste management facilities at the compressor station were performed from 1988 to 1993. The RFI began in 1996 with the signing of the CACA, and numerous phases of data collection and evaluation have been performed as of the date of this CMS/FS. Since 2005, investigative and remedial activities have been performed in accordance with the requirements of both RCRA Corrective Action and CERCLA.[1]

1.1.1 RCRA Facility Investigation/Remedial Investigation

The *Revised Final RCRA Facility Investigation and Remedial Investigation Report, Volume 1 – Site Background and History* (CH2M HILL, 2007a) was completed in August 2007 and was subsequently approved by DTSC (2007) and DOI (2007a). The RFI/RI Volume 1 Report contains information on compressor station operations; history; and descriptions of SWMUs, AOCs, and other undesignated areas. The RFI/RI Volume 1 Report identifies the SWMUs, AOCs, and other undesignated areas at the Topock Compressor Station to be carried forward in the RFI/RI characterization phase, as shown in Figure 1-2. An addendum to RFI/RI Volume 1 will be prepared in the future.

The *Revised Final RCRA Facility Investigation and Remedial Investigation Report, Volume 2 - Hydrogeological Characterization and Results of Groundwater and Surface Water Investigations* (CH2M HILL, 2009a) was completed in February 2009 and was approved by DTSC (2009a) and DOI (2009a). The RFI/RI Volume 2 report contains information on the hydrogeologic characterization and results of groundwater, surface water, pore water, and river sediment

[1] Pursuant to the Administrative Consent Agreement between PG&E and the federal agencies, remedial actions at the site must comply with the requirements of CERCLA and the National Oil and Hazardous Substances Pollution Contingency Plan in Title 40 of the Code of Federal Regulations Part 300.

investigations to evaluate and characterize the historic discharge of wastewater from the PG&E Topock Compressor Station to the former percolation bed in Bat Cave Wash (SWMU 1/AOC 1) and injection well PGE-8 (SWMU 2). Based on site history and characterization data, the RFI/RI Volume 2 report recommends that SWMU 1/AOC 1 (the former percolation bed in Bat Cave Wash and area around the former percolation bed) be carried forward from the RFI/RI into the CMS/FS (CH2M HILL, 2009a). Based on site history and site characterization data, SWMU 2 (Inactive Injection Well PGE-8) will not be carried forward into this CMS/FS An addendum to the RFI/RI Volume 2 report confirmed the conclusions of the RFI/RI Volume 2 Report (CH2M HILL, 2009b); the addendum was completed in June 2009 and was approved by DTSC (2009b) and DOI (2009b).

In November 2009, PG&E completed the *Final Human Health and Ecological Risk Assessment of Groundwater Impacted by Activities at Solid Waste Management Unit (SWMU) 1/Area of Concern (AOC) 1 and SWMU 2, Topock Compressor Station, Needles, California* (ARCADIS, 2009) that evaluated potential risks to human health and ecological receptors associated with groundwater and surface water affected by historical discharges to SWMU 1/AOC 1 and SWMU 2 to supplement the RFI/RI Volume 2 Report. The risk assessment provides information to assist risk management decision making about the constituents of concern in groundwater and surface water and risk-based concentrations of those constituents. DTSC and DOI approved the risk assessment in December 2009 (DTSC 2009c, DOI 2009c).

Subsequent to the RFI/RI Volume 2 and Volume 2 Addendum, PG&E completed additional hydrogeologic and groundwater characterization activities in the East Ravine (AOC 10). The additional hydrogeologic and groundwater characterization in the East Ravine has been incorporated into the conceptual site model for this remedial action. The results of the East Ravine groundwater investigation are provided as Appendix A to this report and additional investigation is planned for this area as outlined in the last section of Appendix A.

Following completion of additional investigations at the site, PG&E will prepare RFI/RI Volume 3. RFI/RI Volume 3 will include final characterization data to complete the RFI/RI requirements for remaining Topock Compressor Station operations, including the results of investigations of the other SWMUs, AOCs and undesignated areas. To supplement RFI/RI Volume 3, PG&E will also prepare a risk assessment that evaluates potential risks to human and ecological receptors that could be exposed to constituents at the other AOCs and undesignated areas at the Topock Compressor Station. A separate CMS/FS and/or an addendum to this CMS/FS will be prepared for additional media and SWMUs/AOCs at the Topock Compressor Station, if appropriate, based on the conclusions and recommendations in RFI/RI Volume 3 and associated risk assessment.

Applicable or relevant and appropriate requirements (ARARs) for the Topock site have been identified through an iterative process. A preliminary list of ARARs was issued by DOI in December 2007 (DOI, 2007b), updated in June 2008 (DOI, 2008a) and updated again to reflect comments submitted on the Draft CMS/FS (DOI, 2009d). The ARARs for the Topock site are listed in Appendix B of this CMS/FS.

This document addresses groundwater contamination resulting from the historic discharge of wastewater to the percolation beds in Bat Cave Wash, as well as groundwater contamination within the East Ravine. The area of the chromium plume is approximately 175 acres. Concentrations of total chromium (Cr[T]) in groundwater are greater than federal and

California regulatory standards, and concentrations of hexavalent chromium (Cr[VI]) in groundwater exceed background levels (there are no federal or California regulatory standards for Cr(VI) in groundwater). The groundwater risk assessment has concluded that Cr(VI) is present in groundwater at concentrations that could pose a potential hazard to the future hypothetical groundwater user, if the groundwater were to be used in the future as a potable source of water. The RFI/RI Volume 2 Report and Volume 2 Addendum concluded that, in addition to Cr(VI), three constituents in groundwater—namely molybdenum, selenium, and nitrate—may be associated with SWMU 1/AOC 1; however, the groundwater risk assessment concluded that these three constituents were not present in groundwater at levels of potential concern to future human health or the environment (ARCADIS, 2009).

DTSC and DOI, however, concluded that although the noncancer hazards associated with these constituents are much lower than those associated with Cr(VI), these constituents do have risks above a hazard index (HI) of 1 and they do contribute to a hazard quotient greater than 1 at localized areas within the plume. The agencies directed that molybdenum, selenium, and nitrate be monitored in the groundwater monitoring program and their associated impacts be considered in future soil and soil to groundwater risk evaluations (DTSC 2009c, DOI 2009c).

1.1.2 Interim Measures, Treatability Studies, and Other Relevant Studies

PG&E has been implementing an Interim Measure (IM) at the site since March 2004. Implementation of the IM is expected to continue until a final corrective action/remedial action for the site is operating properly and successfully and the regulatory agencies terminate the requirement for IM. The Interim Measure at the Topock site has held various designations since 2004 as IM No. 1, IM No. 2, and IM No. 3, which are collectively referred to in this report as the Interim Measure or IM. The IM currently consists of (1) groundwater extraction for hydraulic control of the groundwater plume in the Colorado River floodplain, (2) treatment of extracted groundwater in a groundwater treatment plant, and (3) reinjection of treated water through groundwater injection wells.

Concurrent with the RFI/RI, risk assessment, ARARs development, and IM implementation, PG&E has collected data and has implemented several studies to assist in the identification, screening, and evaluation of remedial technologies. These studies include:

- Extensive data collection as part of the IM to evaluate groundwater extraction, *ex-situ* groundwater treatment, and groundwater injection.
- Groundwater-level measurements, hydraulic testing, and groundwater modeling to determine the direction and rate of groundwater movement to support design and operation of extraction and injection wells.
- Anaerobic core testing of floodplain (fluvial) sediments to evaluate the capacity of anaerobic zone materials to chemically and biochemically reduce Cr(VI) to trivalent chromium (Cr[III]).
- Aerobic core testing to evaluate the degree of sorption or other interactions between Cr(VI) in groundwater and the aquifer material in the aerobic zone.
- Soil borings and seismic surveys to determine depth to bedrock.

- Groundwater model calibration updates to estimate cleanup times for various scenarios and to model simulations to predict effects of *in-situ*, pump/inject, and barrier wall technologies.
- *In-situ* pilot testing to evaluate site-specific effectiveness of *in-situ* treatment, longevity of reactants, ability to distribute reactants in the subsurface, and to assess potential effects of injected reagents on aboveground treatment systems. The effectiveness of *in-situ* reduction is being evaluated through pilot testing in both the fluvial aquifer in the floodplain and the Alluvial Aquifer in the upland portion of the site.
- A chromium isotope study to evaluate whether isotopic signatures of chromium could be used to distinguish anthropogenic from naturally occurring Cr(VI) in groundwater.

Data and information collected for the RFI/RI and during implementation of the IM, as well as the data and information collected from the above studies, are used in this document to identify and evaluate remedial alternatives.

1.2 Description and History of SWMU 1/AOC 1 and AOC 10

This document addresses the substances released into the environment from past discharges of wastewater into the Former Percolation Bed (SWMU 1) and the area around the Former Percolation Bed (AOC 1) within Bat Cave Wash near the Topock Compressor Station. This document also addresses groundwater within East Ravine (AOC 10). The following presents a description and history of SWMU 1/AOC 1 and AOC 10, summarized from the RFI/RI Volume 1 (CH2M HILL, 2007a), and the *Revised Work Plan for the East Ravine Groundwater Investigation, Topock Compressor Station, Needles, California* (CH2M HILL, 2008a).

SWMU 1 was formerly the site of wastewater percolation within Bat Cave Wash. AOC 1 is defined as areas affected by flow of wastewater from the percolation bed, including the floor of Bat Cave Wash in the area surrounding the location of the discharge area (SWMU 1) and the floor of Bat Cave Wash downstream from the discharge area towards the Colorado River. From 1951 to 1970, facility wastewater was discharged to this area and was allowed to percolate into the ground and/or evaporate. In addition, there have been several incidental releases of facility wastewater, a few of which have resulted in wastewater released to Bat Cave Wash, as described in the RFI/RI Volume 1 Report (CH2M HILL, 2007a).

Wastewater discharged to Bat Cave Wash consisted primarily of cooling tower blowdown (about 95 percent) and a minor volume of effluent from an oil/water separator (OWS) and other facility maintenance operations (about 5 percent). From 1951 until 1964, cooling tower blowdown was not treated prior to being released to the wash. During that period, the cooling tower blowdown contained Cr(VI). From 1964 to 1969, the cooling tower blowdown was treated with a one-step system to reduce Cr(VI) in the wastewater to Cr(III) prior to discharge to the wash. Beginning in late 1969, cooling tower blowdown was treated with a two-step system to reduce Cr(VI) to Cr(III) and then to remove Cr(III) from the wastewater prior to discharge to Bat Cave Wash. The continuous discharge of wastewater to Bat Cave Wash ceased in May 1970 when injection well PGE-08 was brought online. From May 1970 to September 1971, however, some treated wastewater may have been temporarily discharged to the percolation bed in Bat Cave Wash when injection well PGE-08 was offline for repairs or maintenance. All wastewater discharges to the percolation bed in Bat Cave Wash stopped when the first of four single-lined evaporation ponds was installed in September 1971. Since 1989, industrial wastewater from the compressor station has been disposed at Class II (double-lined) evaporation ponds.

AOC 10 (East Ravine) is located southeast of the compressor station, and includes four subareas, designated as AOC 10a, 10b, 10c, and 10d. Subarea 10a is the location of the termination of a storm drain leading from the southeastern portion of the compressor station. The remaining subareas are locations within the East Ravine where water and sediment have collected within low areas or behind one of three earthen embankments. Two historical aerial photographs of this portion of the site show a low area within the AOC 10c subarea that apparently contained liquids behind the largest embankment. While the composition of such liquids is not known, it is noted that this is the location of some of the highest chromium concentrations detected in site soil sampling. Thin layers of white powdery material have also been identified in the East Ravine area that are visually similar to the white waste layers located in Bat Cave Wash and the Railroad Debris Site (DTSC, 2008a). Drainage to this ravine includes minor runoff from the access road to the facility, runoff from the mountains to the south, and some runoff from the compressor station.

1.3 CMS/FS Report Objectives and Organization

The *Final Corrective Measures/Feasibility Study Work Plan, Topock Compressor Station, Needles, California* (CMS/FS Work Plan) (CH2M HILL, 2008b) was completed in March 2008 and was approved by DTSC (2008b) and DOI (2008b). The CMS/FS Work Plan conceptually describes the planned activities and schedule to complete the CMS/FS at the PG&E Topock Compressor Station in accordance with the requirements of RCRA Corrective Action and CERCLA.

This document is the CMS/FS for the remedial action addressing groundwater contamination associated with SWMU 1/AOC 1 and AOC 10 at the PG&E Topock Compressor Station. The purpose of this document is to identify and evaluate remedial alternatives and to provide the basis for the selection of a recommended alternative to address the defined objectives for this remedial action. This document is based on the conclusions and recommendations in the RFI/RI Volume 2 Report and Addendum (CH2M HILL, 2009a-b), groundwater risk assessment (ARCADIS, 2009), and results of the East Ravine investigation (Appendix A). This document has been prepared pursuant to the requirements in Section IV.C of the CACA (DTSC, 1996); Section 9.3 of the Administrative Consent Agreement (DOI, 2005); and the approved CMS/FS Work Plan (DTSC, 2008b; DOI, 2008b).

The Draft CMS/FS Report was originally published in January 2009[2] (CH2M HILL 2009c). In letters dated March 20, 2009 and March 26, 2009, DOI and DTSC provided comments to the January 2009 CMS/FS Report, and also forwarded comment letters from five stakeholder entities (DOI, 2009e; DTSC, 2009d). On June 2, the BLM also forwarded comments from three Native American tribes (BLM, 2009). This Final CMS/FS Report has been modified in response to these comments; responses to agency and stakeholder comments on the Draft CMS/FS Report are provided in Appendix C-1. A revised CMS/FS Report was sent to DTSC

[2] The Draft CMS/FS report included specified information as directed by DTSC in late 2008 (DTSC 2008c-d), as well as changes in response to letters from the Fort Mojave Indian Tribe dated January 12, 2009 and the Colorado River Indian Tribe dated January 9, 2009.

and DOI in November 2009 (CH2M HILL, 2009d), and additional agency review followed; this Final CMS/FS Report has been further modified in response to these additional comments, as outlined in Appendix C-2. Resolution of comments was a joint effort between PG&E and its contractors, including CH2M HILL; DTSC staff; DOI staff and its contractors; and the DOI Solicitor's office. As documented in Appendices C-1 and C-2, text in certain sections of this report were provided directly by agency or agency contractors, to be published herein.

To comply with the requirements of the CACA, the Administrative Consent Agreement, and the approved CMS/FS Work Plan,[3] this CMS/FS report contains:

- Description of current conditions (Section 2.0).
- Remedial action objectives (Section 3.0).
- Identification and screening of technologies (Section 4.0).
- Development and evaluation of remedial action alternatives (Section 5.0).
- Discussion of recommended remedial action alternative (Section 6.0).

Following approval of this Final CMS/FS by DOI and DTSC, DTSC will identify a preferred alternative through a RCRA Statement of Basis and DOI will identify a preferred alternative in a CERCLA Proposed Plan. The preferred alternative(s) will be based substantially on one of the alternatives evaluated in the CMS/FS Report and will be proposed for selection based upon the comparative evaluation of alternatives presented therein, but may deviate in certain respects from the alternative as specifically described in the CMS/FS Report.

[3] USEPA guidance (1988a-b, 1990, 1995, 1996a-b, 1997a, 1999, 2000, 2004, 2007, 2008) was also consulted during preparation of this document.

FIGURE 1-2
SOLID WASTE MANAGEMENT UNITS, AREAS OF CONCERN, AND OTHER UNDESIGNATED AREAS TO BE ADDRESSED IN RFI/RI

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/FEASIBILITY STUDY REPORT
FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

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2.0 Description of Current Conditions

This section provides descriptive information about the Topock site, the nature and extent of impacted groundwater, land uses, and site constraints important for identifying and evaluating remedial alternatives. The purpose of this section is to provide context for site conditions that were considered during development of this CMS/FS. For additional detail on the topics discussed herein, refer to the RFI/RI Report and other referenced documents.

2.1 Site Location, Property Ownership, and Land Uses

The Topock Compressor Station is located in eastern San Bernardino County, California about 15 miles southeast of Needles, as shown in Figure 2-1. The compressor station is located approximately 1,500 feet west of the Colorado River and the California/Arizona state border. The Topock Compressor Station began operations in December 1951 to compress natural gas supplied from the southwestern United States for transport through pipelines to PG&E's service territory in central and northern California. The compressor station is still active and is anticipated to remain an active facility into the foreseeable future. As discussed in Section 1.2, the station has not released untreated blowdown water containing Cr(VI) since 1964, and there have been no wastewater discharges to the percolation bed in Bat Cave Wash since 1971.

The groundwater plume underlies an area of approximately 175 acres located to the north of the compressor station. For the purposes of this remedial action, the site is defined as the areal extent of contamination and areas in proximity to the contamination necessary for implementation of the remedial action, assumed to be the 1,800-acre Area of Potential Effect (APE).

2.1.1 Land Ownership/Management

Land ownership/management within the APE is shown in Figure 2-2. Property within the APE includes land owned and/or managed by a number of government agencies and private entities including the BLM, BOR, USFWS, San Bernardino County, Burlington Northern Santa Fe Railroad, PG&E, and the Southern California Metropolitan Water District. As shown in Figure 2-2, land within the 175-acre plume area is divided among multiple property owners/managers: PG&E, BOR (managed by BLM), Burlington Northern Santa Fe Railroad, and the USFWS (which manages the Havasu National Wildlife Refuge [HNWR]). PG&E transferred parcel 650-151-06i to the Fort Mojave Indian Tribe in late October 2009. Under the terms of the land transfer the Tribe will hold the land in fee and PG&E will maintain an easement on the property (including access) to construct, operate and maintain existing and future facilities as needed for remediation of the site. In addition, several other entities have easements and/or rights-of-way within the 175-acre plume area, including California Department of Transportation, San Bernardino County, Southern California Gas Company, Transwestern Pipeline Company, Mojave Pipeline Company, PG&E, City of Needles Electric, Southwest Gas Corporation, and Frontier Telephone.

2.1.2 Land Use and Nearby Communities and Development

The site is located in a sparsely-populated, rural area. Land uses near the site are predominantly open space, interspersed with industrial facilities, recreational uses, and transportation infrastructure. Open space near the uplands portion of the site is characterized primarily by sparse desert vegetation on elevated mesas and steep, rocky slopes. The area is bisected by several steep-sided ephemeral streambeds, including Bat Cave Wash and several unnamed washes oriented north/northeast to their confluences with the Colorado River. Open space on the Colorado River floodplain is characterized by shifting sand dunes and associated riparian vegetation, primarily arrowweed and non-native tamarisk (salt cedar).

The nearest communities are mobile home parks and private residences at Topock, Arizona and Moabi Regional Park, California. The Topock mobile home park is located at the Topock Marina on the Arizona (or eastern) side of the Colorado River about 0.5 mile east of the site. Moabi Regional Park is located on the California (or western) side of the Colorado River about 1.5 miles northwest of the site. The community of Golden Shores, the largest nearby community outside the APE, is located approximately 5 miles north of the compressor station on the east side of the Colorado River.

A major gas utility and transportation corridor is located within the APE. This corridor includes six natural gas transmission pipelines, the Burlington Northern Santa Fe Railway, and the Interstate 40 freeway. Other developed land uses and existing structures are shown in Figure 2-3 and include the Topock Compressor Station, National Trails Highway, former Route 66, overhead electric lines, county roads, and various unnamed access roads. In addition, an interim remedial measures groundwater treatment plant and numerous groundwater well clusters related to the ongoing groundwater investigation activities are located within the APE.

The HNWR encompasses approximately 37,515 acres along the Colorado River in Mohave and La Paz Counties, Arizona and in San Bernardino County, California. Most of the refuge extends from the upper end of Topock Marsh southward to the head of Lake Havasu on the Arizona side of the river. A portion of the refuge borders the compressor station. Recreational activities at the HNWR include sightseeing, bird watching, fishing, hunting, camping, and canoeing (USFWS, 1999).

2.1.3 Groundwater and Surface Water Uses

Groundwater beneath and in the immediate vicinity of the groundwater plume is not used as a water supply. The nearest groundwater supply wells in California are located approximately 1.3 miles west-northwest of the plume at the Park Moabi Marina. Additionally, groundwater supply wells are located at private residences south of the Topock Marina on the eastern side of the Colorado River approximately 0.3 mile east-southeast of the plume.

The Colorado River, located adjacent to and east of the plume, is a major source of water for irrigation, drinking, and other uses by humans and wildlife. The closest downstream supply intake is located approximately 21 river miles downstream of the railroad bridge over the Colorado River. The Colorado River also supports recreational uses of swimming, boating, and fishing. In addition, the Colorado River serves as an aquatic habitat that supports various plant and wildlife species, including threatened or endangered species. Additional information on biological resources is discussed in Section 2.2.7.

2.2 Physical Characteristics

This section describes the physical characteristics that are important for identifying and evaluating remedial alternatives. As discussed above, for the purposes of this remedial action, the site is defined as the approximately 175-acre areal extent of groundwater contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the remedial action, assumed to be the 1,800-acre APE, which also equates to the approximate study area boundaries for the RFI/RI (CH2M HILL, 2009a).

2.2.1 Surface Features and Topography

Topography at the site is shown in Figure 2-4. The site is located in the southern portion of the Mohave Valley, north of the Chemehuevi Mountains, and south and west of the Colorado River floodplain. Overlying the plume, topography ranges from approximately 455 feet above mean sea level at the Colorado River floodplain to approximately 600 to 625 feet above mean sea level at the compressor station.

The site consists of a series of terraces divided by dry desert washes. The terraces are considerably eroded with very steep slopes. The compressor station is located on a prominent alluvial terrace. Incised drainage channels separate the alluvial terraces. Overlying the plume, the largest incised channel is Bat Cave Wash, a north-south dry wash that bisects the plume. Bat Cave Wash flows on the surface only intermittently (as an ephemeral stream) following intense rainfall events and extends to the Colorado River.

2.2.2 Meteorology

The climate is typical of low desert areas in the lower Colorado River basin, with hot summer and mild winter seasons. The average daily average maximum temperature ranges from 63.8 degrees Fahrenheit (°F) in January to 108.6°F in July. The average daily maximum temperature exceeds 100°F during June, July, August, and September (National Oceanic and Atmospheric Administration, 2000), and rarely does the temperature drop below freezing.

Based on the 30-year period of 1961 through 1990, average precipitation was 4.67 inches per year in Needles.[4] From 1950 through 1965, the maximum annual rainfall was 9.5 inches. Rain occurs primarily during summer thunderstorms from July through early September and during the winter rainy season from December through March. May and June are typically the driest months. Based on data from the Needles Airport, the predominant wind direction is south-southwest, with an average speed of 8.8 miles per hour. The second most predominant wind direction is north-northwest, with an average speed of 10.7 miles per hour. Wind direction and speed are more variable at the compressor station site due to the extreme topography and proximity to the river channel.

[4] Data available from http://www.weather.com/activities/otther/weather/climo-monthly.html?locid_USCA0753.

2.2.3 Colorado River and Surface Water Features

Figure 2-5 depicts surface waters and wetlands within and near the site as determined by field surveys in 2005 (CH2M HILL, 2005a).

The primary surface water feature is the Colorado River. The Colorado River channel ranges from approximately 600 to 700 feet wide in the area upstream of the bridge crossing at Topock. In 2005, the river depths ranged from 4 to 12 feet on two cross-river transects measured at and north of the Interstate-40 bridge. On the river transect measured at the I-3 pipeline bridge, the channel depths ranged from 5 feet near the Arizona shoreline to a maximum of 22 feet near the California shoreline (CH2M HILL, 2006a). Additional historical information on Colorado River dredging, river morphology, and bridge crossing subsurface investigations were incorporated in the surface water characterization, as summarized in the Final RFI/RI Report, Volume 2 Addendum (CH2M HILL, 2009b).

The flow of the Colorado River is dynamic and fluctuates daily and seasonally as a result of BOR's power and water delivery schedule. The flow of the Colorado River at Topock is regulated by BOR, primarily by the controlled release of water from Davis Dam on Lake Mohave approximately 33 miles upstream. River levels at the site fluctuate by 2 to 3 feet per day, and flows vary anywhere from 4,000 to 25,000 cubic feet per second according to the dam releases (CH2M HILL, 2009a).

Based on data collected during the monitoring period of the RFI/RI, no site-related contamination of surface water in the Colorado River is observed. Over 700 surface water samples were collected from 43 locations in the Colorado River to determine the occurrence and extent of constituents of potential concern (COPCs) in surface water for the RFI/RI. None of the average concentrations for the samples from the shoreline, in-channel, and pore water study surface water locations exceeds the most stringent chemical-specific ARAR. There was no discernable difference between results in samples collected upstream or downstream of Bat Cave Wash in the Colorado River. None of the Cr(VI) and Cr(T) concentrations from the RFI/RI samples collected from the Colorado River exceeded the chemical-specific ARARs criteria of 11 and 50 micrograms per liter (µg/L), respectively. The one exception is the Cr(VI) shoreline samples collected in June 2002 that data quality review indicated were false positives, as discussed in the RFI/RI Volume 2 Report (CH2M HILL, 2009a).

As mentioned previously, Bat Cave Wash is a north-south incised channel bisecting the plume that flows only intermittently (as an ephemeral stream) following intense rainfall events and extends to the Colorado River. Other surface water features within the APE include the Park Moabi inlet/slough, the Topock Marsh inlet, other dry wash drainages, and the Colorado River floodplain and sand dune shoreline features.

2.2.4 Geology

The site is in the Basin and Range geomorphic province, characterized by roughly parallel north/south fault-block mountains separated by alluvial valleys. The oldest rocks in the surrounding area are exposed in the Chemehuevi Mountains and include Precambrian and Mesozoic-age metamorphic and igneous rocks. Miocene-age sedimentary and volcanic rocks, associated with the tectonic uplift and faulting in the region, were deposited on the metamorphic and plutonic bedrock complex. The bedrock basement formations are, in turn, overlain by younger Tertiary and Quaternary to Recent-age sedimentary deposits.

The most prominent geologic structural feature is the detachment fault that forms the northern boundary of the Chemehuevi Mountains. The Chemehuevi detachment fault, located near the southern boundary of the APE, is inferred to be a low-angle (15- to 20-degree), northeast-dipping normal fault that has displaced pre-Tertiary metamorphic bedrock and Miocene sedimentary rocks (upper plate) across underlying, lower plate crystalline bedrock. The surface trace of the Chemehuevi detachment fault is mapped in western Mohave County, Arizona, approximately 2 miles southeast of the site, indicating that this regional fault extends eastward from California into Arizona.

Figure 2-6 is a geologic map of the APE. Within the APE, the primary geologic mapped units are Quaternary Colorado River and recent floodplain deposits, Quaternary alluvium and surficial deposits, older Tertiary alluvium, and bedrock formations that include Miocene Conglomerate and pre-Tertiary metamorphic and igneous rocks. Additional description and details on the site geology are presented in the RFI/RI Volume 2 Report (CH2M HILL, 2009a).

2.2.5 Hydrogeologic Conditions

The hydrogeologic conditions of the site described below are summarized from the RFI/RI Volume 2 Report (CH2M HILL, 2009a), Volume 2 Addendum (CH2M HILL 2009b), and the East Ravine Groundwater Investigation (Appendix A). The site is located at the southern downstream end of the Mohave Valley groundwater basin. Groundwater in the Mohave Basin occurs in the Tertiary and younger alluvial fan and fluvial deposits. The unconsolidated alluvial and fluvial deposits are underlain by the Miocene Conglomerate and pre-Tertiary metamorphic and igneous bedrock. The bedrock typically has lower permeability; therefore groundwater movement occurs primarily in the overlying unconsolidated deposits. In the Mohave groundwater basin, water-bearing zones may occur locally where bedrock formations are weathered or fractured, although no areas have been identified where saturated bedrock formations are capable of yielding significant quantities of groundwater.

Groundwater occurs under unconfined to semi-confined conditions within the alluvial fan and fluvial sediments beneath most of the site. The alluvial sediments consist primarily of clayey/silty sand and clayey gravel deposits interfingered with more permeable sand and gravel deposits. The alluvial deposits exhibit considerable variability in hydraulic conductivity between fine- and coarse-grained sequences. The fluvial sediments similarly consist of interbedded sand, sandy gravel, and silt/clay. The fluvial deposits at the site include the older Pleistocene deposits as well as more recent fluvial deposits associated with the Colorado River. The saturated portion of the alluvial fan and fluvial sediments are collectively referred to as the Alluvial Aquifer.

Figure 2-7 presents a schematic cross-section to illustrate the hydrogeologic setting between the Topock Compressor Station and the Colorado River. In the floodplain area adjacent to the Colorado River, the fluvial deposits interfinger with, and are hydraulically connected to, the alluvial fan deposits. The interface between alluvial and fluvial units occurs near the western edge of the floodplain. The Topock Compressor Station is located on an upland alluvial terrace near the southern edge of the Alluvial Aquifer where the aquifer pinches out against the underlying, sloping bedrock.

As shown in Figure 2-7, the water table in the Alluvial Aquifer is flat and typically equilibrates to an elevation within 2 to 3 feet of the river level. On the basis of the variable topography, the depth to groundwater ranges from as shallow as 5 feet below ground surface (bgs) in floodplain wells next to the river to approximately 170 feet bgs at the upland alluvial terrace areas. The saturated thickness of the Alluvial Aquifer is about 100 feet in the floodplain and thins to the south, pinching out along the Miocene Conglomerate and bedrock outcrops. In the western portions west of the site, where the depth to bedrock increases, the saturated Alluvial Aquifer is over 200 feet thick.

Additional hydrogeologic data collected during February through July 2009 for the East Ravine groundwater investigation refined the site hydrogeologic conceptual model presented in the RFI/RI Volume 2, specifically mapping bedrock structure and the bedrock/Alluvial Aquifer contact, characterization of hydraulic properties, groundwater gradient and flow, and groundwater quality in bedrock. The hydrogeologic results and findings from the East Ravine investigation are described in Appendix A of this report.

Hydrogeologic and hydrogeochemical features of the site are summarized below:

- Under natural conditions, groundwater flows from west-southwest to east-northeast across the site. Localized areas of northward flow likely occur along the mountain front to the south of the compressor station. Gradients are very small due to the limited recharge, with a typical value of 0.0005 foot/foot in the alluvial area. Under average conditions, groundwater velocity ranges from about 25 to 46 feet/year, according to numerical model estimates. Gradients are upward between bedrock and the overlying Alluvial Aquifer and typically, but not universally, upward within the Alluvial Aquifer.
- Investigation and monitoring in the East Ravine area shows that the groundwater in fractured bedrock is in hydraulic communication with the Alluvial Aquifer and equilibrates to an approximate elevation similar to the water table in the Alluvial Aquifer. Compared to the Alluvial Aquifer, the fractured rock permeabilities are overall very low, consistent with the RFI/RI data.
- Under ambient conditions in the vicinity of the site, the river recharges groundwater during the higher-flow stages in the spring and summer months, and groundwater discharges to the river during the months of lower river stages in fall and winter. Since 2004, the IM groundwater extraction and treatment system has maintained a consistent, year-round landward gradient in the area where the plume is present in the floodplain.
- The total dissolved solids (TDS) of site groundwater varies considerably, ranging from as low as 300 milligrams per liter (mg/L) (at MW-1) to over 40,000 mg/L (MW-30-30 and MW-32-20). Most site monitoring wells are in the 1,000 to 10,000 mg/L range. In general, high TDS is associated with (1) bedrock wells, (2) deep alluvial/fluvial wells, and (3) a few shallow fluvial wells. Low TDS is found in shallow fluvial wells close to the river and in shallow alluvial wells in the western parts of the site. Distribution of TDS in groundwater at the site is provided in Figures 5-18a, b, c, and 5-19 of the RFI/RI Volume 2 Report (CH2M HILL, 2009a). In general, TDS typically increases with depth, with the highest TDS concentrations found in deepest alluvial and bedrock wells. The

TDS in fluvial groundwater increases with distance away from the river and with depth, becoming similar to alluvial groundwater quality in deeper fluvial wells west of the floodplain.

- Groundwater oxidation-reduction (redox) data show a distinction between alluvial and shallow fluvial zones of the Alluvial Aquifer. Field measurements of redox potential and other chemical data and field observations of collected core indicate that organic-rich sediments in the fluvial deposits result in naturally-reducing conditions. Reducing conditions are also found in the bedrock and in some deeper zones of the Alluvial Aquifer. The majority of the Alluvial Aquifer does not exhibit reduced conditions.

2.2.6 Cultural Resources

The following information is derived from reports on cultural resource surveys conducted in the project area between 2004 and 2007. These are summarized in the report *Archaeological and Historical Investigations, Third Addendum: Survey of the Original and Expanded APE for Topock Compressor Station Site Vicinity* (Applied Earthworks, 2007). Additional research, including field visits, archival research, and ongoing meetings and interviews with tribal representatives, has been conducted by DTSC and its consultants for use in evaluating potential environmental impacts according to the California Environmental Quality Act (CEQA) Guidelines. A programmatic environmental impact report (EIR) is currently under preparation to meet DTSC's responsibilities under CEQA. Current environmental conditions summarized here will be described in greater detail in the EIR, along with an analysis of the potential effects of implementing the proposed cleanup action. Nine federally-recognized Native American tribes have ancestral ties to the area and have expressed interest in the project to DTSC. These include the Chemehuevi Indian Tribe, Cocopah Tribe of Arizona, Colorado River Indian Tribes, Fort Mojave Indian Tribe, Havasupai Indian Tribe, Hualapai Indian Tribe, Quechan Tribe of the Fort Yuma Indian Reservation, Twenty-Nine Palms Band of Mission Indians, and Yavapai-Prescott Tribe. The project site lies within a larger area of traditional cultural importance and spiritual significance to some of these tribes.

Thousands of years of human history are evident in the area surrounding the Topock Compressor Station. Among the larger and better-known cultural resources on the site is an expansive desert geoglyph or intaglio known as the Topock Maze. Although the Maze is viewed as one contiguous element of a larger area having unique value to some tribes, archaeological documents refer to three geographically-distinct parts, two of which overlie the groundwater plume. Prominent historic-era features in the landscape, several of which intrude upon the Maze and also overlie the groundwater plume, include segments of historic United States Route 66, the National Old Trails Highway, and the right-of-way of the Atlantic and Pacific/Atchison, Topeka and Santa Fe Railroad. A broad spectrum of archaeological resources is also present within the project site and on adjacent lands. Properties on and near the project site that are listed on the National Register of Historic Places include Native American cultural resources and elements of the historic "built environment."

In carrying out their respective responsibilities under the National Historic Preservation Act, CEQA, and all ARARs for cultural resource protection, the DOI and DTSC have indicated that they will ensure that the projects' potential effects on significant historic properties are taken into account in the remedy selection process (DTSC, 2009e).

2.2.7 Biological Resources

A large portion of the site and surrounding area is the HNWR. The *Lower Colorado River National Wildlife Refuges Comprehensive Management Plan 1994-2014*, adopted in 1994, currently guides land management at the HNWR. The Comprehensive Management Plan emphasizes that the HNWR should be used in a manner that will facilitate protection of (1) the endangered and threatened species found at the refuge; (2) marsh and wetland habitat for both endangered and threatened species; and (3) habitat for migratory, wintering, and nongame avian species and their habitat.

The site and surrounding area is characterized by arid conditions and high temperatures. As mentioned previously, the site consists of a series of terraces divided by dry desert washes, with Bat Cave Wash the largest incised channel. Bat Cave Wash flows on the surface only briefly (as an ephemeral stream) following intense rainfall events and drains to the Colorado River. Terraces are composed of rocky soils with very sparse vegetation.

Terrestrial wildlife found at the site are those adapted to the interrelated stresses of drought, temperature extremes, and the sparse or unpredictable food supply of the desert habitats found at the site. Trees and patches of native vegetation near the Colorado River may provide habitat for avian species and other wildlife species. Additional information on biological resources at the site are described in the *Biological Resources Survey Report for the Area of Potential Effect (APE) Topock Compressor Station Expanded Groundwater Extraction and Treatment System, Needles, California* (CH2M HILL, 2005a) and the *Programmatic Biological Assessment for Pacific Gas and Electric Topock Compressor Station Remedial and Investigative Actions* (CH2M HILL, 2007b). The conclusions of these reports are briefly summarized below for ease of reference.

Figure 2-8 shows the 10 plant communities that have been identified within the APE, with the boundary between these communities characterized by a transitional zone in which representative species from each community are found. The dominant plant communities at the site consist of creosote bush scrub (generally west of National Trails Highway) and salt cedar (generally between National Trails Highway and the Colorado River and at the mouth of Bat Cave Wash). These plant communities support a variety of common wildlife species and have provided habitat for several species that are currently designated as threatened or endangered by state and federal endangered species acts. These dominant plant communities and associated threatened or endangered species include:

- **Creosote Bush Scrub.** The desert tortoise (*Gopherus agassizii*) is the only threatened (state and federal) wildlife species that may occur in the creosote bush scrub. Tortoise protocol surveys conducted in the APE from 2005 through 2009 detected one desert tortoise carcass and four sets of highly deteriorated bone shell fragments. The carcass and bone shell fragments were estimated to be more than 4 years old and may indicate historical use of the site by tortoises. Alternatively, the tortoise sign observed in the drainages may have washed in from outside the survey area during a rainstorm. However, no desert tortoise scats, tracks, or other evidence of live tortoises or recent tortoise use was observed within the survey area (Garcia and Associates, 2009a).

- **Salt Cedar.** This plant community is characterized by dense thickets of salt cedar (*Tamarix* sp.), sometimes with an understory of arrowweed (*Pluchea sericea*). Salt cedar is highly successful in arid climates with saline or alkaline soils and often occurs in monotypic stands in riparian areas. Considered a noxious weed, salt cedar is fire-, flood- and drought-tolerant and resprouts readily after cutting or burning. It spreads through growth of adventitious roots and by dispersal of large amounts of seed. Salt cedar also out-competes native plant species for water and can increase soil salinity as it sheds foliage where it accumulates excess salt, thereby making conditions less tolerable for other species. Although salt cedar provides habitat and nest sites for some wildlife, many biologists conclude that it provides low-quality habitat for most native amphibians, reptiles, birds, and mammals. However, some literature has documented the endangered (federal and state) southwestern willow flycatcher (SWFL) (*Empidonax traillii extimus*) as nesting in the tamarisk thickets near watercourses, including the Colorado River (McLeod et al., 2005). Designated critical habitat for the SWFL does not exist within the APE. Flycatcher protocol surveys conducted near the site from 2005 through 2009 did not positively detect this species nesting. However, SWFL were detected and confirmed in 2008 and 2009 surveys but were determined to be migrants passing through the area (Garcia and Associates, 2008, 2009b). Although tamarisk is not known to provide optimal wildlife habitat, the trees appear to provide the only significant roosting and nesting structure due to limited structural tree diversity in the area.

The primary aquatic habitat within the APE is the Colorado River. The Colorado River supports several fish species listed as endangered. Additionally, game fish species were introduced into the river. There are also a number of water-associated avian and mammalian species that use the river and its banks. The fish species that are federally listed as threatened or endangered that may occur within the Colorado River in the study area vicinity include the bonytail chub *(Gila elegans)*,[5] Colorado pikeminnow *(Ptychocheilus lucius)*, and the razorback sucker *(Xyrauchen texanus)*. Within the APE, designated critical habitat for the bonytail chub is the Colorado River and the 100-year floodplain.

2.3 Nature and Extent of Groundwater Impacted by Chromium

This subsection describes the nature and extent of impacted groundwater near the compressor station that is attributable to the historic wastewater discharge from compressor station operations to the Alluvial Aquifer in Bat Cave Wash (SWMU 1/AOC 1), and the bedrock formations in AOC 10. This subsection also includes a description of the chromium plume, chromium fate and mobility, and background groundwater concentrations.

The principal constituents of concern (COCs) in groundwater at the site are Cr(VI) and Cr(T), which are the result of past wastewater disposal practices in Bat Cave Wash as described in Section 1.2 and as identified in the East Ravine. Selenium, molybdenum, and nitrate were found to exceed an HI of 1 and contribute to a hazard quotient greater than 1 at localized areas within the plume. Due to limited sampling data and comparatively lower risks contributions at the site, these constituents will be monitored throughout the remediation process (DTSC 2009c, DOI 2009c). Aside from these constituents, other

[5] This fish is also often referred to as the bonytail.

constituents detected in groundwater were determined to either not be associated with SWMU 1/AOC 1 and/or were not present in site groundwater at levels of potential concern to future human health or the environment (CH2M HILL, 2009a-b; ARCADIS, 2009; Appendix A). Nearly all of the Cr(VI) releases to alluvial groundwater at the site are believed to have occurred during the 1951 to 1964 period when untreated wastewater from the compressor station was discharged to Bat Cave Wash. The extent of Cr(T) and Cr(VI) is defined sufficiently well for the purpose of establishing remedial action objectives and for evaluating remedial alternatives.

A schematic diagram of the groundwater chromium plume and key site features are depicted in Figure 2-9. From the percolation area in Bat Cave Wash, the wastewater infiltrated into the coarse sand and gravel of the wash bed and percolated approximately 75 feet downward through the unsaturated zone to reach groundwater. Testing to characterize the extent of the chromium plume indicates that the plume extends from the former percolation bed in Bat Cave Wash approximately 3,000 feet north/northeast to the Colorado River floodplain, along the general direction of groundwater flow. As discussed above, groundwater gradients at the site are slight, on the order of 0.0005 foot per feet, and the hydraulic conductivity of the Alluvial Aquifer along the axis of the plume is moderate, averaging about 30 feet per day. Chromium is present at all depth intervals of the alluvial portion of the aquifer but is generally not present in shallow and middle-depth fluvial wells near the Colorado River where reducing conditions predominate. Elevated concentrations of chromium are also present in wells completed within the shallow portion of the bedrock formations in the East Ravine to the southeast of the compressor station.

2.3.1 Chromium Plume Description

The chromium plume is defined as that part of the aquifer where Cr(VI) concentrations exceed natural background levels. The calculated statistical upper tolerance limit (UTL) of natural background levels for Cr(VI) in alluvial groundwater, obtained from sampling monitoring and water supply wells surrounding the Topock site, is 31.8 μg/L (CH2M HILL, 2008c, 2009i). The calculated statistical UTL for Cr(VI) of 31.8 μg/L is rounded to 32 μg/L for discussion of the extent of impacted groundwater below. The majority of the plume is located in the Alluvial Aquifer.

Figures 2-10, 2-11, and 2-12 illustrate the extent of Cr(VI) contamination in the Alluvial Aquifer and bedrock formations based on recent groundwater sample results for 118 wells. These maps were prepared using primarily Cr(VI) data from the October 2008 sitewide groundwater monitoring event (74 wells) for alluvial wells and the July 2009 sampling event for alluvial and bedrock wells completed in or near the East Ravine (16 wells). Since not all site wells were sampled during these two events, additional data for November and December 2008 (27 wells) and 2007 (17 wells), were combined with the October 2008 and July 2009 Cr(VI) data for completeness. With the exception of data collected from alluvial and bedrock wells completed in or near the East Ravine, the data used to prepare these maps were previously reported in the RFI/RI Volume 2 (CH2M HILL, 2009a) and groundwater monitoring and compliance monitoring reports (CH2M HILL, 2008d and 2009e-f). Sample results for alluvial and bedrock wells completed in or near the East Ravine are presented in Appendix A of this report.

In each of the Alluvial Aquifer depth monitoring zones,[6] the location of Cr(VI) concentrations for groundwater greater than or equal to 32 µg/L follows Bat Cave Wash northward approximately 3,000 feet from the compressor station. For the shallow and mid-depth zones, the 32 µg/L concentration limit extends west of Bat Cave Wash and into the western portion of the floodplain. In the deep zone of the Alluvial Aquifer, the 32 µg/L concentration limit extends further west of Bat Cave Wash and further eastward into the floodplain in the area between monitoring wells MW-27 and MW-28. The variability in the vertical distribution and trends for chromium within the aquifer are believed to result from the combined effects of: (1) proximity to the source area, (2) heterogeneity and permeability variations (vertical and lateral) of the aquifer media, (3) long-term groundwater gradients within the aquifer, and (4) site-specific geochemical conditions affecting the stability of Cr(VI). Pumping at former facility supply wells PGE-1 and PGE-2, located adjacent to Bat Cave Wash at the present site of the Interstate-40 right of way, may have also created downward gradients that acted to distribute Cr(VI) over multiple depth intervals beneath the wash. Since startup of the IM groundwater extraction in 2004, concentration trends in floodplain wells have been generally stable or decreasing (CH2M HILL, 2009g).

During the 2009 East Ravine Groundwater Investigation, Cr(VI) was also found within the Miocene conglomerate and pre-tertiary metadiorite bedrock formations east and southeast of the Topock Compressor Station (Appendix A). Cr(VI) concentrations in bedrock groundwater appear to be limited in extent to shallow and to a much lesser extent, mid-depth intervals (using the same elevation intervals for the Alluvial Aquifer). Currently, investigation data suggest Cr(VI) greater than or equal to 32 µg/L in the shallow and mid-depth wells extends approximately 1,500 feet east southeast of the compressor station. However, the mass of Cr(VI) in bedrock likely represents less than one percent of the total plume mass due to the low porosity of these bedrock formations.

Based on the site characterization data, the existing dimensions of the plume exceeding natural background levels underlie an area that is approximately 175 acres, including alluvium and bedrock. The depth to groundwater in the area of the plume ranges from approximately 28 to over 135 feet bgs, and the thickness of the aquifer in the area of the plume ranges from less than 50 feet near the bedrock interface to over 150 feet near National Trails Highway. The volume of contaminated groundwater in the Alluvial Aquifer is currently estimated to be approximately 1.50 billion gallons (approximately 4,600 acre-feet).This estimate was calculated by interpolating the Cr(VI) concentration contours shown in Figures 2-10, 2-11, and 2-12 over the model grid, integrating the concentration intervals over the depth of each zone (shallow, middle, and deep), and applying a total porosity of 35 percent for the alluvial/fluvial portion of the plume (from measurements of site materials presented in Ecology and the Environment, Inc. (E&E), 2004). Because the volume of the plume within the East Ravine bedrock formations is believed to represent less than 1 percent of the total plume, and the effective porosity of the bedrock formations is uncertain, the plume volume in bedrock is not included in this volume estimate.

[6] The depth zones are primarily defined based on the relative depth and position of screen intervals within the Alluvial Aquifer; however, there are no aquitards separating the zones.

2.3.2 Chromium Fate and Mobility

Cr(VI) is relatively stable under the non-reducing conditions of the Alluvial Aquifer beneath the uplands portions of the Topock site. It is in the form of the chromate anion (CrO_4^{2-}) in the pH range of site groundwater. The chromate anion is a relatively mobile ion that does not form insoluble precipitates nor does it adsorb strongly to mineral surfaces (Hering and Harmon, 2004). This stability is evidenced by the presence of Cr(VI) from the original discharge area in Bat Cave Wash throughout all the predicted flow paths in the non-reducing alluvial material.

Once Cr(VI) encounters a sufficiently reducing geochemical environment as found in portions of fluvial materials in the floodplain, it quickly reverts to Cr(III). Trivalent chromium is essentially immobile except either under highly acidic pH conditions or in the presence of strong complexing agents, neither of which is present at the Topock site. Strongly-reducing geochemical conditions are observed in groundwater in most of the fluvial deposits along the Colorado River floodplain. Reducing conditions in floodplain areas of the site are derived from organic carbon in the younger fluvial deposits. The high-TDS and low oxidation reduction potential water found in several site bedrock wells located out of and within the East Ravine (MW-24BR, MW-58-205, MW-62-190, PGE-7BR, and PGE-8) is presumed to be very old water given the low permeability of the bedrock at these wells. As a groundwater's residence time increases, the slow bacterial reactions that tend to lower the redox potential cause the water to become more reducing over time (Drever, 1997). Groundwater in the shallow bedrock of the East Ravine area is notably less reducing, presumably due to the stronger hydraulic communication with alluvial groundwater and/or surface runoff (Appendix A).

Wherever the natural reducing capacity of the fluvial material is present, chromium is converted to its stable form of Cr(III) and is essentially immobile. The reducing conditions in the fluvial sediments provide a natural geochemical barrier that would, at the very least, greatly limit the movement of Cr(VI) in groundwater through the fluvial sediments adjacent to and beneath the Colorado River. The reduction capacity and extent of the reducing zone are not precisely known, but the combinations of available core testing and groundwater data provide an approximate horizontal and vertical distribution of a predominantly reducing portion of the fluvial material, as described in the RFI/RI Volume 2 Report (CH2M HILL, 2009a).

The presence of the reducing material in the shallow and mid-depth fluvial deposits and beneath the river has been confirmed by laboratory testing. The capacity of the reducing fluvial material to reduce Cr(VI) has been investigated by conducting three phases of anaerobic core study (CH2M HILL, 2005b, 2008e and 2009h). Laboratory evidence confirms that the fluvial sediments in the anaerobic zone beneath the floodplain have the capacity to remove Cr(VI) from groundwater via a chemical reduction process. Chemical reduction of Cr(VI) to Cr(III) is effectively permanent and irreversible under site conditions. The only naturally-occurring oxidant that can accomplish reoxidation is solid manganese dioxide, MnO_2 (Fendorf, 1995). If this solid is present, the Cr^{3+} ion can adsorb to the MnO_2 surface, where a redox reaction can occur which causes the chromium to be oxidized and manganese to be reduced. However, under the reducing conditions present in the fluvial materials, MnO_2 is not stable, and manganese tends to exist as the dissolved cation Mn^{2+}, as shown by the detectable manganese concentrations in these wells (CH2M HILL 2009a).

Calculations suggest that there is sufficient capacity within the floodplain and beneath the river in the Alluvial Aquifer to reduce at least a significant portion of the Cr(VI) plume were the plume to come in contact with these sediments (CH2M HILL, 2008e, 2009h). The estimate of total plume Cr(VI) mass is approximately 30,800 pounds. Using this value and assuming a total porosity of 0.35 and soil particle density of 2.65 grams per cubic centimeter, the range of measured capacities from cores collected from the boring for well MW-56 indicates that from 2 to 65 million cubic feet of anaerobic aquifer would be needed to reduce all of the Cr(VI) in the plume. Using the assumptions described in the previous anaerobic core testing report (CH2M HILL, 2009h), the current data indicate that there is an existing capacity in the aquifer from 1.8 to 55 times the required capacity for plume reduction. These calculations, although only approximate, suggest that there is capacity within the floodplain and beneath the river to reduce at least a significant portion of the Cr(VI) plume were the plume to reach the anaerobic portions of the floodplain and beneath the river. What is not known or reflected in these calculations is the potential for imperfections or “windows” in the reducing zone where reducing conditions may be weak or absent. This calculation does not apply to the bedrock aquifer.

Movement of chromium by density-driven flow is not currently considered to be a significant transport mechanism at the site based on the observed profiles of groundwater density at the site. During the time that blowdown water was being discharged to Bat Cave Wash, differences in fluid density between brackish blowdown water and the fresher groundwater in the upper portion of the aquifer may have resulted in some density flow effects, at least during the initial discharge. When the salinity of the blowdown water was reduced after the first few years of facility operation, the density gradients would have diminished or disappeared. Density-driven flow would not be expected to be a significant process for groundwater transport given the relatively small range of groundwater density in the Alluvial Aquifer at Topock today (CH2M HILL, 2009a).

2.3.3 Background Study Results for Chromium

Natural background Cr(VI) concentrations exist in groundwater in the Alluvial Aquifer at Topock. The source of natural Cr(VI) is primarily from pyroxene and amphibole minerals in area rocks. The chromium contained in these minerals is mobilized by oxidation of Cr(III) to Cr(VI) on the surfaces of manganese oxide minerals. Because Cr(VI) is very soluble, the natural background concentration in an oxidizing environment is limited by: (1) the amount of chromium in the natural rock material, (2) the formation of dissolved Cr(III) from the natural rock material, and (3) the presence and availability of reactive manganese oxides. In order for Cr(III) to react with manganese oxides, it first must undergo dissolution. The groundwater pH at Topock limits the ability of Cr(III) to dissolve (Cr(III) is only very sparingly soluble at the slightly alkaline groundwater pH). In addition, not all of the Cr(III) present in the natural rock material is reactive, rather only a portion may be reactive due to weathering of the chromium minerals in the rock and the creation of labile forms of Cr(III). Aquifer materials derived from granitic rocks in the Mojave Desert to the west have shown natural Cr(VI) concentrations up to 36 µg/L (Ball and Izbicki, 2004). More mafic rocks, such as diorite, basalt, and serpentinite, would be expected to produce higher groundwater concentrations of Cr(VI) since these rocks contain a higher concentration of the chromium source minerals. The background value of 31.8 µg/L found in the Topock area is consistent with these observations, as the source rock for the alluvium is metadiorite.

As described in the Final Background Study Report (CH2M HILL, 2008c), depending on the interpretation criteria used, the background study data may be viewed as belonging to a single population or may be split into separate populations on the basis of multiple factors. General chemistry and oxygen/deuterium isotopic analysis indicate that many of the fluvial samples have different chemical characteristics compared to alluvial samples. This is due to the influence of the Colorado River for the shallow fluvial groundwater. In addition to the geographic/geologic criteria, separate populations may be defined on the basis of depth because the Topock Alluvial Aquifer is stratified. The highest mean concentrations of Cr(VI) and Cr(T) in the groundwater background study are found at the MW-18 well. This well is screened at or near the water table as are some of the other shallow (non-background study) monitoring wells in the general vicinity (such as OW-2S and OW-5S) that have similar concentrations. Deeper wells in the area have much lower concentrations, suggesting the naturally elevated background Cr(VI) concentrations are confined to shallow depth. DOI approved the Final Background Study Report in August 2008 (DOI, 2008c).

The Final Background Study Report was revised to incorporate DTSC’s comments received in October 2009. DOI and DTSC approved the Revised Final Background Study Report (CH2M HILL, 2009i) in December 2009 (DOI, 2009d and DTSC, 2009f).

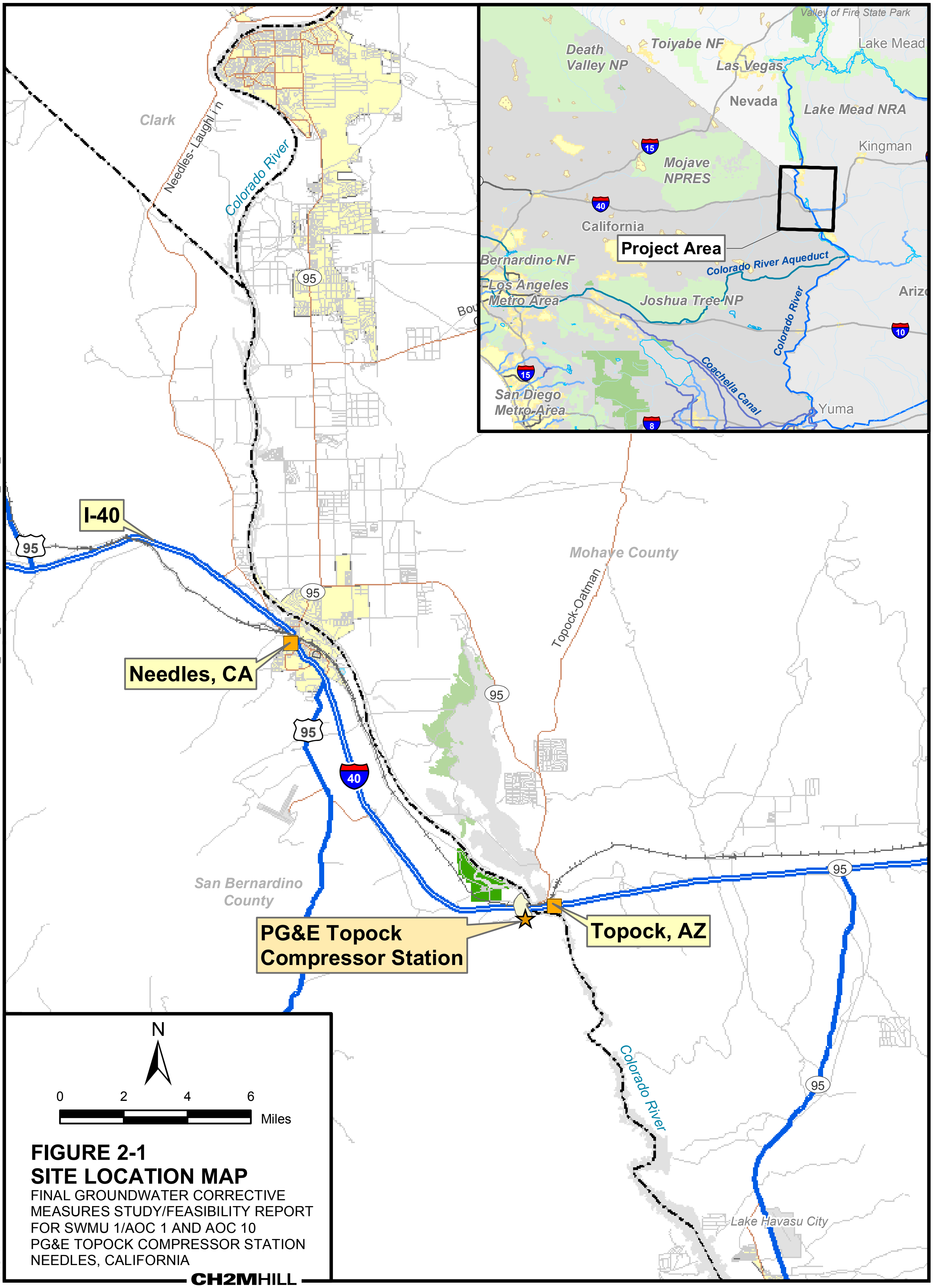

FIGURE 2-1
SITE LOCATION MAP
FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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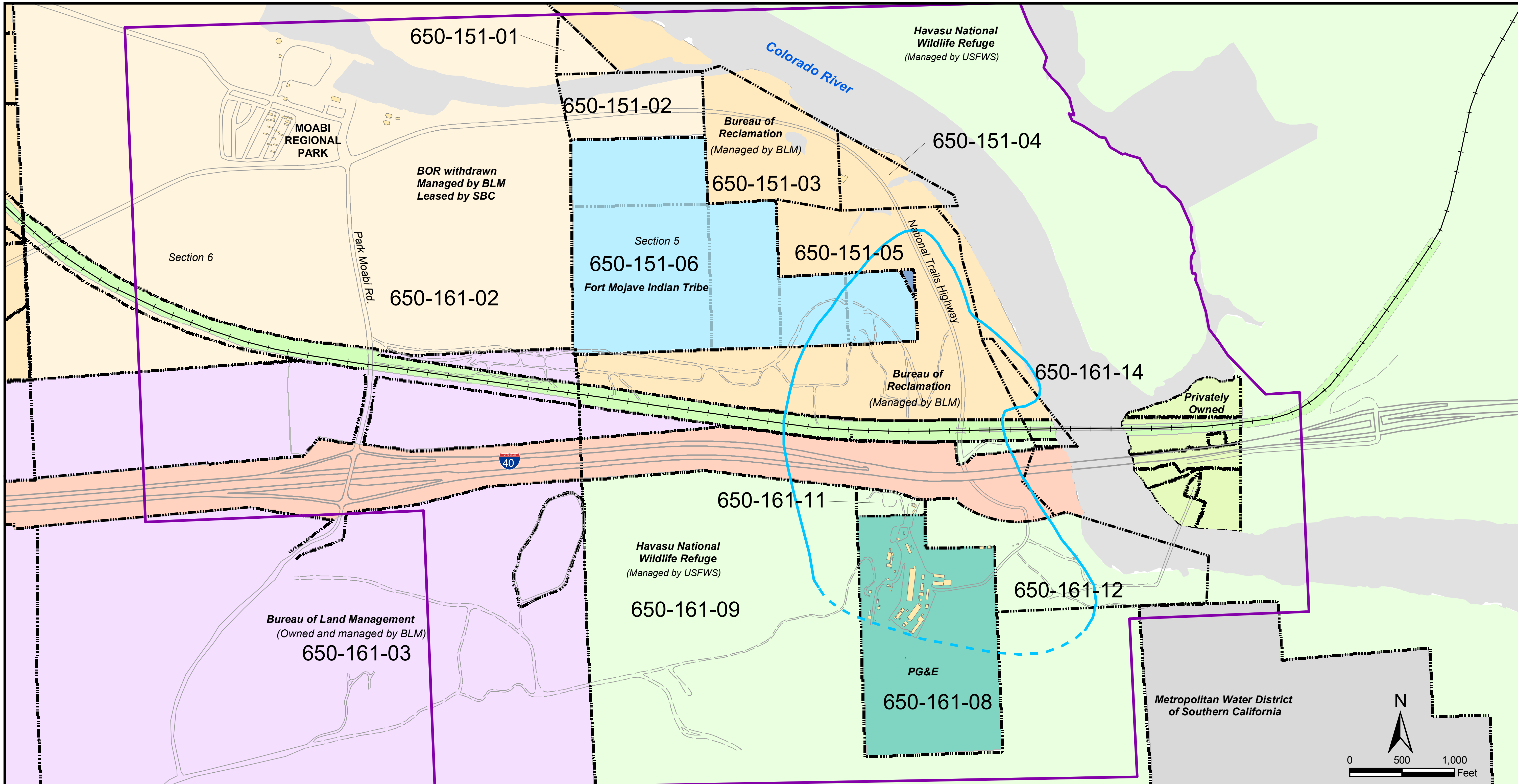

Legend

- 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 2-2
SURROUNDING PROPERTIES
FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

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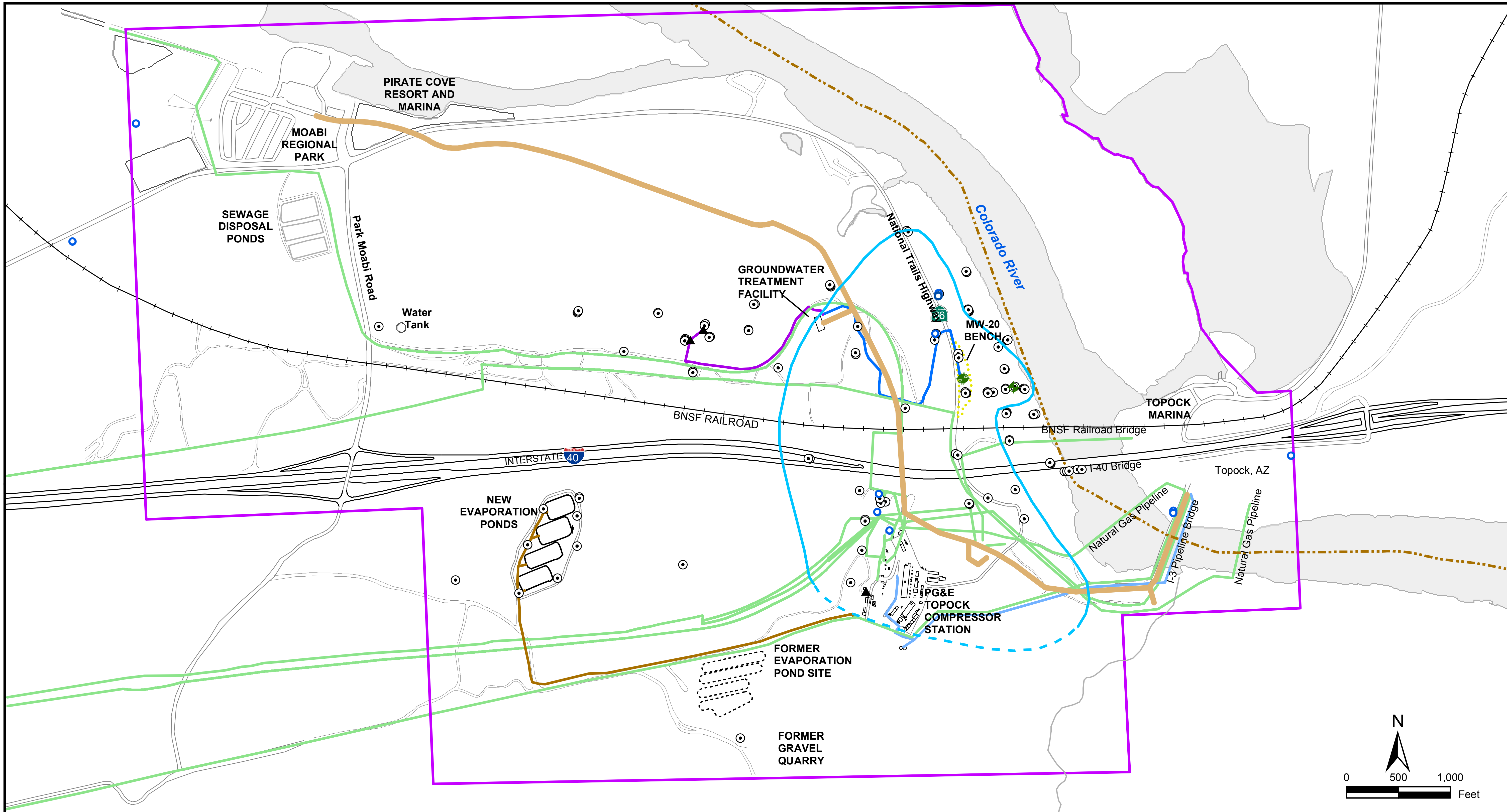

LEGEND

- Groundwater Monitoring Well
- Test Well or Supply Well
- Injection Well
- Extraction Well
- Overhead Electric
- Gas Transmission Pipeline
- Potable Water Pipeline
- Underground Wastewater Pipeline
- Effluent Pipeline
- Multi-Utility Trench
- MW-20 Bench
- California-Arizona Border
- Area of Potential Effect (APE)
- 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 locations of pipelines and existing infrastructure are approximate. The figure is not intended to be a comprehensive depiction of all existing infrastructure in the APE.

FIGURE 2-3
DEVELOPED LAND USES AND EXISTING INFRASTRUCTURE

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/
FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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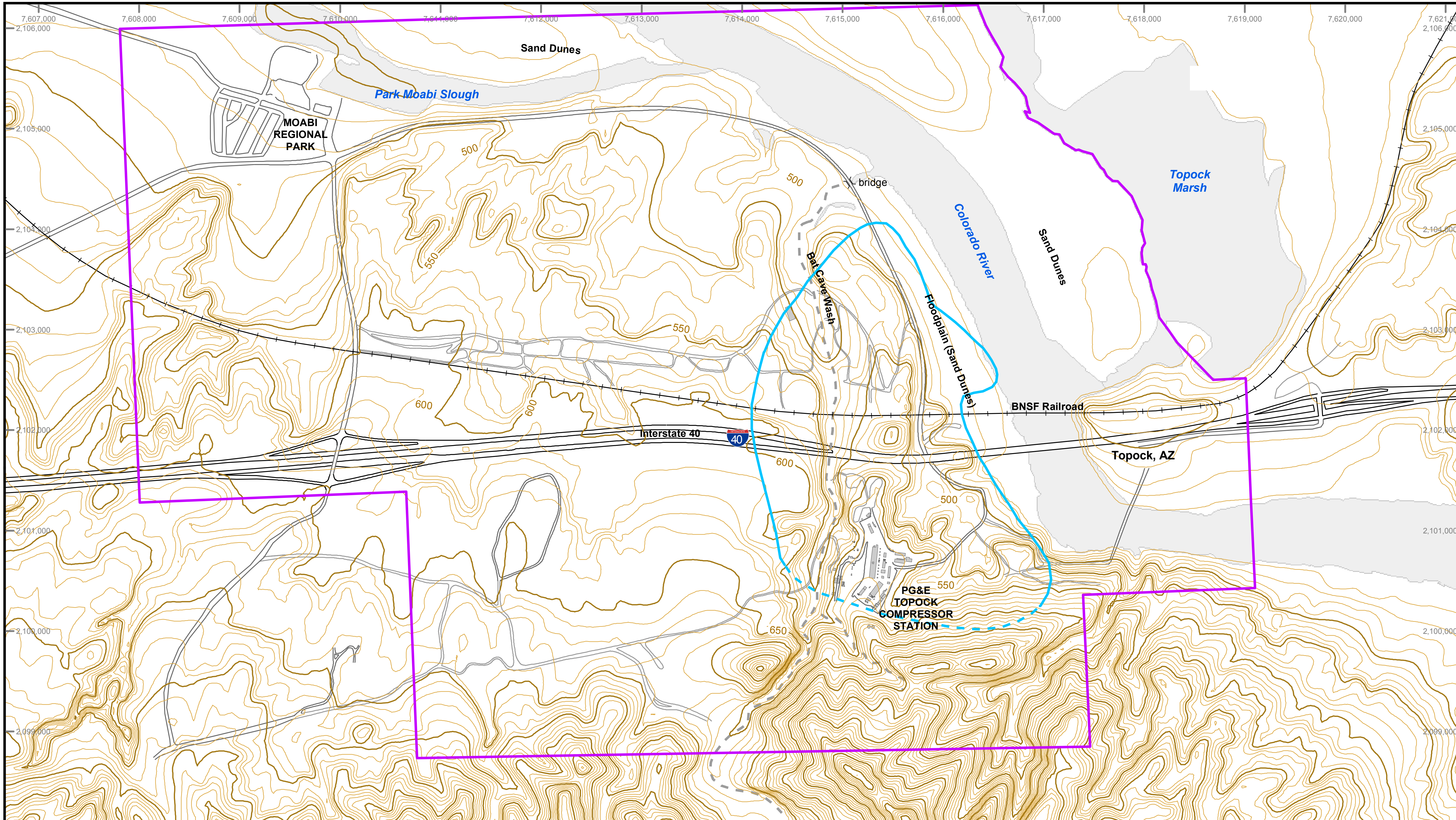

LEGEND

- Area of Potential Effect (APE)
- 10 foot contour
- 50 foot contour
- 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.

California State Plane, NAD 83, Zone 5, US Feet
Contour interval is 10 feet, with indexes at 50 feet.

Sources:
Topographic data from E & E, Inc. (1994), with additional aerial topographic mapping flown April 2004 (CH2M HILL)

N

0 500 1,000 Feet

FIGURE 2-4
SITE TOPOGRAPHY

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

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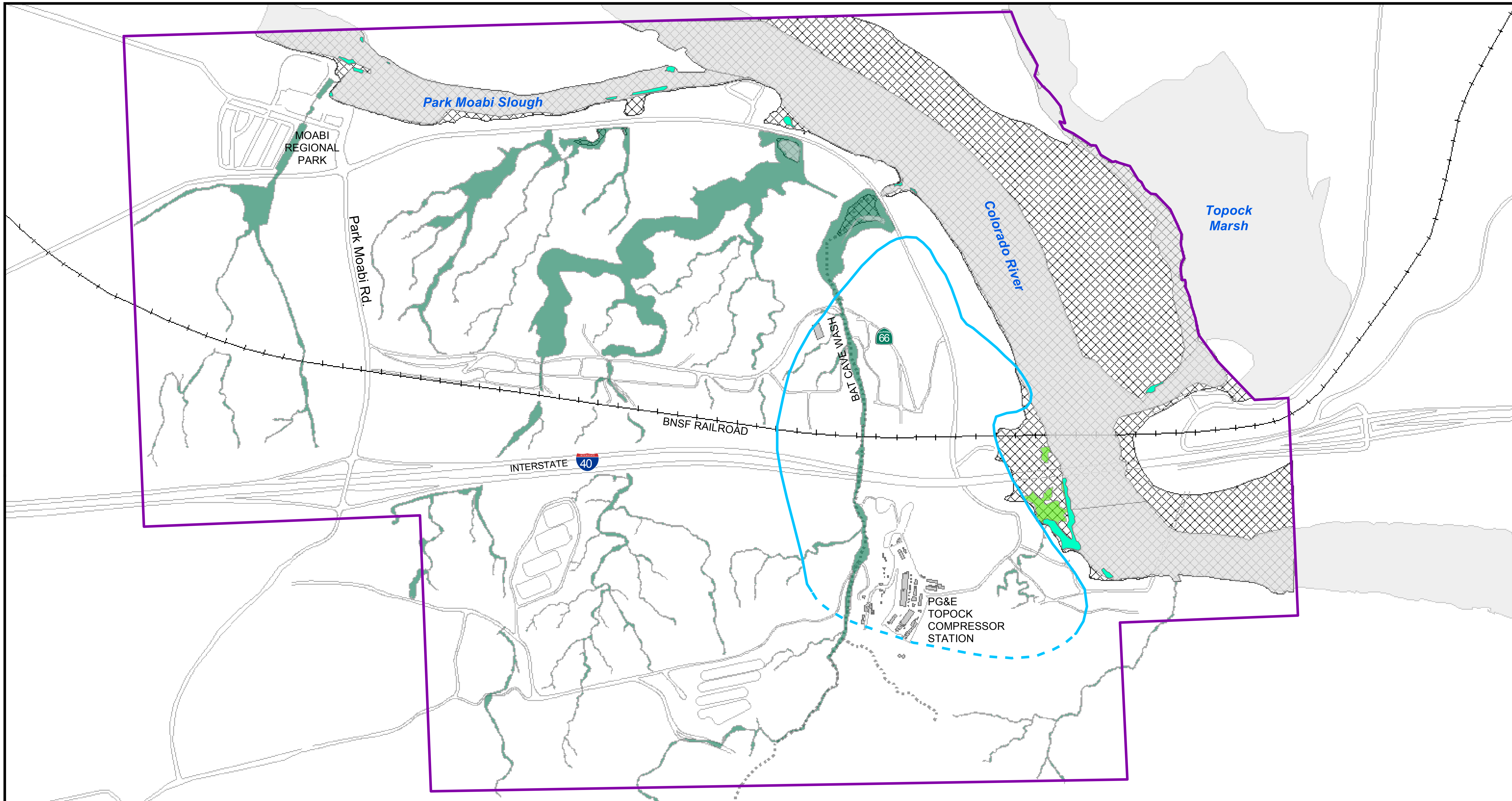

LEGEND

- Area of Potential Effect (APE)
- 100 –year floodplain/ bonytail chub critical habitat
- Fringe Wetlands
- Adjacent wetlands
- USACE Waters of U.S. - Colorado River
- USACE Waters of U.S.
- 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.

Source:
Biological Resources survey for the Area of Potential Effect (APE) Topock Compressor Station (CH2M HILL 2005a) and the *Programmatic Biological Assessment for Pacific Gas and Electric Topock Compressor Station Remedial and Investigative Actions* (CH2M HILL 2007b).

N

0 500 1,000 Feet

FIGURE 2-5
UNITED STATES ARMY CORPS OF ENGINEERS JURISDICTIONAL WATERS AND WETLANDS

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT
FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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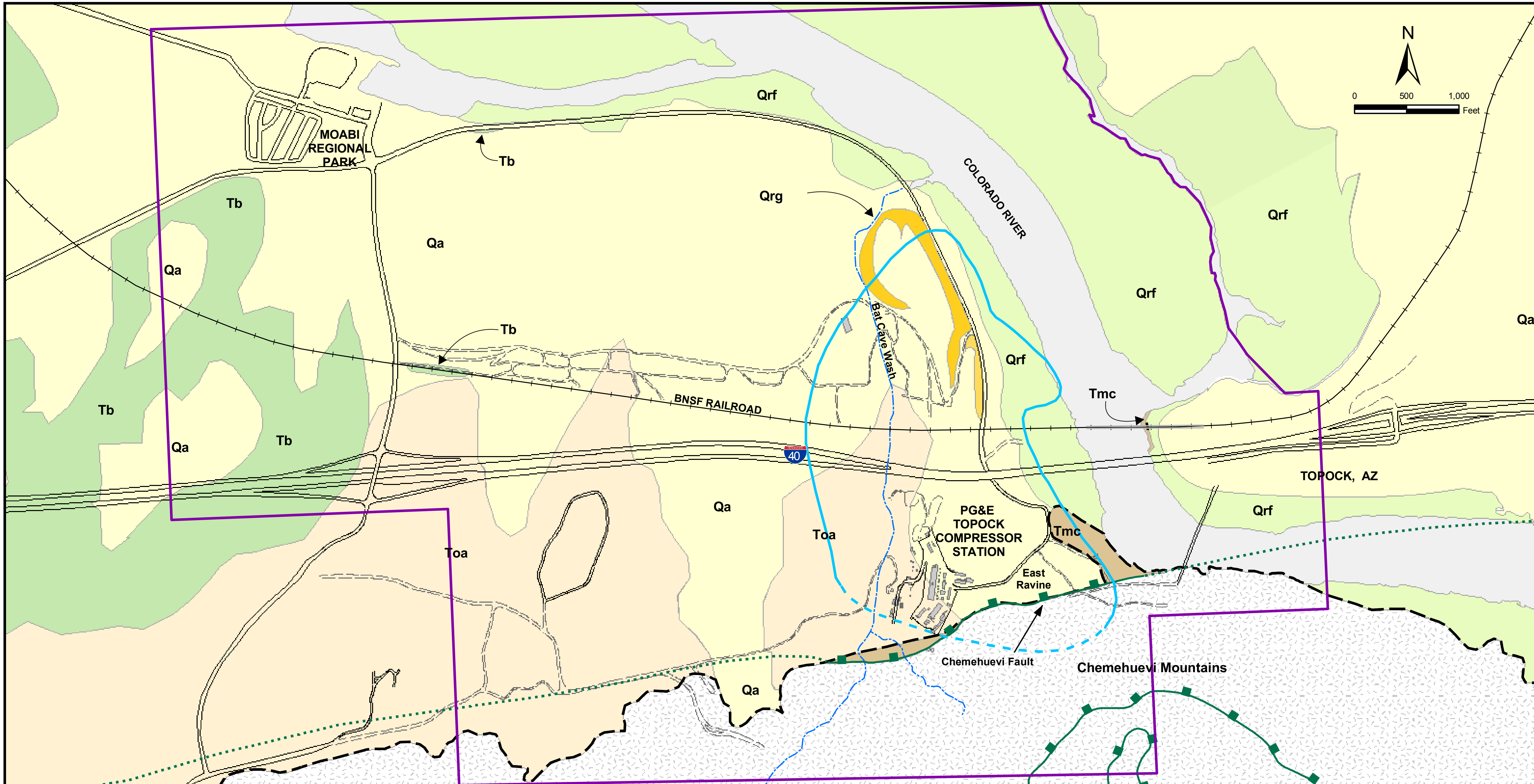


LEGEND

- Qrf = Quaternary Colorado River and recent Floodplain Deposits
- Qrg = Quaternary River Gravels
- Qa = Quaternary Alluvium and surficial deposits, undifferentiated
- Tb = Bouse Formation
- Toa = Tertiary Alluvium (Fanglomerate of Metzer and Loeltz)
- Tmc = Miocene Conglomerate (Bedrock)
- pTbr = Pre-Tertiary Bedrock (Metadiorite, Gneiss, Granitic Rocks)

- Detachment Fault barbs on downthrown side
- Detachment Fault concealed

- Area of Potential Effect (APE)
- 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.

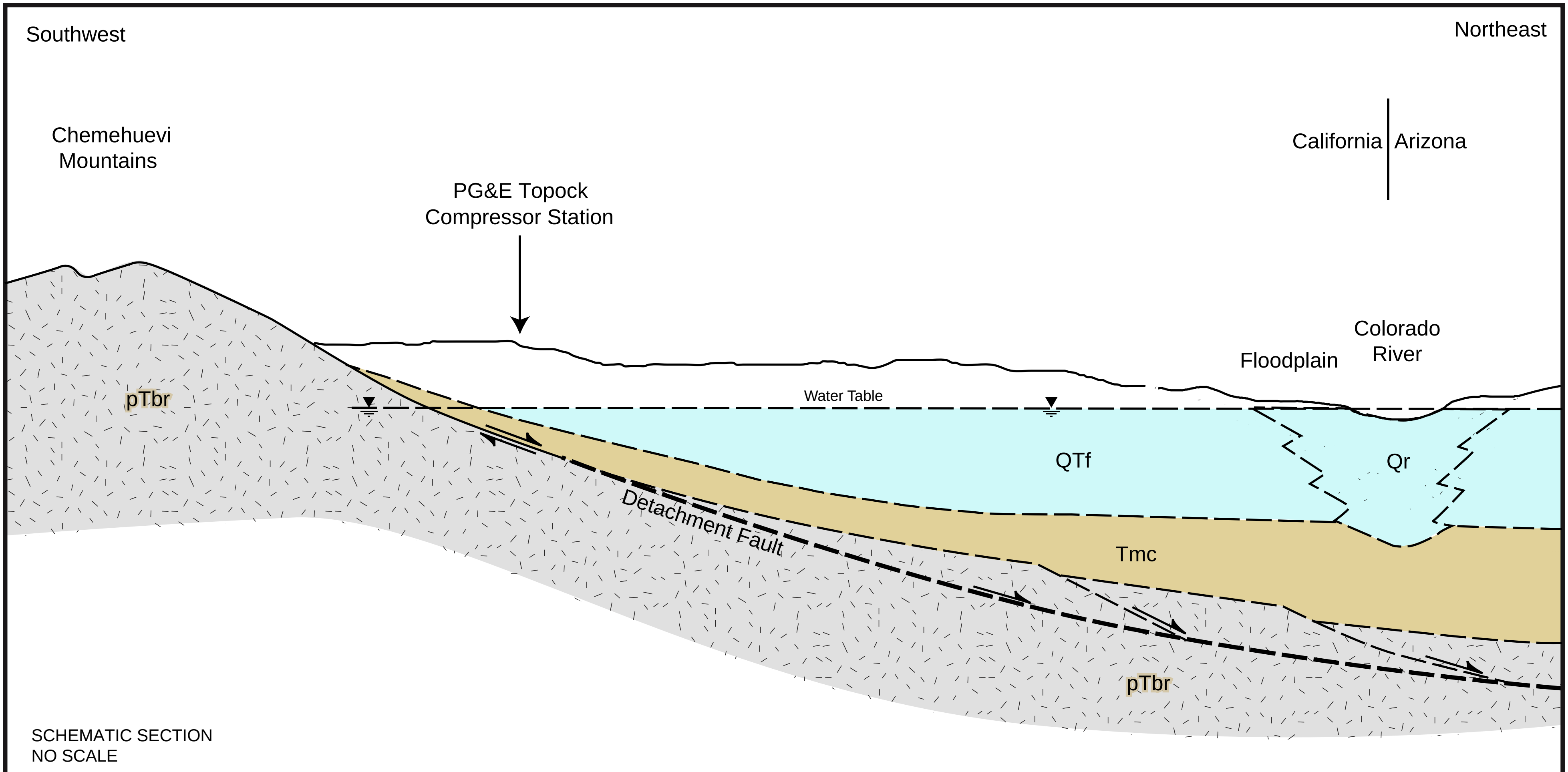
Note:
1. Generalized surface geologic map compiled from Metzger and Loeltz (1973), John (1987), Howard and others (1997), and PG&E technical reports.

2. The geologic map east of the Compressor Station was updated with mapping from the 2009 East Ravine investigation.

FIGURE 2-6
GEOLOGIC MAP

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL



PRIMARY GEOLOGIC UNITS

QTf	Alluvial Fan Deposits (Qoa, Toa units)	Alluvial Aquifer
Qr	Colorado River Fluvial Deposits (Qr0, Qrl, Qr2, Qr3 units)	Alluvial Aquifer
Tmc	Miocene Conglomerate	Bedrock
pTbr	Metamorphic and Igneous Rocks	Bedrock

FIGURE 2-7
SCHEMATIC HYDROGEOLOGIC CROSS SECTION
FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY STUDY REPORT
FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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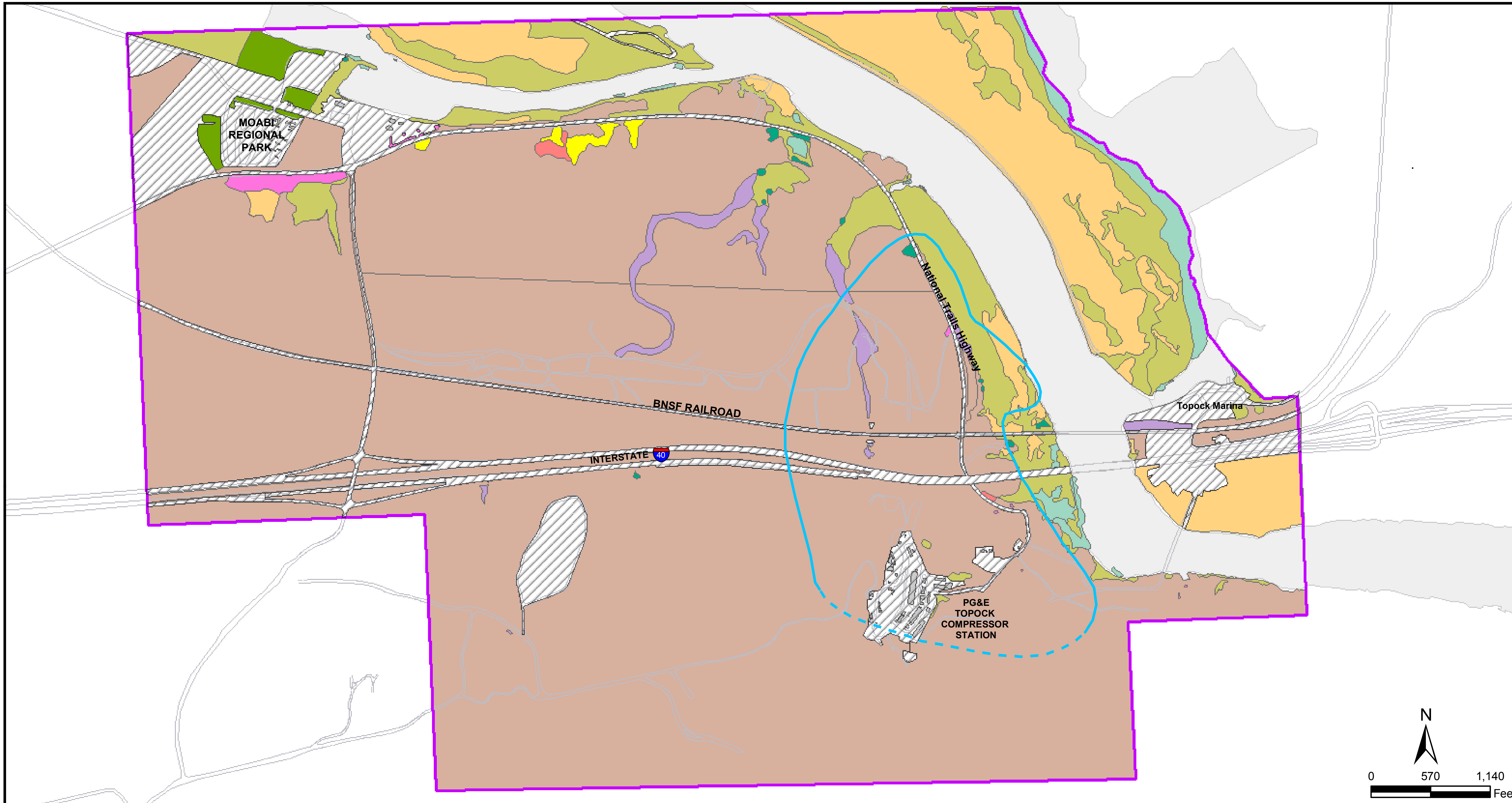

LEGEND

Area of Potential Effect (APE)

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.

Source: *Programmatic Biological Assessment for Pacific Gas and Electric Topock Compressor Station Remedial Investigative Actions* (CH2M HILL, 2007b)

Vegetation Communities	Approximate Acreage	Approximate % Composition
Arrow Weed	114	8.3
Creosote Bush Scrub	973	70.9
Landscaped	8	0.6
Mesquite	2	0.1
Mesquite/Palo Verde	8.3	0.9
Palo Verde	8.3	0.3
Salt Bush	8.3	0.1
Salt Cedar	8.3	8.1
Salt Cedar/Mesquite	3	.02
Wetland	15	1.1
Developed	130	9.5

FIGURE 2-8
TOPOCK VEGETATION COMMUNITIES

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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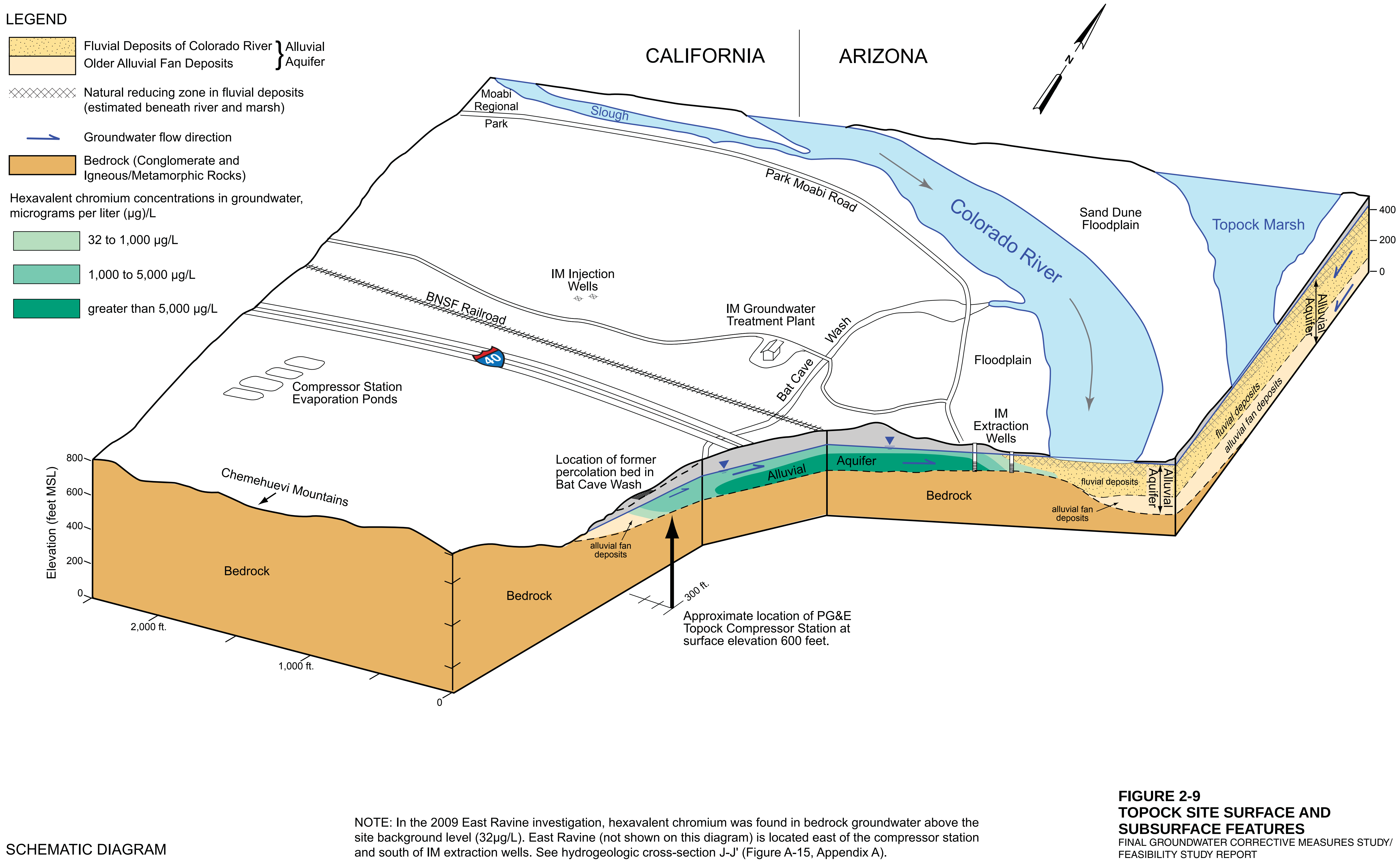

NOTE: In the 2009 East Ravine investigation, hexavalent chromium was found in bedrock groundwater above the site background level (32µg/L). East Ravine (not shown on this diagram) is located east of the compressor station and south of IM extraction wells. See hydrogeologic cross-section J-J' (Figure A-15, Appendix A).

FIGURE 2-9
TOPOCK SITE SURFACE AND SUBSURFACE FEATURES
FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY STUDY REPORT
FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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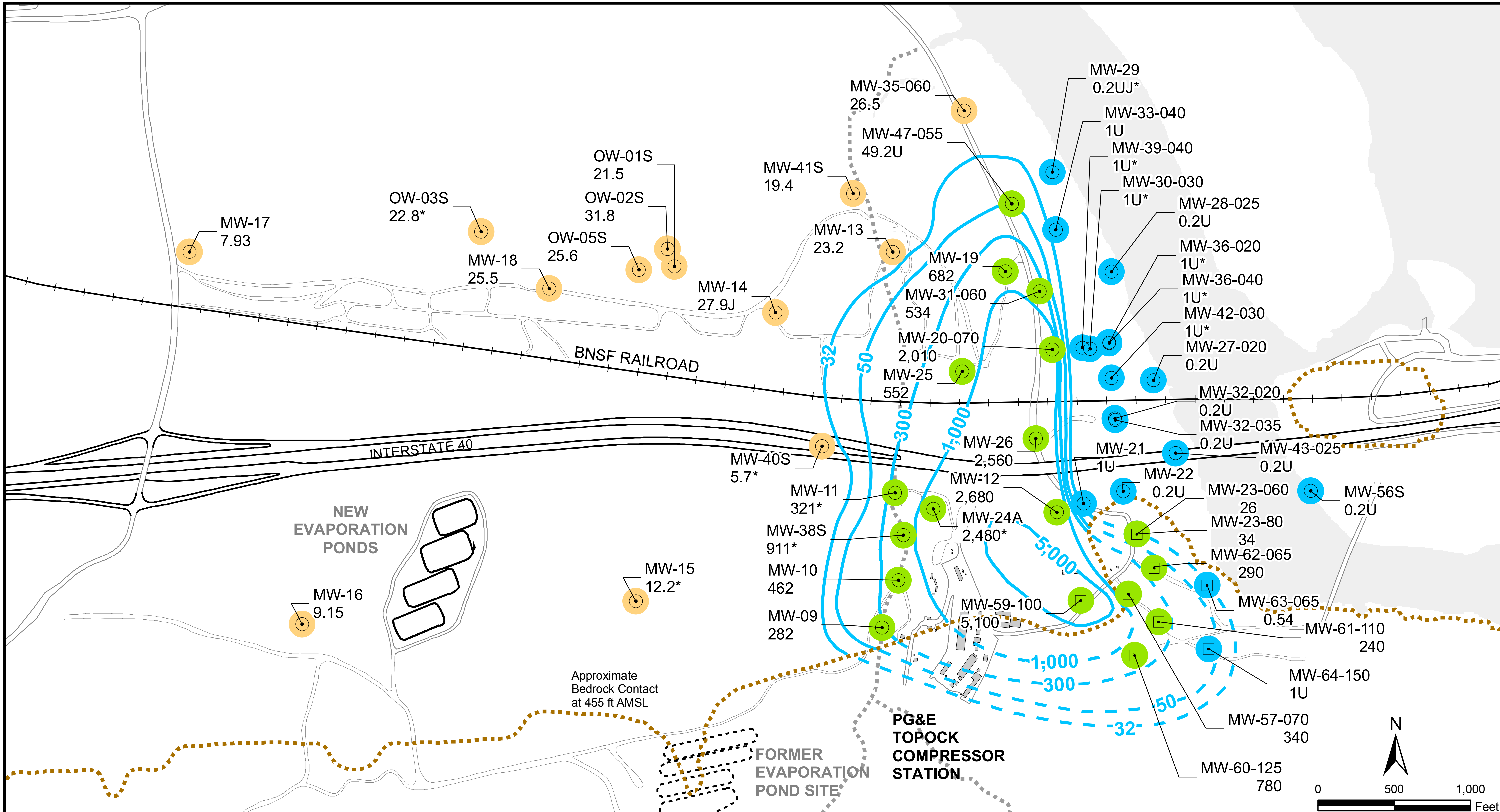

LEGEND

- Bedrock Well
- Bedrock Contact at 455-feet AMSL
- Monitoring, Test, or Supply Well
- Extraction Well

6.5 Concentration of Cr(VI) in micrograms per liter (µg/L)

U (0.2) Cr(VI) not detected at listed reporting limit

__Cr(VI) Concentrations in Alluvial Aquifer__

- Not detected at analytical reporting limit
- Concentration between reporting limit and 32 µg/L
- Concentration greater than 32 µg/L

- Approximate outline of hexavalent chromium [Cr(VI)] concentrations of 32 µg/L in shallow alluvial wells October 2008
- Approximate outline of hexavalent chromium [Cr(VI)] concentrations of 32 ug/L or higher in shallow bedrock wells July 2009

Notes:

1. Results shown are maximum concentrations in primary and duplicate samples from wells completed in **shallow zone** of Alluvial Aquifer, October 2008 sampling.
2. Bedrock Well Sample result from July 2009.
3. *Results from 2007 or December 2008 (well not sampled during October 2008). OW and CW results are from November 2008 unless denoted by * (then they are from 2007).

FIGURE 2-10
GROUNDWATER Cr(VI) RESULTS IN SHALLOW WELLS
OCTOBER 2008 AND JULY 2009

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/
FEASIBILITY STUDY REPORT FOR SWMU 1/AOC 1 and AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

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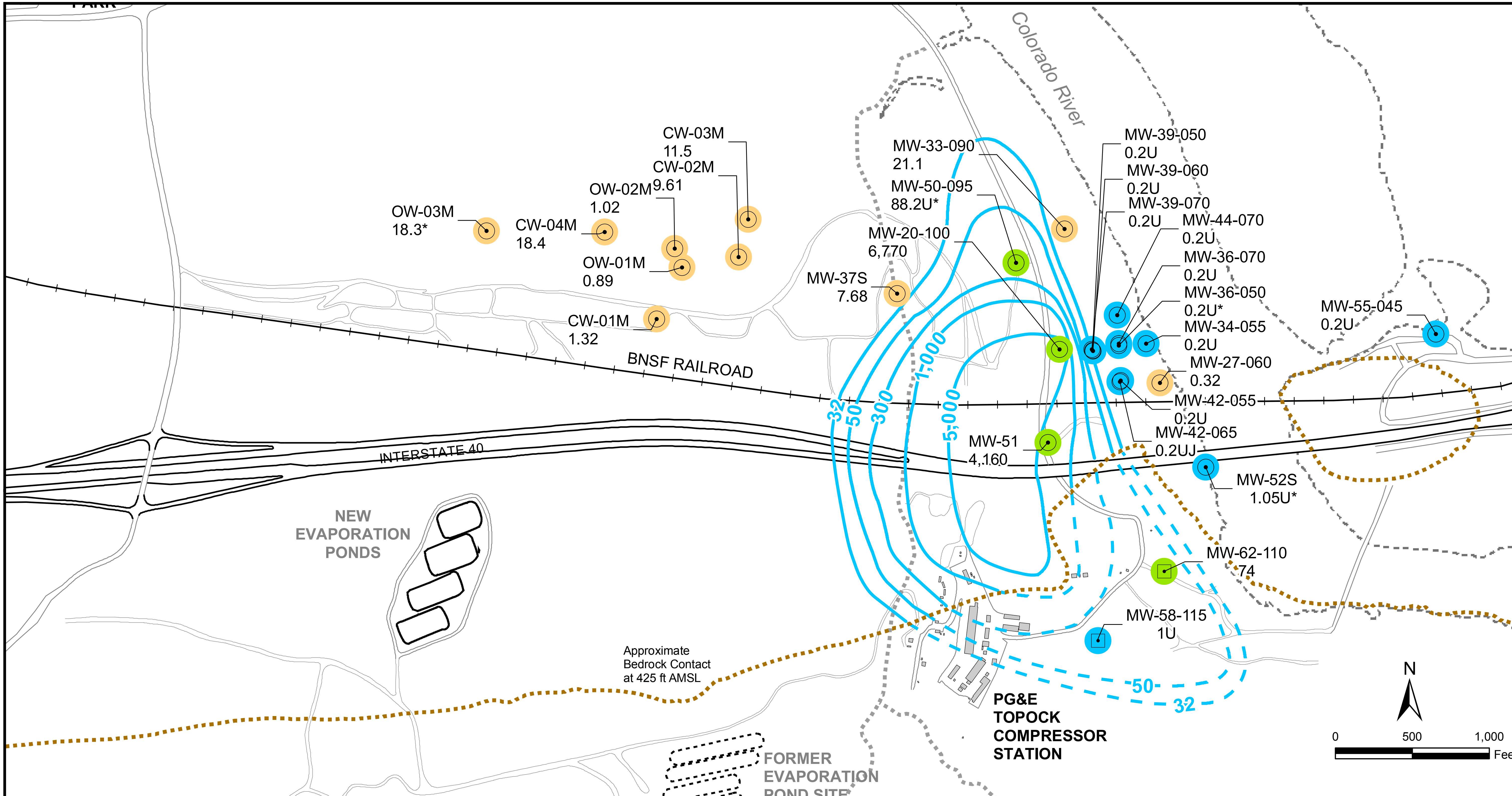

LEGEND

- ⊙ Monitoring, Test, or Supply Well
- ⊕ Extraction Well
- ⊡ Bedrock Well
- Bedrock Contact
- 21 Concentration of Cr(VI) in micrograms per liter (μg/L)
- U (0.2) Cr(VI) not detected at listed reporting limit

Cr(VI) Concentrations in Alluvial Aquifer

- Not detected at analytical reporting limit
- Concentration between reporting limit and 32 μg/L
- Concentration greater than 32 μg/L

- Approximate outline of hexavalent chromium [Cr(VI)] concentrations of 32 μg/L or higher in mid-depth alluvial wells October 2008
- Approximate outline of hexavalent chromium [Cr(VI)] concentrations of 32 ug/L or higher in mid-depth bedrock wells July 2009

Notes:

1. Results shown are maximum concentrations in primary and duplicate samples from wells completed in **mid-depth zone** of Alluvial Aquifer, October 2008 sampling.
2. * Results from 2007 or December 2008 (well not sampled during October 2008). OW and CW well results are from November 2008 unless denoted by * (then they are from 2007).
3. Bedrock Well Sample Results from July 2009.

FIGURE 2-11
GROUNDWATER Cr(VI) RESULTS IN MID-DEPTH WELLS OCTOBER 2008 AND JULY 2009

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY STUDY REPORT FOR SWMU 1/AOC 1 and AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

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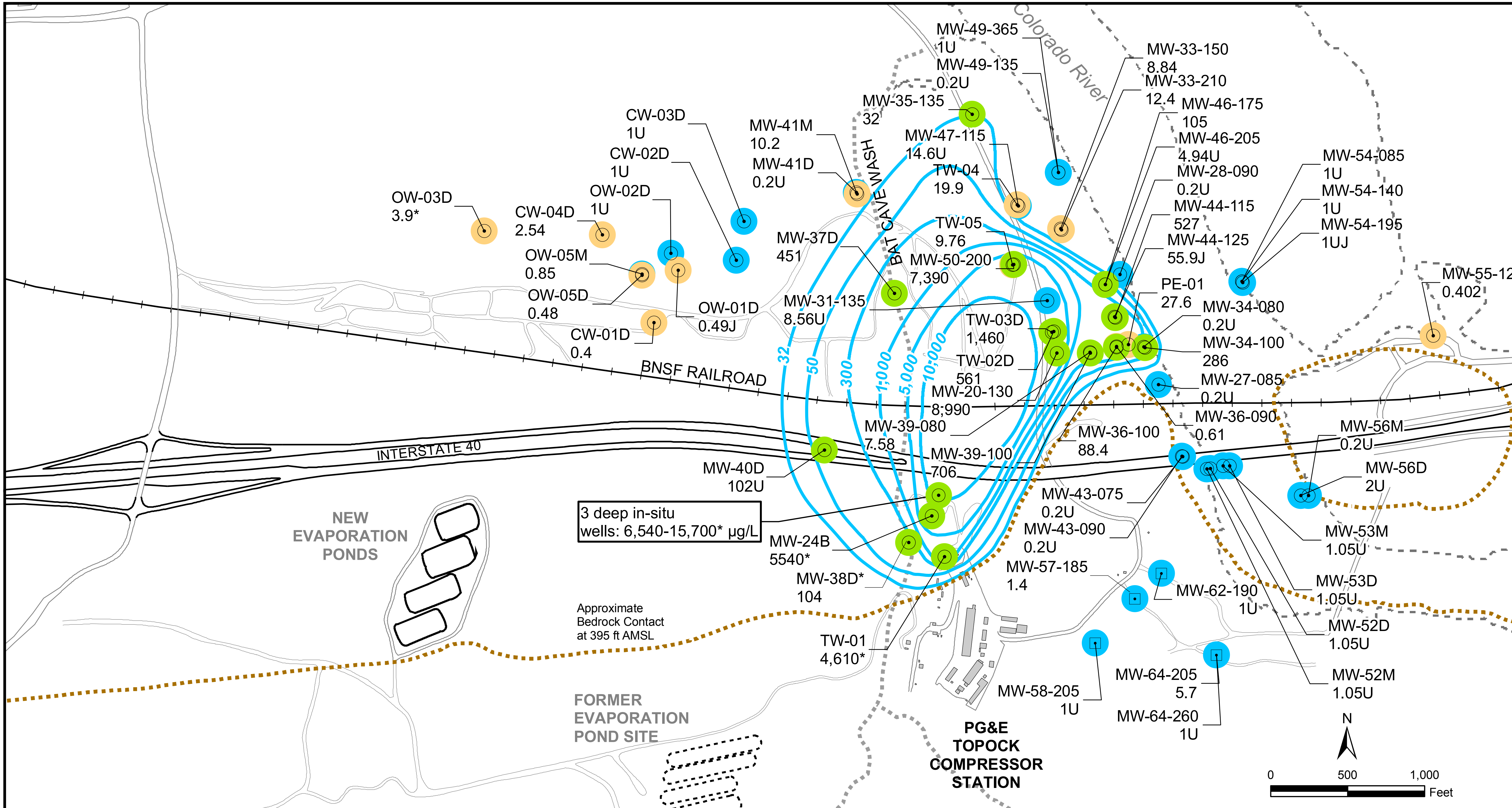

LEGEND

Bedrock Contact

Monitoring, Test, or Supply Well

Extraction Well

Bedrock Well

3.9 Concentration of Cr(VI) in micrograms per liter (µg/L)

U (0.2) Cr(VI) not detected at listed reporting limit

Cr(VI) Concentrations in Alluvial Aquifer

Not detected at analytical reporting limit

Concentration between reporting limit and 32 µg/L

Concentration greater than 32 µg/L

Approximate outline of hexavalent chromium [Cr(VI)] concentrations of 32 µg/L in Deep alluvial wells October 2008

Notes:

1. The estimated extent of Cr(VI) in the deep zone (80-90 feet below the Colorado River) is based upon data from nearby wells, hydraulic gradients, and flow lines predicted by the groundwater flow model. There are no wells or samples confirming the presence or extent of Cr(VI) under the Colorado River.
2. Results shown are maximum concentrations in primary and duplicate samples from wells completed in **Deep zone** of Alluvial Aquifer, October 2008 sampling.
3. Bedrock wells MW-57-185, MW-58-205, MW-62-190, MW-64-205 and MW-64-260 sample results from July 2009.
3. *Results from 2007 or December 2008 (well not sampled during October 2008). OW and CW well results are from November 2008 unless denoted by * (then they are from 2007).

FIGURE 2-12
GROUNDWATER Cr(VI) RESULTS IN DEEP WELLS OCTOBER 2008 AND JULY 2009

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY STUDY REPORT FOR SWMU 1/AOC 1 and AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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3.0 Remedial Action Objectives

This section identifies the objectives of this remedial action based on the results of the groundwater human health and ecological risk assessment (GWRA) and identification of ARARs. Section 3.1 summarizes the baseline GWRA, Section 3.2 summarizes the potential ARARs, and Section 3.3 identifies the remedial action objectives (RAOs).

3.1 Groundwater Human Health and Ecological Risk Assessment Conclusions Summary

The mandate of both the RCRA Corrective Action and CERCLA programs is to protect human health and the environment from current and potential threats posed by uncontrolled releases of hazardous substances into the environment. The *Final Human and Ecological Risk Assessment of Groundwater Impacted by Activities at Solid Waste Management Unit (SWMU) 1/Area of Concern (AOC 1) and SWMU 2, Topock Compressor Station Site Vicinity* (ARCADIS, 2009) was completed to assist risk management decision-making by quantitatively evaluating COPCs in groundwater and surface water and determining whether the COPCs are potential threats to human health or the environment. The COPCs that are related to the facility and are identified as potential risks to human or ecological receptors are identified as COCs that then become the focus of the RAOs and remedial alternatives.

The GWRA documented the conceptual site model, including identified sources of groundwater contamination, potential transport mechanisms, potential exposed populations and exposure pathways, and potential exposure point concentrations for impacts by activities at SWMU 1/AOC 1 and SWMU 2 (ARCADIS, 2009). The key conclusions of the GWRA, for purposes of defining objectives for this remedial action, are:

- The potential transport of constituents in groundwater to the Colorado River represents an insignificant transport pathway; floodplain COPCs are not being transported to the Colorado River at concentrations that exceed screening-level surface water criteria.
- There are no current direct or indirect complete exposure pathways for human contact with impacted site groundwater; thus, there are no human populations currently at risk of adverse health effects due to groundwater at the Topock site.
- There is no significant ecological exposure pathway for contact with impacted site groundwater; thus, there is no ecological population currently at risk of adverse effects due to the presence of COPCs in groundwater.
- Due to the possibility of future development of the groundwater as a drinking water supply, the GWRA included a quantitative risk characterization of future hypothetical human groundwater users that may be exposed to site groundwater in a residential setting. Both child and adult future hypothetical residential groundwater users were considered. Potential exposure through ingestion and dermal contact while bathing and

showering were evaluated. Potential cumulative cancer risks and noncancer hazard indices were estimated for all COPCs, including the constituents that were not related to SWMU 1/AOC 1. The risk characterization concluded that:

- Hexavalent chromium is present in site groundwater at concentrations that could pose a potential hazard to the future hypothetical human groundwater user, if the groundwater were to be developed as a potable source of water in the future. Based on the results of the risk estimates and the fact that the presence of Cr(VI) is related to historical releases from SWMU 1/AOC 1, Cr(VI) is a COC for this remedial action.
- The calculated noncarcinogenic risk-based remediation goal for Cr(VI) is 46 µg/L based on the hypothetical child receptor.

The GWRA determined that other COPCs were not either associated with SWMU 1/AOC 1 and/or not present in site groundwater at levels of potential concern to human health or the environment. DTSC and DOI, however, concluded that although the noncancer hazards associated with selenium, molybdenum, and nitrate are much lower than those associated with Cr(VI), these constituents do have risks above a hazard index of 1 and they do contribute to a hazard quotient greater than 1 at localized areas within the plume. DTSC directed that molybdenum, selenium, and nitrate be monitored in the groundwater monitoring program and their associated impacts be considered in future soil and soil to groundwater risk evaluations (DTSC 2009c, DOI 2009c).

3.2 Applicable or Relevant and Appropriate Requirements Summary

CERCLA requires that remedial alternatives attain ARARs unless they are waived. ARARs consist of regulations, standards, criteria, or limitations promulgated under federal or more stringent state laws.

ARARs are classified as chemical-specific, location-specific, or action-specific. Chemical-specific ARARs are generally health- or risk-based numerical values or methodologies applied to site-specific conditions that result in the establishment of a remediation goal. Location-specific ARARs are restrictions on the concentrations of hazardous substances or the conduct of activities because of the characteristics of the site or its immediate environment. Action-specific ARARs specify how a remedial alternative must be achieved. They are generally technology- or activity-based requirements or limitations and apply to specific remedial approaches rather than to a site.

The identification of site-specific ARARs is provided in Appendix B (DOI, 2009e). As the CERCLA remediation process advances past the CMS/FS, new information may become available, prompting DOI to revise the list of ARARs for the final Record of Decision. A summary of the key chemical, location, and action-specific ARARs, as described in Appendix B, for this remedial action are provided below.

3.2.1 Chemical-specific ARARs

The identified chemical-specific ARARs for Cr(VI), Cr(III), and Cr(T) in groundwater and surface water are shown in Table 3-1.

TABLE 3-1
Chemical-specific ARARs for Cr(VI), Cr(III), and Cr(T) in Groundwater and Surface Water
Final Groundwater Corrective Measures Study /Feasibility Study Report for SWMU 1/AOC 1 and AOC 10
PG&E Topock Compressor Station, Needles, California

ARAR	Unit	Cr(VI)	Cr(III)	Cr(T)
Groundwater				
Federal Safe Drinking Water Act (42 USC §300f, et seq., 40 CFR 141)	μg/L	N/A	N/A	100
California Safe Drinking Water Act (22 CCR δ64431, §64444, §64449)	μg/L	N/A[a]	N/A	50
Surface Water				
Federal Water Pollution Control Act (33 USC §§ 1251-1387, 40 CFR 131.38)	μg/L	11[c]	438[b]	N/A

Notes:

[a] In 2001, a law was enacted that requires the California Department of Public Health to establish a maximum contaminant level for Cr(VI) at a level as close as is technically and economically feasible to the contaminant's public health goal. In August 2009, the Office of Environmental Health Hazard Assessment released a draft public health goal for Cr(VI); however, the final public health goal will not be an ARAR because it is not a promulgated requirement, but any future maximum contaminant level developed by California Department of Public Health would be an ARAR.

[b] Freshwater aquatic life, chronic, assuming water hardness = 300,000 μg/L (calcium carbonate [$CaCO_3$] equivalents).

[c] Dissolved concentration.

μg/L = micrograms per liter.

CCR = California Code of Regulations.
CFR = Code of Federal Regulations.
N/A = not applicable.
USC = United States Code.

Source: DOI, 2009e (Appendix B).

3.2.2 Location-specific ARARs

Remedial action alternatives addressing chromium in groundwater at the Topock Compressor Station must consider the following location-specific requirements, depending on the location of the physical infrastructure associated with each alternative:

- **Federal Land Policy and Management Act.** In managing public lands, BLM is directed to take any action necessary to prevent unnecessary or undue degradation of the lands. Actions taken on the public land (i.e., BLM-managed land) portions of the Topock site should provide the optimal balance between authorized resource use and the protection and long-term sustainability of sensitive resources. Figure 2-2 in Section 2.0 illustrates the portions of the groundwater plume within BLM-managed land.

- **National Wildlife Refuge System Administration Act.** This Act governs the use and management of the HNWR portion of the Topock site. It requires that the USFWS evaluate ongoing and proposed activities and uses to ensure that such activities are appropriate and compatible with the mission of the National Wildlife Refuge System, as well as the specific purposes for which the HNWR was established. Figure 2-2 illustrates the portions of the groundwater plume within the HNWR. The Topock site includes portions of the HNWR. Prior to the selection of a remedial action by DOI/USFWS, that remedial action must be found by the Refuge Manager to be both an appropriate use of the HNWR and compatible with the mission of the HNWR and the Refuge System as a whole. Any remedial action proposed to be implemented on the HNWR that was not selected by DOI/USFWS would be subject to the formal appropriate use/compatibility determination process.

- **Fish and Wildlife Coordination Act.** This Act requires that any federally-funded or authorized modification of a stream or other water body must provide adequate provisions for conservation, maintenance, and management of wildlife resources and their habitat. Necessary measures should be taken to mitigate, prevent, and compensate for project-related losses of wildlife resources.

- **National Historic Preservation Act.** This statute and the implementing regulations require that a federal agency undertaking a remedial action at or near historic properties must take into account the effects of such undertaking on the historic properties. The federal agency must determine, based on consultation, if an undertaking's effects would be adverse and seek ways that could avoid, mitigate, or minimize such adverse effects on a National Register or eligible property. The agency must then specify how adverse effects will be avoided or mitigated or acknowledge that such effects cannot be avoided or mitigated. The APE includes historic properties, as discussed in Section 2.2.6. Measures to avoid or mitigate adverse effects of any selected remedial action that are adopted by the agency through federal consultation must be implemented by the remedial action to comply with the National Historic Preservation Act.

- **National Archaeological and Historical Preservation Act. This statute requires the evaluatio**n and preservation of historical and archaeological data that might otherwise be irreparably lost or destroyed through any alteration of terrain as a result of federal construction projects or a federally licensed activity. The APE includes historical and archaeological data, as discussed in Section 2.2.6.

- **Archaeological Resources Protection Act.** This statute provides for the protection of archeological resources located on public and tribal lands. The Act establishes criteria that must be met for the land manager's approval of any excavation or removal of archaeological resources if a proposed activity involves soil disturbances.

- **Historic Sites Act.** Pursuant to this Act, federal agencies must consider the existence and location of historic sites, buildings, and objects of national significance, using information provided by the National Park Service, to avoid undesirable impacts upon such landmarks. There are no designated historic landmarks within the APE, although 16 USC 461, through Public Law 106-45, provides for a cooperative program "for the preservation of the Route 66 corridor" through grants and other measures.

- **Native American Graves Protection and Repatriation Act.** This Act regulates the removal and trafficking of human remains and cultural items, including funerary and sacred objects. If remediation activities result in the discovery of Native American human remains or related objects, these requirements must be met. The APE contains archaeological areas that may contain human remains.

- **American Indian Religious Freedom Act.** This Act requires that the United States protect and preserve for American Indians their inherent right of freedom to believe, express, and exercise their traditional religions.
- **Floodplain Management and Wetlands Protection.** Before undertaking an action, agencies are required to perform certain measures to avoid the long- and short-term impacts associated with the destruction of wetlands and the occupancy and modification of floodplains and wetlands. Figure 2-5 in Section 2.0 illustrates the locations of floodplain and wetlands in relation to the groundwater plume.

3.2.3 Action-specific ARARs

Action-specific requirements most likely to be triggered by this remedial action include:

- **Safe Drinking Water Act, Underground Injection Control.** Underground Injection Control Regulations ensure that any underground injection performed onsite will not endanger drinking water sources. Substantive requirements include, but are not limited to, regulation of well construction and well operation. These requirements will be applicable to alternatives that include underground injection as a part of the remedy.
- **Clean Water Act, Stormwater Management.** These regulations define the necessary requirements with respect to the discharge of stormwater under the National Pollutant Discharge Elimination System program. These regulations will apply if proposed remedial actions disturb more than 1 acre of soil and result in stormwater runoff that comes in contact with any construction activity from site remediation, or if proposed remedial actions involve specified industrial activities.
- **Endangered Species Act.** This Act makes it unlawful to remove or "take" threatened and endangered plants and animals and protects their habitats by prohibiting certain activities. As discussed in Section 2.2.7, examples of such species in or around the APE may include, but are not limited to, SWFL, desert tortoise, Colorado pikeminnow, razorback sucker, and bonytail chub. This Act will apply if the proposed remedial actions will result in the take of, or adverse impacts to, threatened and endangered species or their habitats.
- **Hazardous Waste Control Law and Regulations.** The California Hazardous Waste Control Law and regulations establish requirements for hazardous waste generators; operators of hazardous waste treatment, storage, or disposal units; and for corrective action taken in response to releases of hazardous waste from regulated units. Hazardous waste generators must determine if their waste is hazardous, manage the waste in accordance to specified requirements for accumulation in tanks and containers, use a hazardous waste manifest for offsite transportation of hazardous waste, send hazardous waste to an appropriately permitted offsite treatment or disposal facility, and retain specified records. These requirements will apply to all hazardous waste generated by onsite remedial activities. Units constructed to treat hazardous waste as part of the remediation must comply with additional operational and closure requirements.

- **Religious Freedom Restoration Act.** Under this Act, the government shall not substantially burden a person's exercise of religion, unless the application of the burden is in furtherance of a compelling government interest, and it is the least restrictive means of furthering that compelling interest. To constitute a "substantial burden" on the exercise of religion, a government action must (1) force individuals to choose between following the tenets of their religion and receiving a governmental benefit or (2) coerce individuals to act contrary to their religious beliefs by the threat of civil or criminal sanctions. If any remedial action selected imposes a substantial burden on a person's exercise of religion, it must be in furtherance of a compelling government interest and be the least restrictive means of achieving that interest.
- **Requirement for Land Use Covenants.** This regulation requires appropriate restrictions on use of property in the event that a proposed remedial alternative results in hazardous materials remaining at the property at levels that are not suitable for unrestricted use of the land. This is an ARAR with respect to privately-owned land at the Topock site.
- **SWRCB Resolution 68-16.** This resolution requires that any activity that discharges to existing high-quality waters must implement best practicable treatment necessary to assure that pollution or a nuisance will not occur and that the highest water quality consistent with maximum benefit to people of the State will be maintained. This resolution will apply to discharges from any remedial activity at the Topock site.
- **SWRCB Resolution 88-63.** This resolution specifies that, with certain exceptions, all surface and ground waters of the State are to be considered suitable, or potentially suitable, for municipal or domestic water supply. The Regional Water Quality Control Board and State Water Resources Board have designated the beneficial use of the ground and surface waters in the Topock Site area as "municipal and domestic water supply." This designation is set forth in the Basin Plan.
- **SWRCB Resolution 92-49.** This resolution establishes policies and procedures for investigation and cleanup and abatement of discharges under Water Code Section 13304, including the requirement that cleanup attain background water quality or the best water quality that is reasonable if background water quality cannot be restored. In addition, Section III.A of this Resolution states that the Regional Water Board shall" "concur with any investigative and abatement proposal which the discharger demonstrates and the Regional Water Board finds to have a substantial likelihood to achieve compliance within a reasonable time frame…"
- **Water Quality Control Plan: Colorado River Basin-Region 7, June 2006**. The Basin Plan designates the Colorado River and Colorado Hydrologic unit as having the beneficial use of "MUN" (municipal or domestic water supply). The Basin Plan also prescribes General Surface Water Objectives and Ground Water Objectives in addition to Specific Surface Water Objectives for the Colorado River, which include a flow-weighted average annual numeric criterion for salinity for the portion of the Colorado River on the Topock Site of 723 mg/L. This TDS value must not be exceeded in any remedial alternative being considered.

3.3 Remedial Action Objectives

The objectives of this remedial action are defined based on the conclusions of the GWRA and ARARs identification. The RAOs are intended to provide a general description of the cleanup objectives and to provide the basis for the development of site-specific remediation goals. In accordance with CERCLA guidance, RAOs specify the contaminant of concern, the exposure routes and receptors, and an acceptable contaminant concentration for each exposure pathway (United States Environmental Protection Agency [USEPA], 1988a-b). Protectiveness can be achieved by limiting or eliminating the exposure pathway, reducing or eliminating chemical concentrations, or both. RCRA Corrective Action guidance describes goals for final cleanup both in terms of protecting human health and the environment as well as performance standards that must also include controlling future sources of releases (USEPA, 2004).

The proposed RAOs for groundwater in this remedial action are to:

1. Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI).
2. Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI)).
3. Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI).
4. Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.

3.3.1 Preliminary Cleanup Goals

Preliminary cleanup goals are developed to provide risk reduction targets early in the RI/FS process. Cleanup goals may be refined based on the baseline risk assessment, ARARs, feasibility alternative analysis, and risk management considerations.

The preliminary cleanup goals to address the first RAO of reducing potential future human health risk from exposure to Cr(T) and Cr(VI) by ingestion of groundwater considered the exposure pathway and chemical concentrations of Cr(T) and Cr(VI) in groundwater at the site. As previously described, there is no existing use of groundwater within the Cr(VI) plume area and, therefore, no current complete pathway exists. However, to address the possibility that groundwater may be developed as a drinking water source in the future, the preliminary cleanup goals consider both the chemical-specific ARARs for drinking water, as well as the calculated noncancer risk-based remediation goal for Cr(VI), assuming future hypothetical human groundwater users that may be exposed to site groundwater in a residential setting. The California and federal maximum contaminant level for Cr(T) are 50 µg/L and 100 µg/L, respectively, and represent the chemical concentrations in drinking water considered safe for human consumption. No maximum contaminant level (MCL) exists for Cr(VI) although, in general, Cr(VI) has been shown to be more toxic than Cr(III) (United States Department of Human Health Services, 2008). Hexavalent chromium is currently regulated under the MCL for Cr(T). In 2001, a law was enacted that requires the California Department of Public Health to establish an MCL for Cr(VI) at a level as close as is technically and economically feasible to the contaminant's public health goal. In August 2009, the Office of Environmental Health Hazard Assessment released a draft public health goal for Cr(VI); however, the final public health goal will not be an ARAR because it is not a promulgated requirement, but any future MCL developed by California Department of Public Health would be an ARAR. As described in the GWRA, the calculated noncancer risk-based remediation goal for Cr(VI) is 46 µg/L.

Considering the above, and as a conservative measure, PG&E is considering the background level of Cr(T) and Cr(VI) in groundwater at the site as the preliminary cleanup goal for addressing risks associated with a hypothetical future groundwater user, rather than the MCL or the calculated noncancer risk-based remediation goal. Based on the results of a multi-year study, the background concentration for Cr(VI) in groundwater at the Topock site is 32 µg/L,[7] and the background concentration for Cr(T) in groundwater is 34 µg/L[8] (CH2M HILL, 2008c). The background values represent the calculated statistical UTL of natural background levels for Cr(VI) and Cr(T) in groundwater near the Topock site The preliminary cleanup goal of 32 µg/L of Cr(VI) is less than the calculated noncancer risk-based remediation goal of 46 µg/L for future hypothetical human groundwater users that may be exposed to site groundwater in a residential setting, and the preliminary cleanup goal of 34 µg/L Cr(T) is less than the California and federal MCLs for Cr(T) of 50 µg/L and 100 µg/L, respectively.

The second RAO—ensuring concentrations of Cr(T) and Cr(VI) in groundwater at the site do not cause exceedances in water quality standards that support the designated beneficial uses of the Colorado River—is being addressed in a similar manner as the first RAO. As previously described, evidence shows that the plume is not causing exceedance in water quality standards of the Colorado River. Surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than the federal water quality criteria for Cr(VI) (CH2M HILL, 2009a), and the GWRA concluded that the potential transport of constituents in groundwater to the Colorado River represents an insignificant transport pathway (ARCADIS, 2009). Similar to addressing the first RAO, PG&E is addressing the second RAO by using a conservative means to increase the level of certainty that surface water quality will continue to remain below surface water quality standards in the future by applying the background concentration for Cr(VI) and for Cr(T) as a cleanup goal in groundwater.

The third RAO—reduction of mass to achieve risk and ARAR target levels—is also being addressed in a manner similar to the first and second RAOs. Rather than achieving protectiveness or ARARs compliance by limiting or eliminating the exposure pathways, the RAO focuses on reducing or eliminating the chemical concentrations comprising the contaminant source. As a conservative measure, PG&E is proposing a preliminary cleanup goal of background concentrations for Cr(VI) and for Cr(T) for attainment of the third RAO. The background concentrations are lower than the MCL and lower than the calculated noncancer risk-based remediation goal.

[7] The calculated statistical UTL for Cr(VI) is 31.8 µg/L; the 32 µg/L goal is the UTL rounded to the nearest whole number.

[8] The calculated statistical UTL for Cr(T) is 34.1 µg/L; the 34 µg/L goal is the UTL rounded to the nearest whole number.

The fourth RAO—ensuring that the geographic location of the target remediation area does not permanently expand following completion of the remedial action—included as requested by DTSC, is being addressed through implementation of the third RAO. By reducing the mass of Cr(VI) to achieve compliance with ARARs (50 µg/L Cr(VI) in groundwater and 11 µg/L Cr(VI) in surface water), the target remediation area will not expand following completion of the remedial action.

Under the geochemical conditions of site groundwater, dissolved chromium exists nearly entirely as Cr(VI). Historical data show that Cr(T) is equal to Cr(VI), allowing for analytical scatter. The reduced form, Cr(III), is highly insoluble, with precipitation reactions maintaining the concentration less than the analytical detection limit. As a result, measurement of RAO attainment in this remedial action will be focused on attaining the preliminary cleanup goal for Cr(VI) rather than Cr(T), and the treatment technologies will be focused on Cr(VI) rather than Cr(T).

3.3.2 Point of Compliance

The point of compliance for attainment of cleanup goals is throughout the area of contaminated groundwater, assuming that development of groundwater beneath the plume as a water supply may ultimately be pursued in the future. In establishing the point of compliance throughout the area of contaminated groundwater, the following are recognized:

- Attaining the cleanup goals at the point of compliance may be through active remediation or through natural means.
- Different areas of the plume may reach the media cleanup goal at different times.

3.3.3 Other Constituents Potentially Associated with SWMU1/AOC1

As described in the RFI/RI Volume 2 Report and RFI/RI Volume 2 Addendum, there are three other constituents in addition to Cr(VI) that are potentially related to releases from SWMU 1/AOC 1: molybdenum, selenium, and nitrate. The GWRA presents a thorough and conservative analysis of the potential human health risks posed by these three constituents under the assumption that a future resident consumes the water at a given well on a daily basis. Based on multiple lines of evidence presented in the GWRA, the GWRA concludes that molybdenum, nitrate, and selenium do not represent a significant health risk to future hypothetical users of the groundwater.

Although the GWRA concludes that these three constituents are not believed to be a source of significant risk/noncancer hazard, the regulatory agencies have requested that molybdenum, selenium, and nitrate continue to be monitored through the remediation process (DTSC 2009c, DOI 2009c). On a well-by-well basis (assuming water quality data from an individual groundwater monitoring or testing well would represent water quality from a future water supply well), the noncancer HI exceeded the threshold of 1.0 in one or more wells in the quantitative evaluation for these three constituents (ARCADIS, 2009). Specifically, selenium exceeds an HI of 1.0 in one well (with an HI of 2.0), nitrate exceeds an HI of 1.0 in one well (with an HI of 1.3), and molybdenum exceeds an HI of 1.0 in the baseline analysis at six wells (with an HI from 1.1 to 2.5). Taking into account essential nutrient considerations, molybdenum exceeds an HI of 1.0 at only one well (with an HI of

1.1). The methodology used in the GWRA conformed to USEPA risk assessment methods that are designed to be health protective and tend to overestimate rather than underestimate risk (ARCADIS, 2009). Key assumptions regarding exposure and toxicity tend to lead to a conservative bias in the estimates of risk/hazard, and for the GWRA included:

- **The assumption that water quality data from an individual groundwater monitoring or testing well would represent water quality from a future water supply well.** Monitoring wells are typically small-diameter wells with relative short screens, with screen locations biased towards the zones of highest contamination in the aquifer. Water supply wells are often screened across expanded aquifer thicknesses to optimize capacity and are constructed of sufficient diameter to house continuous supply pumping equipment.
- **The assumption that future human exposures are represented by the concentrations measured at an individual monitoring well, without accounting for mixing either horizontally or vertically as water is pulled into the well for supply needs.**
- **The assumption that the reasonably anticipated future land use anywhere within the site is residential use, leading to exposure assumptions that the future hypothetical residential groundwater users will use an onsite groundwater well for supplying all domestic water and will use this groundwater daily for an uninterrupted 30-year period.** Current (i.e., nonresidential) land uses at the site are likely to remain the same in the future. PG&E plans to continue owning and operating the Topock Compressor Station and associated property as an industrial operation for the foreseeable future. The railroad and highway will also continue in their current use for the foreseeable future. The primary conservation mission of USFWS, as it applies to the HNWR, limits human use of HNWR property, and in the future, human use of HNWR property will likely continue to be restricted to recreational uses (DOI, 2007c). Similarly, future use of the BLM-owned land at the site is likely to remain recreational, although DOI has indicated that residential use of that property cannot be precluded. Of the wells in the GWRA with an HI greater than 1.0 for molybdenum, selenium, and nitrate, and considering molybdenum's role as an essential nutrient, only one well (MW-46-175) is located on land where future residential land use is not specifically precluded as a reasonable future scenario.

Nevertheless, as a result of the well-by-well conclusions for molybdenum, selenium, and nitrate in the GWRA, as a conservative measure, institutional controls should be enforced throughout the treatment area during implementation of the remedial action to restrict ingestion of groundwater, and monitoring for these three constituents should continue. In order to attain the RAOs for Cr(VI) identified above, substantial movement of groundwater in the target remediation area—either through natural or induced measures—will be necessary, and under active treatment for Cr(VI), it is expected that significant mixing of groundwater in the target remediation area would occur both vertically and horizontally. As a result, concentrations of molybdenum, selenium, and nitrate measured at individual monitoring wells are expected to change during the course of remediation from the concentrations present today as, for example, multiple pore volumes of groundwater are moved through the aquifer. It is expected that following attainment of the RAOs for Cr(VI) and prior to removing the institutional controls, the concentration and distribution of these three constituents will be re-evaluated. Also, it is expected that monitoring and test wells at the site would be decommissioned at the completion of the remedial action following the determination that additional data collection from the wells are no longer needed to measure attainment of the RAOs.

In summary, within the treatment area, Cr(VI) in groundwater represents the predominant health hazard associated with any potential future domestic use of the groundwater; other potential facility-related constituents (molybdenum, selenium, and nitrate) were detected at elevated levels in localized areas associated with lower levels of risk. Institutional controls should be enforced during implementation of the remedial action to restrict ingestion of groundwater, and monitoring for these three constituents should be continued. Following attainment of the RAOs for Cr(VI) and prior to removing the institutional controls, the concentration and distribution of molybdenum, selenium, nitrate, and chromium should be re-evaluated.

4.0 Identification and Screening of Remedial Action Technologies

This section describes the identification and screening of remedial technologies to satisfy the identified RAOs for this remedial action. The identification and screening approach is consistent with the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA, 1988a). The content of this section is summarized as:

- **General Response Actions.** The broad range of actions that will potentially satisfy the RAOs are identified.
- **Screening of Remedial Technologies and Process Options.** For each general response action, the potentially applicable remedial technologies and associated process options are identified and screened against the criterion of technical implementability.
- **Evaluation of Process Options.** Remedial technologies and associated process options are evaluated against the criteria of effectiveness, implementability, and relative cost.
- **Selection of Representative Process Options.** Process options are chosen for each technology type by considering the screening results and by identifying those that can represent the entire range of process options for a given technology type during the evaluation of alternatives.

4.1 General Response Actions

General response actions describe the broad range of actions that will satisfy the RAOs. General response actions may include no action, institutional controls, containment, removal, treatment, disposal, monitoring, or a combination of these. Similar to RAOs, general response actions are medium-specific. The media-specific general response actions for groundwater are:

- **No Action.** No attempt is made to satisfy the RAOs, and no remedial measures are implemented. The National Contingency Plan stipulates that any evaluation of remedial alternatives includes evaluation of the No Action alternative.
- **Institutional Controls.** These are actions using non-engineering methods to prevent interference with other remedial activities and/or to prevent access to, contact with, or use of contaminated groundwater.
- **Containment.** These are actions that result in contaminated groundwater being contained or controlled, thereby minimizing or eliminating the migration of contaminants and preventing direct exposure to contamination.
- **Removal.** These are actions taken to physically collect and remove the contaminated groundwater.

- **Treatment.** These are *in-situ* or *ex-situ* actions taken to treat groundwater using thermal, physical, chemical, and/or biological processes to reduce the toxicity, mobility, and/or volume of contamination.
- **Disposal.** These are actions taken to dispose or re-use treated or untreated groundwater at onsite or offsite locations.
- **Monitoring.** This is the short- and/or long-term collection and evaluation of data to record site conditions, monitor contamination levels, and evaluate progress of remedial actions to meet the RAOs.

Except for the No Action general response action, each general response action can be addressed by a number of remedial technologies. In this context, the following definitions apply:

- Remedial technologies are defined as the general categories of remedies under a general response action.
- Process options are specific categories of remedies within each remedial technology. The process options are used to implement each remedial technology.

4.2 Screening of Remedial Technologies and Process Options

Many technology types and process options are available to implement the general response actions described in Section 4.1. Table 4-1 (located at the end of this section) provides an initial list of technologies and process options. The purpose of initially considering a wide range of technologies and process options is to ensure that potentially applicable options are not overlooked early in the CMS/FS process.

The screening of these remedial technologies and process options is accomplished in three steps:

1. Technical implementability screening
2. Evaluation of process options
3. Selection of representative process options

The first step in the process involves screening the initial list of technologies and process options against the criterion of technical implementability. This first screening eliminates those technologies or process options that are not applicable or not workable for the contaminants and site characteristics found at the site. A second screening of the remaining process options against the criteria of effectiveness, implementability (both technical and administrative), and relative cost further reduces this list. The last step involves the selection of representative process options for each technology type to simplify the subsequent development and evaluation of remedial alternatives. These steps are specifically discussed in the following subsections.

4.2.1 Technical Implementability Screening

In this step, the initial list of technology types and process options is reduced by evaluating the implementability of the options. Technical implementability refers to the ability of the remedial technology or process option to meet the RAOs for the site. This first screening eliminates those technologies and process options that are clearly not applicable or are not workable for the contaminants or characteristics of the site.

The technical implementability screening of potential groundwater remediation technologies and process options is presented in Table 4-1. This table provides brief descriptions of the technologies and process options and provides screening rationale. Technologies and process options that are screened out because they are not technically implementable are shaded.

4.2.2 Evaluation of Process Options

After the technical implementability screening, the remaining technologies and process options are evaluated in greater detail using the criteria of effectiveness, implementability, and relative cost. In accordance with the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA, 1988a), the evaluation of process options focuses more on effectiveness factors with less effort directed at the implementability and cost evaluation. A description of the screening criteria and how they are applied to the evaluation of process options is presented below.

- **Effectiveness**: Specific process options are evaluated for effectiveness by considering:
    - The ability of a process option to address the estimated areas or volumes of contaminated media and meet identified RAOs.
    - The potential impacts to human health and the environment during the construction and implementation phases.
    - The reliability and demonstrated success the process has shown with respect to the types of contamination and site conditions that will be encountered.
- **Implementability**: Implementability includes both the technical and administrative feasibility of implementing a technology process option. As discussed in Section 4.2.1, technical implementability is used as the initial screen to eliminate those options that are clearly not appropriate at the site. Therefore, this subsequent evaluation of process options places greater emphasis on the administrative or institutional aspects of using a process option such as potential restrictions on future land use of the site; the availability and capacity of treatment, storage, and disposal services; and the availability of the equipment and workers to implement the technology. Other aspects of implementability such as stakeholder acceptance will be discussed as part of the alternative evaluation in Section 5.0.
- **Relative Cost:** Cost plays a limited role in the screening of process options. Relative capital costs plus operations and maintenance costs are used rather than detailed estimates. The costs for each process option are evaluated on the basis of engineering judgment as high, medium, or low relative to the other process options in the same technology type.

The evaluation of process options is depicted in Table 4-2 (located at the end of this section). Technologies and process options that were screened out on the basis of effectiveness and/or implementability are shaded. None of the process options were screened out based on cost.

4.2.3 Selection of Representative Process Options

Following evaluations of effectiveness, implementability, and relative cost, process options are chosen to represent the range of options within a remedial technology type. These representative process options are chosen for each technology type by considering the screening results and by identifying those that can represent the entire range of process options. The representative process option may be chosen because performance and cost information is readily available, it has been previously identified or used at the site, or it otherwise ranks favorably among the other process options. The purpose of selecting a representative process option from all remaining options for each technology type (rather than including every remaining process option) is to simplify the subsequent development and evaluation of alternatives by reducing the number of alternatives formulated (USEPA, 1988a). For example, the use of conventional extraction wells is identified in Table 4-2 as the representative process option for groundwater collection. This was chosen because it is a proven, well-understood option and ranks high among the three options for groundwater collection (conventional extraction wells, horizontal wells, and trenches/drains). Cost and performance data for extraction wells are readily available. As a component of an alternative, conventional extraction wells will adequately represent groundwater collection during the evaluation against other alternatives. Use of conventional extraction wells in the alternative evaluation does not preclude the consideration of other groundwater collection options during the remedial design phase.

More than one process option may be selected for a technology type if the processes are sufficiently different in their performance that one would not adequately represent the other. For example, if horizontal wells and vertical wells were both applicable at a site, separate alternatives may be required to evaluate the groundwater extraction technology since the performance and cost of the two process options can be very different. Within a given technology, the specific process option implemented at the site may be modified during the remedial design phase, as well as during future optimization of the remedy, without compromising the evaluation and selection of alternatives in the CMS/FS (USEPA, 1988a).

The representative process options that were selected to be included in the alternative evaluations in Section 5.0 are presented in Table 4-2 and are summarized in Table 4-3.

TABLE 4-1
Primary Screening of Remedial Technologies and Process Options for Groundwater Remediation
Final Groundwater Corrective Measures Study /Feasibility Study Report for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
No Action	None	None	No further actions are taken to address contaminated groundwater.	Required for consideration by the National Contingency Plan.	Yes
Institutional Controls	Access and Use Restrictions	Land Use Covenants/ Deed Restrictions	Deed restrictions or covenants are issued for property within potentially contaminated areas to prevent interference with other remedial activities and/or to prevent access to, contact with, or use of contaminated groundwater.	Retained as a potential component of the remedy until RAOs are achieved.	Yes
		Fences	Security fences are installed around potentially contaminated areas to limit access.	The contaminated groundwater ranges from approximately 28 to 135 feet bgs. Surface access restrictions via fences are not necessary to limit exposure to contaminated groundwater.	No
		Permits	Permits can be used to control future actions within the plume to prevent accidental exposure or prevent damage to the remedial activities. Substantive requirement for promulgated regulations would need to be met during implementation of the remedial action. Actual permits are not required for onsite CERCLA actions.	Substantive requirements of ARARs would need to be met during implementation of the remedy. Permits are retained as a potential component of the remedy until RAOs are achieved.	Yes
	Alternative Drinking Water Source	Cisterns or Tanks	Drinking water is dispensed to users from a centralized point.	Groundwater beneath and immediately adjacent to the plume is not currently being used as a drinking water source. However, future development of alternative water supplies may be necessary to support future development; therefore, this technology is retained.	Yes
		Bottled Water	Drinking water is obtained from a commercial vendor.	Groundwater beneath and immediately adjacent to the plume is not currently being used as a drinking water source. However, future development of alternative water supplies may be necessary to support future development; therefore, this technology is retained.	Yes
		Deeper or Upgradient Wells	Wells are installed deep or upgradient if these areas are isolated from contamination.	Groundwater beneath and immediately adjacent to the plume is not currently being used as a drinking water source. However, future development of alternative water supplies may be necessary to support future development; therefore, this technology is retained.	Yes

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Institutional Controls, continued	Alternative Drinking Water Source (continued)	Relocation of Intake	Intake is relocated to an uncontaminated area.	Groundwater beneath and immediately adjacent to the plume is not currently being used as a drinking water source. However, future development of alternative water supplies may be necessary to support future development; therefore, this technology is retained.	Yes
		Municipal Water Supply	Additional water sources are established.	Groundwater beneath and immediately adjacent to the plume is not currently being used as a drinking water source. However, future development of alternative water supplies may be necessary to support future development; therefore, this technology is retained.	Yes
Containment	Capping	Native Soil	Uncontaminated native soil is placed over contaminated areas.	A surface barrier is not necessary to prevent direct contact to groundwater. The contaminated groundwater ranges from approximately 28 to 135 feet bgs. Capping might be used to mitigate localized infiltration and contaminant transport. This has not been assessed in the context of a technology for groundwater but may have application as a soils technology based on future evaluation of soils data.	No
		Clay Cap	Compacted clay is placed over contaminated area. Clay should be covered by at least 1 foot of silty sand or sandy soil to maintain the integrity of the clay cap.	A surface barrier is not necessary to limit infiltration or prevent direct contact to groundwater. The contaminated groundwater ranges from approximately 28 to 135 feet bgs. Precipitation in the area of the site is low. Groundwater moves very slowly at the site due to minimal local recharge. Capping might be used to mitigate localized infiltration and contaminant transport. This has not been assessed in the context of a technology for groundwater but may have application as a soils technology based on future evaluation of soils data.	No

TABLE 4-1
Primary Screening of Remedial Technologies and Process Options for Groundwater Remediation
Final Groundwater Corrective Measures Study /Feasibility Study Report for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Containment (continued)	Capping (continued)	Synthetic Membranes	Synthetic membrane is placed over prepared soil or geotextile surface that is over a contaminated area. The membrane is seamed by a variety of methods. The membrane must be compatible with the wastes present.	A surface barrier is not necessary to limit infiltration or prevent direct contact to groundwater. The contaminated groundwater ranges from approximately 28 to 135 feet bgs. Precipitation in the area of the site is low. Groundwater moves very slowly at the site due to minimal local recharge. Capping might be used to mitigate localized infiltration and contaminant transport. This has not been assessed in the context of a technology for groundwater but may have application as a soils technology based on future evaluation of soils data.	No
		Asphalt or Concrete Cap	Paving grade asphalt or concrete is placed over prepared contaminated area. Fill settlement must be evaluated in considering a concrete cap design.	A surface barrier is not necessary to limit infiltration or prevent direct contact to groundwater. The contaminated groundwater ranges from approximately 28 to 135 feet bgs. Precipitation in the area of the site is low. Groundwater moves very slowly at the site due to minimal local recharge. Capping might be used to mitigate localized infiltration and contaminant transport. This has not been assessed in the context of a technology for groundwater but may have application as a soils technology based on future evaluation of soils data.	No
		Multilayered Cap	Cap may be composed of natural soils, soil admixtures, clay, synthetic membranes, spray-on asphalts, asphalts concrete, or Portland cement concrete and placed over contaminated areas.	A surface barrier is not necessary to limit infiltration or prevent direct contact to groundwater. The contaminated groundwater ranges from approximately 28 to 135 feet bgs. Precipitation in the area of the site is low. Groundwater moves very slowly at the site due to minimal local recharge. Capping might be used to mitigate localized infiltration and contaminant transport. This has not been assessed in the context of a technology for groundwater but may have application as a soils technology based on future evaluation of soils data.	No

TABLE 4-1
Primary Screening of Remedial Technologies and Process Options for Groundwater Remediation
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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Containment (continued)	Vertical Barriers	Chemical Sealant/ Stabilizers	Water-dispersible emulsions and/or resins are placed over contaminated areas to form a crust that reduces water and wind or dust erosion. Most are nontoxic to plants and animals; temporary cover only.	A surface barrier is not necessary to limit infiltration or prevent direct contact to groundwater. The contaminated groundwater ranges from approximately 28 to 135 feet bgs. Precipitation in the area of the site is low. Groundwater moves very slowly at the site due to minimal local recharge. Capping might be used to mitigate localized infiltration and contaminant transport. This has not been assessed in the context of a technology for groundwater but may have application as a soils technology based on future evaluation of soils data.	No
		Soil-bentonite Slurry Wall	A vertical trench is excavated and filled with bentonite slurry to support the trench and is subsequently backfilled with a mixture of low-permeability material (1 x 10^{-6} cm/sec or lower) to redirect the groundwater flow.	Potential application in some portions of the site in conjunction with groundwater extraction for plume containment.	Yes
		Cement-bentonite Slurry Wall	A vertical trench is excavated and filled with bentonite slurry to support the trench and is subsequently backfilled with a mixture of cement and bentonite to form a solid barrier and redirect the groundwater flow.	Potential application in some portions of the site in conjunction with groundwater extraction for plume containment.	Yes
		Vibrating Beam Barrier Installation	Vibratory force is used to advance steel beam into ground; injection of a relatively thin wall of cement or bentonite as beam is withdrawn.	Vertical barriers may be used in conjunction with groundwater extraction for plume containment.	Yes
		Grout Curtains	Grout is pressure-injected along contamination boundaries in a regular overlapping pattern of drilled holes.	Less effective than other vertical barrier methods; may be applicable in some areas in conjunction with other technologies for plume containment.	Yes
		Sheet Piling	Steel sheet piling is driven along contamination boundaries.	Depth to groundwater contamination and depth to bedrock make implementation at this site impractical.	No
		Permeability Reduction Agents	Cement chemical grout or organic polymer is injected into the soil matrix to reduce permeability; experimental process option.	Similar implementation difficulties as other vertical barriers but is less effective; would require more intensive groundwater extraction and management than other vertical barriers.	No
		Ground Freezing (CRYOCELL process)	Conventional ground freezing technology is used to form a flow-impervious, removable, and fully monitored ice barrier that circumscribes the contaminant source *in-situ*.	Too energy-intensive; not feasible for the climate at the site.	No

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Containment (continued)	Horizontal Barriers	Block Displacement	Controlled injection of slurry in notched injection holes produces a horizontal barrier beneath contamination; experimental process option.	Horizontal barriers are not necessary to achieve RAOs. The groundwater contamination is distributed vertically throughout the Alluvial Aquifer. Bedrock underlies the Alluvial Aquifer, and vertical hydraulic gradients in the Alluvial Aquifer are primarily upward.	No
		Grout Injection	Grout pressure is injected at depth through closely-spaced drilled holes.	Horizontal barriers are not necessary to achieve RAOs. The groundwater contamination is distributed vertically throughout the Alluvial Aquifer. Bedrock underlies the Alluvial Aquifer, and vertical hydraulic gradients in the Alluvial Aquifer are primarily upward.	No
		Ground Freezing	Similar to vertical barriers by ground freezing; experimental process option.	Horizontal barriers are not necessary to achieve RAOs. The groundwater contamination is distributed vertically throughout the Alluvial Aquifer. Bedrock underlies the Alluvial Aquifer. and vertical hydraulic gradients in the alluvial aquifer are primarily upward.	No
		Liners	Liners are placed to restrict vertical flow can be constructed of the same materials considered for cap construction.	Horizontal barriers are not necessary to achieve RAOs. The groundwater contamination is distributed vertically throughout the alluvial aquifer. Bedrock underlies the alluvial aquifer and vertical hydraulic gradients in the alluvial aquifer are primarily upward.	No
	Hydraulic Barriers	Extraction/Injection wells	Groundwater wells are used to control the movement of groundwater and create a hydraulic barrier.	Applicable to site conditions. Hydraulic containment by extraction requires management of extracted groundwater.	Yes
		Trenches/Drains	Low-permeability trenches are constructed to control the movement of groundwater and create a hydraulic barrier.	Applicable to site conditions. Hydraulic containment requires treatment and disposal of extracted groundwater.	Yes

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Removal	Groundwater Collection	Conventional Extraction Wells	Conventional groundwater extraction/collection is pumping in vertical wells. Other extraction devices include vacuum-enhanced recovery, jet-pumping systems, etc. Extracted groundwater is treated *ex-situ* as required and is discharged or re-injected.	Applicable to site conditions. Extraction necessary for *ex-situ* treatment processes.	Yes
		Horizontal Wells or Angled Wells	A horizontal or angled well configuration is used for increasing production rate from low-permeability sites or to access areas that are inaccessible with vertical well technology.	May have limited applicability in some portions of the site. Angled and horizontal wells may assist in minimizing disturbance to the land. The existing aquifer permeability and the depth to contaminated groundwater make horizontal wells less appropriate than vertical wells for this site.	Yes
		Trenches/Drains	Trenches are filled with gravel or other high-permeability material to increase the production rate from low-permeability aquifers. Tile or perforated pipe can also be installed in the trench to collect and convey the contaminated groundwater.	Depths of contamination and existing hydrogeologic properties make this technology less effective than conventional extraction.	Yes
	Enhanced Extraction through Injection	Injection of clean or contaminated water	Clean water from an outside source, or clean or contaminated water re-circulated from within the site, is injected into the aquifer to increase hydraulic gradients toward the extraction wells and to increase the flushing rate.	Applicable to site conditions. Relatively flat water table and slow moving water within the aquifer means the natural flushing is slow.	Yes
	Enhanced Oil Recovery (EOR)	Thermal EOR	Many reservoir volumes of hot water, steam, or air are injected into a heavy-oil reservoir to reduce the viscosity of the oil, thus inducing flow used for clean up of low levels of oil.	Not applicable for hexavalent chromium.	No
		Chemical EOR	Micellular solution, polymer, or alkaline chemicals are injected into water/flooded reservoirs to reduce the surface tension between oil and the flooding medium. May spread contamination. Not applicable for cleanup of low levels of oil.	Not applicable for hexavalent chromium.	No
	Free-product Recovery	Free-product Recovery	Undissolved liquid-phase organics are removed from subsurface formations, either by active methods (pumping) or by a passive collection system.	Not applicable for hexavalent chromium.	No

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Treatment	*In-situ* Biological Treatment	Aerobic Cometabolic Bioremediation	Water containing inducers and electron acceptor (oxygen) is injected to enhance aerobic biodegradation. Inducers serve as carbon sources that activate aerobic enzyme systems known to degrade chlorinated volatile organic compounds (VOCs) (fortuitous cometabolism).	Not applicable for hexavalent chromium.	No
		Biochemical Reduction	Electron donors are delivered via the subsurface within the target zone to stimulate anaerobic biodegradation of compounds. Biochemical reduction involves both biological reduction and biofacilitated chemical reduction, stimulated by injection of carbon substrate.	Applicable to site and contaminants.	Yes
		Phytoremediation	Plants and their associated rhizospheric microorganisms are used to remove, degrade, or contain chemical contaminants in groundwater.	Groundwater contamination is too deep for this to be applicable as an *in-situ* technology.	No
		Bioremediation Enhancements	Various process options (thermal, physical, and/or biochemical) are used to optimize *in-situ* anaerobic or aerobic biodegradation.	Applicable to site and contaminants.	Yes
	In-situ Physical-Chemical Treatment	Pneumatic Fracturing	Relatively low-pressure, high-volume injection of gas is used to create self-propped subsurface fracture patterns that minimize contaminant travel time via diffusion. Complements vapor or fluid extraction technologies.	The alluvial aquifer at Topock has adequate permeability so that fracturing methods are not needed; however, this technology is retained for potential application to supplement treatment in low-permeability portions of the site.	Yes
		Hydraulic Fracturing	High-pressure injection of fluids, followed by granular slurry, is used to create subsurface fracture patterns that minimize contaminant travel time via diffusion. Complements vapor or fluid extraction technologies.	The Alluvial Aquifer at Topock has adequate permeability so that fracturing methods are not typically needed; however, this technology is retained for potential application to supplement treatment in low-permeability portions of the site.	Yes
		Air Sparging	Air is injected into saturated matrices to remove contaminants through volatilization.	Not applicable for hexavalent chromium.	No
		Electrokinetic Treatment	Electrical fields are created by application of low-voltage power to subsurface electrodes, inducing contaminant transport. Can be used to extract contaminants, immobilize them *in-situ*, or to deliver chemical reactants or bioremediation enhancements.	Typically used in lower-permeability formations and in areas of high contaminant concentrations. The size of the groundwater plume and relatively high permeability of the aquifer are not well-suited for this technology.	No

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Treatment (continued)	*In-situ* Physical-Chemical Treatment (continued)	Dual Phase Extraction	A high-powered vacuum system is applied to simultaneously remove soil vapors, groundwater, and other liquid (i.e., nonaqueous-phase liquid) from low-permeability or heterogeneous subsurface environments.	Not applicable for hexavalent chromium.	No
		Permeable Reactive Barriers	Permeable treatment walls are installed using trenches, fracturing, boreholes or other means to create a barrier wall across the flow path of a contaminant plume. As groundwater moves through the treatment wall, contaminants are passively removed in the treatment zones by physical, chemical, and/or biological processes.	Applicable to chromium, but traditional trench installation methods have not been used at the required depths. Other methods, such as fracturing or installing boreholes to create the walls, are less effective since these methods do not provide a continuous barrier.	Yes
		In-situ Air Stripping (Circulating Cells, Vacuum Vapor Extraction)	Groundwater is aerated and lifted within a well bore, re-infiltrates a different strata of the formation, and creates groundwater circulation. VOCs in groundwater are transferred to vapor phase and are removed from well.	Not applicable for hexavalent chromium.	No
		Surfactant/Cosolvent Flushing	A solution is delivered that enhances the transport of the targeted contaminants by physical displacement, solubilization, desorption, with subsequent recovery of both the solution and target contaminants.	Not necessary because chromium is soluble in water and does not adsorb appreciably to the soil matrix.	No
		In-situ Chemical Oxidation	Aqueous oxidizing agents (peroxide/iron, permanganate, or ozone) are injected to promote abiotic *in-situ* oxidation of chlorinated organic compounds.	Not applicable for hexavalent chromium.	No
		In-situ Chemical Reduction	Aqueous reducing agents are injected to promote *in-situ* reduction of compounds.	Is applicable to reduce hexavalent chromium.	Yes
	In-situ Thermal Treatment	Hot Water or Steam Flushing/Stripping	Steam is forced into an aquifer through injection wells to vaporize volatile and semi volatile contaminants. Vaporized components rise to the unsaturated zone, where they are removed by vacuum extraction and treated.	Not applicable for hexavalent chromium.	No

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Treatment (continued)	*In-situ* Thermal Treatment (continued)	Dynamic Underground Stripping	*In-situ* steam injection, electrical resistance heating, and fluid extraction are combined to enhance contaminant removal from the subsurface. Contaminants are volatilized, driven to centrally-located extraction wells, removed to surface, and treated.	Not applicable for hexavalent chromium.	No
		Hydrous Pyrolysis/ Oxidation	Steam (and possibly oxygen) is injected to the subsurface. Injection is halted and steam condenses, allowing displaced groundwater to return to heated zone. Groundwater mixes with steam and oxygen, destroying contaminants *in-situ* by chemical oxidation.	Not applicable for hexavalent chromium.	No
	Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation	Actions that rely on monitoring to show that natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, dispersion, and chemical reactions with subsurface materials are reducing contaminant concentrations to acceptable levels within the desired period of time.	Potentially applicable given site geochemical conditions.	Yes
	Ex-situ Biological Treatment	Aerobic cometabolic bioremediation	Contaminants, inducers, and electron acceptor (oxygen) are combined in a bioreactor to enhance aerobic biodegradation. Inducers serve as carbon sources that activate aerobic enzyme systems known to degrade chlorinated VOCs (fortuitous cometabolism).	Not applicable for hexavalent chromium.	No
		Bioreactor	Contaminants and electron donors are combined in a bioreactor to stimulate anaerobic biodegradation of compounds.	May be applicable to reduce chromium.	Yes
		Phytoremediation	Plants and their associated rhizospheric microorganisms are used to remove, degrade, or contain chemical contaminants in groundwater.	Potential component of *ex-situ* treatment.	Yes
	Ex-situ Physical/ Chemical Treatment	Chemical Oxidation	Oxidizing agents are used to oxidize organic contaminants or inorganic reagents in an *ex-situ* reactor. Potential oxidizing agents are UV radiation, ozone, and/or hydrogen peroxide/ferrous iron, or permanganate.	Not applicable as a primary treatment option. In an *ex-situ* application, this technology may be a secondary process.	Yes[a]

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Treatment (continued)	*Ex-situ* Physical/ Chemical Treatment (continued)	Chemical Reduction	Reducing agents (e.g., zero-valent iron) are used to reduce hexavalent chromium in an *ex-situ* reactor.	Potential component of *ex-situ* treatment.	Yes
		Air Stripping	Volatile organics are partitioned from groundwater by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.	Not applicable for hexavalent chromium.	No
		Filtration	Solid particles are isolated by running a fluid stream through a porous medium. The driving force is either gravity or pressure across the filtration medium.	Potential component of *ex-situ* treatment.	Yes[a]
		Ion Exchange	Ions from the aqueous phase are removed by exchange with innocuous ions on the exchange medium.	Potential component of *ex-situ* treatment, although ion exchange is not efficient in the relatively salty water at the site.	Yes
		Electrocoagulation Process	Electricity is passed through iron plates to generate ferrous iron to reduce the chromium and precipitate it from solution. The resulting sludge is settled in a clarifier for disposal.	Harder to control and offers no advantage over chemical dosing; energy intensive.	Yes
		Evaporation Technology	Contaminants are concentrated by using dry air to evaporate water vapor from contaminated water stream. Water vapor is then condensed and the concentrated water is heated until the desired concentration is reached in the dilute water.	Energy consumption is high; costs are high. Likely problems with formation of salt/gypsum.	No
		Reverse Osmosis	Water pressure is used to force water molecules through a very fine membrane, leaving the contaminants behind. Purified water is collected from the “clean” or “permeate” side of the membrane, and water containing the concentrated contaminants is disposed.	Not applicable as a primary treatment option because reverse osmosis cannot remove Cr(VI) down to the levels needed to meet the cleanup goals. In an *ex-situ* application, this technology may be a secondary process.	Yes[a]
		Liquid-phase Carbon Adsorption	Groundwater is pumped through a series of canisters or columns containing activated carbon to which dissolved organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.	Not applicable for hexavalent chromium.	No

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Treatment (continued)	*Ex-situ* Physical/ Chemical Treatment (continued)	Precipitation	Dissolved contaminants are transformed into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. Usually uses pH adjustment, addition of a chemical precipitant, and flocculation.	Potential component of *ex-situ* treatment.	Yes
	Ex-situ Thermal Treatment	Incineration	Recovered free product is heated to very high temperatures to combust organic contaminants in the presence of oxygen.	Not applicable for hexavalent chromium.	No
Disposal	Land Application	Land Application	Aqueous wastes are applied to the upper soil horizon so they can be degraded, transformed, or immobilized and the water can infiltrate.	Possible disposal option to help flush the groundwater and enhance removal.	No
	Untreated Groundwater Discharge	Offsite permitted facility	Aqueous streams generated from remedial activities are removed from the site without treatment and transported to an offsite permitted facility for treatment.	This option is not well-suited as the primary disposal because the site is located in a sparsely-populated, rural area requiring long transport distances, potential for spill during transportation, and a high volume of truck traffic would be required. However, this option has been implemented as an interim measure at the site and will be retained as a contingency or limited action for interim periods.	Yes
	Treated Groundwater Discharge	Publicly Owned Treatment Works (POTW)	Aqueous streams are discharged to a POTW for treatment.	Site is located in a sparsely-populated, rural area. Long distances, need for pretreatment, and availability of POTW capacity reduce likelihood of implementing this option.	Yes
		Surface Waters	Aqueous streams are discharged to surface receiving streams.	Possible option, but not favorable due to sensitivities associated with the receiving waters.	Yes
		Injection	Treated groundwater or surface water is injected into onsite wells.	Potential application at this site. May help flush the groundwater and enhance movement. Need to evaluate compatibility for hydraulic control.	Yes
		Deep Well Injection	Aqueous wastes are injected into Class I wells. Recent guidance may further regulate this practice.	Potential application at this site.	Yes
		Evaporation Ponds	Surface impoundments are used to contain treated or untreated wastewater or groundwater until it evaporates.	Possible disposal for excess water.	Yes

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Primary Screening Comments	Pass Primary Screen?
Disposal (continued)	Treated Groundwater Discharge (continued)	Onsite Reuse	Treated water is used onsite.	Possible uses at the compressor station.	Yes
		Agricultural	Treated water is distributed for agricultural use.	Possible, but low demand in the area of the site, high TDS, and long distances reduce likelihood of implementing this option at this site.	Yes
Monitoring	Monitoring	Monitoring	Short-and/or long-term monitoring is implemented to record site conditions and contamination levels.	Useful in combination with other technologies to measure attainment of RAOs.	Yes

Notes:

[a] Retained for possible use as secondary component of a treatment train, but the option is not applicable as a primary treatment option for hexavalent chromium.

Shading indicates process option or technology is not retained for further consideration.

TABLE 4-2
Evaluation of Process Options for Groundwater Remediation
Final Groundwater Corrective Measures Study /Feasibility Study Report for SWMU 1 /AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost	Screening Comment
No Action	None	None	No further actions are taken to address contaminated groundwater.	Does not achieve remedial action objectives.	Implementable.	None.	Retained per the National Contingency Plan.
Institutional Controls	Access and Use Restrictions	Land Use Covenants/ Deed Restrictions	Deed restrictions or covenants are issued for property within potentially contaminated areas to prevent interference with other remedial activities and/or to prevent access to, contact with, or use of contaminated groundwater.	Can be effective to prevent accidental exposure to contaminated groundwater and to protect wells and facilities associated with the remedial action. The long-term effectiveness is dependent on continued monitoring and enforcement of the controls.	Would require coordination with multiple landowners and lease holders of property overlying the site to establish the control and ensure a mechanism is in place that provides a long-term commitment to enforce and monitor the controls to ensure controls are functioning as intended.	Low.	Retained as a potential component of the remedy until RAOs are achieved.
		Permits	Permits can be used to control future actions within the contaminated areas to prevent accidental exposure or prevent damage to the remedial activities. Substantive requirement for promulgated regulations would need to be met during implementation of the remedial action. Actual permits not required for onsite CERCLA actions.	Protects human health and the environment by ensuring the substantive requirements of applicable or relevant and appropriate regulations would be satisfied during implementation of the remedy.	Requires coordination with agencies overseeing substantive requirements of promulgated regulations.	Low.	Retained.
	Alternative Drinking Water Source	Cisterns or tanks, bottled water, deeper or upgradient wells, relocation of intakes, or municipal water supply	Alternate sources of water are obtained. Note that groundwater beneath and immediately adjacent to the plume is not currently being used as a drinking water source. However future development of alternative water supplies may be necessary to support future development.	Protects human health by preventing exposure to contaminated groundwater.	Alternate sources of drinking water are available and readily implemented if required.	Low to high capital and operation and maintenance cost, depending on process option chosen.	Retained.
Containment	Vertical Barriers	Soil-bentonite Slurry Wall	Slurry wall barriers consist of a vertical trench excavated perpendicular to the groundwater flow direction, filled with bentonite slurry to support the trench, and subsequently backfilled with a mixture of low-permeability material (1 x 10^{-6} cm/sec or lower).	Effectiveness is dependent on the continuity of the wall and the ability to key into the bedrock, which will be difficult to achieve at this site because of the depth of bedrock; does not reduce toxicity or volume of contaminants by itself. This technology requires groundwater extraction to control groundwater pressures from building up behind the barrier and potentially damaging the barrier or causing groundwater to flow under or around the barrier. The barrier has the potential to degrade or deteriorate over time. While the vast majority of the Cr(VI) plume is upgradient of the most promising area to construct an impermeable barrier wall, there are portions of the plume that are located closer to the Colorado River than the location on the floodplain where a wall could feasibly be constructed.	Implementation of a barrier to the required depths (>150 feet) is not proven and would involve a significant amount of heavy construction at the surface that will disturb large areas. Access may be a problem, as a 70- to 100-foot-wide construction corridor is generally needed. It is difficult to construct the barrier under the Burlington Northern Santa Fe Railroad and I-40 bridge due to low overhead access and the need to protect the integrity of the bridge foundations and roadbeds. Geotechnical analyses at the site indicate that excavation of the older alluvium overlying the bedrock may be impossible with conventional methods.	High capital cost; moderate operation and maintenance (O&M) cost due to need for groundwater extraction.	Not retained. Lack of a continuous aquitard at a depth that is within the vertical limits of traditional trenching equipment means extensive surface disturbance would be necessary to implement this technology.
		Cement-bentonite Slurry Wall	A vertical trench is excavated perpendicular to the groundwater flow direction filled with bentonite and cement slurry to support the trench and form a solid barrier.	Same as soil-bentonite slurry wall.	Same as soil-bentonite slurry wall.	Same as soil-bentonite slurry wall.	Not retained. See above reasons for soil-bentonite slurry wall.
		Vibrating Beam Barrier Installation	Vibratory force is used to advance steel beam into ground; injection of a relatively thin wall of cement or bentonite as beam is withdrawn.	Similar to the slurry wall barriers. Likely to result in higher permeability than slurry wall barriers because it becomes more difficult at depths of >150 feet to achieve continuity in the beam barrier due to difficulties keeping the sections vertical and aligned with one another.	This technology can be used at depths greater than 150 feet bgs and would have fewer surface impacts during construction than the slurry walls.	High capital cost; moderate O&M cost due to need for groundwater extraction.	Not retained. See above reasons for soil-bentonite slurry wall.

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost	Screening Comment
Containment (continued)	Vertical Barriers (continued)	Grout Curtains	Grout is pressure-injected along contamination boundaries in a regular overlapping pattern of drilled holes.	Same as slurry walls, but less effective than other vertical barriers due to discontinuities in the curtain.	Proven technology that has been extensively used in civil engineering projects but less frequently for site remediation. Equipment and vendors are readily available to implement.	High capital cost (usually more expensive than other techniques at moderate depths). Moderate O&M cost due to need for groundwater extraction.	Not retained. See above reasons for soil-bentonite slurry wall.
	Hydraulic Barriers	Extraction/Injection Wells	Groundwater wells are used to control the movement of groundwater and create a hydraulic barrier.	Effective method of hydraulic control; vertical wells are proven technology in widespread use for remediation projects. The hydrogeologic properties at the site are very conducive to groundwater extraction/injection with vertical wells. However, extraction wells may not be effective if the contamination is contained in low-permeability, fine-grained layers and, depending on the array of the wells, there could be extensive surface disturbance.	Readily implementable and currently being used to control groundwater at this site.	Low to moderate capital cost, low O&M cost.	Retained as representative process option for groundwater containment and removal.
		Trenches/Drains	Low-permeability trenches are constructed to control the movement of groundwater and create a hydraulic barrier.	Effective method of hydraulic control, particularly well suited to shallow, low-permeability aquifers.	Readily implementable. Commonly implemented at remediation sites. Depths of contamination and hydrogeologic properties at the PG&E Topock site make this technology less favorable than vertical wells.	Moderate capital cost, low O&M cost.	Retained. May have limited applicability in some portions of the site, but depths of contamination and existing hydrogeologic properties make this technology less effective than conventional extraction.
Removal	Groundwater Collection	Conventional Extraction Wells	Conventional groundwater extraction/ collection is pumping in vertical wells. Other extraction devices include vacuum enhanced recovery, jet-pumping systems, etc. Extracted groundwater treated *ex-situ* as required and discharged or re-injected.	Effective method of groundwater extraction; vertical wells are proven technology in widespread use for remediation projects. The hydrogeologic properties at the site are very conducive to groundwater extraction with vertical wells. However, these techniques may not be effective if the contamination is contained in low-permeability, fine-grained layers.	Readily implementable and currently being used to control groundwater at this site.	Low to moderate capital cost, low O&M cost.	Retained as representative process option for groundwater extraction.
		Horizontal Wells or Angled Wells	A horizontal or angled well configuration is used for increasing production rate from low-permeability sites or to access areas inaccessible with vertical well technology.	Effective method of groundwater extraction from large areas, and areas of lower permeability. Depths of contamination and site hydrogeologic condition make horizontal or angled wells less effective than vertical wells for this site. Vertical wells are preferred at the site since they are easier to install develop and maintain than horizontal wells. The site hydrogeology does not necessitate the use of horizontal wells. However, horizontal and angled wells are retained as they may have application in some portions of the site.	Readily implementable; more difficult to construct and develop than vertical wells.	Low to moderate capital cost, low O&M cost.	Retained. May have limited applicability in some portions of the site.
		Trenches/Drains	Trenches are filled with gravel or other high-permeability material to increase the production rate from low-permeability aquifers. Tile or perforated pipe can also be installed in the trench to collect and convey the contaminated groundwater.	Effective method of groundwater extraction, particularly well-suited to shallow, low-permeability aquifers.	Readily implementable. Commonly implemented at remediation sites. Depths of contamination and hydrogeologic properties at the PG&E Topock site make this technology less favorable than vertical wells.	Moderate capital cost, low O&M cost.	Retained. May have limited applicability in some portions of the site, but depths of contamination and existing hydrogeologic properties make this technology less effective than conventional extraction.
	Enhanced Extraction through Injection	Injection of clean or contaminated water	Clean water from an outside source, or clean or contaminated water re-circulated from within the site, is injected into the aquifer to increase hydraulic gradients toward the extraction wells and increase the flushing rate.	Effective for improving hydraulic gradients and increasing flushing rates through the aquifer potentially reducing cleanup times. However, these techniques may not be effective if the contamination is contained in low-permeability, fine-grained layers and, depending on the array of the wells, there could be extensive surface disturbance.	Readily implementable; offsite water source could be the same as the source for the compressor station.	Low to moderate capital cost, low to moderate O&M costs.	Retained. Offers advantages to traditional groundwater extraction.

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost	Screening Comment
Treatment	*In-situ* Biological Treatment	Biochemical Reduction	Electron donors are delivered via the subsurface within the target zone to stimulate anaerobic biodegradation of compounds. Biochemical reduction involves both biological reduction and biofacilitated chemical reduction, stimulated by injection of carbon substrate.	Effective *in-situ* technology, particularly in homogeneous and permeable aquifers where the distribution of donors within the target area is more successful. Heterogeneity of aquifers can cause problems with vertical flow, limiting circulation.	The substrate can be delivered through injection, extraction and reinjection, or recirculation wells typically installed in a line to create a treatment zone across the groundwater flow path. Pilot testing at the site is underway to determine optimum spacing and operation of wells. Aquifer tests indicate the site may be amenable to recirculation.	Moderate capital cost, moderate O&M cost depending on number and type of wells.	Retained. Applicable to site and contaminants.
		Bioremediation Enhancements	Various process options (physical, and/or biochemical) are used to optimize *in-situ* anaerobic or aerobic biodegradation.	Similar to anaerobic bioremediation, with the addition of enhancements to improve treatment and/or distribution of media.	Similar to anaerobic bioremediation.	Similar to anaerobic bioremediation.	Retained. Applicable to site and contaminants.
	In-situ Physical-Chemical Treatment	Pneumatic Fracturing	Relatively low-pressure (less than 100 psig) high volume injection of gas is used to create self-propagating subsurface fracture patterns that minimize contaminant travel time. The fractures can facilitate removal of contaminants out of the geologic formation. The fractures may also be used to introduce beneficial substrates into the formation. The overall objective of fracturing is to overcome the transport limitations that are inherent at some remediation sites.	The technology is effective to supplement treatment in low-permeability portions of the site and to create pathways that minimize contaminant travel time.	Fracturing is an established concept that has been applied in various forms within the petroleum and water well industries for more than 50 years. Implementation for site remediation typically requires pilot studies and the collection of detailed geologic and geotechnical information. The target depths of most pneumatic fracturing projects have ranged from 10 to 50 feet. Deeper applications become inhibited by the soil/rock overburden pressures. The deepest applications of pneumatic fracturing for site remediation purposes have been 180 feet, but are inhibited by the soil overburden pressures.	Moderate capital cost, moderate O&M cost depending on number and type of wells.	Retained for potential use in low-permeability portions of the site
		Hydraulic Fracturing	High-pressure injection of fluids, followed by granular slurry, is used to create subsurface fracture. Complements vapor or fluid extraction technologies. The overall objective of fracturing is to overcome the transport limitations that are inherent at many remediation sites	The technology is effective to supplement treatment in low-permeability portions of the site and to create pathways that minimize contaminant travel time.	Fracturing is an established concept that has been applied in various forms within the petroleum and water well industries for more than 50 years. Implementation for site remediation typically requires pilot studies and the collection of detailed geologic and geotechnical information.	Moderate capital cost, moderate O&M cost depending on number and type of wells.	Retained for potential use in low-permeability portions of the site.
	In-situ Physical-Chemical Treatment (continued)	Permeable Reactive Barriers	Permeable treatment walls are installed across the flow path of a contaminant plume. As groundwater moves through the treatment wall, contaminants are passively removed in the treatment zones by physical, chemical, and/or biological processes.	Effective for chromium treatment. The effectiveness depends on the continuity and integrity of the wall. The treatment wall is subject to clogging and reduced permeability over time due to the buildup of chemical precipitates or microbial biofouling.	Traditional trench installation methods have not been used at the required depths. Trench stability becomes an issue at depths of 150 feet or greater. Other construction methods such as fracturing or the use of closely spaced or overlapping boreholes are implementable, but difficult to achieve the continuity required for effective passive treatment.	High capital cost, moderate O&M cost	Retained. Applicable to chromium, and may have limited applicability in areas where the noted implementability and effectiveness challenges can be overcome (e.g., in areas of shallower bedrock). The use of injection or recirculation wells to introduce a reactive media is more favorable for widespread implementation at this site.
		In-situ Chemical Reduction	Aqueous reducing agents are injected to promote *in-situ* reduction of compounds.	Effective *in-situ* technology, particularly in homogeneous and permeable aquifers where the distribution of reactive media within the target area is more successful.	The reactive treatment media can be delivered through injection, extraction and reinjection, or recirculation wells typically installed in a line to create a treatment zone across the groundwater flow path. Pilot testing at the site is underway to determine optimum spacing and operation of wells. Aquifer tests indicate the site may be amenable to recirculation.	Moderate capital cost, moderate O&M cost depending on number and type of wells.	Retained. Applicable to site and contaminants.

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost	Screening Comment
Treatment (continued)	Monitored Natural Attenuation	Monitored Natural Attenuation	Actions that rely on monitoring to show that natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, dispersion, and chemical reactions with subsurface materials are reducing contaminant concentrations to acceptable levels within the desired period of time.	Site characterization data have determined that reducing conditions are present in shallow to mid-depth fluvial wells and sediments near and underlying the river promoting chemical reduction and conversion of Cr(VI) to Cr(III). MNA works best where the source of contamination has been controlled or removed. Groundwater moves very slowly at the Topock site, so attenuation of the entire chromium plume upgradient of the floodplain area would require on the order of hundreds of years unless groundwater gradients are increased.	Typical monitoring networks for MNA include compliance wells to confirm that the constituents are being attenuated and that the plume is not expanding or migrating to undesirable locations. Additional wells might also be needed within the reducing zone to monitor the geochemical conditions where the attenuation is occurring. Throughout the duration of the MNA remedy, groundwater monitoring would be performed to evaluate the presence and extent of reducing conditions and to confirm that the plume was stable or shrinking.	Low capital cost, low operation and maintenance (O&M) cost.	Retained. MNA could be used alone or in conjunction with an active remedy such as pump-and-treat or *in-situ* remediation.
	Ex-situ Biological Treatment	Bioreactor	Contaminants and electron donors are combined in a bioreactor to stimulate anaerobic biodegradation of compounds.	Effective.	Implementable; vendors and equipment readily available.	High capital cost, moderate O&M cost.	Retained. Could be used in conjunction with other *ex-situ* treatment technologies to reduce chromium
		Phytoremediation	Plants and their associated rhizospheric microorganisms are used to remove, degrade, or contain chemical contaminants in groundwater.	Effective for removing metals. Additional research is required to verify effectiveness for site conditions.	Implementable, however, would require large surface area and would require extended period of time to establish the phytoremediation system.	High capital cost, low O&M cost.	Retained. Applicable to chromium. May not be appropriate for large flows due to space constraints, but could be used for treating a portion of the flow.
	Ex-situ Physical/ Chemical Treatment	Chemical Oxidation	Oxidizing agents are used to oxidize organic contaminants or inorganic reagents in an *ex-situ* reactor. Potential oxidizing agents are UV radiation, ozone, and/or hydrogen peroxide/ferrous iron, or permanganate.	Not appropriate for primary treatment of hexavalent chromium. In an *ex-situ* application, this technology may be a secondary process.	Implementable; equipment readily available.	High capital cost, moderate to high O&M cost.	Not retained. Other treatment methods are better suited for use as a secondary process in an *ex-situ* treatment train.
		Chemical Reduction	Reducing agents (e.g., zero-valent iron) are used to reduce hexavalent chromium in an *ex-situ* reactor.	Effective for chromium treatment.	Implementable; vendors and equipment readily available. Currently used in IM treatment plant.	Moderate capital cost, low to moderate O&M cost.	Retained.
		Filtration	Solid particles are isolated by running a fluid stream through a porous medium. The driving force is either gravity or pressure across the filtration medium.	Effective for chromium treatment.	Implementable. Vendors and equipment readily available. Currently used in Interim Measure treatment plant.	Moderate capital cost, low to moderate O&M cost.	Retained as potential component of *ex-situ* treatment.
		Ion Exchange	Ions from the aqueous phase are removed by exchange with innocuous ions on the exchange medium.	Effective treatment for metals, although not efficient in the relatively salty water at the site.	Readily implementable.	High capital cost, moderate O&M cost.	Retained as potential component of *ex-situ* treatment; however, not cost-effective because of the large waste stream generated and high TDS concentrations.
		Electrocoagulation Process	Electricity is passed through iron plates to reduce the chromium and precipitate it from solution. The resulting sludge is settled in a clarifier for disposal.	Effective for chromium treatment.	Implementable. Relies on electrochemical generation of ferrous iron, which may be harder to control than chemical dosing of the ferrous iron.	Moderate to high capital cost, high O&M cost.	Not retained. Harder to control and offers no advantage over chemical dosing. Energy intensive.
		Reverse Osmosis	Water pressure is used to force water molecules through a very fine membrane leaving the contaminants behind. Purified water is collected from the "clean" or "permeate" side of the membrane, and water containing the concentrated contaminants is disposed.	Not appropriate for primary treatment of hexavalent chromium but is an effective secondary process for the treatment of the reduced chromium.	Implementable. Equipment readily available.	High capital cost, high O&M cost.	Retained for use as a secondary process in an *ex-situ* treatment train; however, not cost-effective because of the large waste stream generated and high TDS concentrations.

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General Response Actions	Remedial Technology Types	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost	Screening Comment
Treatment (continued)	*Ex-situ* Physical/ Chemical Treatment (continued)	Precipitation	Dissolved contaminants are transformed into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. Usually uses pH adjustment, addition of a chemical precipitant, and flocculation.	Effective for chromium treatment.	Implementable. Vendors and equipment readily available. Currently used in Interim Measure treatment plant.	High to moderate capital cost, low to moderate O&M cost.	Retained as potential component of *ex-situ* treatment.
Disposal	Untreated Groundwater Discharge	Offsite permitted facility	Aqueous streams generated from remedial activities are removed from the site without treatment and transported to an offsite permitted facility for treatment.	Effective	Implementability is limited by the fact that the site is located in a sparsely-populated, rural area requiring long transport distances, potential for spill during transportation, and a high volume of truck traffic would be required. This option has been implemented as an interim measure at the site.	Low capital cost, moderate to high O&M cost.	Retained for possible use as a contingency or limited action for interim periods.
	Treated Groundwater Discharge	Publicly-owned Treatment Works (POTW)	Aqueous streams are discharged to a POTW for treatment.	Effective. May require some minimal pretreatment of water.	Implementable, but site is located in a sparsely-populated, rural area, so long distances and the availability of a POTW willing to or capable of accepting the water is limited.	Moderate to high capital cost depending on distance and pretreatment needs. Moderate O&M cost.	Not retained. Long distances and availability of POTW capacity reduce likelihood of implementing this option.
		Surface Waters	Aqueous streams are discharged to surface receiving streams.	Effective.	Implementable, but not favorable due to sensitivities of the Colorado River; low acceptance to downstream users.	Low to moderate capital cost, low O&M cost.	Not retained. Not favorable due to sensitivities associated with the receiving waters
		Injection	Treated groundwater or surface water is injected into onsite wells.	Effective. May help flush the groundwater and enhance groundwater movement. However, these techniques may not be effective if the contamination is contained in low-permeability, fine-grained layers, and depending on the array of the wells, there could be extensive surface disturbance.	Readily implementable at the site. Currently used in the IM. The wells may be subject to clogging due to the buildup of chemical precipitates or microbial biofouling.	Low to moderate capital cost, low to moderate O&M cost.	Potential application at this site.
		Deep Well Injection	Aqueous streams are injected into Class I wells. Recent guidance may further regulate this practice.	Effective.	Potentially implementable at the site, but more difficult than shallow reinjection. Regulatory acceptance may be lower, and there are not the same flushing benefits as with reinjection into the upper contaminated portions of the aquifer.	Moderate to high capital and O&M cost.	Not retained. More difficult and expensive and less favorable than shallow reinjection.
		Evaporation Ponds	Surface impoundments are used to contain treated or untreated wastewater or groundwater until it evaporates.	Effective disposal option for the climate conditions at the site.	Existing ponds at the Topock Compressor Station may have additional capacity but would require modifying regulatory and lease agreements to allow additional waste streams to use the existing ponds.	Moderate capital cost assuming use of existing ponds; high capital costs for construction of new ponds, low O&M cost.	Retained for possible water disposal option.
		Onsite Reuse	Treated water is used onsite.	Effective. May be appropriate for some portion of the treated water.	Readily implementable at the site/ currently limited potential uses.	Low capital cost, low O&M cost.	Retained for possible uses at the compressor station.
		Agricultural	Treated water is distributed for agricultural use.	Effective for disposing of treated water.	Readily implementable, but low demand in the area of the site, high TDS of the groundwater, and long distances reduce likelihood of implementing this option at this site.	Low capital cost, low O&M cost.	Not retained; limited agriculture surrounding the site.
Monitoring	Monitoring	Monitoring	Short-and/or long-term monitoring is implemented to record site conditions and contamination levels.	Effective for measuring the performance of the remedy, compliance with standards, and progress of the remedial action.	Readily implementable.	Low capital cost, low O&M cost.	Retained for use with other technologies to measure attainment of RAOs.

Notes:

Blue shading indicates the process option is selected as the representative process option for developing alternatives in Section 5.0.
Grey shading indicates the process option is not retained for further consideration.

TABLE 4-3
Representative Process Options for Groundwater Remediation
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PG&E Topock Compressor Station, Needles, California

General Response Action	Remedial Technology	Representative Process Option
No Action	None	None
Institutional Controls	Access and Use Restrictions	Land Use Covenants/ Deed Restrictions
Containment	Hydraulic Barriers	Extraction/Injection Wells
Removal	Groundwater Collection	Conventional Extraction Wells
	Enhanced Extraction through Injection	Injection of Clean or Contaminated Water
In-situ Treatment	Biological Treatment	*In-situ* Biochemical Reduction
	Monitored Natural Attenuation	Monitored Natural Attenuation
Ex-situ Treatment	Physical/Chemical Treatment	Chemical Reduction
Disposal	Treated Groundwater Discharge	Injection
Monitoring	Monitoring	Monitoring

5.0 Development and Analysis of Remedial Action Alternatives

5.1 Approach

Remedial action alternatives for the Alluvial Aquifer and bedrock in the East Ravine are identified and evaluated in this section. The remedial action alternatives are assembled from the technologies and process options identified in Section 4.0 and are evaluated in accordance with the requirements of both RCRA Corrective Action and CERCLA and to the level of specificity required for a CMS/FS analysis. For this CMS/FS, a focused number of alternatives are assembled by considering certain factors and criteria, as described in Section 5.2. Following description of the remedial alternatives in Section 5.3, the alternatives are evaluated individually against the evaluation criteria (Section 5.4) and then in comparison with each other (Section 5.5).

5.2 Assembly of Alternatives

In this section, remedial alternatives are assembled to address Cr(VI) in alluvial groundwater and in bedrock groundwater in the East Ravine. The alternatives are formulated by considering the site-specific conditions at the Topock site as described in Section 2.0, the RAOs discussed in Section 3.0, and the remedial process options selected in Section 4.0.

There are many possible combinations of technologies and process options that could be used to formulate alternatives. It is not practical to assemble every possible combination, nor is it necessary for the purposes of the alternative development and evaluation because many of the possible combinations are similar in performance and cost. Furthermore, selection of some options necessitates selection of other options (e.g., extraction of groundwater requires that a water disposal option also be selected). The intent of the alternative assembly process is to create a set of alternatives that represents a range of performance and cost options so that the alternatives can be comparatively evaluated against each other to determine a preferred alternative while meeting the requirements of RCRA and the National Contingency Plan (NCP). Once a preferred alternative is selected, changes to the specific process options within a given technology type can be made during remedial design and can be subsequently implemented without compromising the remedy selection process in the CMS/FS.

To assemble an appropriate range of alternatives, several factors are considered, including the factors identified in 40 CFR Section 300.430(a)(1)(iii). The NCP (40 Code of Federal Regulations [CFR] Section 300.430(e)) requires that, at a minimum, the following alternatives be considered:

- A no-action alternative.

- Source control alternatives that, as their principal element, employ treatment to reduce toxicity, mobility, and/or volume of contaminants. At least one of these alternatives should, to the degree possible, reduce the need for long-term management at the site.
- Source control alternatives that treat the principal risk posed by site contaminants but that vary the degree of treatment employed and the quantities and characteristics of the treatment residuals and untreated waste that must be managed.
- At least one source control alternative that provides containment of contaminants through engineering or institutional controls, with little or no treatment, but protects human health and the environment by preventing potential exposure or by reducing the mobility of contaminants.
- Alternatives that attain site-specific remediation levels within different restoration time periods using one or more technologies.
- Alternatives that include innovative treatment technologies if those technologies offer the potential for comparable or superior performance or implementability, fewer or less adverse impacts than other available approaches, or lower costs for levels of performance similar to that of demonstrated treatment technologies.

To meet the RAOs identified in Section 3.0, PG&E has established the following specific considerations for the development of alternatives. These considerations are consistent with RCRA and the NCP requirements listed above and help to further focus the assembly of alternatives. These considerations are to:

- Protect the Colorado River through geochemical barriers or hydraulic gradients to prevent Cr(VI) from entering the river.
- Target Alluvial Aquifer cleanup (estimated as the time at which 98 percent mass reduction occurs in the groundwater model simulations) in 40 years or less for those remedies that use active remediation.
- Provide sustainable treatment alternatives that minimize energy use and minimize the amount of residual treatment byproducts that require handling and offsite disposal.
- Develop alternatives that maximize the environmental benefit and ecological and human use associated with implementation, such as minimizing disturbance to sensitive cultural and biological resources by citing most remedial facilities in previously disturbed areas.

Technology types and the representative process options that passed the screening in Section 4.0 are discussed in the subsections below. The discussion is grouped by the general response action and includes both the site-specific considerations and rationale for incorporating the technologies and associated representative process options into the alternatives presented in Section 5.3.

5.2.1 No Action

As required by the NCP, a no action alternative will be formulated. No active construction or operational activities would occur. There would be no active treatment to reduce chromium concentrations in groundwater. While natural attenuation would occur within the fluvial sediments near the Colorado River, there would be no institutional control to restrict use of groundwater in locations where concentrations exceed the cleanup goals. No additional groundwater monitoring facilities would be constructed under this alternative, nor would any ongoing sampling or well maintenance activities be conducted to determine concentrations of contaminants in groundwater or in the Colorado River.

5.2.2 Institutional Controls

Institutional controls are legal and administrative tools used to maintain protection of human health and the environment. Land use covenants or deed restrictions to prevent groundwater use within the plume until cleanup goals are attained are the most appropriate institutional control for the Topock site. Such an institutional control would be effective for managing risk by restricting direct human contact with groundwater. However, a restriction on groundwater use alone would not meet long-term cleanup goals. Therefore, an institutional control is considered to be a single component of assembled remedial alternatives for risk management and should be combined with other technologies that are focused on reducing chromium concentrations within the plume.

Administration of an institutional control restricting groundwater use would have to be coordinated with the various landowners/managers that overlie the plume, identified on Figure 2-2: PG&E, BOR (managed by BLM), Caltrans (leased from federal owners), Burlington Northern Santa Fe Railroad, the USFWS (manager of the HNWR), and the Fort Mojave Indian Tribe (with easement and access to PG&E).

5.2.3 Removal

Removal of contaminated groundwater is an essential common component of an alternative involving *ex-situ* treatment. Removal of groundwater is also effectively used in combination with other remedial technologies that require controlling groundwater movement to enhance effectiveness of *in-situ* treatment or containment technologies. Extraction systems have generally demonstrated positive control of plumes at many sites and thus serve well as plume management tools but have historically failed to achieve widespread remediation of plumes due to the difficulty associated with achieving efficient mass removal during the latter stages of cleanup due primarily to rate-limited back diffusion of contaminants from low-permeable material (USEPA, 1997b; Palmer and Wittbrodt, 1991). The representative process option identified in Section 4.0 for removal of groundwater beneath the Topock site is conventional extraction wells in which pumps are used to draw groundwater into the wells and bring it to the surface. As noted in Tables 4-1 and 4-2 in Section 4.0, injection of water can be used to complement the groundwater extraction. Extraction and injection wells have been used successfully at the Topock site as part of the IM and *in-situ* pilot studies. Construction (drilling and completion) of extraction and injection wells is relatively straightforward in most instances and typically involves common construction equipment and material. Figure 5-1 shows a typical pump-and-treat system.

The main considerations for the number and locations of wells at the site pertain to site hydrogeology, plume location and depth, time to cleanup, and access considerations. Further considerations include appropriate mitigation measures to protect wildlife habitat and cultural resources, identified by the HNWR Manager and federal consultation related to cultural and historic properties. Extraction and injection wells included as part of the assembled alternatives would control groundwater gradients to prevent spreading of the plume and to optimize removal of contaminants in groundwater. In general, target extraction rates can be attained with a higher number of wells at lower individual pumping rates or a lower number of wells at higher individual pumping rates, although site conditions limit how much water a single well can yield. Pumping rates can be adjusted up or down, depending on project goals and capacity of the facilities to manage the extracted groundwater. As cleanup progresses, wells at different locations may be needed to optimize cleanup and/or replace wells that may become ineffective due to fouling or poor recovery of contaminants.

In addition to the siting issues associated with groundwater capture efficiency, wells also must be located in areas that are accessible for construction, operation and maintenance, and management of extracted groundwater. Because much of the plume is outside of PG&E property, permission from the respective landowners for locating the wells and associated facilities is needed. Construction of wells and associated facilities, such as pipelines at the site, must also consider areas of the site that are of cultural or religious significance so that construction or other disturbance is minimized to the extent feasible. Other location constraints include sensitive habitats, historical sites, and topographic constraints, as discussed in Section 2.0. Major transportation and pipeline corridors cross the site and construction and operation of remedial facilities would be designed to not interrupt those existing operations.

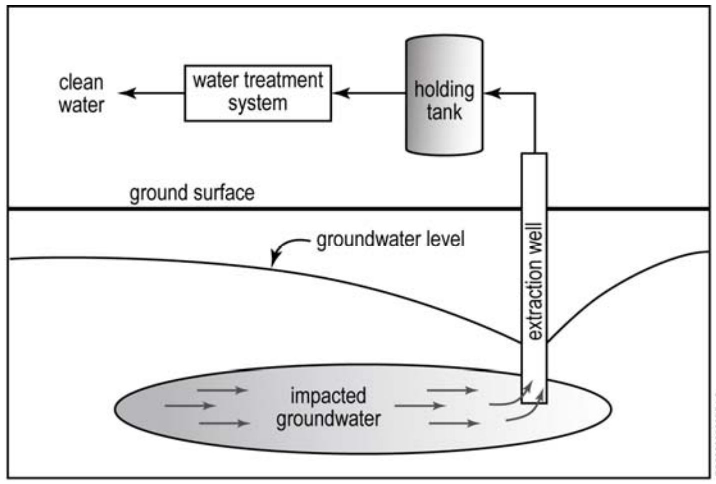

FIGURE 5-1
Typical Extraction and *Ex-situ* Treatment System
Source: USEPA, 2001a

Typically, extracted groundwater is transferred by pipeline, either aboveground or belowground. Aboveground piping does not require trenching and may be more appropriate in some applications such as short-term piping needs. Belowground piping provides more protection from the elements and from physical damage but is more expensive and is more disruptive to the environment to construct. Extraction wells can be piped individually or can be joined into a common manifold pipe. Pipelines containing untreated groundwater have to be designed and operated to prevent spills and leaks (e.g., appropriate containment, leak detection, security). Construction of pipelines involves the use of common construction equipment and materials and requires excavation of pipe trenches if the piping is located belowground. The number, size, and location of wells installed will affect the extent of piping and disturbances at the surface.

5.2.4 Disposal

Following removal of contaminated groundwater for *ex-situ* treatment, the groundwater must be managed and disposed of either onsite or offsite. Injection and land application are the representative process options selected in Section 4.0 for disposal of groundwater. The option of using onsite injection wells is incorporated into the alternatives for the Topock site. There are several advantages to injection wells over land application. Properly placed injection wells can enhance cleanup efficiency by creating larger hydraulic gradients that control groundwater flow and can help push the contaminants toward the extraction wells. Land application requires large areas of relatively flat ground and typically results in large losses of water to evaporation, which can increase the salt content of the aquifer below the land treatment area. With injection wells, there is no evaporative loss so there is no increase in salinity, and a larger proportion of the extracted groundwater is returned to the groundwater basin. Injection wells are also an essential component of remedial alternatives (in combination with extraction systems) that are predicated on the distribution of substrates throughout the aquifer to support *in-situ* treatment or to create hydraulic gradients that enhance the movement of contaminated groundwater toward and through *in-situ* remediation zones. Proper monitoring and careful design of the well locations are necessary to avoid the potential spread of contamination through uncontrolled movement of contaminated groundwater. Injection wells have been used successfully at the Topock site as part of the IM and the upland and floodplain *in-situ* pilot studies. Construction (drilling and completion) of injection wells is relatively straightforward in most instances and typically involves common construction equipment and materials. Two injection wells have been operating at the site as part of IM No. 3 since mid-2004. As is typical of injection wells, regular backwashing and periodic rehabilitation have been required to maintain the performance of these wells, but no unusual maintenance or operational challenges have been encountered.

The main considerations for the number and locations of injection wells at the site pertain to site hydrogeology, access considerations (for installation, monitoring, and maintenance), water chemistry, and purpose of the injection. Further considerations include appropriate mitigation measures to protect wildlife habitat and cultural resources, identified by the HNWR Manager and federal consultation related to cultural and historical properties. Injection wells included as part of the assembled alternatives would be located to facilitate the attainment of the remedial action objectives. Injection wells located at the outer and upgradient edges of the plume would serve to direct and accelerate plume migration toward cleanup facilities (e.g., *in-situ* reactive zone [IRZ] or extraction wells). Injection wells installed for establishing IRZs using groundwater recirculating strategies would be located to efficiently distribute reagent material. Number, size, and locations of injection wells are also affected by design flow rates and aquifer characteristics and capacity. As cleanup progresses, injection wells at different locations may be needed to optimize cleanup and/or replace wells that may become ineffective due to fouling or other means.

In addition to the siting issues associated with cleanup efficiency, injection wells also must be located in areas that are accessible for construction and operation and maintenance. Because much of the plume is outside of PG&E property, permission from the respective landowners for locating the injection wells is needed. Construction of injection wells and associated facilities such as pipelines at the site must also consider areas of the site that are of cultural or religious significance so that construction or other disturbance is minimized to the extent feasible. Other location constraints include sensitive habitats, historical sites, and topographic constraints, as discussed in Section 2.0. Major transportation and pipeline corridors cross the site and construction and operation of remedial facilities would be designed to not interrupt those existing operations.

Typically, groundwater is transferred to injection wells by pipeline, either aboveground or belowground. Pipelines containing untreated groundwater have to be designed and operated to prevent spills and leaks (e.g., appropriate containment, leak detection, security). Construction of pipelines involves common construction equipment and materials and requires excavation of pipe trenches for belowground piping. The number, size, and location of wells installed will affect the extent of piping and disturbances at the surface.

5.2.5 Monitored Natural Attenuation

Natural attenuation (also known as intrinsic remediation) relies on natural processes to reduce chemical concentrations. At the Topock site, attenuation occurs naturally in the fluvial sediments near the Colorado River, where reducing materials in the aquifer chemically and biochemically convert Cr(VI) to low solubility Cr(III) that precipitates out of solution and binds to the aquifer formation. Reducing conditions have been documented in shallow to mid-depth fluvial wells and sediments near and underlying the river. South of the railroad tracks, these reducing conditions are also encountered in deep wells near and beneath the river. The observed natural reducing conditions are characterized by the presence of organic carbon, dissolved iron, dissolved manganese, and ammonia in groundwater samples.

Under non-pumping conditions, as Cr(VI) migrates in groundwater from non-reducing conditions in the alluvial and deep fluvial sediments to reducing conditions near and beneath the river, it undergoes chemical reduction and reverts to Cr(III), which is immobilized in the sediments, as evidenced by its absence in groundwater samples collected from fluvial wells screened in reducing material. Stable isotope data from floodplain monitoring wells indicate that the decrease in Cr(VI) concentration does not occur by dilution, and laboratory testing of fluvial anaerobic core samples provides direct evidence of the reduction reaction. The general absence of Cr(VI) in reducing groundwater and the results of laboratory testing in fluvial core samples, indicate that there is significant capacity in the fluvial deposits underlying the river to reduce and remove Cr(VI) from groundwater (CH2M HILL, 2008e, 2009h). This process is a beneficial factor limiting Cr(VI) migration to the river under current conditions.

Chemical reduction of Cr(VI) to Cr(III) is effectively permanent and irreversible under site conditions. The only naturally-occurring oxidant that can accomplish the conversion of Cr(VI) to Cr(III) is solid manganese dioxide, MnO_2 (Fendorf, 1995). If this solid is present, the Cr^{3+} ion can adsorb to the MnO_2 surface, where a redox reaction can occur, with chromium oxidized and manganese reduced. However, under the reducing conditions present in the fluvial materials, MnO_2 is not stable, and manganese tends to exist as the dissolved cation Mn^{2+}, as shown by the detectable manganese concentrations in these wells (CH2M HILL, 2009a).

While natural attenuation is recognized as a viable remediation approach, it is often accompanied by active treatment methods. Natural attenuation applied alone must be supported by sufficient evidence of its effectiveness, must be accommodated by a robust monitoring program, and would require a long time to achieve cleanup goals at the Topock site, where uncertainties remain regarding the extent to which reducing conditions in fluvial deposits provide a pervasive and permanent barrier to Cr(VI) contaminant migration to the river. Further, due to the relatively flat natural hydraulic gradients at the site, it is estimated that it would likely take more than 1,000 years to clean up groundwater by allowing natural groundwater flow to move the Cr(VI) plume through the reducing zone in the floodplain. The existing floodplain and river monitoring programs may be enhanced to ensure adequate monitoring of the effectiveness of natural attenuation. As it is recognized that natural attenuation occurs at the Topock site, natural attenuation may be considered a feature of the site that augments those active remedial alternatives that allow chromium in groundwater to contact the fluvial materials.

Conversely, active remedial alternatives that rely on groundwater flushing or extraction may alter these beneficial natural reducing conditions, as groundwater flushing/extraction causes an influx of toxic water and thus more oxidizing conditions can develop in the shallow floodplain aquifer. The reduction capacity and extent of the reducing zone are not precisely known, but the combinations of available core testing and groundwater data provide an approximate horizontal and vertical distribution of a predominantly reducing portion of the fluvial material, as described in the RFI/RI Volume 2 Report (CH2M HILL, 2009a). The flow regime of the Colorado River changed greatly following the closure of Hoover and Davis dams. Spring flooding that previously deposited organic detritus in the floodplain sediments no longer occurs. It is not clear how the change in flow regime will affect the reducing conditions in the floodplain in the coming decades and centuries, and it is not possible to accurately quantify the capacity of the fluvial sediments to retain their capability to reduce Cr(VI) contamination with sustained IM pumping or during pumping at potentially greater extraction rates. If the fluvial materials are flushed with enough oxic river water, it could result in a loss of their reductive capacity.

Regular monitoring of floodplain geochemistry has occurred since IM pumping began in 2004. To date, data collected do not strongly indicate that the reductive capacity of the fluvial materials has been compromised. However, the relatively short period of IM pumping (approximately 5 years) at relatively modest flow rates does not provide a sufficient dataset to make conclusions about the potential effects of much longer-term or higher-volume pumping that may be associated with a remedial action. As presented in the 2006 through 2009 combined Fourth Quarter and Annual Performance Evaluation Reports (CH2M HILL, 2006b, 2007c, 2008f, and 2009g), there are multiple lines of evidence that IM pumping has induced strong landward and downward hydraulic gradients from shallow floodplain wells and the river towards the IM pumping wells and that previously oxic river water has been drawn in towards pumping wells.

These lines of evidence (as documented in the reports) include:

- Changing deuterium isotope concentrations.
- Increasing oxidation reduction potential data for MW-33-40 and MW-33-90.
- Decreasing TDS concentrations in floodplain wells.

If pumping were to eventually reduce the reductive capacity of the fluvial materials, the loss of the reductive capacity could be partially mitigated by the injection of soluble carbon substrates to provide short-term replenishment or enhancement of the reducing capacity.

5.2.6 *In-situ* Treatment

In-situ treatment involves treating the contaminated groundwater belowground in the aquifer and can be accomplished by: (1) establishing discrete IRZs through which contaminated groundwater flows, (2) establishing reducing conditions across large portions of the Cr(VI) plume, or (3) a combination of the two. The main considerations for active *in-situ* treatment at the site are the type of reagent (which affects treatment residuals, contaminant half lives), the hydrogeology affecting distribution of reagent to all appropriate (contaminated) areas of the aquifer, and the methodology to deliver the reagent to the contaminated groundwater or move the contaminated groundwater toward an *in-situ* treatment zone. The reagent can be delivered through injection, extraction and reinjection, or recirculation wells and can include chemical reactive compounds or biological substrates that create or enhance an environment that favors the desired chemical alteration of the contaminant. For the purpose of assembling and evaluating groundwater alternatives at the Topock site, the representative process option for *in-situ* chemical treatment is termed biochemical reduction. In the context of this report, biochemical reduction refers to the reduction of Cr(VI) to Cr(III) using an organic substrate that promotes microbial growth which, in turn, creates an environment where the chromium is reduced and precipitated.

Two key factors are expected to limit the re-conversion of Cr(III) to Cr(VI) after *in-situ* reduction: the limited solubility of Cr(III) and the lack of availability and reactivity of an adequate oxidizer (MnO_2). Together, these factors are expected to limit any reoxidized Cr(VI) concentrations to levels similar to ambient background. Specifically, reduction of Cr(VI) to Cr(III) results in the formation of Cr(III) oxides that have a low solubility under the neutral and alkaline pH encountered in site groundwater. Appendix G presents the case that *in-situ* treatment of the aquifer will create reducing conditions where MnO_2 is not stable and Mn^{2+} will be present along with reduced levels of MnO_2. The appendix also presents data demonstrating the formation of more stable Cr(III) precipitates as a result of the IRZ and discusses the occlusion and passivation of MnO_2 surfaces as a result of the precipitation of a variety of non-reactive minerals formed in the IRZ. Thus, it is possible that MnO_2 capable of re-oxidizing Cr(III) could still be present in the same area of the aquifer where Cr(VI) has been reductively precipitated. While over the long term it cannot be said that the Cr(VI) reduction reaction is completely irreversible, the evidence presented in Appendix G, Section G.7, indicates that re-oxidation of Cr(III) to Cr(VI) is expected to be minimal and not lead to concentrations that exceed background. Two general methods for *in-situ* treatment would involve: (1) building a reactive barrier, with treatment occurring when groundwater moved through the barrier, or (2) building a reagent delivery system to distribute reagent throughout the plume. Both of these options could work at the site.

Constructing a reactive barrier could be accomplished by excavating a trench and backfilling the trench with reactive materials to create a subsurface wall that allows groundwater to pass through while prohibiting the movement of constituents. Other options include fracturing or the use of boreholes to inject reactive materials (such as zero valent iron) that the groundwater will pass through. Another option for creating a reactive barrier is to establish an IRZ using a line of wells that circulates reactive materials between each well. In any case, the barrier is installed across the flow path of the constituent plume, thereby allowing groundwater to move through the barrier below grade to reduce Cr(VI) to low solubility and less toxic Cr(III). The reactive barrier must be constructed down to an impermeable layer, such as bedrock, to prevent contaminated groundwater from passing beneath the barrier. A cross section of a typical IRZ barrier is shown in Figure 5-2.

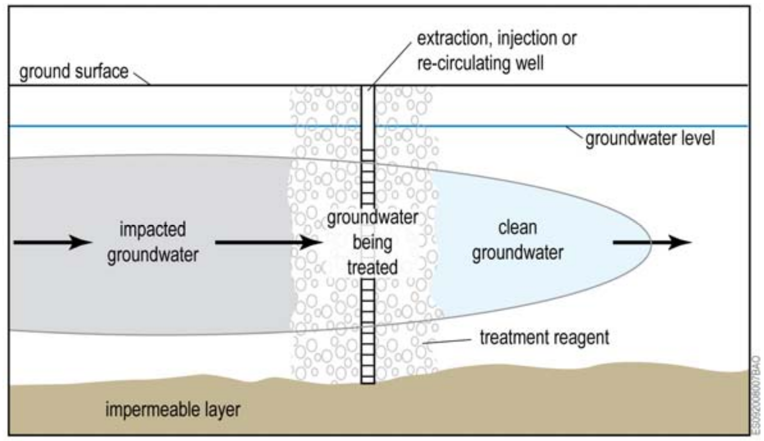

FIGURE 5-2
Typical Cross Section of an IRZ Barrier
Source: USEPA, 2001b

At the Topock site, the depth to bedrock at many places throughout the plume limits the constructability of a reactive barrier by trenching. The areas of the site with the shallowest bedrock are located in the southern floodplain. Bedrock in the northern portion of the floodplain dips sharply such that the distance from the ground surface increases from a surface outcrop to the south to more than 200 feet bgs. Depths of more than 100 feet bgs exceed the limits of most conventional barrier construction methods. Techniques for construction of a reactive barrier greater than 100 feet deep would disturb extensive surface area within the sensitive habitat of the floodplain. For these reasons, the IRZ is considered the most appropriate construction method for reactive barriers and is included in the assembled *in-situ* treatment alternatives.

Generally, reactive treatment zones are created by installing the media delivery wells in a line perpendicular to groundwater flow to allow spatial coverage of the plume. These may consist of wells for the injection or placement of reactive media into the aquifer or may consist of wells designed to both deliver the media and mix the groundwater by circulation. Circulation can be designed as vertical circulation or horizontal circulation. Well spacing, pumping circulation rates, and screen intervals can be designed based on aquifer properties to maximize coverage between circulation wells in a treatment line. Typical reactive treatment zone wells are shown in Figure 5-3.

The main considerations for the number and locations of *in-situ* treatment at the site pertain to site hydrogeology, plume location and depth, desired time to cleanup, and access considerations. Further considerations include appropriate mitigation measures to protect wildlife habitat and cultural resources, identified by the HNWR Manager and federal consultation related to cultural and historic properties. Greater numbers of wells and IRZ lines would distribute the substrate more quickly than fewer wells and IRZ lines. Combining IRZ lines with extraction and injection technologies would allow manipulation of groundwater flow to enhance distribution of reactant material.

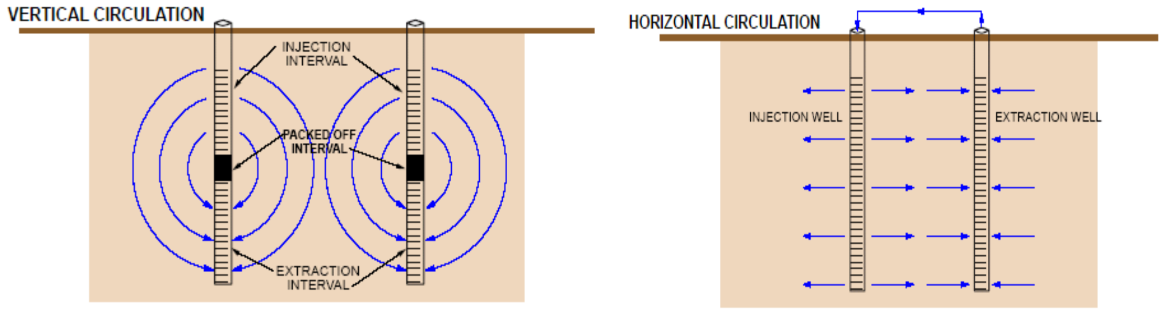

FIGURE 5-3
Typical Reactive Treatment Zone Well Configuration

Considerations for siting a reactive treatment zone include ensuring that facilities are located in areas that are accessible for construction, operation and maintenance, and management of the substrate storage and injection equipment. Utility lines (e.g., power) need to be constructed to operate the circulating and reagent delivery systems. Because much of the plume is outside the PG&E property, permission from the respective landowners for locating the *in-situ* treatment equipment would be required. Siting of the *in-situ* facilities must consider areas of the site that are of cultural or religious significance. Other location constraints include sensitive habitats, historical sites, and topographic constraints. Major transportation and pipeline corridors cross the site and construction and operation of remedial facilities would be designed to not interrupt those existing operations.

The type of reagent or substrate could affect the amount of infrastructure necessary for delivery (e.g., closer well spacing for reagents/substrates that move slower and have shorter half lives, or wider well spacing for reagents/substrates that move more quickly and have longer half lives). Delivery systems can be designed to allow for more frequent operation and maintenance (e.g., smaller storage tanks) or less frequent operation and maintenance (e.g., larger storage tanks).

There is potential for transient byproducts such as arsenic and manganese to exceed baseline and background concentrations during implementation of *in-situ* methods. Under ideal geochemical and hydrologic conditions described in Appendix G, arsenic and manganese byproducts should not be a significant issue. However, because of uncertainty in the complexity of aquifer lithology and geochemistry, large-scale implementation of *in-situ* treatment could result in elevated concentrations of arsenic and manganese that persist for longer than expected periods of time in some portions of the aquifer. Careful monitoring during the initial phase(s) of *in-situ* operation will enable early detection of these conditions. Specific contingencies will be in place to address any potential threat to the Colorado River or the aquifer.

Appendix G provides more detailed information on performance data from pilot studies conducted at the Topock site and other sites with chromium impacted groundwater, including *in-situ* byproducts. Different reactant materials may be applied to different areas of the site (e.g., floodplain vs. upland) to reflect different natural geochemical conditions.

There is a wide spectrum of organic carbon substrates available for anaerobic IRZ applications, including fermentable soluble substrates such as molasses, lactate, and whey; alcohols such as ethanol and methanol; semi-soluble substrates such as emulsified vegetable oil; and solids such as chitin and bark mulch. The selection of the appropriate substrate for a site depends on the balance between the mode of delivery and the substrate properties, and the rate of carbon utilization and the ability to overcome the ambient electron acceptor recharge (to establish a sufficiently reducing environment). More details on the various donor types as they relate to IRZ activities at Topock are discussed in Appendix G.

5.2.7 *Ex-situ* Treatment

Ex-situ treatment involves treating the contaminated groundwater in a system constructed aboveground. *Ex-situ* treatment must be combined with removal and disposal to transport the contaminated groundwater to the treatment system and manage the treated groundwater.

The main considerations when assembling *ex-situ* remedial alternatives for the Topock site include type of treatment, location of treatment, and capacity of treatment. *Ex-situ* treatment of groundwater has been effectively used at the Topock site as part of the IM. The IM treatment system involves chemical reduction by ferrous iron compounds followed by alkaline precipitation and filtration to remove chromium from the groundwater. While there are other technologies that may be used for *ex-situ* treatment, such as anaerobic bioremediation, ion exchange, electrochemical reduction followed by alkaline precipitation, or acidic reduction, the type of treatment used at the existing IM treatment plant is the representative treatment option included in the assembled alternatives. The other *ex-situ* treatment options would be considered during remedial design or during the future operation if another option is found to offer better treatment performance or implementability, fewer adverse impacts, or lower costs for similar levels of performance.

Ideally, *ex-situ* treatment facilities should be located close to the extraction and injection facilities to minimize the amount of pipelines and pump stations necessary to transport groundwater to and from the treatment system. The location should also be close to the power source, have available space for construction, and be in an accessible location for construction and operation. The location of treatment facilities must also consider areas of the site that are of cultural or religious significance so that construction or other disturbance is minimized to the extent feasible. Other location constraints include sensitive habitats, historical sites, topographic constraints, and existing infrastructure as discussed in Section 2.0. Possible locations for an *ex-situ* treatment plant are on the Topock Compressor Station property and at the current IM No. 3 treatment plant location.

The design flow rate is a critical variable in determining the size and layout of the *ex-situ* treatment facility. Larger design flows would require more treatment system capacity, and smaller design flows would require lower capacity. Flexibility of the treatment system over time will be necessary to accommodate changes in treatment flow and changes in the chromium concentrations in extracted groundwater.

Construction of the treatment system typically would involve construction of a building and storage tanks. The treatment plant and other aboveground equipment must be present for the entire duration of the active cleanup, with the associated space requirements and visual impact. The locations and number of wells installed will affect the extent of piping and disturbances at the surface.

An *ex-situ* treatment plant would require large amounts of energy and/or chemical inputs and would likely generate residuals such as sludge and cleaning waste that must be managed, typically through an offsite permitted facility. The *ex-situ* treatment plant would require continuous operation and maintenance.

5.2.8 Monitoring

Either short- or long-term monitoring is implemented to evaluate site conditions and contaminant levels. Monitoring alone will not reduce chromium concentrations; therefore, monitoring is combined with other technologies to form alternatives that are focused on reducing chromium concentrations within the plume. With the exception of the no action alternative, monitoring is a component of all of the assembled alternatives for measuring the performance of the remedy, compliance with standards, and progress of the remedial action. The monitoring incorporated into the alternatives includes the collection, management, and reporting of groundwater quality, surface water quality, and remedial system operational data.

Monitoring wells need to be located in areas that provide relevant data on groundwater hydraulics and chemistry. In addition, the monitoring wells need to be located in areas that are accessible. Additionally, and the same considerations previously described for extraction and injection wells regarding property ownership, the existence of major transportation and pipeline corridors, and sensitive areas of the site also apply to the monitoring wells. As remediation progresses and the plume changes in size and shape, monitoring wells may need to be abandoned or additional monitoring wells may need to be installed to provide adequate data for control and optimization of the remedial alternative.

5.2.9 Summary of Alternative Assembly

The technologies and process options have been assembled into the following alternatives for further evaluation in accordance with the considerations previously described:

- Alternative A – No Action
- Alternative B – Monitored Natural Attenuation (MNA)
- Alternative C – High-volume *In-situ* Treatment
- Alternative D – Sequential *In-situ* Treatment
- Alternative E – *In-situ* Treatment with Fresh Water Flushing
- Alternative F – Pump and Treat
- Alternative G – Combined Floodplain *In-situ*/Pump and Treat
- Alternative H – Combined Upland *In-situ*/Pump and Treat
- Alternative I – Continued Operation of Interim Measure

The assembly of remedial action alternatives from the various technologies and process options is shown in Table 5-1. Each of the general response actions, remedial technologies, and representative process options retained in Table 4-3 are listed in the left-hand columns, and the alternatives are listed across the top of Table 5-1. A check mark is placed under an alternative in the rows corresponding to the options that are included in that alternative. For example, use restrictions, groundwater collection, *in-situ* biochemical/chemical reduction, injection, and monitoring are all included for Alternative C – High-volume *In-situ* Treatment. As previously discussed, biochemical/chemical reduction is included in the alternative for the purpose of the CMS/FS, but other *in-situ* treatment options, such as anaerobic bioremediation, could be considered during remedial design. Similarly, injection is chosen as the disposal option because of the advantages stated previously in improving the extraction efficiency.

TABLE 5-1
Assembly of Alternatives
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

General Response Action	Remedial Technology	Representative Process Option	Alternative[a]								
			A	B	C	D	E	F	G	H	I
No Action	None	None	X								
Institutional Controls	Access and Use Restrictions	Land Use Covenants/ Deed Restrictions		X	X	X	X	X	X	X	X
Containment	Hydraulic Barriers	Extraction/Injection Wells			X	X	X	X	X	X	X
Removal	Groundwater Collection	Extraction Wells			X	X	X	X	X	X	X
	Enhanced Extraction through Injection	Injection of Clean or Contaminated Water			X	X	X	X	X	X	X
In-situ Treatment	Biological Treatment	*In-situ* Biochemical Reduction			X	X	X		X	X	
	Monitored Natural Attenuation	Monitored Natural Attenuation [b]		X							
Ex-situ Treatment	Physical/Chemical Treatment	Chemical Reduction						X	X	X	X
Disposal	Treated Groundwater Discharge	Injection			X	X	X	X	X	X	X
Monitoring	Monitoring	Monitoring		X	X	X	X	X	X	X	X

Notes:

a) Alternative A – No Action
Alternative B – Monitored Natural Attenuation
Alternative C – High-volume *In-situ* Treatment
Alternative D – Sequential *In-situ* Treatment
Alternative E – *In-situ* Treatment with Fresh Water Flushing
Alternative F – Pump and Treat
Alternative G - Combined Floodplain *In-situ*/Pump and Treat
Alternative H - Combined Upland *In-situ*/Pump and Treat
Alternative I - Continued Operation of Interim Measure

b) Natural attenuation is a component of all remedial alternatives due to presence of reducing material in the shallow and mid-depth fluvial deposits along the Colorado River floodplain.

Because the site-specific considerations described in this section were used to focus the assembly of alternatives, all of the alternatives are considered viable for the site. An initial screening based on the criteria of effectiveness, implementability, and cost is not performed since all alternatives would pass the screening and would proceed to the detailed analysis. However, all three of these factors are considered in the detailed evaluation of alternatives presented in Sections 5.4 and 5.5.

5.3 Remedial Action Alternative Descriptions

The nine remedial action alternatives for the Alluvial Aquifer and bedrock groundwater in the East Ravine are described in the following subsections. The remedial alternatives were designed to a conceptual level of detail, sufficient to perform a comparative analysis on the alternatives and to develop the remedial cost estimates consistent with USEPA guidance for developing cost estimates for feasibility studies (USEPA, 2000). Appendix D provides the cost estimates, including alternative components, assumptions, and cost estimating factors.

In addition, a general description of potential technologies to address chromium in the bedrock of the East Ravine is provided herein. The bedrock remedy will be developed further during design.

The Topock groundwater model, originally documented in the *Groundwater Model Update Report, Topock Compressor Station, Needles California,* (CH2M HILL, 2005c), was used for conceptual design of the alternatives. Appendix E includes an evaluation demonstrating that this groundwater model is appropriate for conceptual design and analysis of alternatives to the level needed in the CMS/FS. The groundwater flow model was used in the development and analysis of alternatives to estimate well locations, flow rates, and time frames to achieve certain objectives (e.g., distribution of organic carbon substrate in a one pore volume flush, or movement of five pore volumes of water through aquifer materials). These objectives are assumed to be realistically achievable based on the conceptual hydrogeologic and contaminant model of the project site. Appendix F provides a more detailed description of how the model was used to develop the remedial alternatives and to estimate the time to reach objectives. Appendix F also includes simulated flowline maps for the active remedial alternatives. Supporting information for *in-situ* treatment design elements is included in Appendix G.

A large degree of uncertainty is inherent in the predicted time frames to achieve these objectives because of the limitations of this groundwater flow model in simulating the complex processes that control contaminant behavior in groundwater at this site. Furthermore, the degree to which these predicted time frames represent actual time frames for contaminant concentrations to reduce to background levels throughout the aquifer is not known. If a substantial amount of contamination is present in low-permeability zones, or if heterogeneous conditions limit the ability to flush water through or inject organic substrate into portions of the aquifer, time frames to achieve background levels throughout the aquifer using the active treatment alternatives will be considerably longer than estimated and could range from many decades to in excess of 100 years.

The alternatives discussions in this section present estimated time frames to achieve the stated objectives. These time frames remain the subject of considerable uncertainty and should not be construed to represent consensus estimates of the actual cleanup times that may be required to reach RAOs.

With the exception of Alternative I (Continued Operation of the Interim Measure), the active remediation alternatives (Alternatives C through H) were all designed to treat the entire area of the Cr(VI) plume, as defined by the 32 µg/L contour line, and to provide protection of the river either through geochemical barriers or hydraulic gradients. To facilitate meaningful comparison of the relative footprint and effectiveness of the active alternatives, all were designed to achieve certain goals (e.g., distribution of organic carbon substrate in a one pore volume flush or movement of five pore volumes of water through aquifer materials) in a roughly similar period of time (~40 years or less). Alternative I (Continued Operation of the Interim Measure) has been incorporated into this CMS/FS Report per DTSC's request (DTSC, 2008c-d); the configuration of Alternative I has not been modified to adjust to the goals of the remedial action (Section 3.0) but instead focuses on the goals of the IM (hydraulic control of the plume only).

As stated above, the remedial action alternatives were designed to a conceptual level of detail, sufficient to develop the remedial cost estimates consistent with USEPA guidance for developing cost estimates for feasibility studies (USEPA, 2000). Numbers and locations of remedial facilities and described operational elements are largely assumptions at this point in the definition of the alternatives and are used as a means to compare alternatives against each other. It is fully expected that changes to the numbers, locations, methods, configuration, and other assumptions made in developing the remedial costs will change for the selected alternative as it moves through the design, construction, and operational phases. Changes to the conceptual design for the alternative ultimately selected will be made during design, construction, and implementation to optimize the remedy to enhance performance to attain the RAOs, provide for adjustments due to field conditions, and comply with location- and action-specific ARARs and landowner and leaseholder requirements. An identification of the types of changes to the remedial alternatives that may be made during design, construction, and/or implementation to reduce the time to attain RAOs or reduce the footprint (type, location, and amount of infrastructure or operational activities) is identified in Table 5-2. An identification of the types of changes to the remedial alternatives that may be made during implementation to address contingency scenarios is identified in Table 5-3.

PG&E acknowledges that there are sensitive resources in the vicinity of the remedial action alternatives. At this early stage of analysis, the conceptual design of the remedial alternatives considered sensitive resources by re-positioning some infrastructure into previously disturbed areas. Important parameters throughout the design and implementation phases of the selected remedy will include: (1) implementing a remedial action in a manner that is respectful of, and causes minimal disturbance to, cultural resources particularly, resources that are of special significance to tribes in the area; (2) implementing a remedial action in a manner that limits disturbance to wildlife and their habitats; and (3) implementing a remedial action in a manner that complies with sensitive resource protection ARARs.

TABLE 5-2
Approaches to Optimizing Remedial Alternatives for Time and Footprint
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

	Factors Affected				Approach	
					Time Optimized	Footprint Optimized
Alternative	**Extraction Wells**	**Injection Wells**	**IRZ Arrays**	**Above-Ground Treatment Plant**	**Description**	**Description**
A – No Action					Not applicable – cannot change time to cleanup.	Not applicable – cannot change footprint.
B – MNA					Not applicable – cannot change time to cleanup.	Not applicable – cannot change footprint.
C – High-volume *In-situ* Treatment	X	X	X		**Phase 1: Floodplain cleanup:** Adding another line of *in-situ* wells could somewhat shorten the floodplain cleanup. **Phase 2: Upland treatment by *in situ*:** The only way to significantly shorten the time to cleanup would be to increase the number of injection/extraction well arrays, which would start to approximate Alternative D. Increasing flow in the existing wells would have only limited benefit because the wells are already designed to push carbon most of the way across the distance between the injection and extraction wells.	**Phase 1: Floodplain cleanup:** Fewer injection wells could be used in the floodplain at the cost of achieving only partial distribution of carbon substrate and having to wait for natural groundwater flow to move contaminated groundwater through treatment zone. Because of the slow movement of groundwater at the site, this could add substantially to the cleanup time. **Phase 2: Upland treatment by *in situ*:** Fewer wells would result in partial distribution of carbon substrate between injection and extraction wells. It would then be necessary to wait until natural groundwater flow moved the remaining contaminated water through a treatment zone around the injection wells.
D – Sequential *In-situ* Treatment	X	X	X		Simultaneous implementation of two or more treatment zones could shorten time to cleanup	Fewer wells would result in partial distribution of carbon substrate between injection and extraction wells. It would then be necessary to wait until natural groundwater flow moved the remaining contaminated water through a treatment zone around the injection wells.
E – *In-situ* Treatment with Fresh Water Flushing	X	X	X		Assuming that there was adequate freshwater available, cleanup time could be shortened by increasing the rate of clean water flushing by injection wells and/or extraction in the floodplain.	Alternative E was designed with minimal footprint as a key design concept, so further optimization of footprint is not likely to be substantial.
F – Pump and Treat	X	X		X	Time could be shortened by increasing the pumping/injection rate and/or adding additional extraction/ injection wells. The increased flow rate would require a larger treatment plant. At higher flow rates, new well locations would be required to control interference between wells and maintain adequate capture.	Reducing flow could reduce size of treatment plant and number of injection wells. A pump–and-treat system with approximately half the capacity of IM No. 3 (with extraction during low river cycles only) could provide a minimum level of hydraulic control of the plume and would represent the minimum footprint for a pump-and-treat system, but this would add substantially to the cleanup time.
G – Combined Floodplain *In-situ*/Pump and Treat	X	X	X	X	**Floodplain cleanup:** Adding another line of *in-situ* wells could somewhat shorten the floodplain cleanup. **Upland treatment by pump-and-treat:** Time could be shortened by increasing the pumping/injection rate and/or adding additional extraction/injection wells. The increased flow rate would require a larger treatment plant. At higher flow rates, new well locations would be required to control interference between wells and maintain adequate capture.	**Floodplain cleanup:** Fewer injection wells could be used in the floodplain at the cost of achieving a slower distribution of carbon substrate and having to wait for groundwater flow to move contaminated groundwater through treatment zone. Because of the slow landward movement of floodplain groundwater under the influence of the upland pump and treat system at the site, this could add substantially to the cleanup time. **Upland treatment by pump and treat**: Due to high flows, this alternative currently has two or three wells at each location. Reducing flow rates could reduce number of injection wells to one at each of the four locations, but this would add substantially to the cleanup time.
H – Combined Upland *In-situ*/ Pump and Treat	X	X	X	X	Time could be shortened by increasing the pumping/injection rate and/or adding additional extraction/ injection wells. The increased flow rate would require a larger treatment plant. At higher flow rates, new well locations would be required to control interference between wells and maintain adequate capture. Additional IRZ lines could also be installed to shorten cleanup time.	Reducing flow could reduce size of treatment plant and number of extraction/injection wells. One of the IRZ lines could be eliminated, but this would likely result in substantially longer cleanup time.

TABLE 5-2
Approaches to Optimizing Remedial Alternatives for Time and Footprint
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

	Factors Affected				**Approach**	
					Time Optimized	**Footprint Optimized**
Alternative	**Extraction Wells**	**Injection Wells**	**IRZ Arrays**	**Above-Ground Treatment Plant**	**Description**	**Description**
I – Continued Operation of IM					Not applicable – cannot change time to cleanup (by alternative definition).	Not applicable – cannot change footprint (by alternative definition).
					Time-optimized alternatives may be constrained: • By the amount of water that can be extracted and re-injected from the aquifer within the areas that are accessible. There is a limit to how much water can be produced from one well. Higher flows will mean more wells. Wells that pump large volumes of water must be located far enough apart to avoid interference, which can reduce the total pumping rate. • By the inability to access some areas. • In pump-and-treat options, by the maximum flow throughput of the treatment plant. The locations currently being considered—the Topock Compressor Station and the IM No. 3 area—have finite space availability due to cultural resources, existing infrastructure, and existing topography. Although it is difficult to accurately estimate the maximum flow capacity that can be fit within the available spaces, there clearly is a limit to that capacity. It can be assumed that the larger the plant, the more visible impact and more footprint it will have. • By the finite time required for remediation system implementation. Implementation includes designing; permitting and clearing with stakeholders, land owners, leaseholders, and regulators; constructing, and starting up a system. • For *in-situ* treatment options, by the time required to develop reducing conditions in the subsurface. *In-situ* treatment requires several months of time for delivery of reductant and growth of microorganisms across a given area to develop an IRZ.	Footprint-optimized alternatives may be constrained: • In several alternatives, by the need to prevent the plume from escaping ‘capture’ established by extraction or injection wells. • By the physical infrastructure required. *Ex-situ* treatment requires treatment plants including tanks, control systems, pumps, pipes, etc. *In-situ* treatment requires tanks for reductants and a structure to house the control system. Smaller flows will require smaller infrastructure. • By the effectiveness of natural attenuation and the acceptable time to cleanup. Reducing the footprint to eliminate active cleanup in portions of the plume causes the alternative to rely more on natural gradients and natural attenuation capacities at the site for the attainment of RAOs.

TABLE 5-3
Example Contingency Actions During Remedial Alternative Implementation
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Remedial Alternative	RAO/Criterion	Example Failure Modes	Example Causes	Example Contingency Action
B - Monitored Natural Attenuation	RAO #1: Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI)	Development of potable water supply in area of plume prior to attainment of MCLs/plume migration to existing domestic supply wells.	Increased pumping of local domestic supply wells/ modification of existing land uses that result in installation of domestic supply wells within plume area.	Modification and enforcement of land use covenants/ provision of an alternative water supply.
	RAO #2: Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI)).	Floodplain reducing zone allows passage of groundwater without sufficient natural reduction of Cr(VI).	Change in natural conditions over time.	Under a pure natural attenuation remedy, no contingency plan would be available. Therefore, if this event occurred, an alternative remedy would be implemented.
	RAO #3: Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI)).	Floodplain reducing zone allows passage of groundwater without sufficient natural reduction of Cr(VI).	Change in natural conditions over time or insufficient reductive zone at depth.	Under a pure natural attenuation remedy, no contingency plan would be available. Therefore, if this event occurred, an alternative remedy would be implemented.
	RAO #4: Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.	Same as RAO #3.	Same as RAO #3.	Under a pure natural attenuation remedy, no contingency plan would be available. Therefore, if this event occurred, an alternative remedy would be implemented.
	Comply with ARARs during implementation of the remedial action.	Change in natural conditions results in site contaminants in Colorado River in exceedance of ARARs.	Change in natural conditions over time.	Under a pure natural attenuation remedy, no contingency plan would be available. Therefore, if this event occurred, an alternative remedy would be implemented.
C - High-volume *In-situ* Treatment	RAO #1: Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI).	Development of potable water supply in area of plume prior to attainment of MCLs/plume migration to existing domestic supply wells.	Increased pumping of local domestic supply wells/ modification of existing land uses that result in installation of domestic supply wells within plume area.	Modification and enforcement of land use covenants/ provision of an alternative water supply/Modify current remedy.
	RAO #2: Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI)).	IRZ array in floodplain allows passage of groundwater without sufficient treatment. Extraction and injection strategies are not effectively controlling gradients. Floodplain reducing zone allows passage of groundwater without sufficient treatment.	Insufficient well spacing or ineffective amendment delivery. Unexpected hydrogeologic conditions. River water adds oxygen due to landward gradient/ change in natural conditions over time.	Add wells and/or modify amendment delivery rates or methods. Add wells or modify extraction/injection rates. Add IRZ wells and/or modify amendment delivery rates or methods.
	RAO #3: Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI).	Insufficient *in-situ* treatment.	Insufficient well spacing/insufficient dosing type, quantity, or method/insufficient flow rates.	Add wells/modify extraction and injection rates/modify amendment type, delivery rates, and/or methods.
	RAO #4: Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.	Same as RAO #3.	Same as RAO #3.	Same as RAO #3.
	Comply with ARARs during implementation of the remedial action.	Treatment byproducts result in concentrations in Colorado River in exceedance of ARARs.	Unexpected geochemical conditions in floodplain, inefficient treatment.	Add wells/modify reductant type, dosage, and/or delivery method.
D - Sequential *In-situ* Treatment	RAO #1: Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI).	Development of potable water supply in area of plume prior to attainment of MCLs/plume migration to existing domestic supply wells.	Increased pumping of local domestic supply wells/ modification of existing land uses that result in installation of domestic supply wells within plume area.	Modification and enforcement of land use covenants/ provision of an alternative water supply/modify current remedy.

TABLE 5-3
Example Contingency Actions During Remedial Alternative Implementation
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Remedial Alternative	RAO/Criterion	Example Failure Modes	Example Causes	Example Contingency Action
	RAO #2: Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI)).	IRZ array in floodplain allows passage of groundwater without sufficient treatment. Extraction and injection strategies are not effectively controlling gradients. Floodplain reducing zone allows passage of groundwater without sufficient treatment.	Insufficient well spacing or ineffective amendment delivery. Unexpected hydrogeologic conditions. Change in natural conditions over time.	Add wells and/or modify amendment delivery rates or methods. Add wells modify injection/extraction rates. Add IRZ wells and/or modify amendment delivery rates or methods.
	RAO #3: Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI).	Insufficient *in-situ* treatment.	Insufficient well spacing/insufficient dosing type, quantity, or method.	Add wells/modify amendment type, delivery rates, and/or methods.
	RAO #4: Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.	Same as RAO #3.	Same as RAO #3.	Same as RAO #3.
	Comply with ARARs during implementation of the remedial action.	Treatment byproducts result in concentrations in Colorado River in exceedance of ARARs.	Unexpected geochemical conditions in floodplain, inefficient treatment.	Add wells, modify reductant type, dosage, and/or delivery method.
E - *In-situ* Treatment with Fresh Water Flushing	RAO #1: Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI).	Development of potable water supply in area of plume prior to attainment of MCLs/plume migration to existing domestic supply wells.	Increased pumping of local domestic supply wells/ modification of existing land uses that result in installation of domestic supply wells within plume area.	Modification and enforcement of land use covenants/ provision of an alternative water supply/modify current remedy.
	RAO #2: Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI)).	Extraction and injection strategies are not effectively controlling gradients. Floodplain reducing zone allows passage of groundwater without sufficient treatment.	Unexpected hydrogeologic conditions. River water adds oxygen due to landward gradient/ change in natural conditions over time.	Add wells or modify extraction/injection rates. Add IRZ wells and/or modify the amendment delivery rates or methods.
	RAO #3: Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI).	Insufficient *in-situ* treatment. Flushing not sufficiently moving mass to treatment zones.	Insufficient well spacing/Insufficient dosing type, quantity, or methods. Unexpected hydrogeologic conditions/Inefficient well locations, injection and extraction rates.	Add wells/modify amendment type, delivery rates and/or methods. Add wells/modify extraction and injection rates.
	RAO #4: Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.	Same as RAO #3.	Same as RAO #3.	Same as RAO #3.
	Comply with ARARs during implementation of the remedial action.	Treatment byproducts result in concentrations in Colorado River in exceedance of ARARs.	Unexpected geochemical conditions in floodplain/ inefficient treatment process/extraction and injection strategies are not effectively controlling gradients.	Add wells/modify reductant type, dosage, delivery rates and/or methods. Add wells/modify extraction and injection rates.
F - Pump and Treat	RAO #1: Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI).	Development of potable water supply in area of plume prior to attainment of MCLs/plume migration to existing domestic supply wells.	Increased pumping of local domestic supply wells/ modification of existing land uses that result in installation of domestic supply wells within plume area.	Modification and enforcement of land use covenants/ provision of an alternative water supply/Modify current remedy
	RAO #2: Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI)).	Extraction and injection strategies are not effectively controlling gradients. Floodplain reducing zone allows passage of groundwater without sufficient treatment.	Unexpected hydrogeologic conditions. River water adds oxygen due to landward gradient/ change in natural conditions over time.	Add wells or modify extraction and injection rates. Move wells or modify extraction and injection rates.
	RAO #3: Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI).	Flushing not sufficiently moving mass to extraction points.	Unexpected hydrogeologic conditions/inefficient well locations, injection and extraction rates.	Add wells and/or modify extraction and injection rates.

TABLE 5-3
Example Contingency Actions During Remedial Alternative Implementation
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Remedial Alternative	RAO/Criterion	Example Failure Modes	Example Causes	Example Contingency Action
	RAO #4: Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.	Same as RAO #3.	Same as RAO #3.	Same as RAO #3.
	Comply with ARARs during implementation of the remedial action.	Injection of groundwater outside plume at concentrations that would result in exceedance of MCLs at water supply wells.	Ineffective control of treatment system byproducts, unanticipated hydrogeologic or geochemical conditions, extraction of groundwater with ambient concentrations of constituents.	Modify treatment process, add injection or extraction wells, modify flow rates.
G - Combined Floodplain *In-situ*/Pump and Treat	RAO #1: Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI).	Development of potable water supply in area of plume prior to attainment of MCLs/plume migration to existing domestic supply wells.	Increased pumping of local domestic supply wells/ modification of existing land uses that result in installation of domestic supply wells within plume area.	Modification and enforcement of land use covenants/ provision of an alternative water supply/modify current remedy.
	RAO #2: Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI)).	IRZ array in floodplain allows passage of groundwater without sufficient treatment. Extraction and injection strategies are not effectively controlling gradients. Floodplain reducing zone allows passage of groundwater without sufficient treatment.	Insufficient well spacing or ineffective amendment delivery. Unexpected hydrogeologic conditions. River water adds oxygen due to landward gradient/ change in natural conditions over time.	Add wells and/or modify amendment delivery rates or methods. Add wells or modify injection/extraction rates. Add IRZ wells and/or modify amendment delivery rates or methods.
	RAO #3: Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI).	Insufficient *in-situ* treatment. Flushing not sufficiently moving mass to treatment zones or extraction points.	Insufficient well spacing/Insufficient dosing type, quantity, or methods. Unexpected hydrogeologic conditions/Inefficient well locations, injection and extraction rates .	Add wells/modify amendment type, delivery rates, and/or methods. Add wells and/or modify extraction injection rates.
	RAO #4: Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.	Same as RAO #3.	Same as RAO #3.	Same as RAO #3.
	Comply with ARARs during implementation of the remedial action.	Treatment byproducts result in concentrations in Colorado River in exceedance of ARARs. Injection of groundwater outside plume at concentrations that would result in exceedance of MCLs at water supply wells.	Unexpected geochemical conditions in floodplain, inefficient treatment. Ineffective control of treatment system byproducts, unanticipated hydrogeologic or geochemical conditions, extraction of groundwater with ambient concentrations of constituents.	Add wells, modify reductant type, dosage, delivery rate and/or methods. Modify treatment process, add injection or extraction wells, modify flow rates.
H - Combined Upland *In-situ*/Pump and Treat	RAO #1: Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI).	Development of potable water supply in area of plume prior to attainment of MCLs/plume migration to existing domestic supply wells.	Increased pumping of local domestic supply wells/ modification of existing land uses that result in installation of domestic supply wells within plume area.	Modification and enforcement of land use covenants/ provision of an alternative water supply/Modify current remedy.
	RAO #2: Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI).	Extraction and injection strategies are not effectively controlling gradients. Floodplain reducing zone allows passage of groundwater without sufficient treatment.	Unexpected hydrogeologic conditions. River water adds oxygen due to landward gradient/ change in natural conditions over time.	Add wells or modify extraction/injection rates. Move wells or modify extraction and injection rates.
	RAO #3: Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI).	Insufficient *in-situ* treatment. Flushing not sufficiently moving mass to treatment zones or extraction points.	Insufficient well spacing/insufficient dosing type, quantity, or method. Unexpected hydrogeologic conditions/inefficient well locations, injection and extraction rates	Add wells/modify amendment type, delivery rates and/or methods. Add wells/modify extraction and injection rates.
	RAO #4: Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.	Same as RAO #3.	Same as RAO #3.	Same as RAO #3.

TABLE 5-3
Example Contingency Actions During Remedial Alternative Implementation
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Remedial Alternative	RAO/Criterion	Example Failure Modes	Example Causes	Example Contingency Action
	Comply with ARARs during implementation of the remedial action.	Treatment byproducts result in concentrations in Colorado River in exceedance of ARARs. Injection of groundwater outside plume at concentrations that would result in water quality degradation, for example exceedance of MCLs at water supply wells.	Unexpected geochemical conditions in floodplain, inefficient extraction locations and rates. Ineffective control of treatment system byproducts, unanticipated hydrogeologic conditions, extraction of groundwater with ambient concentrations of constituents.	Add wells, modify reductant type and dosage. Modify treatment process, add injection or extraction wells, modify flow rates.
I - Continued Operation of IM	RAO #1: Prevent ingestion of groundwater as a potable water source having Cr(VI) in excess of the regional background concentration of 32 µg/L Cr(VI).	Development of potable water supply in area of plume prior to attainment of MCLs/plume migration to existing domestic supply wells.	Increased pumping of local domestic supply wells/ modification of existing land uses that result in installation of domestic supply wells within plume area.	Modification and enforcement of land use covenants/ provision of an alternative water supply/modify current remedy.
	RAO #2: Prevent or minimize migration of Cr(T) and Cr(VI) in groundwater to ensure concentrations in surface water do not exceed water quality standards that support the designated beneficial uses of the Colorado River (11 µg/L Cr(VI)).	Extraction and injection strategies are not effectively controlling gradients. Floodplain reducing zone allows passage of groundwater without sufficient treatment.	Unexpected or change in hydrogeologic conditions. River water adds oxygen due to landward gradient/ change in natural conditions over time.	
	RAO #3: Reduce the mass of Cr(T) and Cr(VI) in groundwater at the site to achieve compliance with ARARs in groundwater. This RAO will be achieved through cleanup goal of regional background of 32 µg/L of Cr(VI).	Flushing not sufficiently moving mass to extraction points. Floodplain reducing zone allows passage of groundwater without sufficient treatment.	Unexpected hydrogeologic conditions/inefficient well locations, injection and extraction rates. River water adds oxygen due to landward gradient/ change in natural conditions over time.	
	RAO #4: Ensure that the geographic location of the target remediation area does not permanently expand following completion of the remedial action.	Same as RAO #3.	Same as RAO #3.	
	Comply with ARARs during implementation of the remedial action.	Injection of groundwater outside plume at concentrations that would result in exceedance of MCLs at water supply wells.	Ineffective control of treatment system byproducts, unanticipated hydrogeologic or geochemical conditions, extraction of groundwater with ambient concentrations of constituents.	

Notes:

Per the Corrective Action Consent Agreement (DTSC, 1996), a contingency plan/plans will be submitted with the Operations and Maintenances plan and the Construction work plan for the selected remedy.

Failure modes are hypothetical, and an informed contingency plan will be drafted in the design, construction, and operating plans for the elements of the selected remedy.

5.3.1 Addressing Chromium in Bedrock in East Ravine

As discussed in Section 2.3, groundwater containing elevated Cr(VI) was discovered in bedrock during investigations in the East Ravine. Additional investigation to determine the source and confirm the full extent of Cr(VI) in East Ravine bedrock is forthcoming. Based on data currently available, it appears that the Cr(VI) in bedrock is most prevalent in the mid- and shallow-depth wells. This is consistent with the observed upward hydraulic gradients in the bedrock and the observations of reducing conditions in the deeper bedrock wells. The average permeability of the bedrock is estimated to be less than 1 foot per day, much lower than the Alluvial Aquifer. Water-conducting fractures were found to be relatively sparsely distributed in East Ravine bedrock. Typically, the porosity in bedrock is much smaller than in Alluvial Aquifers. Thus it is estimated that the mass of Cr(VI) contained in the East Ravine bedrock is less than 1 percent of the total Cr(VI) mass in the plume.

Over small distances, the detailed groundwater flow pattern in fractured rock can differ substantially from flow in porous media because groundwater tends to follow the fractures as it moves downgradient. Although overall the rock contains and yields relatively little water, the velocity of groundwater flow through an individual fracture can be much larger than the typical groundwater velocity in a porous medium. At larger scales, the influence of individual fractures on groundwater flow direction and velocity becomes less important and groundwater in fractured rock can behave much like groundwater in a porous medium. The scale at which a fractured rock system can behave like a porous medium is not easily determined and varies depending on the density and orientation of conductive fractures. The groundwater model used to evaluate remedial alternatives for the Alluvial Aquifer is based on the assumption that the Bedrock Aquifer can be approximated as a porous medium. Although it is not uncommon to use such models to simulate flow in fractured rock, it has not yet been determined whether the East Ravine bedrock can be adequately simulated as an equivalent porous medium.

The existing model was used to evaluate a potential hydraulic capture system for East Ravine bedrock. Although the size and shape of the capture zone might be different if the hydraulic system is dominated by one or more primary fractures, the existing model can provide a representative estimate of the total pumping rate and approximate number and location of wells needed to provide hydraulic capture in the East Ravine bedrock.

The development of a hydraulic capture system for bedrock is assumed herein instead of developing and evaluating a range of remedial alternatives to attain RAOs in bedrock. The design of the East Ravine remedy will occur during the remedial design phase of the project. Due to the low volume of water from the bedrock compared to the volume of water in the Alluvial Aquifer, it is anticipated the remedial design for bedrock can be readily incorporated within any of the proposed active remedial alternative for the Alluvial Aquifer.

For purposes of this CMS/FS, the hydraulic containment component for the bedrock would involve pumping from a group of wells near the eastern (downstream) end of the East Ravine. The assumed location for these wells from a hydraulic and infrastructure perspective would be along the former National Trails Highway. A gas pipeline is buried beneath and alongside this portion of the National Trails Highway, but it is likely that well locations could be identified that would be sufficiently far from the pipeline yet still accessible from the roadway. Initial estimates are that approximately 15 wells, pumping a combined total of up to 10 gallons per minute, would be required to provide hydraulic capture of the area of Cr(VI) in East Ravine bedrock.

If it is determined that additional remedial effort is needed to reach RAOs in East Ravine bedrock, other technologies could be applied to supplement the pumping wells. In addition to pumping for hydraulic control, technologies that may be applicable to East Ravine bedrock would include, but are not limited to, freshwater injection for flushing and injection of carbon amendments for *in-situ* reduction of Cr(VI).

5.3.2 Alternative A – No Action

No active construction or operational activities would occur under this alterative. The operation of the existing IM system would not continue. There would be no active treatment to reduce Cr(VI) concentrations in groundwater. While natural attenuation would occur within most of the fluvial sediments near the Colorado River, there would be no land ownership changes initiated as part of the remedy and no institutional controls imposed to restrict use of groundwater in locations where Cr(VI) concentrations exceed the cleanup goals. No additional groundwater monitoring facilities would be constructed under this alternative nor would any ongoing sampling or well maintenance activities occur. This alternative does not include decommissioning of the existing wells or the IM treatment facilities.

5.3.3 Alternative B – Monitored Natural Attenuation

No active treatment to reduce Cr(VI) concentrations in groundwater would occur under this alternative. This alternative would rely only on the naturally reducing conditions in shallow floodplain areas of the site to remove Cr(VI) from groundwater. These reducing conditions are derived from naturally occurring organic carbon in the fluvial deposits associated with the river. Wherever the natural reducing capacity of the fluvial material is present, Cr(VI) is converted to its stable and less toxic form of Cr(III), which is essentially immobile. The reducing conditions in the fluvial sediments provide a natural geochemical barrier that greatly limits or prevents the movement of Cr(VI) through the fluvial sediments adjacent to and beneath the Colorado River, as discussed in Section 2.3. The estimate of the time for five pore volumes to be flushed through the reducing zone with this alternative is 540 years. The actual cleanup time will be dependent on the flushing efficiency of the aquifer and transport of Cr(VI) from all parts of the plume under natural hydraulic gradients to the natural reductive conditions in the floodplain. These factors are subject to considerable uncertainty. The estimated range of cleanup time is from 220 years (based on flushing of two pore volumes) to 2,200 years (based on flushing of 20 pore volumes). Figure 5-4 illustrates the conceptual remedial approach for Alternative B. (The remainder of the figures referenced in this section are included at the end of the section.)

Under this alternative, an institutional control would be maintained during the remediation period to restrict use of impacted groundwater until the cleanup goals are attained, thereby eliminating the pathway for human health risk from direct exposure to groundwater.

Under this alternative, the existing groundwater monitoring network would potentially be enhanced with additional groundwater monitoring wells, and the long-term corrective action monitoring program of routine sampling, analysis, and reporting would occur until the cleanup goals are attained.

Groundwater monitoring wells throughout the site would be decommissioned following the determination that additional information from the wells would not be needed to evaluate attainment of the cleanup goals. The roadways associated with accessing the monitoring wells would be restored using decompaction and grading techniques designed to decrease erosion and accelerate revegetation of native species or other as directed by the land manager.

5.3.3.1 Limitations

Although the reducing conditions in the shallow fluvial deposits within the floodplain and beneath the river have been present at every location where a well has been installed or a pore water sample has been collected, there is no way to prove that these conditions exist everywhere. Further, reducing conditions in fluvial deposits do not extend to deeper zones in some parts of the aquifer near the Colorado River, and non-reducing conditions are prevalent in the Alluvial Aquifer where the majority of the Cr(VI) plume exists. Over the centuries that would be required for MNA to reach cleanup goals, it is possible that the geochemistry or groundwater flow directions, or even the location of the Colorado River channel, could change significantly.

5.3.4 Alternative C – High-volume *In-situ* Treatment

Alternative C would involve active *in-situ* groundwater treatment by distributing an organic carbon substrate across the entire plume through high-volume pumping using a minimum number of wells installed primarily in previously disturbed areas. This alternative was designed to meet the RAOs stated in Section 3.0 by active groundwater treatment until cleanup goals are attained. This would involve construction of injection wells within the center of the plume and extraction wells at the plume margin. An organic carbon substrate would be injected to create geochemically-reduced conditions and to remove Cr(VI) from groundwater by converting it *in-situ* to insoluble Cr(III), thereby removing chromium from groundwater. Groundwater would be extracted along National Trails Highway and along the western margin of the plume, amended with a carbon substrate, and injected into the injection wells within the center of the plume. The extraction/injection well lines would form a recirculation system to induce a hydraulic gradient to distribute the carbon substrate throughout the plume. Although this remedy has been designed to minimize the number of wells outside previously disturbed areas, it still requires a sufficient number of wells due to the limited distance that carbon substrates can travel in the aquifer before they are fully metabolized by the microbes. Figure 5-5 illustrates the conceptual remedial approach for Alternative C. This alternative would consist of two phases: floodplain cleanup and interior plume cleanup.

5.3.4.1 Floodplain Cleanup

Phase 1 involves construction of an IRZ line across the width of the plume along National Trails Highway and construction of IRZ lines between National Trails Highway and the Colorado River. Organic carbon would be injected in the IRZ lines to treat the existing Cr(VI) in the alluvial zone of the floodplain aquifer. The IRZ along National Trails Highway would be constructed using a line of wells that could be used either as injection or extraction wells to circulate groundwater and to distribute the organic carbon substrate. The floodplain IRZs could be constructed using arrays of injection and extraction wells, or they could be constructed with injection wells only. The final design may be adjusted based on stakeholder and engineering considerations and the exact conditions present in the floodplain at the time of final remedy design. IRZ systems are operated in a flexible manner guided by real-time monitoring data, as discussed in Appendix G, Section G.5. Phase 1 would operate until cleanup goals within the plume east of National Trails Highway are attained, approximately 2 years. The purpose of Phase 1 is to provide a robust, wide barrier to convert Cr(VI) to Cr(III) in the area of the site nearest the Colorado River. The current monitoring well network in the floodplain and the additional Phase 1 monitoring wells would provide an extensive monitoring network to measure chromium concentrations and adjust the active interior plume cleanup following completion of Phase 1.

5.3.4.2 Interior Plume Cleanup

Phase 2 involves construction of extraction wells around the perimeter of the plume and injection wells through the interior of the plume. Water is pumped from the extraction wells, organic carbon is added, and the amended water is injected into the core of the plume. The organic carbon in the injected water creates geochemically-reduced conditions in the aquifer to remove the Cr(VI) from groundwater. The assumed total pumping/injection rate would be approximately 2,000 gallons per minute (gpm). Depending on the results of hydraulic testing of the injection and extraction wells, this phase of the alternative may be implemented in stages so that not all the wells are pumping at once. This staged implementation could allow for maximization of the injection rate at each injection well to improve the distribution of the organic carbon. It is estimated that approximately 16 years would be required in Phase 2 to distribute the organic carbon and flush recalcitrant zones. Due to the relatively large distance between the injection and extraction wells, it is anticipated that there will be areas of the plume where organic carbon is not able to reach. Alternative C provides for continued operation of the pumping and injection systems to flush the remaining Cr(VI) from those portions of the aquifer not adequately treated by *in-situ* methods. During this flushing period, carbon would continue to be added only at levels sufficient to treat the water being injected as part of aquifer flushing. After the initial distribution of carbon has been achieved, there is no need to continue to distribute the carbon across large areas of the aquifer since the water drawn from the perimeter will be treated and injected, while the water from the central portion of the plume will also be treated as it flows through the reduced zone generated from the initial high concentration injection of carbon around the injection wells.

The estimated time to complete the Phase 1 floodplain cleanup and to distribute the organic carbon and flush recalcitrant zones during Phase 2 is 18 years. The actual cleanup time will be dependent on the rate at which organic carbon can be distributed to all areas of contaminated groundwater and/or contaminated groundwater in recalcitrant zones can be flushed to areas where it will be treated by injected organic carbon. These factors are subject to considerable uncertainty. The estimated range of cleanup time is from 10 to 60 years. The estimated time for this alternative is derived based on the assumed configuration, as described above. The time to cleanup for this alternative could be adjusted by modifying the number and location of wells and/or by modifying the flow rates.

Under Alternative C, an institutional control would be maintained during the remediation period to restrict use of groundwater in the plume area until the cleanup goals are attained, thereby eliminating the pathway for human health risk from direct exposure to groundwater. The area subject to the institutional control would include a buffer area surrounding the plume to prevent the consumption of water that potentially could migrate from the plume in other directions as a result of pumping from hypothetical future local water supply wells.

Preliminary estimates suggest that construction activities for this alternative would include installation of approximately 33 dipolar-type IRZ well locations, approximately 22 extraction well locations at the plume margins; approximately 41 injection well locations within the plume center for carbon-amended water; approximately15 bedrock extraction well locations in the East Ravine;[9] and associated piping, substrate storage and delivery systems, and power distribution and process controls/instrumentation systems. Operation and maintenance activities for the *in-situ* systems would include periodic well maintenance, groundwater sample collection and analysis, refinement of the injection/recirculation systems, management of the substrates, equipment inspections, and periodic replacement of wells and other structures that become clogged or damaged.

Optimization of the remedy would occur throughout the design, construction, and operational phases of remedy implementation. Changes to the number, location, and configuration of the extraction, treatment, and injection systems, and/or changes to the type, method, and configuration of the treatment delivery systems, as approved by appropriate agencies, may occur to enhance performance of the remedy to attain the cleanup goals, and to respond to site conditions and performance issues. Contingency measures would be established for this alternative to address system breakdowns and operational issues (e.g., emergency backup equipment and procedures) and to specify alternate procedures to prevent non-attainment of RAOs.

Under this alternative, the existing groundwater monitoring network would be enhanced with additional groundwater monitoring wells, and the corrective action monitoring program of routine sampling, analysis, and reporting would occur until the cleanup goals are attained, including long-term monitoring following completion of the active treatment.

Following attainment of the cleanup goals, the final remedy facilities (extraction wells, injection wells, IRZ wells, reagent storage, and delivery systems) would also be decommissioned. Groundwater monitoring wells throughout the site would be abandoned following the determination that additional information from the wells would not be needed to evaluate attainment of the cleanup goals. After deconstruction and decommissioning of the facilities, the areas would be restored using decompaction and grading techniques designed to decrease erosion and accelerate revegetation of native species or other as directed by the land manager.

[9] IRZ wells are intended for distribution of amendment along a single IRZ line to create a linear barrier. Injection and extraction wells are meant to distribute amendment across a broad area of the site. IRZ wells would likely be a smaller diameter and would be designed for lower flow rates than injection/extraction wells.

5.3.4.3 Limitations

In-situ technology has not often been applied to treat an entire plume of this size and depth. Alternative C would result in a plume-wide IRZ being established at the Topock site. There is uncertainty regarding the ability to obtain complete distribution of substrates across this large an area. Due to the limitations in achieving complete distribution of substrates, there would likely be some zones of the aquifer where RAOs would not be met in a timely manner without further optimization of the remedy. The calculation of reductant substrate delivery time throughout each targeted area is based on an assumption of a modeled single-pore-volume flush and an assumed half-life of reductant in the aquifer (explained in more detail in Appendix G). The uncertainty associated with these assumptions is applied equally to all alternatives that include *in situ* as part of the remedy. Concentrations of byproducts such as manganese and arsenic are likely to temporarily increase within portions of the treatment zone. These byproducts are not expected to be a significant issue as documented in Appendix G.

5.3.5 Alternative D – Sequential *In-situ* Treatment

Under this alternative, treatment of Cr(VI) in the plume would occur by injecting an organic carbon substrate throughout the plume to create geochemically reduced conditions to convert Cr(VI) to insoluble Cr(III), thereby removing chromium from groundwater. This alternative was designed to meet the RAOs stated in Section 3.0 by active groundwater treatment until cleanup goals are attained. Approximately 10 treatment zones, consisting of lines of injection and extraction wells, would be constructed and operated in phases to distribute an organic carbon substrate over the entire plume. Wells would be switched from extraction to injection as the implementation progress through different phases of treatment. Lines of wells would be constructed with piping and power to allow each line to be operated in either an injection or extraction mode. Water would be pumped from one line of wells and injected into the adjacent line of wells. Carbon substrate would be added to extracted water prior to injection. The carbon would be distributed throughout the aquifer in the area between the active injection and extraction well lines. The floodplain would be treated in the initial phase by pumping from wells near the river and injecting into wells near National Trails Highway. The final design may be adjusted based on stakeholder and engineering considerations. IRZ systems are operated in a flexible manner guided by real time monitoring data as discussed in Appendix G, Section G.5. Once carbon distribution is complete and Cr(VI) is below cleanup goals in the floodplain, the line of wells along National Trails Highway would be converted to extraction wells and injection would be moved to the adjacent line of wells west of National Trails Highway. This "leapfrog" pattern of moving the injection and extraction after each segment of the plume was treated would be repeated throughout all the lines of wells until the entire plume had been treated. It is estimated that approximately 1.5 to 2 years would be required to fully distribute carbon across each of the treatment zones. Figure 5-6 illustrates the conceptual remedial approach for Alternative D.

The estimate of the time to distribute organic carbon throughout the plume for this alternative is 15 years. The actual cleanup time will be dependent on the rate at which organic carbon can be distributed to all areas of contaminated groundwater and/or contaminated groundwater in recalcitrant zones can be flushed to areas where it will be treated by injected organic carbon. These factors are subject to considerable uncertainty. The estimate of the range of cleanup time is from 10 to 20 years. The estimated time to distribute organic carbon for this alternative is derived based on the assumed configuration as described above. The time for this alternative could be adjusted by modifying the number and location of wells and/or by modifying the flow rates. Operating more than one phase at a time would reduce the time to distribute organic carbon for this alternative.

Preliminary estimates suggest that construction activities for this alternative would include installation of wells that would alternate between extraction and injection at approximately 72 locations, 15 bedrock extraction well locations in the East Ravine, associated piping, substrate storage and delivery systems, power distribution, and process controls/instrumentation systems. Operation and maintenance activities for the *in-situ* systems would include periodic well maintenance, groundwater sample collection and analysis, refinement of the injection/recirculation systems, management of the substrates, equipment inspections, and replacement of wells and other structures that become clogged or damaged.

Optimization of the remedy would occur throughout the design, construction, and operational phases of remedy implementation. Changes to the number, location, and configuration of the extraction, treatment, and injection systems, and/or changes to the type, method, and configuration of the treatment delivery systems, may occur to enhance performance of the remedy to attain the cleanup goals and to respond to site conditions and performance issues. Contingency measures would be established for this alternative to address system breakdowns and operational issues (e.g., emergency backup equipment and procedures) and to specify alternate procedures to prevent non-attainment of RAOs.

Under this alternative, an institutional control would be maintained during the remediation period to restrict use of groundwater in the plume area until the cleanup goals are attained, thereby eliminating the pathway for human health risk from direct exposure to groundwater. The area subject to the institutional control would include a buffer area surrounding the plume to prevent the consumption of water that potentially could migrate from the plume in other directions as a result of pumping from hypothetical future local water supply wells.

Under this alternative, the existing groundwater monitoring network would be enhanced with additional groundwater monitoring wells, and the corrective action monitoring program of routine sampling, analysis, and reporting would occur until the cleanup goals are attained, including long-term monitoring following completion of the active treatment.

Following attainment of the cleanup goals, the final remedy facilities (extraction wells, injection wells, substrate storage, and delivery systems) would be decommissioned. Groundwater monitoring wells throughout the site would be decommissioned following the determination that additional information from the wells would not be needed to evaluate attainment of the cleanup goals. After deconstruction and decommissioning of the facilities, the areas would be restored using decompaction and grading techniques designed to decrease erosion and accelerate revegetation of native species or other as directed by the land manager.

5.3.5.1 Limitations

In-situ technology has not often been applied to treat an entire plume of this size and depth. Alternative D would result in a plume-wide IRZ being established at the Topock site. There is uncertainty regarding the ability to obtain complete distribution of substrates across this large an area. Due to the limitations in achieving complete distribution of substrates, there would likely be some zones of the aquifer where RAOs would not be met in a timely manner without further optimization of the remedy. Concentrations of byproducts such as manganese and arsenic are likely to temporarily increase within portions of the treatment zone. These byproducts are not expected to be a significant issue, as documented in Appendix G.

5.3.6 Alternative E – *In-situ* Treatment with Fresh Water Flushing

Alternative E involves flushing to accelerate plume movement through an IRZ barrier located along National Trails Highway. Flushing would be accomplished through a combination of fresh water injection and injection of carbon amended water in wells to the west of the plume. This alternative also includes extraction wells near the Colorado River to provide hydraulic capture of the plume, accelerate cleanup of the floodplain, and flush the groundwater with elevated Cr(VI) through the IRZ line. Additional extraction wells are located in an area northeast of the compressor station where the flushing efficiency from injection wells alone is relatively poor. This alternative was designed to meet the RAOs stated in Section 3.0 by active groundwater treatment until cleanup goals are attained. Figures 5-7a and 5-7b illustrate the conceptual remedial approach for Alternative E.

This alternative consists of three main elements: an IRZ line along the length of National Trails Highway, extraction wells near the Colorado River pumping carbon-amended water to the western area of the plume, and freshwater injected west of the plume to accelerate groundwater flow.

The IRZ along National Trails Highway would be constructed using a line of wells that could be used either as injection or extraction wells to circulate groundwater and distribute the organic carbon source.

The extraction wells near the river will provide hydraulic control to prevent water originating in the plume from reaching the river. Extraction near the river will also help to draw carbon-amended water a portion of the way across the floodplain to treat the existing Cr(VI) in the alluvial zone of the floodplain aquifer east of National Trails Highway. The extracted water will be amended with carbon substrate and re-injected in the western portion of the plume where it will help induce a hydraulic gradient to accelerate the movement of the site groundwater through the IRZ, where it would be treated. The assumed flow rate of groundwater extracted from the extraction wells, amended with carbon substrate, and re-injected is approximately 640 gpm. The primary purpose of adding carbon to the injected water would be to create treatment zones in the vicinity of each injection well where any Cr(VI) in the injected water would be reduced. In contrast to Alternatives C and D, which treat the upland entire area by *in-situ*, Alternative E does not result in a large volume of upland aquifer material being converted to a reducing zone. Therefore, the total amount of *in-situ* byproducts generated by Alternative E would be considerably less than with Alternatives C and D. To further accelerate the movement of groundwater towards reducing zones and to enhance distribution of the organic carbon, additional injection wells would be constructed in areas further to the west and north of the plume, and within the southern portion of the plume for freshwater injection. Freshwater injection would involve piping freshwater to the site from an offsite source. The injection of freshwater at an assumed rate of approximately 500 gpm would induce a hydraulic gradient to accelerate the movement of the site groundwater through the IRZ, where it would be treated. This fresh water injection also serves to constrain westward movement of the carbon amended water and flush much of this water eastward toward the extraction wells.

The estimated time for five pore volumes to be flushed with this alternative is approximately 29 years. The actual cleanup time will be dependent on the rate at which organic carbon can be distributed to all areas of contaminated groundwater in the floodplain and/or contaminated groundwater in recalcitrant zones in the upland areas can be flushed to the IRZ treatment line where it will be treated by injected organic carbon. These factors are subject to considerable uncertainty. It is estimated that the range of cleanup time is from 10 (based on two pore volumes) to 110 years (based on 20 pore volumes). The estimated time for this alternative is derived based on the assumed configuration described above. The estimated time for this alternative could be adjusted by modifying the number and location of wells and/or by modifying the flow rates. Under this alternative, an institutional control would be maintained during the remediation period to restrict use of groundwater in the plume area until the cleanup goals are attained, thereby eliminating the pathway for human health risk from direct exposure to groundwater. The area subject to the institutional control would include a buffer area surrounding the plume to prevent the consumption of water that potentially could migrate from the plume in other directions as a result of pumping from hypothetical future local water supply wells.

The offsite source of fresh water for this alternative could be the same as the water source for the Topock Compressor Station and is assumed to be available over the implementation period. The Topock Compressor Station is currently purchasing its water from wells in Arizona owned by Southwest Water Inc. Future water supply may be from the Colorado River or from wells on the California side of the river. Pipelines would be constructed to convey fresh water from the source to the injection wells. Potential sources of injection water would be tested for contaminants and to ensure compatibility with the aquifer where the water would be injected. Depending on the source of water, some minor pH adjustment might be required to make the water chemically compatible with the aquifer where it is injected and to prevent scaling in the injection wells. If needed, this pH adjustment would require a small system located along the pipeline corridor with equipment such as chemical storage tank(s), secondary containment, feed pump, and security enclosure such as a building or fence. If surface water source is used, filtration may be needed for sediment and bacteria removal (for injection well maintenance). Preliminary estimates suggest that construction activities for this alternative would include installation of approximately 18 dipolar-type IRZ well locations; approximately one extraction well location offsite for production of freshwater; approximately nine extraction well locations in the floodplain and immediately northeast of the compressor station; approximately 15 bedrock extraction well locations in the East Ravine; approximately four injection well locations for carbon-amended water; approximately four injection well locations for fresh water; and associated piping, substrate storage and delivery systems, power distribution, and process controls/instrumentation systems. Operation and maintenance activities for the *in-situ* systems would include periodic well maintenance, groundwater sample collection and analysis, refinement of the injection/recirculation systems, management of the substrates, equipment inspections, and periodic replacement of wells and other structures that become clogged or damaged. Optimization of the remedy would occur throughout the design, construction, and operational phases of remedy implementation. Changes to the number, location, and configuration of the extraction, treatment, and injection systems, and/or changes to the type, method, and configuration of the treatment delivery systems may occur to enhance performance of the remedy to attain the cleanup goals and to respond to site conditions and performance issues. Contingency measures would be established for this alternative to address system breakdowns and operational issues (e.g., emergency backup equipment and procedures) and to specify alternate procedures to prevent non-attainment of RAOs.

Under this alternative the existing groundwater monitoring network would be enhanced with additional groundwater monitoring wells, and the corrective action monitoring program of routine sampling, analysis, and reporting would occur until the cleanup goals are attained, including long-term monitoring following completion of the active treatment.

Following attainment of the cleanup goals, the final remedy facilities (IRZ wells, injection wells, substrate storage, and delivery systems) would be decommissioned. Groundwater monitoring wells throughout the site would be decommissioned following the determination that additional information from the wells would not be needed to evaluate attainment of the cleanup goals. After deconstruction and decommissioning of the facilities, the areas would be restored using decompaction and grading techniques designed to decrease erosion and accelerate revegetation of native species or other as directed by the land manager.

5.3.6.1 Limitations

Alternative E relies primarily on flushing to remove contaminants from the upland portion of the aquifer. This is analogous to the mass removal process used by pump-and-treat systems; however, in this alternative, the treatment is provided by an IRZ rather than a treatment plant. Extraction systems have generally demonstrated positive control of plumes at many sites—including Topock—and thus serve well as plume management tools. However, these systems historically have failed to achieve widespread remediation of plumes due to the difficulty associated with achieving efficient hydraulic recovery of a plume and the rate-limited back diffusion of contaminants from low-permeability material that result in prolonged cleanup times. At many sites, remedial alternatives that rely on flushing to remove contaminants (typical pump/treat systems) have reached a limit where concentrations are no longer being reduced effectively, but cleanup goals have not been met (USEPA, 1997b; Palmer and Wittbrodt, 1991). Hexavalent chromium does not strongly sorb to soils, which makes it more amenable to flushing type cleanup than some other contaminants, but it may still be difficult to reach cleanup levels across the entire plume by methods that rely on flushing. Due to the limitations of flushing as a remedial technology, there would likely be some zones of the aquifer where RAOs would not be met in a timely manner without further optimization of the remedy. It is not possible to predict what the limit of concentration reduction might be for flushing technology at the Topock site.

5.3.7 Alternative F – Pump and Treat

This alternative would involve pumping groundwater, *ex-situ* treatment to remove chromium from the groundwater, and reinjection of the treated water back to the aquifer. This alternative was designed to meet the RAOs stated in Section 3.0 by active groundwater treatment until cleanup goals are attained. The *ex-situ* treatment process is likely to include chemical reduction by addition of ferrous iron; oxidation, pH adjustment, and settling in a clarifier; and final filtration for a process that is essentially similar to the *ex-situ* treatment processes at the current IM No. 3 treatment plant, with the exception that reverse osmosis will not be a part of the *ex-situ* treatment process, as it is assumed salinity removal will not be needed. Extraction wells would be placed in the plume to extract groundwater. Extracted groundwater would be transported via piping to an aboveground treatment plant for treatment, and treated groundwater would be piped to injection wells. For this alternative, preliminary design suggests that extraction wells would be installed at approximately five locations within the plume In addition, bedrock extraction wells would be installed at approximately 15 locations in the East Ravine area. The assumed combined flowrate is approximately 1,280 gpm. Treated groundwater would be injected into injection wells at approximately three locations to the west of the plume and three locations in the southern portion of the plume near the mountain front. Chromium removed from the groundwater via *ex-situ* treatment would be collected in the sludge from the clarifier and filtration systems and would be transported offsite by truck to an appropriately-licensed disposal facility. Figure 5-8 illustrates the conceptual remedial approach for Alternative F.

The estimated time for five pore volumes to be flushed with this alternative is approximately 37 years. The actual cleanup time will be dependent on the flushing efficiency of the aquifer and is subject to considerable uncertainty. The length of time needed to attain cleanup goals in the Alluvial Aquifer would be longer if the flushing efficiency of the Alluvial Aquifer is less than estimated. It is estimated that the range of cleanup time could be from 15 years (based on two pore volumes) to 150 years (based on 20 pore volumes). The estimated time for five pore volumes to be flushed from the aquifer for this alternative is derived based on the assumed configuration described above. The estimated time for this alternative could be adjusted by modifying the number and location of wells and/or by modifying the flow rates.

As discussed above, the *ex-situ* treatment facilities should ideally be located close to the extraction and injection facilities to minimize the amount of pipelines and pump stations necessary to transport groundwater to and from the treatment system. The location should also be close to the power source, have available space for construction, and be in an accessible location for construction and operation. The location of treatment facilities must also consider areas of the site that are of cultural or religious significance so that construction or other disturbance is minimized to the extent feasible. Other location constraints include sensitive habitats, historical sites, and topographic constraints, as discussed in Section 2.0. Based on these factors, the location of the *ex-situ* treatment facilities is assumed to be within the lower yard of the Topock Compressor Station. An alternate location being considered, as required by DTSC's letter dated November 6, 2008 (DTSC, 2008c), is the location of the current IM treatment plant. The 1,280-gpm treatment plant anticipated under this alternative is considerably larger than the existing IM treatment plant. Sufficient level area for this larger plant is available at the lower yard of the compressor station. Substantially less level area is available at the current IM treatment plant location. Construction of a 1,280-gpm treatment plant at the current IM treatment plant location may require grading that would not be required at the compressor station or use of the IM construction staging area north of the existing IM treatment plant.

Alternatively, if it were necessary to construct the plant at the IM treatment plant location without grading, it might be necessary to extend the height of the building housing the plant to accommodate the needed equipment. The compressor station also offers a more reliable long-term source of electrical power for treatment plant operations. Figure 5-8 shows the anticipated locations for the *ex-situ* treatment facilities for this alternative.

Under this alternative, an institutional control would be maintained during the remediation period to restrict use of groundwater in the plume area until the cleanup goals are attained, thereby eliminating the pathway for human health risk from direct exposure to groundwater. The area subject to the institutional control would include a buffer area surrounding the plume to prevent the consumption of water that potentially could migrate from the plume in other directions as a result of pumping from hypothetical future local water supply wells.

Preliminary estimates suggest that construction activities would include: (1) installation of approximately five extraction well locations, approximately six injection well locations, approximately 15 bedrock extraction well locations in the East Ravine, and associated pipelines and (2) construction of an approximately 1,280-gpm treatment plant assumed to be located either on the Topock Compressor Station property or at the location of the present IM No. 3 treatment plant. See Appendix D for discussion of assumed flow per well.

Optimization of the remedy would occur throughout the design, construction, and operational phases of remedy implementation. Changes to the number, location, and configuration of the extraction, treatment, and injection systems may occur to enhance performance of the remedy to attain the cleanup goals and to respond to site conditions and performance issues. Contingency measures would be established for this alternative to address system breakdowns and operational issues (e.g., emergency backup equipment and procedures) and to specify alternate procedures to prevent non-attainment of RAOs.

Operation and maintenance of the aboveground treatment plant would include periodic groundwater sample collection and analysis, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Operation and maintenance of the extraction and injection wells would also occur throughout the remediation period, including replacement of wells and other structures that become clogged or damaged.

Under this alternative the existing groundwater monitoring network would be enhanced with additional groundwater monitoring wells, and the corrective action monitoring program of routine sampling, analysis, and reporting would occur until the cleanup goals are attained, including long-term monitoring following completion of the active treatment.

Following attainment of the cleanup goals, the final remedy facilities (e.g., extraction wells, injection wells, treatment plant) would also be decommissioned. Groundwater monitoring wells throughout the site would be decommissioned following the determination that additional information from the wells would not be needed to evaluate attainment of the cleanup goals. After deconstruction and decommissioning of the facilities, the areas would be restored using decompaction and grading techniques designed to decrease erosion and accelerate revegetation of native species or other as directed by the land manager.

5.3.7.1 Limitations

The fundamental limitation of pump-and-treat technology as a final remedy is the ability of the extraction portion of the system to effectively remove contaminant mass from the aquifer. Extraction systems have generally demonstrated positive control of plumes at many sites—including Topock—and thus serve well as plume management tools. However, these systems have failed historically to achieve widespread remediation of plumes due to the difficulty associated with achieving efficient hydraulic recovery of a plume and the rate-limited back diffusion of contaminants from low-permeability material that result in prolonged cleanup times. At many sites, pump-and-treat systems, which rely on flushing to remove contaminants, have reached a limit where concentrations are no longer being reduced effectively, but cleanup goals have not been met (USEPA, 1997b; Palmer and Wittbrodt, 1991). Due to the limitations of flushing as a remedial technology, there would likely be some zones of the aquifer where RAOs would not be met in a timely manner without further optimization of the remedy. It is not possible to predict what the limit of concentration reduction might be for flushing technology at the Topock site. The pumping associated with Alternative F provides a landward gradient towards the extraction wells and away from the river, but in the process, river water may be drawn into the aquifer. The river water is aerobic and would become reduced as it moved out of the river and into the fluvial aquifer. Over the long period of time that this remedy would operate, the passage of this aerobic water through the fluvial sediments could result in some degradation of the natural reducing capacity. It is not possible to accurately predict where or to what extent this degradation in reducing capacity would occur.

5.3.8 Alternative G – Combined Floodplain *In-situ*/Pump and Treat

This alternative would combine floodplain cleanup by *in-situ* treatment with treatment of the uplands portion of the plume by extraction and reinjection with *ex-situ* treatment. The floodplain cleanup would involve construction of IRZ lines at National Trails Highway and between National Trails Highway and the Colorado River, as described in Phase 1 of Alternative C. Chromium in the upland portions of the site would be addressed by pumping groundwater, *ex-situ* treatment to remove chromium from the groundwater, and reinjection of the treated water back to the aquifer. This alternative is designed to meet the RAOs stated in Section 3.0 by active groundwater treatment until cleanup goals are attained.

The floodplain cleanup would involve construction of an IRZ line across the width of the plume along National Trails Highway and construction of IRZ lines between National Trails Highway and the Colorado River. Organic carbon would be injected in the IRZ lines to treat the existing Cr(VI) in the alluvial zone of the floodplain aquifer. The IRZ along National Trails Highway would be constructed using a line of wells that could be used either as injection or extraction wells to circulate groundwater and to distribute the organic carbon substrate. The floodplain IRZs could be constructed using arrays of injection and extraction wells or they could be constructed with injection wells only. The floodplain IRZs would operate until cleanup goals within the plume east of National Trails Highway are attained, estimated to require approximately 2 years to distribute organic carbon throughout the floodplain.

Concurrent with the floodplain cleanup, treatment of the plume in the upland portions of the site would be by an *ex-situ* process likely to involve a process that is essentially similar to the treatment processes at the current IM No. 3 treatment plant: chemical reduction by addition of ferrous iron; oxidation, pH adjustment, and settling in a clarifier; and final filtration. As with Alternative F, it is assumed that salinity removal will not be needed and that reverse osmosis will not be a part of the *ex-situ* treatment process. Extraction wells would be placed in the central portions of the plume to extract groundwater. Extracted groundwater would be transported via piping to an aboveground treatment plant for treatment, and treated groundwater would be piped to injection wells. For this alternative, preliminary design suggests that extraction wells would be installed at approximately five locations within the plume. In addition, bedrock extraction wells would be installed at approximately 15 locations in the East Ravine area. The assumed combined flowrate is approximately 1,230 gpm. Treated groundwater would be injected into injection wells at approximately three locations to the west and north of the plume, and three locations in the southern portion of the plume near the mountain front. Chromium removed from the groundwater via *ex-situ* treatment would be collected in the sludge from the clarifier and filtration systems and would be transported offsite by truck to an appropriately-licensed disposal facility. Figure 5-9 illustrates the conceptual remedial approach for Alternative G.

The estimated time for five pore volumes to be flushed with this alternative is approximately 22 years. The actual cleanup time will be dependent on the flushing efficiency of the aquifer and is subject to considerable uncertainty. The length of time needed to attain cleanup goals in the Alluvial Aquifer would be longer if the flushing efficiency of the Alluvial Aquifer is less than expected. The estimate for the likely range of cleanup time is from 10 years (based on two pore volumes) to 90 years (based on 20 pore volumes). The estimated time for five pore volumes to be flushed from the aquifer for this alternative is derived based on the assumed configuration as described above. The estimated time for this alternative could be adjusted by modifying the number and location of wells and/or by modifying the flow rates.

As discussed in Alternative F, the approximately 1,230-gpm *ex-situ* treatment plant anticipated under this alternative is considerably larger than the IM No. 3 treatment plant. Sufficient level area for this larger plant is available at the lower yard of the compressor station, and substantially less level area is available at the current IM treatment plant location. Construction of a 1,230-gpm treatment plant at the current IM treatment plant location may require grading that would not be required at the compressor station.

Alternatively, if it were necessary to construct the plant at the IM No. 3 location without grading, it might be necessary to extend the height of the building housing the plant to accommodate the needed equipment. The compressor station also offers a more reliable long-term source of electrical power for treatment plant operations. Figure 5-9 shows the anticipated locations for the *ex-situ* treatment facilities for this alternative.

Under this alternative an institutional control would be maintained during the remediation period to restrict use of groundwater in the plume area until the cleanup goals are attained, thereby eliminating the pathway for human health risk from direct exposure to groundwater. The area subject to the institutional control would include a buffer area surrounding the plume to prevent the consumption of water that potentially could migrate from the plume in other directions as a result of pumping from hypothetical future local water supply wells.

Preliminary estimates suggest that construction activities would include installation of approximately 33 dipolar-type IRZ well locations, approximately five extraction well locations, approximately six injection well locations, and approximately 15 bedrock extraction well locations in the East Ravine. See Appendix D for discussion of assumed flow per well. In addition, construction activities would include construction of associated pipelines, *in-situ* substrate storage and delivery systems, an approximately 1,230-gpm treatment plant assumed to be located either on the Topock Compressor Station property or at the location of the present IM No. 3 treatment plant, and power distribution and process controls/instrumentation systems for the *in-situ* and *ex-situ* treatment processes.

Optimization of the remedy would occur throughout the design, construction, and operational phases of remedy implementation. Changes to the number, location, and configuration of the extraction, *in-situ* treatment, *ex-situ* treatment, and injection systems and/or changes to the type, method, and configuration of the treatment delivery systems may occur to enhance performance of the remedy to attain the cleanup goals and to respond to site conditions and performance issues. Contingency measures would be established for this alternative to address system breakdowns and operational issues (e.g., emergency backup equipment and procedures) and to specify alternate procedures to prevent non-attainment of RAOs.

Operation and maintenance activities for the *in-situ* systems in the floodplain would include periodic well maintenance, groundwater sample collection and analysis, refinement of the injection/recirculation systems, management of the substrates, equipment inspections, and periodic replacement of wells and other structures that become clogged or damaged. Operation and maintenance of the aboveground treatment plant would include periodic groundwater sample collection and analysis, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Operation and maintenance of the extraction and injection wells within the upland area would include replacement of wells and other structures that become clogged or damaged.

Under this alternative the existing groundwater monitoring network would be enhanced with additional groundwater monitoring wells, and the corrective action monitoring program of routine sampling, analysis, and reporting would occur until the cleanup goals are attained, including long-term monitoring following completion of the active treatment.

Following attainment of the cleanup goals, the final remedy facilities (e.g., IRZ wells, extraction wells, injection wells, *in-situ* reagent storage and delivery systems, and aboveground treatment plant) would also be decommissioned. Groundwater monitoring wells throughout the site would be decommissioned following the determination that additional information from the wells would not be needed to evaluate attainment of the cleanup goals. After deconstruction and decommissioning of the facilities, the areas would be restored using decompaction and grading techniques designed to decrease erosion and accelerate revegetation of native species or other as directed by the land manager.

5.3.8.1 Limitations

The fundamental limitation of pump-and-treat technology as a final remedy is the ability of the extraction portion of the system to effectively remove contaminant mass from the aquifer. Extraction systems have generally demonstrated positive control of plumes at many sites—including Topock—and thus serve well as plume management tools. However, these systems have failed historically to achieve widespread remediation of plumes due to the difficulty associated with achieving efficient hydraulic recovery of a plume and the rate-limited back diffusion of contaminants from low permeability material that result in prolonged cleanup times. At many sites, pump-and-treat systems, which rely on flushing to remove contaminants, have reached a limit where concentrations are no longer being reduced effectively, but cleanup goals have not been met (USEPA, 1997b; Palmer and Wittbrodt, 1991). Due to the limitations of flushing as a remedial technology, there would likely be some zones of the aquifer where RAOs would not be met in a timely manner without further optimization of the remedy. It is not possible to predict what the limit of concentration reduction might be for flushing technology at the Topock site. The pumping associated with Alternative G provides a landward gradient towards the extraction wells and away from the river, but in the process, river water may be drawn into the aquifer. The river water is aerobic and would become reduced as it moved out of the river and into the fluvial aquifer. Over the long period of time that this remedy would operate, the passage of this aerobic water through the fluvial sediments could result in some degradation of the natural reducing capacity. It is not possible to accurately predict where or to what extent this degradation in reducing capacity would occur. The carbon introduced into the floodplain during the *in-situ* treatment would mitigate some of the degradation of the natural reducing capacity.

5.3.9 Alternative H – Combined Upland *In-situ*/Pump and Treat

This alternative would combine *in-situ* treatment in the upland portions of the plume with pump-and-treat technology in the floodplain. While both Alternative G and Alternative H include a combination of *in-situ* treatment and pump and treat, this alternative differs from Alternative G by relying on *in-situ* to be the dominant feature of the cleanup rather than pump and treat. Chromium in the upland areas of the plume would be addressed by construction of several IRZ lines. The floodplain area of the site would be addressed by constructing a line of extraction wells along National Trails Highway. Extracted water from these wells would be split and managed in two ways: approximately half the extracted water would be treated by an *ex-situ* treatment plant and reinjected at locations outside the plume, while the remaining portion of the extracted water would be reinjected after being amended with a carbon source near the western edge of the plume. This alternative is designed to meet the RAOs stated in Section 3.0 by active groundwater treatment until cleanup goals are attained. Figure 5-10 illustrates the conceptual remedial approach for Alternative H.

The upland *in-situ* cleanup would involve construction of several IRZ lines across the length and width of the plume. Organic carbon would be injected in the IRZ lines to treat the existing Cr(VI) in the alluvial zone of the aquifer. IRZ lines would be constructed by recirculating between adjacent wells within each line or by use of vertical circulation wells.

Concurrent with the upland cleanup, groundwater extraction would be used in the floodplain area of the site to remove chromium-containing water and to provide for hydraulic control of the plume. Groundwater would be extracted through a series of extraction wells across the plume at the National Trails Highway. For this alternative, preliminary design suggests that approximately five extraction wells would be installed for an assumed combined flowrate of approximately 500 gpm. Extracted groundwater would be managed in two ways:

- Approximately one-half (200 to 300 gpm) of the extracted water would be transported via piping to an aboveground treatment plant. The *ex-situ* process is likely to involve a process that is essentially similar to the treatment processes at the current IM No. 3 treatment plant: chemical reduction by addition of ferrous iron; oxidation, pH adjustment, and settling in a clarifier; and final filtration. As with Alternatives F and G, it is assumed that salinity removal will not be needed and that reverse osmosis will not be a part of the *ex-situ* treatment process. Following *ex-situ* treatment, treated groundwater would be transported via pipeline to injection wells. Treated groundwater would be re-injected into injection wells at approximately four locations within and outside the plume boundary. Chromium removed from the groundwater via *ex-situ* treatment would be collected in the sludge from the clarifier and filtration systems and would be transported offsite by truck to an appropriately-licensed disposal facility.
- Approximately one-half (200 to 300 gpm) of the extracted water would be transported to the western edge of the plume, amended with carbon, and reinjected at approximately four locations near the western edge of the plume. The primary purpose of this reinjection is to increase the flushing efficiency by providing additional "push" to move the plume through the IRZ lines. Sufficient carbon would be added to this water to reduce the Cr(VI) in the injected water, thereby providing treatment of this water concurrent with reinjection. The flows would be balanced so that the treated water injection provides containment of all the flow lines emanating from the amended water injection wells, thus limiting the spread of the amended water and forcing it to flow back through the IRZ lines toward the extraction wells.

The estimated time to distribute organic carbon and flush contaminated groundwater for this alternative is 18 years. The actual cleanup time will be dependent on the rate at which organic carbon can be distributed to all areas of contaminated groundwater and/or contaminated groundwater in recalcitrant zones can be flushed. These factors are subject to considerable uncertainty. The estimated range of cleanup time is from 10 to 70 years. The estimated time for this alternative is derived based on the assumed configuration as described above. The time for this alternative could be adjusted by modifying the number and location of wells and/or by modifying the flow rates.

Possible locations for the *ex-situ* treatment plant are on the Topock Compressor Station property and at the current IM No. 3 treatment plant location. In comparison to Alternatives F and G, the *ex-situ* treatment plant for this alternative is considerably smaller and therefore would require less level area or grading than the treatment plant for Alternatives F and G. Figure 5-10 shows the anticipated locations for the *ex-situ* treatment facilities for this alternative.

Under this alternative, an institutional control would be maintained during the remediation period to restrict use of groundwater in the plume area until the cleanup goals are attained, thereby eliminating the pathway for human health risk from direct exposure to groundwater. The area subject to the institutional control would include a buffer area surrounding the plume to prevent the consumption of water that potentially could migrate from the plume in other directions as a result of pumping from hypothetical future local water supply wells.

Preliminary estimates suggest that construction activities for this alternative would include installation of approximately 39 dipolar-type IRZ well locations, approximately five extraction well locations, approximately 15 bedrock extraction well locations in the East Ravine, approximately four injection well locations for treated water, and approximately four injection wells for carbon-amended water. See Appendix D for discussion of assumed flow per well. In addition, construction activities would include construction of associated pipelines, *in-situ* substrate storage and delivery systems, an approximately 200- to 300-gpm treatment plant assumed to be located either on the Topock Compressor Station property or at the location of the present IM No. 3 treatment plant, and power distribution and process controls/instrumentation systems for the *in-situ* and *ex-situ* treatment processes.

Optimization of the remedy would occur throughout the design, construction, and operational phases of remedy implementation. Changes to the number, location, and configuration of the extraction, *in-situ* treatment, *ex-situ* treatment, and injection systems and/or changes to the type, method, and configuration of the treatment delivery systems may occur to enhance performance of the remedy to attain the cleanup goals and to respond to site conditions and performance issues. Contingency measures would be established for this alternative to address system breakdowns and operational issues (e.g., emergency backup equipment and procedures) and to specify alternate procedures to prevent non-attainment of RAOs.

Operation and maintenance activities for the *in-situ* systems would include periodic well maintenance, groundwater sample collection and analysis, refinement of the injection/recirculation systems, management of the substrates, equipment inspections, and periodic replacement of wells and other structures that become clogged or damaged. Operation and maintenance of the aboveground treatment plant would include periodic groundwater sample collection and analysis, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Operation and maintenance of the extraction and injection wells would include replacement of wells and other structures that become clogged or damaged.

Under this alternative the existing groundwater monitoring network would be enhanced with additional groundwater monitoring wells, and the corrective action monitoring program of routine sampling, analysis, and reporting would occur until the cleanup goals are attained, including long-term monitoring following completion of the active treatment.

Following attainment of the cleanup goals, the final remedy facilities (e.g., IRZ wells, extraction wells, injection wells, *in-situ* reagent storage and delivery systems, and aboveground treatment plant) would also be decommissioned. Groundwater monitoring wells throughout the site would be decommissioned following the determination that additional information from the wells would not be needed to evaluate attainment of the cleanup goals. After deconstruction and decommissioning of the facilities, the areas would be restored using decompaction and grading techniques designed to decrease erosion and accelerate revegetation of native species or other as directed by the land manager.

5.3.9.1 Limitations

Alternative H relies on a combination of pump-and-treat and *in-situ* technologies to remove the bulk of the Cr(VI) and minimizes some of the limitations of both technologies. The construction of IRZs along linear axes would tend to minimize the production of byproducts because a minimal area of aquifer would be treated. There would also likely be aerobic zones downgradient from the IRZ lines where reduced species such as manganese and arsenic could be re-oxidized and attenuated. Flushing would be relied upon to remove contaminants from the majority of the aquifer, and the same limitations would apply as for the other alternatives that rely on flushing. Due to the limitations of flushing as a remedial technology, there would likely be some zones of the aquifer where RAOs would not be met in a timely manner without further optimization of the remedy. The presence of the multiple IRZ lines would minimize the distances across which the contaminants had to be moved and would therefore tend to make flushing more effective. Alternative H would draw river water into the floodplain and over time could degrade the natural reducing capacity of the floodplain.

5.3.10 Alternative I – Continued Operation of Interim Measure

This alternative would involve continued operation of the IM as the final remedial action at the site. The IM system would operate with the existing equipment with existing procedures using the existing process at the existing flow rate until RAOs are attained. The estimate of the time to flush five pore volumes of water through the aquifer for this alternative is 240 years. This estimate is subject to considerable uncertainty. The estimated range of cleanup time is from 100 to 960 years. Figure 5-11 illustrates the conceptual remedial approach for Alternative I.

The Interim Measure at the Topock site includes:

- Groundwater extraction by extraction wells in the floodplain area of the site. There are currently four extraction wells (TW-2S, TW-2D, TW-3D, and PE-1), two of which are currently in operation (TW-3D and PE-1).
- Transport of extracted groundwater to an aboveground treatment plant via underground pipelines.
- Treatment of groundwater in an aboveground treatment plant. The current groundwater treatment system is a continuous, multi-step process that involves reduction of Cr(VI) to Cr(III); precipitation and removal of precipitate solids by clarification and microfiltration; and lowering the naturally occurring TDS using reverse osmosis.
- Transport of treated groundwater to an injection well field via aboveground pipelines.
- Injection of treated groundwater into the Alluvial Aquifer. There are currently two injection wells (IW-02 and IW-03), both of which are in operation.

This alternative would involve the continued operation of the IM features above, with no changes to the existing configuration of the extraction, treatment, or injection. Unlike Alternatives C through H, this alternative would not include changes to the number, location, and configuration of remedial systems over time to optimize and enhance the performance of the alternative to meet changing conditions or to enhance performance of the remedy to attain the cleanup goals. Existing contingency procedures for the extraction system, treatment system, and injection system would continue to be implemented to ensure existing performance standards for the remedial components are maintained.

Operation of the aboveground treatment plant would include periodic groundwater sample collection and analysis, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Operation and maintenance of the extraction and injection wells would also occur throughout the remediation period. Construction activities would occur from time to time over the operational period to replace wells or other structures that may become worn, clogged, or damaged. Two waste streams are generated by the aboveground treatment plant: (1) sludge from the filtration process, and (2) brine or concentrate from the reverse osmosis process. Both waste streams are removed from the treatment plant by truck and transported to offsite, permitted disposal facilities.

Under this alternative, an institutional control would be maintained during the remediation period to restrict use of groundwater in the plume area until the cleanup goals are attained, thereby eliminating the pathway for human health risk from direct exposure to groundwater. The area subject to the institutional control would include a buffer area surrounding the plume to prevent the consumption of water that potentially could migrate from the plume in other directions as a result of pumping from hypothetical future local water supply wells.

The existing monitoring systems are assumed to be sufficient to evaluate the performance of this alternative, and no additional monitoring wells would be constructed. The existing monitoring programs are assumed to be retained during the remediation period.

Following attainment of the cleanup goals, the final remedy facilities (e.g., extraction wells, injection wells, piping, and aboveground treatment plant) would also be decommissioned. Groundwater monitoring wells throughout the site would be decommissioned following the determination that additional information from the wells would not be needed to evaluate attainment of the cleanup goals. After deconstruction and decommissioning of the facilities, the areas would be restored using decompaction and grading techniques designed to decrease erosion and accelerate revegetation of native species or other as directed by the land manager.

5.3.10.1 Limitations

The IM No. 3 extraction wells are located to provide landward gradients in the floodplain but are not optimally located to remove Cr(VI) from the aquifer. Thus, operation of IM No. 3 is not an efficient way to remediate the plume. In addition, Alternative I would have all the limitations inherent in pump-and-treat technology as described in the discussion of Alternative F, namely, that pump and treat can control gradients and remove significant fractions of the contaminant mass but has been shown to be ineffective in achieving RAOs at many sites. Due to the limitations of flushing as a remedial technology, there would likely be some zones of the aquifer where RAOs would not be met in a timely manner without further optimization of the remedy.

The pumping associated with Alternative I provides a landward gradient towards the extraction wells and away from the river, but in the process, river water may be drawn into the aquifer. The river water is aerobic and would become reduced as it moved out of the river and into the fluvial aquifer. Over the long period of time that this remedy would operate, the passage of this aerobic water through the fluvial sediments could result in some degradation of the natural reducing capacity. It is not possible to accurately predict where or to what extent this degradation in reducing capacity would occur.

5.4 Detailed Analysis of Alternatives

As stated in Section 1.1, this CMS/FS is being developed in accordance with both RCRA Corrective Action and CERCLA. This section presents an overview of the evaluation criteria of RCRA Corrective Action (DTSC, 1996) and CERCLA (40 CFR Part 300.430), as considered together and applied in this CMS/FS report. It also presents a description of the evaluation criteria used to assess alternatives in the CMS/FS and applies those criteria to the alternatives presented in Section 5.3.

5.4.1 Overview of Evaluation Criteria

For a basis of comparing terminology, Table 5-4 shows the evaluation criteria of RCRA Corrective Action (DTSC, 1996) and CERCLA (40 CFR Part 300.430), as considered together and applied in this CMS/FS report. Table 5-4 presents the relevant foundation criteria of RCRA Corrective Action and CERCLA and shows how these criteria are used in the context of the CMS/FS.

The nine evaluation criteria are delineated into the following three categories:

- Threshold Criteria/Corrective Action Standards
- Balancing Criteria/Remedy Selection Decision Standards
- Modifying Criteria

The first two of the nine criteria are considered “threshold criteria” or “corrective action standards” that define the minimum level of acceptable performance for an alternative, and these must be met for an alternative to be considered eligible for selection. The next five of the nine criteria (referred to as “balancing criteria” under CERCLA or “remedy selection decision standards” under RCRA Corrective Action) are used to make comparisons among alternatives. The final two modifying criteria are used to incorporate regulatory and public concerns and comments into the consideration of alternatives. Descriptions of these three categories of criteria are presented below.

5.4.1.1 Threshold Criteria/Corrective Action Standards

This section presents the threshold criteria/corrective action standards.

Protect Human Health and the Environment, Attain Media Cleanup Goals, and Control Sources of Releases. This criterion must be met for an alternative to be eligible for selection and is used to assess whether and how the alternative achieves and maintains protection of human health and the environment. In accordance with 40 CFR Section 300.430(e)(9)(iii)(A), the evaluation of this criterion uses the assessments conducted under the other evaluation criteria, especially the remedy's long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs—and evaluates how risks are eliminated,

TABLE 5-4
Remedial Alternative Evaluation Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

RCRA Corrective Action (DTSC, 1996)	CERCLA (40 CFR Part 300.430)	Combined RCRA/CERCLA Criteria
Corrective Action Standards • Be protective of human health and the environment • Attain media cleanup standards • Control sources of releases • Comply with applicable standards for management of wastes generated by the corrective action **Remedy Selection Decision Factors** • Long-term effectiveness and reliability • Reduction of toxicity, mobility, or volume through treatment • Short-term effectiveness • Implementability • Cost	**Threshold Criteria** • Overall protection of human health and the environment • Compliance with ARARs **Balancing Criteria** • Long-term effectiveness and permanence • Reduction of toxicity, mobility, or volume through treatment • Short-term effectiveness • Implementability • Cost **Modifying Criteria** • State acceptance • Community acceptance	**Threshold Criteria/Corrective Action Standards** • Protect human health and the environment, attain media cleanup goals, and control sources of releases • Comply with ARARs, including applicable standards for management of wastes generated by the remedial action **Balancing Criteria/Remedy Selection Decision Factors** • Long-term effectiveness, permanence, and reliability • Reduction of toxicity, mobility, or volume through treatment • Short-term effectiveness • Implementability • Cost **Modifying Criteria** • State acceptance • Community acceptance

reduced, or controlled through treatment or engineering or administrative controls. Overall protection to human health and the environment considers both reduction in baseline risks (risks associated with not implementing the remedial alternative), as well as protection of human health and the environment from affects caused by implementing the remedial alternative. This criterion is summarized by addressing:

- Protect human health and the environment.
- Attain media cleanup goals.
- Control sources of releases.

Comply with ARARs. This criterion evaluates whether each alternative would attain federal and state ARARs or whether there is a basis for invoking one of the statutory ARAR waivers with respect to an alternative. The ARARs for the Topock site are identified in Appendix B. ARARs include:

- Chemical-specific ARARS.
- Location-specific ARARs.
- Action-specific ARARs, including standards for management of wastes generated by the remedial action.

5.4.1.2 Balancing Criteria/Remedy Selection Decision Standards

This section presents the balancing criteria/remedy selection decision standards.

Long-term Effectiveness, Permanence, and Reliability. Long-term effectiveness refers to the period after the remedial action is complete. This criterion evaluates: (1) the risk remaining (residual) at the site after RAOs have been achieved from treatment residuals or untreated waste and (2) the extent and effectiveness of controls for managing the risk posed by treatment residuals or untreated wastes. The residual risk from treatment residuals or untreated waste can be measured by chemical concentrations or volume of the material remaining at the site after the remedial action is complete. This criterion also assesses the degree of certainty that the alternative will prove successful and is summarized by addressing the:

- Magnitude of residual risk remaining from untreated waste or treatment residuals at the conclusion of the remedial activities.
- Adequacy and reliability of controls such as containment systems and institutional controls that are necessary to manage the untreated waste or to manage treatment residuals that remain at the site.

Reduction of Toxicity, Mobility, or Volume through Treatment. This criterion considers the degree to which alternatives employ treatment technologies—as well as the anticipated performance of the treatment technologies—by evaluating the amount of hazardous material treated and the amount remaining onsite. The evaluation considers the magnitude of the reductions in toxicity, mobility, or volume of chemicals and the extent to which the treatment is irreversible. This criterion is summarized by addressing the:

- Amount of plume destroyed or treated.
- Degree of expected reduction in toxicity, mobility, and volume.
- Degree treatment is irreversible.
- Type and quantity of residual remaining after treatment.

Short-term Effectiveness. This criterion evaluates the effects of the alternative during the construction and implementation period of the remedial alternative before and until the time the RAOs are achieved. It assesses the short-term implementation effects that could occur to the community, to workers, and to the environment during the remedial action. Protection of the community entails evaluation of effects such as dust, visual considerations, or transportation. Protection of workers during implementation addresses the reliability of protective measures during implementation. Protection of the environment considers potential affects on sensitive resources, including disturbance to cultural resources and wildlife. Additionally, this criterion evaluates the short-term and cross-media impacts that could occur during implementation of the remedy. General consideration of sustainability would also be included in this criterion. This criterion addresses the:

- Time until remedial action objectives are achieved.
- Protection of the community during remedial action.
- Protection of the workers during remedial action.
- Protection of the environment during remedial action.

Implementability. The technical and administrative feasibility of alternatives and the availability of various services and materials is evaluated to assess the remedy's implementability. The ability to construct, operate, and maintain the technology given the site-specific conditions and the ability to monitor effectiveness of the remedy are the factors that comprise the technical implementability criterion. Administrative feasibility is defined as the ability to obtain approvals, rights of way, and permits (for offsite actions) and other administrative activities from other agencies. The availability of services and materials considers offsite treatment, storage capacity, disposal capacity, and services; necessary equipment and specialists; and other services and materials needed to implement the alternative. This criterion is summarized by addressing the:

- Technical feasibility.
- Administrative feasibility.
- Availability of services and materials.

Cost. This criterion includes an evaluation of the direct and indirect capital costs required to implement the alternative, as well as the annual operation and maintenance costs. The costs of each alternative are estimated to a level of accuracy of +50 to -30 percent, consistent with the preliminary nature of the design development (approximately 2 to 5 percent design development). This criterion is summarized by estimating the net present value of the alternative, as shown in Appendix D. Present-value analysis is a method to evaluate expenditures, either capital or operation and maintenance, that occur over different time periods. This standard methodology allows for cost comparisons of different remedial alternatives on the basis of a single cost figure for each alternative. Both the CACA (DTSC, 1996) and the NCP (40 CFR 300.430) require estimation of the net present value of capital and operation and maintenance costs for remedial alternatives. For long-term projects (e.g., project duration exceeding 30 years), USEPA guidance recommends that the present-value analysis also include a "no discounting" scenario (USEPA, 2000).

5.4.1.3 Modifying Criteria

This section presents the modifying criteria.

State Acceptance. This criterion is broadly defined as addressing the technical concerns of state agencies. Assessment of state concerns may not be completed until after comments on the CMS/FS are received and evaluated. State concerns can then be fully discussed in the Proposed Plan for public comment. The state concerns that shall be assessed include:

- The state's position and key concerns related to the preferred alternative and other alternatives.

- State comments on ARARs or the proposed use of waivers.

Community Acceptance. Community acceptance evaluates the public's concerns about each alternative. This assessment includes determining which components of the alternatives interested persons in the community support, have reservations about, or oppose. This assessment may not be completed until comments on the Proposed Plan are received. Community acceptance can then be fully assessed in the Proposed Plan and Record of Decision and/or the RCRA Responsive Summary and Statement of Basis.

5.4.1.4 Tribal Consultation

Federal agency consultation, by and through the BLM in cooperation with FWS, Reclamation, and DOI, has been ongoing throughout the development of this CMS/FS to date. According to DOI, the investigation of groundwater contamination from the Topock Compressor Station has generated significant interest and involvement by several federally recognized tribes that have ties to the area. In particular, several tribes reviewed and provided comments on the Draft CMS/FS through the Consultative Workgroup process and through federal consultation with the federal agencies. The BLM, on behalf of the federal agencies involved, initiated government-to-government consultation, as well as consultation under the National Historic Preservation Act, with nine tribes seeking written comments on the Draft CMS/FS Report, dated January 2009. Federal consultation meetings were conducted with four of these tribes seeking additional tribal input on the alternatives evaluated by the CMS/FS.

Several tribes commented that the Draft CMS/FS Report did not fully evaluate whether and, if so, how each alternative would comply with many of the action and location-specific ARARs pertaining to the identification and mitigation of effects on cultural resources. This concern has been addressed in the Final CMS/FS Report and will continue to be addressed as a preferred alternative is proposed and a selected alternative is designed and implemented.

Some tribes expressed concern that their views regarding the significance of the cultural resources that potentially may be affected by remedial action had not been adequately articulated in the Draft CMS/FS Report. These tribes expressed strong beliefs that remedy selection decisions must fully consider the significance of the cultural resources at the site and the importance of mitigating effects on those resources that may be caused by the groundwater remedy. Tribal views regarding the significance of the cultural resources at issue and the importance of mitigating adverse effects on those resources have been and will continue to be solicited and incorporated into the decision-making process through the CEQA EIR process and through past and future consultation with the federal agencies.

Some tribes felt it was imperative that any remedy selected involve as little impact as possible to the site, including minimizing the number of wells installed and other ground-disturbing activities. In their view, the time required to attain cleanup standards was far less important than minimizing impacts to the site. Accordingly, these tribes expressed a preference for Alternatives A or B. These tribes rejected as too intrusive each of the other alternatives, with the possible exception of Alternative E. One tribe also expressed its strong belief that the existing groundwater treatment facility, built for IM No. 3, should not be included in any final remedy and should be removed as soon as possible.

Other tribes felt strongly about the need to address quickly the potential risks to human health and the environment and protect water quality in the Colorado River and Lake Havasu. These tribes expressed concern about the length of time that could be required to achieve cleanup objectives if Alternatives A or B were selected. These tribes were concerned that existing conditions could change over time, thereby raising questions about the long-term effectiveness of Alternatives A and B. These tribes supported the more active alternatives, notwithstanding the additional surface impacts that would result. These tribes expressed a strong preference for the final remedy to include *ex-situ* treatment to accelerate the time frame of achieving cleanup goals and so that Cr(VI) would be physically removed from the environment rather than converted to Cr(III).

Tribal consultation will continue going forward as a preferred alternative is identified in the Proposed Plan by the federal agencies, and the plan is issued for review and comment by the tribes and members of the public. Once a remedy is selected, federal consultation is expected to continue within the framework of a Programmatic Agreement executed pursuant to the National Historic Preservation Act to ensure that tribal input fully informs decisions pertaining to the design and implementation of the remedial action.

5.4.2 Alternative Analysis

The alternative analysis consists of two steps. The first step is the individual detailed analysis of each alternative against seven of the nine evaluation criteria (Section 5.4.1). This analysis is discussed in detail in Table 5-5.[10] The table identifies how key components of each remedy address the specific criteria. The second step is the comparative analysis of alternatives relative to each other. This analysis is presented in text of Section 5.5.

As discussed in Section 2.1.3, groundwater within the Cr(VI) plume area is not used for potable or other uses; therefore, no complete exposure pathway currently exists. In addition, available data show that the Cr(VI) is not affecting the beneficial uses of the Colorado River (CH2M HILL, 2009a). A number of California requirements, identified as ARARs, require that the ground and surface water on the site shall have the beneficial use designation of "suitable, or potentially suitable, for municipal or domestic water supply." Therefore, even if it is unlikely that groundwater would be developed as a drinking water source in the future, this alternatives analysis applies a conservative cleanup criterion of background level of Cr(T) and Cr(VI) in groundwater. Therefore, the following analysis uses this conservative background level as the cleanup goal for Cr(VI) to increase the level of certainty that no exposure to Cr(VI) in the groundwater will occur in the future.

5.5 Comparative Analysis of Alternatives

In this section, the results of the individual detailed analysis, shown in Table 5-5, are combined to identify the advantages and disadvantages of each alternative relative to one another. As discussed in Section 5.4, seven of the nine criteria are applied to this initial assessment; the last two modifying criteria of state acceptance and community acceptance will continue to be assessed through the public comment period and preparation of the

[10] Only the threshold and balancing criteria are presented in the alternatives analysis in the CMS/FS. The modifying criteria of state and community acceptance will continue to be evaluated following receipt of agency and stakeholder comments on the Proposed Plan.

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
Alternative A – No Action	**Protect Human Health and the Environment.** This alternative would not provide additional protection of human health or the environment at the site, and therefore does not meet this threshold criterion No active remediation would occur under this alternative, and no institutional controls would exist to prohibit groundwater use for potable water supply in the short term. The existing plume would be left on surrounding landowner property without ongoing oversight. This alternative would not include monitoring to verify effectiveness of natural recovery process in fluvial sediments near the river over time, or to assess the effectiveness of natural recovery processes in the East Ravine bedrock. Because there would be no remedial facilities, there would be no disruption to sensitive resources during implementation of the action. **Attain Media Cleanup Goals.** The estimated time to attain RAOs for this alternative is between 220 and 2,200 years, as this alternative relies on natural groundwater flow towards and through the reducing materials near the Colorado River. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup. **Control Sources of Releases.** The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have been eliminated. Therefore, sources of wastewater discharge and hexavalent chromium have been controlled. However, the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	**Chemical-specific ARARs.** Chemical-specific requirements would not be met. Because concentrations of chromium in groundwater would remain above MCLs for approximately 1,000 years without an institutional control preventing development as a drinking water supply, this alternative will not comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater used as a public water supply during this time. It would also not comply with water quality objectives for groundwater established in the Water Quality Control Plan for the Colorado River Basin, which are based on MCLs. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally occurring reducing conditions in sediments near the Colorado River and/or dilution provided by the river are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river. However, over the centuries required for this alternative to achieve cleanup goals, these conditions may change, potentially resulting in a change in compliance status. In addition, further studies will be conducted during remedial design to assess the effectiveness of long-term natural attenuation in the East Ravine to attain water quality criteria. **Location-specific ARARs.** Location-specific requirements would not be triggered because no action is being taken. **Action-specific ARARs, including standards for management of wastes generated by the remedial action.** Action-specific requirements would not be met. This alternative does not comply with California State Water Board Resolution 92-49. Requirement to implement land-use covenant at property not suitable for unrestricted use will not be met (22 CCR 67391.1). Because no action is being taken, other action-specific requirements are not triggered.	**Magnitude of Residual Risk.** Alternative A would rely on natural attenuation processes to attain the cleanup goals. Without monitoring or further investigation activity; however, there would be no way to assess when the RAOs have been achieved or determine the magnitude of risk from residual contamination. Future changes in geochemistry or hydrogeologic characteristics would not be identified. Future exposure to contamination and impacts to the Colorado River or other receptors would not be detected. **Adequacy and Reliability of Controls.** Five year reviews would not be conducted. No long-term containment systems are required and no land disposal of treatment residuals is expected.	**Amount of Plume Destroyed or Treated.** As described in the RFI/RI Volume 2 Report (CH2M HILL, 2009a) and the *Phase II Anaerobic Core Testing Summary Report, PG&E Topock Compressor Station, Needles, California* (CH2M HILL, 2008e), site characterization data and laboratory testing support that there is significant reduction capacity in the anaerobic alluvial aquifer materials to reduce and remove Cr(VI) from groundwater. The results suggest that there is sufficient capacity within the floodplain and beneath the river to reduce at least a significant portion of the Cr(VI) plume were the plume to come in contact with these sediments. However, the extent and average capacity of this area to reduce Cr(VI) will remain an estimate, as it is not possible to quantify these properties at all locations. In addition, further studies to assess the effectiveness of long-term natural attenuation in the East Ravine will continue during remedial design. **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** This alternative relies on the natural recovery processes near the Colorado river to biochemically convert Cr(VI) to Cr(T), reducing the toxicity and mobility of the site contaminants. Cr(III) is a less toxic and essentially immobile form of chromium. **Degree Treatment is Irreversible.** Once reduced to Cr(III), chromium takes the form of the Cr^{3+} ion and forms very low solubility oxides under the neutral and alkaline pH encountered in site groundwater. Solubility of chromium oxide Cr_2O_3 and chromium hydroxide, $Cr(OH)_3$, are low enough to maintain the Cr^{3+} concentration below the detection limit of 0.2 µg/L (Brookins, 1988; Schecher and McAvoy, 1998). Once reduced, Cr(III) does not readily become reoxidized to Cr(VI); however, Cr(III) that comes into contact with manganese oxide (MnO_2) or dissolved oxygen can be re-oxidized to Cr(VI), leading to increased concentrations of Cr(VI) over time. Two key factors are expected to limit the re-conversion of Cr(III) to Cr(VI) after *in-situ* reduction: the limited solubility of Cr(III) and the lack of availability and reactivity of an adequate oxidizer (MnO_2). Together these factors are expected to limit any reoxidized Cr(VI) concentrations to levels similar to ambient background levels. **Type and Quantity of Residual Remaining After Treatment.** The most significant residual byproducts will be manganese and arsenic, natural constituents of the aquifer matrix released into solution by reduction reactions. Because of the uncertainties associated with the aquifer complexities, there is the potential for elevated byproduct concentrations persisting in some portions of the aquifer. Once released, the reduced forms of manganese and arsenic will likely be attenuated through precipitation, sorption, diffusion, and co-precipitation.	**Protection of the Community During Remedial Action.** There would be no institutional control to prohibit use of groundwater prior to achieving the cleanup goals. While the groundwater is not currently used as a potable water source, the lack of institutional controls results in Alternative A ranked as not effective for controlling exposure in the short term. There would be no short-term disturbance to the community from construction, as no active construction or operational activities would occur under this alternative. **Protection of Workers During Remedial Action.** There would be no short-term disturbance to workers from construction, as no active construction or operational activities would occur under this alternative. **Protection of the Environment During Remedial Action.** There would be no short-term disturbance to the environment from construction, as no active construction or operational activities would occur under this alternative. **Time Until RAOs are Achieved.** It is estimated that between 220 and 2,200 years would be required to achieve the RAOs within the alluvial aquifer for this alternative. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.	**Technical Feasibility.** No active construction or operational activities would occur under this alternative. **Administrative Feasibility.** Administratively this alternative would not likely be acceptable with other agencies and surrounding landowners and would require a high level of coordination to gain approval. **Availability of Services and Materials.** No active construction or operational activities would occur under this alternative.	$0

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
Alternative B – Monitored Natural Attenuation (MNA)	**Protect Human Health and the Environment.** Under Alternative B, treatment of chromium would occur within the natural reducing conditions of the fluvial sediments near the Colorado River to convert Cr(VI) to Cr(T). Existing surface water data show that Cr(VI) concentrations in the Colorado River are below water quality standards (CH2M HILL, 2009A). However, ongoing monitoring would be needed to assure continued protection of the river over the long duration of this remedy. Because of the slow movement of groundwater at the site, many centuries would pass before the Cr(VI) concentrations everywhere in the plume reached cleanup goals. During this long period of time, changes in groundwater flow directions or geochemical conditions in the reducing zone around the river could occur, which leads to uncertainty in the long-term protectiveness of this alternative. In addition, further studies o assess the effectiveness of long-term natural attenuation in the East Ravine will continue during remedial design. Alternative B protects human health by administration of an institutional control limiting exposure through restriction of groundwater use for potable supply until cleanup goals are met. There would be minimal remedial facilities (construction and sampling of monitoring wells) and therefore minimal disruption to sensitive resources during implementation of the action. Steps would be taken during construction and operation to limit disturbance to sensitive resources. Steps to limit disturbance to sensitive resources may include moving locations of infrastructure away from sensitive resources, modification of construction techniques (e.g., equipment or schedules), and modification of design elements (e.g., materials, configurations, sizes). Steps may also include programmatic elements such as awareness training for site personnel. **Attain Media Cleanup Goals.** The time to achieve RAOs for this alternative is estimated to be between 220 and 2,200 years because the alternative relies on natural groundwater flow towards and through the reducing soils near the Colorado The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less	**Chemical-specific ARARs.** Chemical-specific requirements will be met. Concentrations of chromium in groundwater would remain above MCLs for a period estimated to range from 220 to 2,200 years; however, during this period, an institutional control would prevent development as a drinking water supply; therefore, this alternative is considered to comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater delivered by a public water supply system. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally occurring reducing conditions in sediments near the Colorado River and dilution provided by the river are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river. However, over the centuries required for this alternative to achieve cleanup goals, these conditions may change, potentially resulting in a change in compliance status. In addition, further studies will be conducted during remedial design to assess the effectiveness of long-term natural attenuation in the East Ravine bedrock to attain water quality criteria. **Location-specific ARARs.** Location-specific requirements will be met. Because surface water bodies are not being modified, USFWS coordination requirements (40 CFR 6.201) will not be triggered. Because RCRA-regulated treatment systems will not be constructed in a floodplain or seismic zone, RCRA seismic and floodplain requirements (40 CFR 264.18) will not be triggered. Construction of wells in floodplain or wetland areas will be performed in a manner that complies with federal floodplain and wetlands protection requirements (40 CFR 6.201). Steps will be taken during design and implementation to ensure compatibility with the National Wildlife Refuge System Administration Act. The requirements of the National Historic Preservation Act (16 U.S.C. § 470, *et seq.*) are applicable based on the presence of and potential impact to historic properties listed on, or eligible for listing on, the National Register of Historic Places. Other cultural resource requirements include those of the National Archaeological and Historic Preservation Act (16 U.S.C. § 469, *et seq.*), the Native American Graves Protection and Repatriation Act (25 U.S.C. § 3001, *et seq.*), and the Archaeological Resources Protection Act (16 U.S.C. § 470aa-ii, *et seq.*). The requirements of the Historic Sites Act (16 U.S.C. § 461 *et seq.*), may apply to Route 66. In addition, there may be applicable requirements of Pub. L. 106-45 to preserve Route 66. Location and action-specific religious freedom requirements are set forth in the American Indian Religious Freedom Act and Religious Freedom Restoration Act. As a threshold matter, this alternative cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues	**Magnitude of Residual Risk.** Similar to Alternative A, this alternative would rely on natural attenuation processes to attain the cleanup goals. Risk from residual contamination would be reduced as Cr(VI) mass within the plume is treated. **Adequacy and Reliability of Controls.** No controls would be included in this alternative following attainment of the RAOs. The reducing conditions in the shallow floodplain and beneath the river have been shown to be present at every location investigated and are expected to effectively treat the Cr(VI). However, the extent and average capacity of this area to reduce Cr(VI) will remain an estimate, as it is not possible to quantify these properties at all locations. In addition, further studies to assess the effectiveness of long-term natural attenuation in the East Ravine will continue during remedial design. Five-year reviews would be required for this alternative. No long-term containment systems are required and no land disposal of treatment residuals is expected.	**Amount of Plume Destroyed or Treated.** As described for Alternative A, site characterization data and laboratory testing support that there is significant reduction capacity in the anaerobic alluvial aquifer materials to reduce and remove Cr(VI) from groundwater. The results suggest that there is sufficient capacity within the floodplain and beneath the river to reduce at least a significant portion of the Cr(VI) plume were the plume to come in contact with these sediments. However, the extent and average capacity of this area to reduce Cr(VI) will remain an estimate, as it is not possible to quantify these properties at all locations. In addition, further studies to assess the effectiveness of long-term natural attenuation in the East Ravine will continue during remedial design. In contrast to Alternative A, this alternative would include monitoring to verify the effectiveness of the reducing zone over time. **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** This alternative relies on the natural recovery processes near the Colorado river to biochemically convert Cr(VI) to Cr(T) in the groundwater plume to insoluble Cr(III) that precipitates out of solution and remains in the formation, reducing the toxicity and mobility of the site contaminants. Cr(III) is a less toxic and essentially immobile form of chromium **Degree Treatment is Irreversible.** Once reduced to Cr(III), chromium takes the form of the Cr^{3+} ion and forms very low solubility oxides under the neutral and alkaline pH encountered in site groundwater. Solubility of chromium oxide Cr_2O_3 and chromium hydroxide, $Cr(OH)_3$, are low enough to maintain the Cr^{3+} concentration below the detection limit of 0.2 µg/L (Brookins, 1988; Schecher and McAvoy, 1998). Once reduced, Cr(III) does not readily become reoxidized to Cr(VI); however, Cr(III) that comes into contact with manganese oxide (MnO_2) or dissolved oxygen can be re-oxidized to Cr(VI), leading to increased concentrations of Cr(VI) over time. Two key factors are expected to limit the re-conversion of Cr(III) to Cr(VI) after *in-situ* reduction: the limited solubility of Cr(III) and the lack of availability and reactivity of an adequate oxidizer (MnO_2). Together these factors are expected to limit any reoxidized Cr(VI) concentrations to levels similar to ambient background levels. **Type and Quantity of Residual Remaining After Treatment.** The most significant residual byproducts will be manganese and arsenic, natural constituents of the aquifer matrix released into solution by reduction reactions. Because of the uncertainties associated with the aquifer complexities, there is the potential for elevated byproduct concentrations persisting in some portions of the aquifer. Once released, the reduced forms of manganese and arsenic will likely be attenuated through precipitation, sorption, diffusion, and co-precipitation.	**Protection of the Community During Remedial Action.** During this period, institutional controls would be in effect to prohibit the future use of the groundwater for drinking water. Monitoring would be ongoing to verify the effectiveness of the reducing conditions in the fluvial sediments to provide a natural geochemical barrier to the Colorado River. The community would face limited disturbance from construction noise, physical hazards such as traffic, material transport from installation, and sampling of monitoring wells. Risks can be reduced through proper controls during construction and monitoring. **Protection of Workers During Remedial Action.** Workers would face general site hazards including heavy equipment, occupational noise exposure, slip and fall, etc. during well installation and sampling. General site hazards would be reduced by site-specific health and safety plans and safety equipment. Workers would be required to wear appropriate personal protective equipment and use best management practices to minimize exposure. **Protection of the Environment During Remedial Action.** Potential disturbance to the environmental impacts would be limited to well construction and ongoing monitoring. Measures will be taken during well construction and sampling to minimize environmental disturbance. Additional protections to the environment and community will be through compliance with ARARs such as for floodplain and wetland protection requirements. Preliminary design estimates suggest that 28 additional monitoring well locations would be required for this alternative. **Time Until RAOs are Achieved.** It is estimated that between 220 and 2,200 years would be required to achieve the RAOs for this alternative. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to	**Technical Feasibility.** MNA is technically implementable. Primary technology is installation, maintenance, and sampling of monitoring wells, which have been shown to be technically implementable at this site. Monitoring wells have been shown to be effective at monitoring the geochemical conditions in the floodplain during the RFI/RI and IM. **Administrative Feasibility.** MNA is administratively implementable. No offsite actions would be associated with MNA that would require permits from other agencies. The existing monitoring network is located off of PG&E property, so installation of any new monitoring facilities to supplement or replace existing monitoring facilities would have to be coordinated with and approved by the respective landowners. There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. This alternative would include administration of an institutional control to prohibit use of groundwater within the plume until attainment of cleanup goals; the institutional control would need to be coordinated with the various landowners that overlie the plume. **Availability of Services and Materials.** Services, equipment, and materials for installation of additional groundwater monitoring wells are readily available. Some specialized equipment may be needed for construction of wells on the floodplain or construction of additional slant wells; however, these services can be made available. Disposal facilities for drill cuttings or development water generated from the well installation are widely available.	$25,000,000 - $54,000,000

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
	than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup. **Control Sources of Releases.** The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have been eliminated; therefore, sources of wastewater discharge and hexavalent chromium have been controlled. However, the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	through the issuance of a Proposed Plan and the Record of Decision and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation Officers, and others to identify potential effects on cultural resources and evaluate and implement reasonable and prudent mitigation measures, thereby ensuring that the selected remedy attains these ARARs. **Action-specific ARARs, including standards for management of wastes generated by the remedial action.** Most but not all action-specific requirements will be met. There will be no discharge of fill to wetlands or waterways (40 CFR 230.10), point source discharge of pollutants to waters of the United States (40 CFR Parts 122, 125), or other activities that alter the course, condition, or capacity of navigable waters (33 U.S.C. § 401 and 403). Remedial activities will comply with applicable National Pollutant Discharge Elimination System [NPDES] construction stormwater requirements (40 CFR 122.26). Remedial activities will not emit regulated hazardous air pollutants (40 CFR Parts 61, 63). Installation of monitoring wells will be performed in a manner that does not result in a "take" of threatened or endangered species, damage their critical habitat (50 CFR part 402), or impact migratory birds (15 USC § 703-712). Waste generated during remedial activities will be handled in compliance with hazardous waste generator requirements (22 CCR Division 4.5, Chapters 11, 12, 18). Regulated waste piles, tank systems, landfills, and miscellaneous units will not be constructed. Monitoring will be performed in accordance with RCRA (22 CCR Division 4.5, Ch. 14, Article 6) and California Water Code (23 CCR Div. 3, Chapter 15; 27 CCR Div. 2, Subdivision 1; Calif. Water Code Section 13801(c)) monitoring requirements. Because RAOs will achieve background levels for chromium, this alternative is consistent with the substantive provisions of State Water Resources Control Board (SWRCB) Resolution 68-16 that requires maintenance of the highest water quality consistent with maximum benefit to the people of the State. It will also result in achieving Basin Plan water quality objectives for chromium in groundwater. This alternative will not comply with California State Water Board Resolution 92-49. Appropriate land use covenants will be implemented (22 CCR 67391.1).			cleanup.		

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
Alternative C - High-volume *In-situ* Treatment	**Protect Human Health and the Environment.** Alternative C would protect human health and the environment in the long term through reduction of Cr(VI) concentrations in groundwater by *in-situ* treatment. Monitoring would provide data to evaluate the effectiveness of *in-situ* treatment. This alternative protects human health in the short term by limiting exposure through restriction of groundwater use as a potable water source until cleanup goals are met. Alternative C includes floodplain cleanup (mass removal and establishment of geochemical barrier) as the initial step in implementation, thereby providing additional protection to the river. Alternative C also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. This alternative involves construction and operation of active treatment facilities, including wells, pipelines, and tanks. Steps would be taken during construction and operation of the remedial facilities to limit disturbance to sensitive resources. Steps to limit disturbance to sensitive resources may include moving locations of infrastructure away from sensitive resources, modification of construction techniques (e.g., equipment or schedules), modification of design elements (e.g., materials, configurations, sizes). Steps may also include programmatic elements such as awareness training for site personnel. **Attain Media Cleanup Goals.** Alternative C includes *in-situ* treatment to attain cleanup goals for constituents in groundwater. The treated water would meet the chemical specific ARARs. **Control Sources of Releases.** The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have been eliminated. Therefore, sources of wastewater discharge and hexavalent chromium have been controlled. However, the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined, and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	**Chemical-specific ARARs.** Chemical-specific requirements will be met. By achieving cleanup goals less than MCLs, the remedy will comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater delivered by a public water supply system. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally occurring reducing conditions in sediments near the Colorado River and dilution provided by the river are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river prior to remedy completion. By achieving cleanup goals in groundwater, the remedy will provide additional certainty that contaminated groundwater will not cause exceedances of Federal water quality criteria established under the Federal Water Pollution Control Act (40 CFR 131.38) for Cr(VI) in the Colorado River in the long term. **Location-specific ARARs.** Location-specific requirements will be met. Because surface water bodies are not being modified, USFWS coordination requirements (40 CFR 6.201) will not be triggered. Because RCRA-regulated treatment systems will not be constructed in a floodplain or seismic zone, RCRA seismic and floodplain requirements (40 CFR 264.18) will not be triggered. Construction of wells and piping in floodplain or wetland areas will be performed in a manner that complies with federal floodplain and wetlands protection requirements (40 CFR 6.201). Steps will be taken during design and implementation to ensure compatibility with the National Wildlife Refuge System Administration Act. The requirements of the National Historic Preservation Act, 16 U.S.C. § 470, *et seq*., are applicable based on the presence of and potential impact to historic properties listed on, or eligible for listing on, the National Register of Historic Places. Other cultural resource requirements include those of the National Archaeological and Historic Preservation Act, 16 U.S.C. § 469, *et seq*., the Native American Graves Protection and Repatriation Act, 25 U.S.C. § 3001, *et seq.*, and the Archaeological Resources Protection Act, 16 U.S.C. § 470aa-ii, *et seq*. The requirements of the Historic Sites Act, 16 U.S.C. § 461 *et seq*., may apply to Route 66. In addition, there may be applicable requirements of Pub. L. 106-45 to preserve Route 66. Location and action-specific religious freedom requirements are set forth in the American Indian Religious Freedom Act and Religious Freedom Restoration Act. As a threshold matter, this alternative cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation	**Magnitude of Residual Risk.** Alternative C includes active *in-situ* treatment to attain cleanup goals for Cr(VI) in groundwater. Alternative C includes a group of bedrock extraction wells in the eastern (downgradient) end of the East Ravine, with the water from the bedrock extraction wells managed within the active treatment system for the alluvial aquifer. Risk from residual contamination would be reduced as Cr(VI) mass within the plume is treated. **Adequacy and Reliability of Controls.** *In-situ* technology has not often been applied to treat an entire plume of this size and depth. There is uncertainty associated with achieving complete distribution of carbon source substrate across this large of an area. Incomplete distribution can be overcome by achieving sufficient coverage to allow natural groundwater flow to transport any residual untreated chromium (that is not treated directly) to an adjacent treatment zone. Incomplete coverage also can be addressed through optimization of the remedy during implementation, which would involve additional dosing in areas where complete coverage was not achieved during the initial dose. Alternative C also requires the balanced operation of extraction wells and injection wells to meet the goal of reductant delivery across the entire plume while at the same time maintaining hydraulic containment of the plume. If an injection well is operated at too high a rate, it is possible that the pumping rate at a downgradient extraction well will be too low to maintain hydraulic containment. Flow adjustments in individual wells are possible but because the total rate of injection must equal the total rate of extraction, increases in pumping rates at one well will mean that pumping rates at other wells need to be reduced. Actual operation of a wellfield, as envisioned in Alternative C, will require a complex and continuous interplay between pumping rates, injection rates, water levels observed in monitoring wells and the stage in the Colorado River. Alternative C includes pumping within the East Ravine bedrock to ensure hydraulic control of East Ravine groundwater. Once the remedy is completed, monitoring inside and outside the plume and continued enforcement of institutional controls may be required to assess treatment byproducts. Five-year reviews would be required for this alternative.	**Amount of Plume Destroyed or Treated.** The intent of this alternative is to address the entire area of groundwater where Cr(VI) concentrations are higher than 32 µg/L. Alternative C also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. If it is determined that additional remedial effort is needed to reach RAOs in East Ravine bedrock, other technologies could be applied to supplement the pumping wells. In addition to pumping for hydraulic control, technologies that may be applicable to East Ravine bedrock would include, but are not limited to, freshwater injection for flushing and injection of carbon amendments for *in-situ* reduction of Cr(VI). The mass of Cr(VI) in East Ravine bedrock is estimated to be less than one percent of the total Cr(VI) plume mass. **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** Alternative C includes *in-situ* treatment by distributing an organic carbon substrate throughout the plume to create geochemically-reduced conditions to convert Cr(VI) in groundwater to insoluble Cr(III), thereby reducing the toxicity and mobility of the site contaminants. Alternative C also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. **Degree Treatment is Irreversible.** The degree of reversibility of the Cr(VI) reduction reaction is expected to ultimately result in Cr(VI) concentrations at levels similar to ambient Cr(VI). **Type and Quantity of Residual Remaining After Treatment.** The most significant residual byproducts will be manganese and arsenic, natural constituents of the aquifer matrix released into solution by reduction reactions. Because of the uncertainties associated with the aquifer complexities, there is the potential for elevated byproduct concentrations persisting in some portions of the aquifer. Once released, the reduced forms of manganese and arsenic will likely be attenuated through precipitation, sorption, diffusion, and co-precipitation. Residual byproducts will be managed through careful system monitoring and operations both inside and outside the plume.	**Protection of the Community During Remedial Action.** The community would be protected during this period by prohibiting the use of the groundwater for drinking water through institutional controls. Treatment byproducts could be temporarily elevated within portions of the treatment zone (Appendix E) but are expected to reduce with time. Monitoring would be ongoing to verify the effectiveness of the reducing conditions in the fluvial sediments in providing a natural geochemical barrier to the Colorado River and to monitor for *in-situ* treatment byproducts. The community would face limited disturbance from construction noise, physical hazards such as traffic, material transport from construction, and operational activities. Risks can be reduced through proper controls during construction and operation. **Protection of Workers During Remedial Action.** Workers would face general site hazards including heavy equipment, occupational noise exposure, slip and fall, etc. General site hazards would be reduced by site-specific health and safety plans and safety equipment. Workers would be required to wear appropriate personal protective equipment and use best management practices to minimize exposure. **Protection of the Environment During Remedial Action.** Potential environmental impacts would be related to disturbance to the environment as a result of construction and operation. Preliminary design estimates suggest that this alternative would result in installation of approximately 111 remediation well locations, and , 32 monitoring well locations, piping, reagent storage and delivery systems, power, and instrumentation. Operation and maintenance activities would include periodic well maintenance, sample collection, refinement of the injection/recirculation systems, management of the reactant material, equipment inspections, and periodic replacement of wells and other structures that become clogged or damaged. Measures will be taken during construction, sampling, and operational activities to minimize environmental disturbance. This alternative includes infrastructure on the floodplain between National Trails Highway and the Colorado River.	**Technical Feasibility.** Alternative C is technically implementable. Installation of extraction wells, injections wells, pipelines, utilities, reagent storage and delivery systems, and process controls/instrumentation is technically implementable. Some wells may be challenging to install due to hydrogeologic conditions and excessive depths. Varied and abrupt topography and access limitations will present challenges to construction of wells, pipelines, and utilities, but the challenges can be overcome. This alternative includes installation of injection wells within Bat Cave Wash that will present challenges associated with maintaining protection against future damage or washout. Pilot testing has shown that *in-situ* treatment is technically implementable at this site. However, some uncertainty exists about the application of *in-situ* technology at this scale. Alternative C also requires the balanced operation of extraction wells and injection wells to meet the goal of reductant delivery across the entire plume while at the same time maintaining hydraulic containment of the plume. If an injection well is operated at too high a rate, it is possible that the pumping rate at a downgradient extraction well will be too low to maintain hydraulic containment. Flow adjustments in individual wells are possible but because the total rate of injection must equal the total rate of extraction, increases in pumping rates at one well will mean that pumping rates at other wells need to be reduced. Actual operation of a wellfield as envisioned in Alternative C will require a complex and continuous interplay between pumping rates, injection rates, water levels observed in monitoring wells and the stage in the Colorado River. Operation of the *in-situ* treatment system will require a high level of oversight during implementation to ensure that the system is optimized and modified as remediation progresses. **Administrative Feasibility.** Alternative C is administratively implementable. No offsite actions would be associated with Alternative C that would require permits from other agencies. Coordination and approval by respective landowners and leaseholders, including Burlington Northern-Santa Fe (BNSF), Caltrans, and other entities, would be required because installation of the extraction wells, injections wells, pipelines, utilities, reagent storage and delivery systems, and process controls/instrumentation would be	$119,000,000 - $255,000,000

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
		Officers, and others to identify potential effects on cultural resources and evaluate and implement reasonable and prudent mitigation measures, thereby ensuring that the selected remedy attains these ARARs. **<u>Action-specific ARARs, including standards for management of wastes generated by the remedial action.</u>** This alternative can be designed and implemented to attain action-specific requirements. Injection of reductant material and recirculation of groundwater will be performed in a manner that meets Federal Underground Injection Control requirements (40 CFR Parts 144-148). There will be no discharge of fill to wetlands or waterways (40 CFR 230.10), point source discharge of pollutants to waters of the United States (40 CFR Parts § 122, 125), or other activities that alter the course, condition, or capacity of navigable waters (33 USC 401 and 403). Remedial activities will comply with applicable NPDES construction stormwater requirements (40 CFR 122.26). Remedial activities will not emit regulated hazardous air pollutants (40 CFR Parts 61, 63). Installation of wells, piping, and reagent storage equipment will be performed in a manner that does not result in a “take” of threatened or endangered species, damage their critical habitat (50 CFR Part 402), or impact migratory birds (15 USC § 703-712). Waste generated during remedial activities will be handled in compliance with hazardous waste generator requirements (22 CCR Division 4.5, Chapters 11, 12, 18). Regulated waste piles, tank systems, landfills, and miscellaneous units will not be constructed. Monitoring will be performed in accordance with RCRA (22 CCR Division 4.5, Ch. 14, Article 6) and California Water Code (23 CCR Div. 3, Chapter 15; 27 CCR Div. 2, Subdivision 1; Calif. Water Code Section 13801(c)) monitoring requirements. Because RAOs will achieve background levels for chromium, this alternative is consistent with the substantive provisions of SWRCB Resolution 68-16 that requires maintenance of the highest water quality consistent with maximum benefit to the people of the State, and with the substantive provisions of SWRCB Resolution 92-49 that requires restoration of background water quality. It will also result in achieving Basin Plan water quality objectives for chromium in groundwater. Appropriate land use covenants will be implemented (22 CCR 67391.1).	No long-term containment systems are required and no land disposal of treatment residuals is expected.		Additional protections to the environment and community will be through compliance with ARARs such as for floodplain and wetland protection and stormwater requirements. **<u>Time Until RAOs are Achieved.</u>** It is estimated that 10 to 60 years would be required to achieve the RAOs for this alternative. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.	constructed primarily outside of PG&E property. There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. Administration of an institutional control to prohibit use of groundwater within the plume until attainment of cleanup goals would be required. The institutional control would need to be coordinated with the various landowners that overlie the plume. Water rights for the extraction systems under this alternative would be covered under existing remediation water rights so that no additional water rights would need to be procured. **<u>Availability of Services and Materials.</u>** Services, equipment, and materials for installation of the extraction wells, injections wells, pipelines, utilities, reagent storage and delivery systems, and process controls/instrumentation are readily available. Some specialized services may be needed for optimization of the reactant mix and delivery systems; however, these services can be made available. No wastes are produced from the *in-situ* treatment process that require offsite disposal. Offsite disposal facilities for drill cuttings or development water generated from the well installation are widely available.	

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
Alternative D - Sequential *In-situ* Treatment	**Protect Human Health and the Environment.** Alternative D would protect human health and the environment in the long term through reduction of Cr(VI) concentrations in groundwater by *in-situ* treatment. Monitoring would provide data to evaluate the effectiveness of *in-situ* treatment. This alternative protects human health in the short term by limiting exposure through restriction of groundwater use as potable water source until cleanup goals are met. Alternative D includes floodplain cleanup as the initial step in implementation, thereby providing additional protection to the river. Alternative D also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. This alternative involves construction and operation of active treatment facilities, including wells, pipelines, tanks, etc. Steps would be taken during construction and operation of the remedial facilities to limit disturbance to sensitive resources. Steps to limit disturbance to sensitive resources may include moving locations of infrastructure away from sensitive resources, modification of construction techniques (e.g., equipment or schedules), modification of design elements (e.g., materials, configurations, sizes). Steps may also include programmatic elements such as awareness training for site personnel. **Attain Media Cleanup Goals.** Alternative D includes *in-situ* treatment to attain cleanup goals for constituents in groundwater. **Control Sources of Releases.** The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have been eliminated; therefore, sources of wastewater discharge and hexavalent chromium have been controlled. However, the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined, and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	**Chemical-specific ARARs.** Chemical-specific requirements will be met. By achieving cleanup goals less than MCLs, the remedy will comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater delivered by a public water supply system. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the River near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally-occurring reducing conditions in sediments near the Colorado River and dilution provided by the river are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river prior to remedy completion. By achieving cleanup goals in groundwater, the remedy will provide additional certainty that contaminated groundwater will not cause exceedances of federal water quality criteria established under the Federal Water Pollution Control Act (40 CFR 131.38) for Cr(VI) in the Colorado River in the long term. **Location-specific ARARs.** Location-specific requirements will be met. Because surface water bodies are not being modified, USFWS coordination (40 CFR 6.201) will not be triggered. Because RCRA-regulated treatment systems will not be constructed in a floodplain or seismic zone, RCRA seismic and floodplain requirements (40 CFR 264.18) will not be triggered. Construction of wells and piping in floodplain or wetland areas will be performed in a manner that complies with federal floodplain and wetlands protection requirements (40 CFR 6.201). Steps will be taken during design and implementation to ensure compatibility with the National Wildlife Refuge System Administration Act. The requirements of the National Historic Preservation Act (16 U.S.C. § 470, *et seq.*) are applicable based on the presence of and potential impact to historic properties listed on, or eligible for listing on, the National Register of Historic Places. Other cultural resource requirements include those of the National Archaeological and Historic Preservation Act (16 U.S.C. § 469, *et seq.*), the Native American Graves Protection and Repatriation Act (25 U.S.C. § 3001, *et seq.*), and the Archaeological Resources Protection Act (16 U.S.C. § 470aa-ii, *et seq.*). The requirements of the Historic Sites Act (16 U.S.C. § 461 *et seq.*) may apply to Route 66. In addition, there may be applicable requirements of Pub. L. 106-45 to preserve Route 66. Location and action-specific religious freedom requirements are set forth in the American Indian Religious Freedom Act and Religious Freedom Restoration Act. As a threshold matter, this alternative cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation Officers, and others to identify potential effects on cultural	**Magnitude of Residual Risk.** Alternative D includes active *in-situ* treatment to attain cleanup goals for Cr(VI) in groundwater. Alternative D includes a group of bedrock extraction wells in the eastern (downgradient) end of the East Ravine, with the water from the bedrock extraction wells managed within the active treatment system for the alluvial aquifer. Risk from residual contamination would be reduced as Cr(VI) mass within the plume is treated. **Adequacy and Reliability of Controls.** *In-situ* technology has not often been applied to treat an entire plume of this size and depth. Limitations for long-term success of this alternative are primarily associated with the ability to obtain complete distribution of substrates across the entire plume. There is uncertainty associated with achieving complete distribution of carbon source substrate across this large of an area. Incomplete distribution can be overcome by achieving sufficient coverage to allow natural groundwater flow to transport any residual untreated chromium (that is not treated directly) to an adjacent treatment zone. Incomplete coverage also can be addressed through optimization of the remedy during implementation, which would involve additional dosing in areas where complete coverage was not achieved during the initial dose. Alternative D includes pumping within the East Ravine bedrock to ensure hydraulic control of East Ravine groundwater. Once the remedy is completed, monitoring inside and outside the plume and continued enforcement of institutional controls may be required to assess *in-situ* treatment byproducts. Five-year reviews would be required for this alternative. No long-term containment systems are required and no land disposal of treatment residuals is expected.	**Amount of Plume Destroyed or Treated.** The intent of this alternative is to address the entire area of groundwater where Cr(VI) concentrations are higher than 32 µg/L. Alternative D also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. If it is determined that additional remedial effort is needed to reach RAOs in East Ravine bedrock, other technologies could be applied to supplement the pumping wells. In addition to pumping for hydraulic control, technologies that may be applicable to East Ravine bedrock would include, but are not limited to, freshwater injection for flushing and injection of carbon amendments for *in-situ* reduction of Cr(VI). The mass of Cr(VI) in East Ravine bedrock is estimated to be less than one percent of the total Cr(VI) plume mass. **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** Alternative D includes *in-situ* treatment by distributing an organic carbon substrate throughout the plume to create geochemically-reduced conditions to convert Cr(VI) in groundwater to insoluble Cr(III) and thereby reducing the toxicity and mobility of the site contaminants. Alternative D also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. **Degree Treatment is Irreversible.** The degree of reversibility of the Cr(VI) reduction reaction is expected to ultimately result in Cr(VI) concentrations at levels similar to ambient Cr(VI) under the current pH conditions of aquifer. **Type and Quantity of Residual Remaining After Treatment.** The most significant residual byproducts will be manganese and arsenic, natural constituents of the aquifer matrix released into solution by reduction reactions. Because of the uncertainties associated with the aquifer complexities, there is the potential for elevated byproduct concentrations persisting in some portions of the aquifer. Once released, the reduced forms of manganese and arsenic will likely be attenuated through precipitation, sorption, diffusion, and co-precipitation. Residual byproducts will be managed through careful system monitoring and operations both inside and outside the plume.	**Protection of the Community During Remedial Action.** The community would be protected during this period by prohibiting the use of the groundwater for drinking water through institutional controls. Treatment byproducts could be temporarily elevated within portions of the treatment zone (Appendix E). The concentrations of byproducts could remain elevated at the site for a time but should eventually return to pre-remediation concentrations by adsorption reactions and be immobilized as the aquifer returned to aerobic conditions. Monitoring would be ongoing to verify the effectiveness of the fluvial sediments to provide a natural geochemical barrier to the Colorado River and to monitor for *in-situ* treatment byproducts. The community would face limited disturbance from construction noise, physical hazards such as traffic, material transport from construction, and operational activities. Risks can be reduced through proper controls during construction and operation. **Protection of Workers During Remedial Action.** Workers would face general site hazards including heavy equipment, occupational noise exposure, slip and fall, etc. General site hazards would be reduced by site specific health and safety plans, safety equipment. Workers would be required to wear appropriate personal protective equipment and use best management practices to minimize exposure. **Protection of the Environment During Remedial Action.** Potential environmental impacts would be related to disturbance to the environment as a result of construction and operation. Preliminary design estimates suggest that this alternative would result in installation of approximately 87 remediation well locations and, 40 additional monitoring well locations, piping, reagent storage and delivery systems, power, and instrumentation. Operation and maintenance activities would include periodic well maintenance, sample collection, refinement of the injection/recirculation systems, management of the reactant material, equipment inspections, and periodic replacement of wells and other structures that become clogged or damaged. Measures will be taken during construction, sampling, and operational activities to minimize environmental	**Technical Feasibility.** Alternative D is technically implementable. Installation of extraction wells, injection wells, pipelines, utilities, reagent storage and delivery systems, and process controls/instrumentation is technically implementable. Some wells may be challenging to install due to hydrogeologic conditions and excessive depths. Varied and abrupt topography and access limitations will present challenges to construction of wells, pipelines, and utilities, but the challenges can be overcome. This alternative includes installation of injection wells within Bat Cave Wash that will present challenges associated with maintaining protection against future damage or wash out. Pilot testing has shown that *in-situ* treatment is technically implementable at this site; however, there is a fair amount of uncertainty about the overall ability of the system to be able to work at this scale and there will be technical challenges associated with the ability to obtain complete distribution of substrates across a large area. Operation of the *in-situ* treatment system will require a high level of oversight during implementation to ensure that the system is optimized and modified as remediation progresses. **Administrative Feasibility.** Alternative D is administratively implementable. No offsite actions would be associated with Alternative D that would require permits from other agencies. Coordination and approval by respective landowners and leaseholders including BNSF, Caltrans, and other entities, would be required because installation of the extraction wells, injections wells, pipelines, utilities, reagent storage and delivery systems, and process controls/instrumentation would be constructed primarily outside of PG&E property. There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. Administration of an institutional control to prohibit use of groundwater within the plume until attainment of cleanup goals would be required. The institutional control would need to be coordinated with the various landowners that overlie the plume. Water rights for the extraction systems under this alternative would be covered under existing remediation water rights so that no additional water rights need to	$118,000,000 - $254,000,000

TABLE 5-5
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Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
		resources and evaluate and implement reasonable and prudent mitigation measures, thereby ensuring that the selected remedy attains these ARARs. **<u>Action-specific ARARs, including standards for management of wastes generated by the remedial action</u>.** This alternative can be designed and implemented to attain action-specific requirements. Injection of reductant material and recirculation of groundwater will be performed in a manner that meets Federal Underground Injection Control requirements (40 CFR Parts 144-148). There will be no discharge of fill to wetlands or waterways (40 CFR 230.10), point source discharge of pollutants to waters of the United States (40 CFR Parts 122, 125), or other activities that alter the course, condition, or capacity of navigable waters (33 USC § 401 and 403). Remedial activities will comply with applicable NPDES construction stormwater requirements (40 CFR 122.26). Remedial activities will not emit regulated hazardous air pollutants (40 CFR Parts 61, 63). Installation of wells, piping, and reagent storage equipment will be performed in a manner that does not result in a "take" of threatened or endangered species, damage their critical habitat (50 CFR Part 402), or impact migratory birds (15 USC § 703-712). Waste generated during remedial activities will be handled in compliance with hazardous waste generator requirements (22 CCR Division 4.5, Chapters 11, 12, 18). Regulated waste piles, tank systems, landfills, and miscellaneous units will not be constructed. Monitoring will be performed in accordance with RCRA (22 CCR Division 4.5, Ch. 14, Article 6) and California Water Code (23 CCR Div. 3, Chapter 15; 27 CCR Div. 2, Subdivision 1; Calif. Water Code Section 13801(c)) monitoring requirements. Because RAOs will achieve background levels for chromium, this alternative is consistent with the substantive provisions of SWRCB Resolution 68-16 that requires maintenance of the highest water quality consistent with maximum benefit to the people of the State and with the substantive provisions of SWRCB Resolution 92-49 that requires restoration of background water quality. It will also result in achieving Basin Plan water quality objectives for chromium in groundwater. Appropriate land use covenants will be implemented (22 CCR 67391.1).			disturbance. This alternative includes infrastructure on the floodplain between National Trails Highway and the Colorado River. Additional protections to the environment and community will be through compliance with ARARs such as for floodplain and wetland protection and stormwater requirements. **<u>Time Until RAOs are Achieved</u>** It is estimated that 10 to 20 years would be required to achieve the RAOs for this alternative The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.	be procured. **<u>Availability of Services and Materials.</u>** Services, equipment, and materials for installation of the extraction wells, injections wells, pipelines, utilities, reagent storage and delivery systems and process controls/instrumentation are readily available. Some specialized services may be needed for optimization of the reactant mix and delivery systems; however, these services can be made available. No wastes are produced from the *in-situ* treatment process that require offsite disposal. Offsite disposal facilities for drill cuttings or development water generated from the well installation are widely available.	

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
Alternative E – *In-situ* Treatment with Fresh Water Flushing	**Protect Human Health and the Environment.** Alternative E would protect human health and the environment in the long term through reduction of Cr(VI) concentrations in groundwater by *in-situ* treatment. Monitoring would provide data to evaluate the effectiveness of *in-situ* treatment. This alternative protects human health in the short term by limiting exposure through restriction of groundwater use as potable water source until cleanup goals are met. Alternative E involves flushing the plume through an IRZ barrier located along Park Moabi road. Flushing would be accomplished through a combination of fresh water injection and injection of carbon amended water in wells to the west of the plume. This alternative also includes extraction wells near the Colorado River to provide hydraulic capture of the plume and to help flush the groundwater with elevated Cr(VI) through the IRZ lines. Additional extraction wells are located in an area northeast of the compressor station where the flushing efficiency from injection wells alone is relatively poor. Alternative E also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. This alternative involves construction and operation of active treatment facilities, including wells, pipelines, and tanks. Steps would be taken during construction and operation of the remedial facilities to limit disturbance to sensitive resources. Steps to limit disturbance to sensitive resources may include moving locations of infrastructure away from sensitive resources, modification of construction techniques (e.g., equipment or schedules), modification of design elements (e.g., materials, configurations, sizes). Steps may also include programmatic elements such as awareness training for site personnel. **Attain Media Cleanup Goals.** Alternative E includes active groundwater treatment through *in-situ* treatment and water flushing to attain cleanup goals. **Control Sources of Releases.** The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have been eliminated; therefore, sources of wastewater discharge and hexavalent	**Chemical-specific ARARs.** Chemical-specific requirements will be met. By achieving cleanup goals less than MCLs, the remedy will comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater delivered by a public water supply system. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally occurring reducing conditions in sediments near the Colorado River and dilution provided by the river, are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river prior to remedy completion. By achieving cleanup goals in groundwater, the remedy will provide additional certainty that contaminated groundwater will not cause exceedances of Federal water quality criteria established under the Federal Water Pollution Control Act (40 CFR 131.38) for Cr(VI) in the Colorado River in the long term. **Location-specific ARARs.** Location-specific requirements will be met. Because surface water bodies are not being modified, USFWS coordination requirements (40 CFR 6.201) will not be triggered. Because RCRA-regulated treatment systems will not be constructed in a floodplain or seismic zone, RCRA seismic and floodplain requirements (40 CFR 264.18) will not be triggered. Construction of wells and piping in floodplain or wetland areas will be performed in a manner that complies with federal floodplain and wetlands protection requirements (40 CFR 6.201). Steps will be taken during design and implementation to ensure compatibility with the National Wildlife Refuge System Administration Act. The requirements of the National Historic Preservation Act 16 U.S.C. § 470, *et seq.*) are applicable based on the presence of and potential impact to historic properties listed on, or eligible for listing on, the National Register of Historic Places. Other cultural resource requirements include those of the National Archaeological and Historic Preservation Act (16 U.S.C. § 469, *et seq.*), the Native American Graves Protection and Repatriation Act (25 U.S.C. § 3001, *et seq.*), and the Archaeological Resources Protection Act (16 U.S.C. § 470aa-ii, *et seq.*), The requirements of the Historic Sites Act (16 U.S.C. § 461 *et seq.*), may apply to Route 66. In addition, there may be applicable requirements of Pub. L. 106-45 to preserve Route 66. Location and action-specific religious freedom requirements are set forth in the American Indian Religious Freedom Act and Religious Freedom Restoration Act. If a well for potable water is located in the future on land owned or controlled by the State of Arizona, the requirements of A.R.S. § 41-841 through 847 require that there will be no excavation of a historic site. Also, if a well for potable water is located on land other than Arizona state land, A.R.S. § 41-861 through 866 require that no human remains or specified cultural objects will be disturbed intentionally, and unintentional disturbances will	**Magnitude of Residual Risk.** Alternative E includes active *in-situ* treatment to attain cleanup goals for Cr(VI) in groundwater. Alternative E includes a group of bedrock extraction wells in the eastern (downgradient) end of the East Ravine, with the water from the bedrock extraction wells managed within the active treatment system for the alluvial aquifer. Risk from residual contamination would be reduced as Cr(VI) mass within the plume is treated. **Adequacy and Reliability of Controls.** Once the remedy is completed, monitoring inside and outside of the plume and continued enforcement of Institutional controls may be required to assess *in-situ* treatment byproducts. There is uncertainty associated with achieving complete distribution of carbon source substrate across this large of an area. Incomplete distribution can be overcome by achieving sufficient coverage to allow natural groundwater flow to transport any residual untreated chromium (that is not treated directly) to an adjacent treatment zone. Incomplete coverage also can be addressed through optimization of the remedy during implementation, which would involve additional dosing in areas where complete coverage was not achieved during the initial dose. Alternative E includes pumping within the East Ravine bedrock to ensure hydraulic control of East Ravine groundwater. Five-year reviews would be required for this alternative. No long-term containment systems are required and no land disposal of treatment residuals is expected. At many sites that rely on flushing to remove contaminants, a limit is reached where concentrations are no longer being reduced effectively, but cleanup goals have not been met. Hexavalent chromium does not strongly sorb to soils, which makes it more amenable to flushing than some other contaminants, but it may still be difficult to reach cleanup levels across the entire plume by relying on flushing technology. Maintaining hydraulic control through pumping or injection can be accomplished at the Topock site due to the flat groundwater gradients and lack of extensive aquitards within the Alluvial Aquifer.	**Amount of Plume Destroyed or Treated.** The intent of this alternative is to address the entire area of groundwater where Cr(VI) concentrations are higher than 32 µg/L. Alternative E also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. If it is determined that additional remedial effort is needed to reach RAOs in East Ravine bedrock, other technologies could be applied to supplement the pumping wells. In addition to pumping for hydraulic control, technologies that may be applicable to East Ravine bedrock would include, but are not limited to, freshwater injection for flushing and injection of carbon amendments for *in-situ* reduction of Cr(VI). The mass of Cr(VI) in East Ravine bedrock is estimated to be less than one percent of the total Cr(VI) plume mass. **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** Alternative E includes *in-situ* treatment by distributing an organic carbon substrate within the floodplain to create geochemically-reduced conditions to convert Cr(VI) in groundwater to insoluble Cr(III) and thereby reducing the toxicity and mobility of the site contaminants. Alternative E also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. **Degree Treatment is Irreversible.** The degree of reversibility of the Cr(VI) reduction reaction is expected to ultimately result in Cr(VI) concentrations at levels similar to ambient Cr(VI) under the current pH conditions of aquifer. **Type and Quantity of Residual Remaining After Treatment.** The most significant residual byproducts will be manganese and arsenic, natural constituents of the aquifer matrix released into solution by reduction reactions. Once released, the reduced forms of manganese and arsenic will likely be attenuated through precipitation, sorption, diffusion, and co-precipitation. Residual byproducts will be managed through careful system monitoring and operations both inside and outside the plume.	**Protection of the Community During Remedial Action.** The community would be protected during this period by prohibiting the use of the groundwater for drinking water through institutional controls. Treatment byproducts could be temporarily elevated within portions of the treatment zone (Appendix E). The concentrations of byproducts could remain elevated at the site for a time but should eventually return to pre-remediation concentrations by adsorption reactions and eventually be immobilized as the aquifer returned to aerobic conditions. Monitoring would be ongoing to verify the effectiveness of the fluvial sediments to provide a natural geochemical barrier to the Colorado River and to monitor for *in-situ* treatment byproducts. The community would face limited disturbance from construction noise, physical hazards such as traffic, and material transport. Risks can be reduced through proper controls during construction and operation. **Protection of Workers During Remedial Action.** Workers would face general site hazards including heavy equipment, occupational noise exposure, slip and fall, etc. General site hazards would be reduced by site specific health and safety plans and safety equipment. Workers would be required to wear appropriate personal protective equipment and use best management practices to minimize exposure. **Protection of the Environment During Remedial Action.** Preliminary design estimates suggest that this alternative would result in installation of approximately 51 remediation well locations and 28 monitoring well locations, piping, reagent storage and delivery systems, and power and instrumentation. Operation and maintenance activities would include periodic well maintenance, sample collection, refinement of the injection/recirculation systems, management of the reactant material, equipment inspections, and periodic replacement of wells and other structures that become clogged or damaged. Measures will be taken during construction, sampling, and operational activities to minimize environmental disturbance. Measures to minimize environmental disturbance may include moving locations of infrastructure away from sensitive resources, modification of	**Technical Feasibility.** Alternative E is technically implementable. Construction of a new water supply well and delivery of the potable water via pipeline to injection wells is technically implementable, using standard pipeline construction methods. Installation of extraction wells, injections wells, pipelines, utilities, reagent storage and delivery systems, and process controls/instrumentation is technically implementable. Some wells may be challenging to install due to hydrogeologic conditions and excessive depths. Varied and abrupt topography and access limitations will present will present challenges to construction of wells, pipelines, and utilities, but the challenges can be overcome. Pilot testing has shown that *in-situ* treatment is technically implementable at this site. Operation of the *in-situ* treatment system will require a high level of oversight during implementation to ensure that the system is optimized and modified as remediation progresses. There will be technical challenges associated with reliance on flushing to remove contaminants due to the possibility of rate-limited back diffusion from low-permeable material, and it is expected that optimization of the remedy would throughout the design, construction, and operational phases to enhance performance of the remedy to attain the cleanup goals and to respond to site conditions and performance issues. **Administrative Feasibility.** Alternative E is administratively implementable. Installation of a water supply well in Arizona would need to be permitted by the Arizona Water Resources Department. Coordination and approval by respective landowners and leaseholders including BNSF and Caltrans and other entities would be required for installation of the extraction wells, injections wells, pipelines, utilities, reagent storage and delivery systems, and process controls/instrumentation that would be constructed primarily outside of PG&E property. Administration of an institutional control to prohibit use of groundwater within the plume until attainment of cleanup goals would be required. The institutional control would need to be coordinated with the various landowners that overlie the plume. Water rights for this alternative would be covered under existing remediation water rights so that no additional water rights need to be procured. There is no net consumptive use in this alternative	$92,000,000 - $198,000,000

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
	chromium have been controlled. However, the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined, and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	be reported. As a threshold matter, this alternative cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision, and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation Officers, and others to identify potential effects on cultural resources and evaluate and implement reasonable and prudent mitigation measures, thereby ensuring that the selected remedy attains these ARARs. **<u>Action-specific ARARs, including standards for management of wastes generated by the remedial action.</u>** This alternative can be designed and implemented to attain action-specific requirements. Injection of reductant material and recirculation of groundwater will be performed in a manner that meets Federal Underground Injection Control requirements (40 CFR Parts 144-148). There will be no discharge of fill to wetlands or waterways (40 CFR 230.10), point source discharge of pollutants to waters of the United States (40 CFR Parts 122, 125), or other activities that alter the course, condition, or capacity of navigable waters (33 USC § 401 and 403). Remedial activities will comply with applicable NPDES construction stormwater requirements (40 CFR 122.26). Remedial activities will not emit regulated hazardous air pollutants (40 CFR Parts 61, 63). Installation of wells, piping, and reagent storage equipment will be performed in a manner that does not result in a "take" of threatened or endangered species, damage their critical habitat (50 CFR part 402), or impact migratory birds (15 USC § 703-712). Waste generated during remedial activities will be handled in compliance with hazardous waste generator requirements (22 CCR Division 4.5, Chapters 11, 12, 18). Regulated waste piles, tank systems, landfills, and miscellaneous units will not be constructed. Monitoring will be performed in accordance with RCRA (22 CCR Division 4.5, Ch. 14, Article 6) and California Water Code (23 CCR Div. 3, Chapter 15; 27 CCR Div. 2, Subdivision 1; Calif. Water Code Section 13801(c)) monitoring requirements. Because RAOs will achieve background levels for chromium, this alternative is consistent with the substantive provisions of SWRCB Resolution 68-16 that requires maintenance of the highest water quality consistent with maximum benefit to the people of the State and with the substantive provisions of SWRCB Resolution 92-49 that requires restoration of background water quality. It will also result in achieving Basin Plan water quality objectives for chromium in groundwater. Appropriate land use covenants will be implemented (22 CCR 67391.1). Arizona well standards (A.A.C. R-12-15-850; A.R.S. Title 5, Chapter 2, Article 10) will be met for potable water supply wells constructed in Arizona.			construction techniques (e.g., equipment or schedules), modification of design elements (e.g., materials, configurations, sizes), or implementation of programmatic elements such as awareness training for site personnel. This alternative includes infrastructure on the floodplain between National Trails Highway and the Colorado River. Additional protections to the environment and community will be through compliance with ARARs such as for floodplain and wetland protection and stormwater requirements. **<u>Time Until RAOs are Achieved.</u>** It is estimated that it would take 10 to 110 years to achieve the RAOs for this alternative. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.	because extracted groundwater is returned to the basin through reinjection. There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. This alternative would require a long-term secure source of potable water. **<u>Availability of Services and Materials.</u>** Services, equipment, and materials for installation of the extraction wells, injections wells, water supply well, pipelines, utilities, reagent storage and delivery systems and process controls/instrumentation are readily available. Some specialized services may be needed for optimization of the reactant mix and delivery systems, however, these services can be made available. No wastes are produced from the *in-situ* treatment process that require offsite disposal. Offsite disposal facilities for drill cuttings or development water generated from the well installation are widely available.	

TABLE 5-5
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Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
Alternative F – Pump and Treat	**Protect Human Health and the Environment.** Alternative F would protect human health and the environment in the long term through reduction of Cr(VI) concentrations in groundwater by *ex-situ* treatment. Monitoring would provide data to evaluate the effectiveness of *ex-situ* treatment. This alternative protects human health in the short term by limiting exposure through restriction of groundwater use as potable water source until cleanup goals are met. The groundwater extraction to remove groundwater for *ex-situ* treatment would provide a landward gradient in the floodplain, thereby preventing movement of Cr(VI) toward the river. However, continued groundwater extraction near the river may lead to long-term damage to the reducing blanket surrounding the riverbed. Alternative F also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. This alternative involves construction and operation of an above-ground treatment plant, and other facilities, including wells, and pipelines, etc. Steps would be taken during construction and operation of the remedial facilities to limit disturbance to sensitive resources. Steps to limit disturbance to sensitive resources may include moving locations of infrastructure away from sensitive resources, modification of construction techniques (e.g., equipment or schedules), modification of design elements (e.g., materials, configurations, sizes). Steps may also include programmatic elements such as awareness training for site personnel. However the energy requirements for operation of the treatment plant will be high and waste byproducts from the treatment plant would need to be transported to an offsite, permitted disposal facility. **Attain Media Cleanup Goals.** Alternative F includes extraction and *ex-situ* treatment to attain cleanup goals for constituents in groundwater. **Control Sources of Releases.** The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have been eliminated; therefore, sources of wastewater discharge and hexavalent chromium have been controlled.	**Chemical-specific ARARs.** Chemical-specific requirements will be met. By achieving cleanup goals less than MCLs, the remedy will comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater delivered by a public water supply system. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally occurring reducing conditions in sediments near the Colorado River and dilution provided by the river are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river prior to remedy completion. By achieving cleanup goals in groundwater, the remedy will provide additional certainty that contaminated groundwater will not cause exceedances of Federal water quality criteria established under the Federal Water Pollution Control Act (40 CFR 131.38) for Cr(VI) in the Colorado River in the long term. **Location-specific ARARs.** Location-specific requirements will be met. Because surface water bodies are not being modified, USFWS coordination requirements (40 CFR 6.201) will not be triggered. Because RCRA-regulated treatment systems will not be constructed in a floodplain or seismic zone, RCRA seismic and floodplain requirements (40 CFR 264.18) will not be triggered. Construction of wells and piping in floodplain or wetland areas will be performed in a manner that compiles with federal floodplain and wetlands protection requirements (40 CFR 6.201). Steps will be taken during design and implementation to ensure compatibility with the National Wildlife Refuge System Administration Act. The requirements of the National Historic Preservation Act (16 U.S.C. § 470, *et seq.*) are applicable based on the presence of and potential impact to historic properties listed on, or eligible for listing on, the National Register of Historic Places. Other cultural resource requirements include those of the National Archaeological and Historic Preservation Act (16 U.S.C. § 469, *et seq.*), the Native American Graves Protection and Repatriation Act (25 U.S.C. § 3001, *et seq.*), and the Archaeological Resources Protection Act (16 U.S.C. § 470aa-ii, *et seq.*). The requirements of the Historic Sites Act, 16 U.S.C. § 461 *et seq.*, may apply to Route 66. In addition, there may be applicable requirements of Pub. L. 106-45 to preserve Route 66. Location and action-specific religious freedom requirements are set forth in the American Indian Religious Freedom Act and Religious Freedom Restoration Act. As a threshold matter, this alternative cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision, and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation	**Magnitude of Residual Risk.** Alternative F includes extraction and *ex-situ* treatment to attain cleanup goals for Cr(VI) in groundwater. Alternative F includes a group of bedrock extraction wells in the eastern (downgradient) end of the East Ravine, with the water from the bedrock extraction wells managed within the active treatment system for the alluvial aquifer .Risk from residual contamination in groundwater would be reduced as Cr(VI) mass within the plume is treated. **Adequacy and Reliability of Controls.** The *ex-situ* treatment process produces waste byproducts that would require long-term controls; transportation to and disposal in an offsite permitted facility is assumed to provide reliable long-term containment of the waste byproducts. Five-year reviews would be required for this alternative. Alternative F includes pumping within the East Ravine bedrock to ensure hydraulic control of East Ravine groundwater. Pump-and-treat technology is capable of reducing the size of plumes, and removing a large portion of the contaminant mass; however, at many sites, pump-and-treat systems which rely on flushing to remove contaminants have reached a limit where concentrations are no longer being reduced effectively, but cleanup goals have not been met. Thus, it may still be difficult to reach cleanup goals across the entire plume under this alternative. Maintaining hydraulic control through pumping or injection can be accomplished at the Topock site due to the flat groundwater gradients and lack of extensive aquitards within the Alluvial Aquifer. The pumping associated with Alternative F provides a landward gradient towards the extraction wells and away from the river, but in the process, river water may be drawn into the aquifer. The river water is aerobic and would become reduced as it moved out of the river and into the fluvial aquifer. Over the long period of time that this remedy would operate, the passage of this aerobic water through the fluvial sediments could result in some degradation of the natural reducing capacity. It is not possible to accurately predict where or to what extent this degradation in reducing capacity would occur.	**Amount of Plume Destroyed or Treated.** The intent of this alternative is to address the entire area of groundwater where Cr(VI) concentrations are higher than 32 µg/L. Alternative F also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. If it is determined that additional remedial effort is needed to reach RAOs in East Ravine bedrock, other technologies could be applied to supplement the pumping wells. In addition to pumping for hydraulic control, technologies that may be applicable to East Ravine bedrock would include, but are not limited to, freshwater injection for flushing and injection of carbon amendments for *in-situ* reduction of Cr(VI). The mass of Cr(VI) in East Ravine bedrock is estimated to be less than one percent of the total Cr(VI) plume mass. **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** Alternative F includes *ex-situ* treatment in an above ground treatment plant likely using chemical reduction by addition of ferrous iron, oxidation, pH adjustment, and settling in a clarifier and final filtration. Similar to *in-situ* treatment, the *ex-situ* process converts Cr(VI) to Cr(III), thereby reducing the toxicity and mobility of the site contaminants. Alternative F also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. **Degree Treatment is Irreversible.** The Cr(VI) reduction reaction is not reversible. The Cr(VI) is removed from the groundwater through chemical reduction by ferrous iron compounds followed by alkaline precipitation and filtration. The resulting sludge is transported offsite to an appropriate permitted disposal facility for long-term management. The reversibility of the Cr(VI) reduction reaction depends on the geochemical conditions in the offsite permitted disposal facility. **Type and Quantity of Residual Remaining After Treatment.** Cr(III) from the treatment process is removed from the site and disposed in an offsite, permitted disposal facility.	**Protection of the Community During Remedial Action.** The community would be protected during this period by prohibiting the use of the groundwater for drinking water through institutional controls. Monitoring would be ongoing to verify the effectiveness of the fluvial sediments provide a natural geochemical barrier to the Colorado River. The community would face limited disturbance from construction noise, physical hazards such as traffic, and material transport. Risks can be reduced through proper controls during construction and operation. **Protection of Workers During Remedial Action.** Workers would face general site hazards including heavy equipment, occupational noise exposure, slip and fall, etc. General site hazards would be reduced by site specific health and safety plans and safety equipment. Workers would be required to wear appropriate personal protective equipment and use best management practices to minimize exposure. **Protection of the Environment During Remedial Action.** Preliminary design estimates suggest that this alternative would result in installation of approximately 26 remediation well locations and 24 monitoring well locations and the treatment plant. Additionally, operation of the *ex-situ* system would result in environmental impacts because substantial amount of electrical power would be required, as well as trucking requirements for delivery of treatment chemicals and disposal of wastes, with associated energy use and traffic hazards. Residuals would consist of waste byproducts containing Cr(III) and iron. Operation and maintenance of the aboveground treatment plant would include periodic sample collection, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Measures will be taken during construction, sampling, and operational activities to minimize environmental disturbance. Additional protections to the environment and community will be through compliance with ARARs such as for floodplain and wetland protection and stormwater requirements. **Time Until RAOs are Achieved.**	**Technical Feasibility.** Alternative F is technically implementable. Installation of extraction wells, injection wells, pipelines, utilities, and *ex-situ* treatment plant is technically implementable. Implementation of the IM has shown that extraction, treatment, and injection are technically implementable at this site. However, there is some amount of uncertainty about the overall ability to remove contaminants relying on flushing technology. Some wells may be challenging to install due to hydrogeologic conditions and excessive depths, and varied and abrupt topography and access limitations will present challenges to construction of wells, pipelines, and utilities but the challenges can be overcome. Operation of the *ex-situ* treatment system will require a high level of oversight during implementation to ensure that the system is optimized and modified as remediation progresses. **Administrative Feasibility.** Alternative F is administratively implementable. No offsite actions would be associated with Alternative F that would require permits from other agencies. Installation of the extraction wells, injection wells, pipelines, and utilities would be constructed primarily outside of PG&E property so construction and operation of these facilities would have to be coordinated with and approved by the respective landowners and leaseholders, including BNSF, Caltrans, and other entities. There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. Administration of an institutional control to prohibit use of groundwater within the plume until attainment of cleanup goals would be required. The institutional control would need to be coordinated with the various landowners that overlie the plume. **Availability of Services and Materials.** Services, equipment, and materials for installation of the extraction wells, injections wells, pipelines, utilities, and *ex-situ* treatment plant are readily available. Some specialized services may be needed for construction and operation of certain treatment components in the *ex-situ* treatment plant; however, these services can be made available. Waste byproducts would need to be	$187,000,000 - $401,000,000

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	However, the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined, and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	Officers, and others to identify potential effects on cultural resources and evaluate and implement reasonable and prudent mitigation measures, thereby ensuring that the selected remedy attains these ARARs. **<u>Action-specific ARARs, including standards for management of wastes generated by the remedial action.</u>** This alternative can be designed and implemented to attain action-specific requirements. Injection of treated groundwater will be performed in a manner that meets Federal Underground Injection Control requirements (40 CFR Parts 144-148). There will be no discharge of fill to wetlands or waterways (40 CFR 230.10), point source discharge of pollutants to waters of the United States (40 CFR Parts 122, 125), or other activities that alter the course, condition, or capacity of navigable waters (33 USC § 401 and 403). Remedial activities will comply with applicable NPDES construction stormwater requirements (40 CFR 122.26). Remedial activities will not emit regulated hazardous air pollutants (40 CFR Parts 61, 63). Installation of wells, piping, and *ex-situ* treatment plant will be performed in a manner that does not result in a "take" of threatened or endangered species, damage their critical habitat (50 CFR part 402), or impact migratory birds (15 USC § 703-712). Waste generated during remedial activities will be handled in compliance with hazardous waste generator requirements (22 CCR Division 4.5, Chapters 11, 12, 18). The treatment system will be constructed and operated in compliance with requirements for hazardous waste tank systems (22 CCR Div. 4.5, Ch. 14, Articles 2, 10); Regulated waste piles, landfills, and miscellaneous units will not be constructed. Monitoring will be performed in accordance with RCRA (22 CCR Division 4.5, Ch. 14, Article 6) and California Water Code (23 CCR Div. 3, Chapter 15; 27 CCR Div. 2, Subdivision 1; Calif. Water Code Section 13801(c)) monitoring requirements. Because RAOs will achieve background levels for chromium, this alternative is consistent with the substantive provisions of SWRCB Resolution 68-16 that requires maintenance of the highest water quality consistent with maximum benefit to the people of the State and with the substantive provisions of SWRCB Resolution 92-49 that requires restoration of background water quality. It will also result in achieving Basin Plan water quality objectives for chromium in groundwater. Appropriate land use covenants will be implemented (22 CCR 67391.1).			It is estimated that 15 to 150 years would be required to achieve the RAOs for this alternative. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.	disposed of at an offsite, licensed disposal facility; although not widely available or close to the site, there are available disposal facilities elsewhere in California, Nevada, and/or Arizona. Offsite disposal facilities for drill cuttings or development water generated from the well installation, development, and sampling are widely available.	

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Alternative G - Combined Floodplain *In-situ*/Pump and Treat	**Protect Human Health and the Environment.** Alternative G would protect human health and the environment in the long term through reduction of Cr(VI) concentrations in groundwater by *in-situ* and *ex-situ* treatment. Monitoring would provide data to evaluate the effectiveness of the *in-situ* and *ex-situ* treatment. This alternative protects human health in the short term by limiting exposure through restriction of groundwater use as potable water source until cleanup goals are met. Alternative G includes floodplain cleanup, and the groundwater extraction to remove groundwater for *ex-situ* treatment would provide a landward gradient in the floodplain. These measures would provide additional protection to the river. However, continued groundwater extraction near the river may lead to long-term damage to the reducing blanket surrounding the riverbed. Alternative G also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. This alternative involves construction and operation of an above-ground treatment plant, and other facilities, including wells and pipelines. Steps would be taken during construction and operation of the remedial facilities to limit disturbance to sensitive resources. Steps to limit disturbance to sensitive resources may include moving locations of infrastructure away from sensitive resources, modification of construction techniques (e.g., equipment or schedules), modification of design elements (e.g., materials, configurations, sizes). Steps may also include programmatic elements such as awareness training for site personnel. However the energy requirements for operation of the treatment plant will be high and waste byproducts from the treatment plant would need to be transported to an offsite, permitted disposal facility. **Attain Media Cleanup Goals.** Alternative G includes *in-situ* treatment and extraction and *ex-situ* treatment to attain cleanup goals for constituents in groundwater **Control Sources of Releases.** The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have	**Chemical-specific ARARs.** Chemical-specific requirements will be met. By achieving cleanup goals less than MCLs, the remedy will comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater delivered by a public water supply system. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally occurring reducing conditions in sediments near the Colorado River and dilution provided by the river are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river prior to remedy completion. By achieving cleanup goals in groundwater, the remedy will provide additional certainty that contaminated groundwater will not cause exceedances of Federal water quality criteria established under the Federal Water Pollution Control Act (40 CFR 131.38) for Cr(VI) in the Colorado River in the long term. **Location-specific ARARs.** Location-specific requirements will be met. Because surface water bodies are not being modified, USFWS coordination requirements (40 CFR 6.201) will not be triggered. Because RCRA-regulated treatment systems will not be constructed in a floodplain or seismic zone, RCRA seismic and floodplain requirements (40 CFR 264.18) will not be triggered. Construction of wells and piping in floodplain or wetland areas will be performed in a manner that complies with federal floodplain and wetlands protection requirements (40 CFR 6.201). Steps will be taken during design and implementation to ensure compatibility with the National Wildlife Refuge System Administration Act. The requirements of the National Historic Preservation Act (16 U.S.C. § 470, *et seq.*) are applicable based on the presence of and potential impact to historic properties listed on, or eligible for listing on, the National Register of Historic Places. Other cultural resource requirements include those of the National Archaeological and Historic Preservation Act (16 U.S.C. § 469, *et seq.*), the Native American Graves Protection and Repatriation Act (25 U.S.C. § 3001, *et seq.*), and the Archaeological Resources Protection Act (16 U.S.C. § 470aa-ii, *et seq.*). The requirements of the Historic Sites Act, 16 U.S.C. § 461 *et seq.*, may apply to Route 66. In addition, there may be applicable requirements of Pub. L. 106-45 to preserve Route 66. Location and action-specific religious freedom requirements are set forth in the American Indian Religious Freedom Act and Religious Freedom Restoration Act. As a threshold matter, this alternative cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision, and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation	**Magnitude of Residual Risk.** Alternative G includes *in-situ* treatment in the floodplain area of the site and *ex-situ* treatment in an above ground treatment plant in uplands areas of the site to attain cleanup goals for Cr(VI) in groundwater. Alternative G includes a group of bedrock extraction wells in the eastern (downgradient) end of the East Ravine, with the water from the bedrock extraction wells managed within the active treatment system for the alluvial aquifer .Risk from residual contamination in groundwater would be reduced as Cr(VI) mass within the plume is treated. **Adequacy and Reliability of Controls.** Once the remedy is completed, monitoring and continued enforcement of institutional controls may be required to assess *in-situ* treatment byproducts There is uncertainty associated with achieving complete distribution of carbon source substrate across this large of an area. Incomplete distribution can be overcome by achieving sufficient coverage to allow natural groundwater flow to transport any residual untreated chromium (that is not treated directly) to an adjacent treatment zone. Incomplete coverage also can be addressed through optimization of the remedy during implementation, which would involve additional dosing in areas where complete coverage was not achieved during the initial dose. The *ex-situ* treatment process produces waste byproducts that would require long-term controls; transportation to and disposal in an offsite permitted facility is assumed to provide reliable long-term containment of the waste byproducts. Alternative G includes pumping within the East Ravine bedrock to ensure hydraulic control of East Ravine groundwater. Five-year reviews would be required for this alternative. This alternative requires long-term containment systems (offsite) and land disposal of treatment residuals. Some residuals may remain after the remedy is completed; monitoring inside and outside the plume would be necessary to verify residual flushing. Pump-and-treat technology has been shown to be capable of reducing the size of plumes and removing a large portion of the contaminant mass. However, at many sites, pump-and-treat systems, which rely on flushing to remove contaminants, have reached a limit	**Amount of Plume Destroyed or Treated.** The intent of this alternative is to address the entire area of groundwater where Cr(VI) concentrations are higher than 32 µg/L. Alternative G also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. If it is determined that additional remedial effort is needed to reach RAOs in East Ravine bedrock, other technologies could be applied to supplement the pumping wells. In addition to pumping for hydraulic control, technologies that may be applicable to East Ravine bedrock would include, but are not limited to, freshwater injection for flushing and injection of carbon amendments for *in-situ* reduction of Cr(VI). The mass of Cr(VI) in East Ravine bedrock is estimated to be less than one percent of the total Cr(VI) plume mass. **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** Alternative G includes *in-situ* treatment in the floodplain area of the site and *ex-situ* treatment in an aboveground treatment plant for uplands areas of the site. *In-situ* treatment in the floodplain would involve distributing an organic carbon substrate to create geochemically-reduced conditions to convert Cr(VI) in groundwater to insoluble Cr(III), thereby reducing the toxicity and mobility of the site contaminants. *Ex-situ* treatment in upland areas of the site in an aboveground treatment plant would likely involve using chemical reduction by addition of ferrous iron, oxidation, pH adjustment, and settling in a clarifier and final filtration. Similar to *in-situ* treatment, the *ex-situ* process converts Cr(VI) to Cr(III), thereby reducing the toxicity and mobility of the site contaminants. Cr(III) from the treatment process is removed from the site and disposed in an offsite, permitted disposal facility. Alternative G also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. **Degree Treatment is Irreversible.** The degree of reversibility of the *in-situ* Cr(VI) reduction reaction is expected to ultimately result in Cr(VI) concentrations at levels similar to ambient Cr(VI). The *ex-situ* Cr(VI) reduction reaction is not reversible. **Type and Quantity of Residual Remaining After Treatment.** The most significant residual byproducts from the *in-situ* treatment process will be manganese and arsenic, natural constituents of the aquifer matrix released into solution by reduction reactions. Once released, the reduced forms of manganese and arsenic will likely be attenuated through precipitation, sorption, diffusion, and co-precipitation. Residual byproducts will be managed through careful system monitoring and operations both inside and outside the plume.	**Protection of the Community During Remedial Action.** The community would be protected during this period by prohibiting the use of the groundwater for drinking water through institutional controls. Treatment byproducts could be temporarily elevated within portions of the treatment zone (Appendix G). The concentrations of byproducts could remain elevated at the site for a time but should eventually return to pre-remediation concentrations by adsorption reactions and eventually be immobilized as the aquifer returned to aerobic conditions. Monitoring would be ongoing to verify the effectiveness of the fluvial sediments provide a natural geochemical barrier to the Colorado River and to monitor for *in-situ* treatment byproducts. The community would face limited disturbance from construction noise, physical hazards such as traffic, and material transport. Risks can be reduced through proper controls during construction and operation. **Protection of Workers During Remedial Action.** Workers would face general site hazards including heavy equipment, occupational noise exposure, slip and fall, etc. General site hazards would be reduced by site specific health and safety plans and safety equipment. Workers would be required to wear appropriate personal protective equipment and use best management practices to minimize exposure. **Protection of the Environment During Remedial Action.** Preliminary design estimates suggest that this alternative would result in installation of approximately 59 remediation well locations and 30 monitoring well locations and the treatment plant. Additionally, operation of the *ex-situ* system would result in environmental impacts because substantial amount of electrical power would be required, as well as trucking requirements for delivery of treatment chemicals and disposal of wastes, with associated energy use and traffic hazards. Residuals would consist of waste byproducts containing Cr(III) and iron. Operation and maintenance of the aboveground treatment plant would include periodic sample collection, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Measures will be taken	**Technical Feasibility.** Alternative G is technically implementable. Installation of extraction wells, injection wells, IRZ wells, pipelines, utilities, and *ex-situ* treatment plant is technically implementable. Implementation of the IM has shown that extraction, treatment, and injection are technically implementable at this site. However, there is some amount of uncertainty about the overall ability to remove contaminants relying on flushing technology. Some wells may be challenging to install due to hydrogeologic conditions and excess depths, and varied and abrupt topography and access limitations will present challenges to construction of wells, pipelines, and utilities but the challenges can be overcome. Operation of the *ex-situ* treatment system will require a high level of oversight during implementation to ensure that the system is optimized and modified as remediation progresses. **Administrative Feasibility.** Alternative G is administratively implementable. No offsite actions would be associated with Alternative G that would require permits from other agencies. The extraction wells, injections wells, pipelines, and utilities would be constructed primarily outside of PG&E property so construction and operation of these facilities would have to be coordinated with and approved by the respective landowners and leaseholders, including BNSF, Caltrans, and other entities. There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. Administration of an institutional control to prohibit use of groundwater within the plume until attainment of cleanup goals would be required. The institutional control would need to be coordinated with the various landowners that overlie the plume. **Availability of Services and Materials.** Services, equipment, and materials for installation of the extraction wells, injections wells, pipelines, utilities, and *ex-situ* treatment plant are readily available. Some specialized services may be needed for construction and operation of certain treatment components in the *ex-situ* treatment plant; however, these services can be made available. Waste byproducts from the *ex-situ*	$177,000,000 - $380,000,000

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Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
	been eliminated; therefore, sources of wastewater discharge and hexavalent chromium have been controlled. However, the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined, and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	Officers, and others to identify potential effects on cultural resources and evaluate and implement reasonable and prudent mitigation measures, thereby ensuring that the selected remedy attains these ARARs. **<u>Action-specific ARARs, including standards for management of wastes generated by the remedial action.</u>** This alternative can be designed and implemented to attain action-specific requirements. Injection of treated groundwater will be performed in a manner that meets Federal Underground Injection Control requirements (40 CFR Parts 144-148). There will be no discharge of fill to wetlands or waterways (40 CFR 230.10), point source discharge of pollutants to waters of the United States (40 CFR Parts 122, 125), or other activities that alter the course, condition, or capacity of navigable waters (33 USC § 401 and 403). Remedial activities will comply with applicable NPDES construction stormwater requirements (40 CFR 122.26). Remedial activities will not emit regulated hazardous air pollutants (40 CFR Parts 61, 63). Installation of wells, piping, reagent storage equipment, and *ex-situ* treatment plant will be performed in a manner that does not result in a “take” of threatened or endangered species, damage their critical habitat (50 CFR part 402), or impact migratory birds (15 USC § 703-712). Waste generated during remedial activities will be handled in compliance with hazardous waste generator requirements (22 CCR Division 4.5, Chapters 11, 12, 18). The treatment system will be constructed and operated in compliance with requirements for hazardous waste tank systems (22 CCR Div. 4.5, Ch. 14, Articles 2, 10); Regulated waste piles, landfills, and miscellaneous units will not be constructed. Monitoring will be performed in accordance with RCRA (22 CCR Division 4.5, Ch. 14, Article 6) and California Water Code (23 CCR Div. 3, Chapter 15; 27 CCR Div. 2, Subdivision 1; Calif. Water Code Section 13801(c)) monitoring requirements. Because RAOs will achieve background levels for chromium, this alternative is consistent with the substantive provisions of SWRCB Resolution 68-16 that requires maintenance of the highest water quality consistent with maximum benefit to the people of the State and with the substantive provisions of SWRCB Resolution 92-49 that requires restoration of background water quality. It will also result in achieving Basin Plan water quality objectives for chromium in groundwater. Appropriate land use covenants will be implemented (22 CCR 67391.1).	where concentrations are no longer being reduced effectively, but cleanup goals have not been met. Thus, it may still be difficult to reach cleanup levels across the entire plume by methods that rely on flushing. It is not possible to predict what the limit of concentration reduction might be for flushing technology at the Topock site. Maintaining hydraulic control through pumping or injection can be accomplished at the Topock site due to the flat groundwater gradients and lack of extensive aquitards within the Alluvial Aquifer. The pumping associated with Alternative G provides a landward gradient towards the extraction wells and away from the river, but in the process, river water may be drawn into the aquifer. The river water is aerobic and would become reduced as it moved out of the river and into the fluvial aquifer. Over the long period of time that this remedy would operate, the passage of this aerobic water through the fluvial sediments could result in some degradation of the natural reducing capacity. It is not possible to accurately predict where or to what extent this degradation in reducing capacity would occur.		during construction, sampling, and operational activities to minimize environmental disturbance. This alternative includes infrastructure on the floodplain between National Trails Highway and the Colorado River. Additional protections to the environment and community will be through compliance with ARARs such as for floodplain and wetland protection and stormwater requirements. **<u>Time Until RAOs are Achieved.</u>** It is estimated that 10 to 90 years would be required to achieve the RAOs for this alternative. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.	treatment plant would need to be disposed of at an offsite, licensed disposal facility; although not widely available or close to the site, there are available disposal facilities elsewhere in California, Nevada, and/or Arizona. Offsite disposal facilities for drill cuttings or development water generated from the well installation, development, and sampling are widely available.	

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
Alternative H - Combined Upland *In-situ*/ Pump and Treat	**Protect Human Health and the Environment.** Alternative H would protect human health and the environment in the long term through reduction of Cr(VI) concentrations in groundwater by *in-situ* and *ex-situ* treatment. Monitoring would provide data to evaluate the effectiveness of the *in-situ* and *ex-situ* treatment. This alternative protects human health in the short term by limiting exposure through restriction of groundwater use as a potable water source until cleanup goals are met. Alternative H includes floodplain cleanup, and the groundwater extraction to remove groundwater for *ex-situ* treatment would provide a landward gradient in the floodplain. These measures would provide additional protection to the river. However, continued groundwater extraction near the river may lead to long-term damage to the reducing blanket surrounding the riverbed. Alternative H also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. This alternative involves construction and operation of an aboveground treatment plant and other facilities, including wells and pipelines. Steps would be taken during construction and operation of the remedial facilities to limit disturbance to sensitive resources. Steps to limit disturbance to sensitive resources may include moving locations of infrastructure away from sensitive resources, modification of construction techniques (e.g., equipment or schedules), modification of design elements (e.g., materials, configurations, sizes). Steps may also include programmatic elements such as awareness training for site personnel. However, the energy requirements for operation of the treatment plant will be high and waste byproducts from the treatment plant would need to be transported to an offsite, permitted disposal facility. **Attain Media Cleanup Goals.** Alternative H includes *in-situ* treatment and extraction and *ex-situ* treatment to attain cleanup goals for constituents in groundwater. **Control Sources of Releases.** The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have	**Chemical-specific ARARs.** Chemical-specific requirements will be met. By achieving cleanup goals less than MCLs, the remedy will comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater delivered by a public water supply system. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally occurring reducing conditions in sediments near the Colorado River and dilution provided by the river are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river prior to remedy completion. By achieving cleanup goals in groundwater, the remedy will provide additional certainty that contaminated groundwater will not cause exceedances of federal water quality criteria established under the Federal Water Pollution Control Act (40 CFR 131.38) for Cr(VI) in the Colorado River in the long term. **Location-specific ARARs.** Location-specific requirements will be met. Because surface water bodies are not being modified, USFWS coordination requirements (40 CFR 6.201) will not be triggered. Because RCRA-regulated treatment systems will not be constructed in a floodplain or seismic zone, RCRA seismic and floodplain requirements (40 CFR 264.18) will not be triggered. Construction of wells and piping in floodplain or wetland areas will be performed in a manner that complies with federal floodplain and wetlands protection requirements (40 CFR 6.201). Steps will be taken during design and implementation to ensure compatibility with the National Wildlife Refuge System Administration Act. The requirements of the National Historic Preservation Act (16 U.S.C. § 470, *et seq.*) are applicable based on the presence of and potential impact to historic properties listed on, or eligible for listing on, the National Register of Historic Places. Other cultural resource requirements include those of the National Archaeological and Historic Preservation Act (16 U.S.C. § 469, *et seq.*), the Native American Graves Protection and Repatriation Act, (25 U.S.C. § 3001, *et seq.*), and the Archaeological Resources Protection Act, 16 U.S.C. § 470aa-ii, *et seq.*). The requirements of the Historic Sites Act (16 U.S.C. § 461 *et seq.*) may apply to Route 66. In addition, there may be applicable requirements of Pub. L. 106-45 to preserve Route 66. Location and action-specific religious freedom requirements are set forth in the American Indian Religious Freedom Act and Religious Freedom Restoration Act. As a threshold matter, this alternative cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision, and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation	**Magnitude of Residual Risk.** Alternative H includes the application of *in-situ* treatment in the upland areas of the site and *ex-situ* treatment in an aboveground treatment plant in the floodplain area of the site to attain cleanup goals for Cr(VI) in groundwater. Alternative H includes a group of bedrock extraction wells in the eastern (downgradient) end of the East Ravine, with the water from the bedrock extraction wells managed within the active treatment system for the alluvial aquifer. Risk from residual contamination in groundwater would be reduced as Cr(VI) mass within the plume is treated. **Adequacy and Reliability of Controls.** Once the remedy is completed, monitoring and continued enforcement of institutional controls may be required to assess *in-situ* treatment byproducts. There is uncertainty associated with achieving complete distribution of carbon source substrate across this large of an area. Incomplete distribution can be overcome by achieving sufficient coverage to allow natural groundwater flow to transport any residual untreated chromium (that is not treated directly) to an adjacent treatment zone. Incomplete coverage also can be addressed through optimization of the remedy during implementation, which would involve additional dosing in areas where complete coverage was not achieved during the initial dose. The *ex-situ* treatment process produces waste byproducts that would require long-term controls; transportation to and disposal in an offsite permitted facility is assumed to provide reliable long-term containment of the waste byproducts. Alternative H includes pumping within the East Ravine bedrock to ensure hydraulic control of East Ravine groundwater. Five-year reviews would be required for this alternative. This alternative requires long-term containment systems (offsite) and land disposal of treatment residuals. Some residuals may remain after the remedy is completed; monitoring inside and outside the plume would be necessary to verify residual flushing. Pump-and-treat technology has been shown to be capable of reducing the size of plumes, and removing a large portion of the contaminant mass. At many sites that rely on pump-and-treat technology and flushing to remove contaminants, a	**Amount of Plume Destroyed or Treated.** The intent of this alternative is to address the entire area of groundwater where Cr(VI) concentrations are higher than 32 µg/L. Alternative H also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. If it is determined that additional remedial effort is needed to reach RAOs in East Ravine bedrock, other technologies could be applied to supplement the pumping wells. In addition to pumping for hydraulic control, technologies that may be applicable to East Ravine bedrock would include, but are not limited to, freshwater injection for flushing and injection of carbon amendments for *in-situ* reduction of Cr(VI). The mass of Cr(VI) in East Ravine bedrock is estimated to be less than one percent of the total Cr(VI) plume mass. **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** Alternative H includes *in-situ* treatment in the upland areas of the site and *ex-situ* treatment in an aboveground treatment plant for the floodplain area of the site. *In-situ* treatment would involve distributing an organic carbon substrate to create geochemically-reduced conditions to convert Cr(VI) in groundwater to insoluble Cr(III), thereby reducing the toxicity and mobility of the site contaminants. *Ex-situ* treatment in the floodplain area of the site in an aboveground treatment plant would likely involve using chemical reduction by addition of ferrous iron, oxidation, pH adjustment, and settling in a clarifier and final filtration. Similar to *in-situ* treatment, the *ex-situ* process converts Cr(VI) to Cr(III), thereby reducing the toxicity and mobility of the site contaminants. Cr(III) from the treatment process is removed from the site and disposed of in an offsite, permitted disposal facility. **Degree Treatment is Irreversible.** The degree of reversibility of the *in-situ* Cr(VI) reduction reaction is expected to ultimately result in Cr(VI) concentrations at levels similar to ambient Cr(VI). The *ex-situ* Cr(VI) reduction reaction is not reversible. Alternative H also includes extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. **Type and Quantity of Residual Remaining After Treatment.** The most significant residual byproducts from the *in-situ* treatment process will be manganese and arsenic, natural constituents of the aquifer matrix released into solution by reduction reactions. Once released, the reduced forms of manganese and arsenic will likely be attenuated through precipitation, sorption, diffusion, and co-precipitation. Residual byproducts will be managed through careful system monitoring and operations both inside and outside the plume.	**Protection of the Community During Remedial Action.** The community would be protected during this period by prohibiting the use of the groundwater for drinking water through institutional controls. Treatment byproducts could be temporarily elevated within portions of the treatment zone (Appendix E). The concentrations of byproducts could remain elevated at the site for a time but should eventually return to pre-remediation concentrations by adsorption reactions and eventually be immobilized as the aquifer returned to aerobic conditions. Monitoring would be ongoing to verify the effectiveness of the fluvial sediments in providing a natural geochemical barrier to the Colorado River and to monitor for *in-situ* treatment byproducts. The community would face limited disturbance from construction noise and physical hazards such as traffic related to material transport. Risks can be reduced through proper controls during construction and operation. **Protection of Workers During Remedial Action.** Workers would face general site hazards including heavy equipment, occupational noise exposure, slip and fall, etc. General site hazards would be reduced by site-specific health and safety plans and safety equipment. Workers would be required to wear appropriate personal protective equipment and use best management practices to minimize exposure. **Protection of the Environment During Remedial Action.** Preliminary design estimates suggest that this alternative would result in installation of approximately67 remediation well locations and 32 monitoring well locations and the treatment plant. Additionally, operation of the *ex-situ* system would result in environmental impacts because a substantial amount of electrical power would be required, as well as trucking requirements for delivery of treatment chemicals and disposal of wastes, with associated energy use and traffic hazards. Residuals would consist of waste byproducts containing Cr(III) and iron. Operation and maintenance of the aboveground treatment plant would include periodic sample collection, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Measures will be taken	**Technical Feasibility.** Alternative H is technically implementable. Installation of extraction wells, injection wells, IRZ wells, pipelines, utilities, and *ex-situ* treatment plant is technically implementable. Implementation of the IM has shown that extraction, treatment, and injection are technically implementable at this site. However, there is some amount of uncertainty about the overall ability to remove contaminants relying on flushing technology. Some wells may be challenging to install due to hydrogeologic conditions and excess depths, and varied and abrupt topography and access limitations will present challenges to construction of wells, pipelines, and utilities but the challenges can be overcome. This alternative includes installation of an IRZ within Bat Cave Wash that will present challenges associated with maintaining protection against future damage or washout. Pilot testing has shown that *in-situ* treatment is technically implementable at this site. However, some uncertainty exists about the application of i*n-situ* technology at this scale. Operation of the *ex-situ* and *in-situ* treatment system will require a high level of oversight during implementation to ensure that the system is optimized and modified as remediation progresses. **Administrative Feasibility.** Alternative H is administratively implementable. No offsite actions would be associated with Alternative H that would require permits from other agencies. The extraction wells, injections wells, pipelines, and utilities would be constructed primarily outside of PG&E property so construction and operation of these facilities would have to be coordinated with and approved by the respective landowners and leaseholders including BNSF, Caltrans, and other entities. There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. Administration of an institutional control to prohibit use of groundwater within the plume until attainment of cleanup goals would be required. The institutional control would need to be coordinated with the various landowners that overlie the plume. **Availability of Services and Materials.** Services, equipment, and materials for installation of the extraction wells,	$127,000,000 - $273,000,000

TABLE 5-5
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Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
	been eliminated; therefore, sources of wastewater discharge and hexavalent chromium have been controlled. However the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined, and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	Officers, and others to identify potential effects on cultural resources and evaluate and implement reasonable and prudent mitigation measures, thereby ensuring that the selected remedy attains these ARARs. **<u>Action-specific ARARs, including standards for management of wastes generated by the remedial action.</u>** This alternative can be designed and implemented to attain action-specific requirements. Injection of treated groundwater will be performed in a manner that meets Federal Underground Injection Control requirements (40 CFR Parts 144-148). There will be no discharge of fill to wetlands or waterways (40 CFR 230.10), point source discharge of pollutants to waters of the United States (40 CFR Parts 122, 125), or other activities that alter the course, condition, or capacity of navigable waters (33 USC § 401 and 403). Remedial activities will comply with applicable NPDES construction stormwater requirements (40 CFR 122.26). Remedial activities will not emit regulated hazardous air pollutants (40 CFR Parts 61, 63). Installation of wells, piping, reagent storage equipment, and *ex-situ* treatment plant will be performed in a manner that does not result in a “take” of threatened or endangered species, damage their critical habitat (50 CFR part 402), or impact migratory birds (15 USC § 703-712). Waste generated during remedial activities will be handled in compliance with hazardous waste generator requirements (22 CCR Division 4.5, Chapters 11, 12, 18). The treatment system will be constructed and operated in compliance with requirements for hazardous waste tank systems (22 CCR Div. 4.5, Ch. 14, Articles 2, 10); regulated waste piles, landfills, and miscellaneous units will not be constructed. Monitoring will be performed in accordance with RCRA (22 CCR Division 4.5, Ch. 14, Article 6) and California Water Code (23 CCR Div. 3, Chapter 15; 27 CCR Div. 2, Subdivision 1; Calif. Water Code Section 13801(c)) monitoring requirements. Because RAOs will achieve background levels for chromium, this alternative is consistent with the substantive provisions of SWRCB Resolution 68-16 that requires maintenance of the highest water quality consistent with maximum benefit to the people of the State and with the substantive provisions of SWRCB Resolution 92-49 that requires restoration of background water quality. It will also result in achieving Basin Plan water quality objectives for chromium in groundwater. Appropriate land use covenants will be implemented (22 CCR 67391.1).	limit is reached where concentrations are no longer being reduced effectively, but cleanup goals have not been met. Hexavalent chromium does not strongly sorb to soils, which makes it more amenable to flushing than some other contaminants, but it may still be difficult to reach cleanup levels across the entire plume. It is not possible to predict what the limit of concentration reduction might be for flushing technology at the Topock site. Maintaining hydraulic control through pumping or injection can be accomplished at the Topock site due to the flat groundwater gradients and lack of extensive aquitards within the Alluvial Aquifer. The pumping associated with Alternative H provides a landward gradient towards the extraction wells and away from the river, but in the process, river water may be drawn into the aquifer. The river water is aerobic and would become reduced as it moved out of the river and into the fluvial aquifer. Over the long period of time that this remedy would operate, the passage of this aerobic water through the fluvial sediments could result in some degradation of the natural reducing capacity. It is not possible to accurately predict where or to what extent this degradation in reducing capacity would occur.		during construction, sampling, and operational activities to minimize environmental disturbance. Additional protections to the environment and community will be through compliance with ARARs such as for floodplain and wetland protection and stormwater requirements. **<u>Time Until RAOs are Achieved.</u>** It is estimated that between 10 and 70 years would be required to achieve the RAOs for this alternative. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.	injections wells, pipelines, utilities, and *ex-situ* treatment plant are readily available. Some specialized services may be needed for construction and operation of certain treatment components in the *ex-situ* treatment plant; however, these services can be made available. Waste byproducts from the *ex-situ* treatment plant would need to be disposed of at an offsite, licensed disposal facility; although not widely available or close to the site, there are available disposal facilities elsewhere in California, Nevada, and/or Arizona. Offsite disposal facilities for drill cuttings or development water generated from the well installation, development, and sampling are widely available.	

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Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
Alternative I – Continued Operation of Interim Measure	**Protect Human Health and the Environment.** Alternative I would protect human health and the environment in the long term throughout most of the site through reduction of Cr(VI) concentrations in groundwater by *ex-situ* treatment. Monitoring would provide data to evaluate the effectiveness of *ex-situ* treatment. Uncertainty exists regarding the flow direction of groundwater in bedrock at AOC 10 for this alternative. This alternative protects human health in the short term by limiting exposure through restriction of groundwater use as potable water source until cleanup goals are met. The groundwater extraction to remove groundwater for *ex-situ* treatment would provide a landward gradient in the floodplain, thereby preventing movement of Cr(VI) toward the river; however, continued groundwater extraction near the river may lead to long-term damage to the reducing blanket surrounding the riverbed. No new construction is initially required, but steps would be taken during future construction (for routine replacement of existing facilities and structures) and during the operation of the remedial facilities to limit disturbance to sensitive resources. Steps to limit disturbance to sensitive resources may include moving locations of infrastructure away from sensitive resources, modification of construction techniques (e.g., equipment or schedules), modification of design elements (e.g., materials, configurations, sizes). Steps may also include programmatic elements such as awareness training for site personnel. The energy requirements for operation of the treatment plant will be high, and two waste streams are generated by the aboveground treatment plant: (1) sludge from the filtration process; and (2) brine or concentrate from the reverse osmosis process. Both waste streams would be removed from the treatment plant by truck and transported to offsite, permitted disposal facilities. **Attain Media Cleanup Goals.** Alternative I includes extraction at the leading edge of the alluvial aquifer and *ex-situ* treatment to attain cleanup goals for constituents in groundwater. The estimated time to achieve the RAOs in bedrock has not yet been estimated, pending the results of further AOC-10 investigations.	**Chemical-specific ARARs.** Chemical-specific requirements will be met. By achieving cleanup goals less than MCLs, the remedy will comply with federal (40 CFR Part 141-Subpart G) and California (22 CCR Division 4, Chapter 15) Drinking Water Act requirements for Cr(T) in groundwater delivered by a public water supply system. This alternative is considered to comply with the Federal Water Pollution Control Act because surface water samples collected within the river near the site, both before and after implementation of the IM, show concentrations less than federal water quality criteria (40 CFR 131.38) for Cr(VI), and naturally occurring reducing conditions in sediments near the Colorado River and dilution provided by the river are expected to continue to prevent contaminated groundwater from causing exceedances of these standards in the river prior to remedy completion. By achieving cleanup goals in alluvial groundwater, the remedy will provide additional certainty that contaminated groundwater will not cause exceedances of federal water quality criteria established under the Federal Water Pollution Control Act (40 CFR 131.38) for Cr(VI) in the Colorado River in the long term. However, as there is uncertainty regarding the flow direction of groundwater in bedrock at AOC 10, further studies would be needed to assess resulting gradient directions and the effectiveness of long-term natural attenuation in East Ravine bedrock in attaining water quality criteria. **Location-specific ARARs.** Location-specific requirements will be met. Because surface water bodies are not being modified, USFWS coordination requirements (40 CFR 6.201) will not be triggered. Because RCRA-regulated treatment systems will not be constructed in a floodplain or seismic zone, RCRA seismic and floodplain requirements (40 CFR 264.18) will not be triggered. Construction of wells and piping in floodplain or wetland areas will be performed in a manner that compiles with federal floodplain and wetlands protection requirements (40 CFR 6.201). Steps will be taken during design and implementation to ensure compatibility with the National Wildlife Refuge System Administration Act. The requirements of the National Historic Preservation Act (16 U.S.C. § 470, *et seq.*) are applicable based on the presence of and potential impact to historic properties listed on, or eligible for listing on, the National Register of Historic Places. Other cultural resource requirements include those of the National Archaeological and Historic Preservation Act (16 U.S.C. § 469, *et seq.*), the Native American Graves Protection and Repatriation Act, 25 U.S.C. § 3001, *et seq.*), and the Archaeological Resources Protection Act (16 U.S.C. § 470aa-ii, *et seq.*). The requirements of the Historic Sites Act (16 U.S.C. § 461 *et seq.*) may apply to Route 66. In addition, there may be applicable requirements of Pub. L. 106-45 to preserve Route 66. Location and action-specific religious freedom requirements are set forth in the American Indian Religious Freedom Act and Religious Freedom Restoration Act.	**Magnitude of Residual Risk.** Alternative I includes extraction and *ex-situ* treatment to attain cleanup goals for Cr(VI) in groundwater. Risk from residual contamination in groundwater would be reduced as Cr(VI) mass within the plume is treated. **Adequacy and Reliability of Controls.** The *ex-situ* treatment process produces sludge and brine that would require long-term controls; transportation to and disposal in offsite permitted facilities is assumed to provide reliable long-term containment of the sludge and brine. Five-year reviews would be required for this alternative. Pump-and-treat technology is capable of reducing the size of plumes and removing a large portion of the contaminant mass. However at many sites, pump-and-treat systems which rely on flushing to remove contaminants have reached a limit where concentrations are no longer being reduced effectively, but cleanup goals have not been met. Thus, it may still be difficult to reach cleanup goals across the entire plume under this alternative. The pumping associated with Alternative I provides a landward gradient towards the extraction wells and away from the river, but in the process, river water may be drawn into the aquifer. The river water is aerobic and would become reduced as it moved out of the river and into the fluvial aquifer. Over the long period of time that this remedy would operate, the passage of this aerobic water through the fluvial sediments could result in some degradation of the natural reducing capacity. It is not possible to accurately predict where or to what extent this degradation in reducing capacity would occur. Alternative I does not include pumping within the East Ravine bedrock.	**Amount of Plume Destroyed or Treated.** This alternative is the continued operation of the Interim Measure, which was designed for hydraulic control of the Cr(VI) in the floodplain area of the site. . **Degree of Expected Reduction in Toxicity, Mobility, and Volume.** Alternative I includes *ex-situ* treatment in an aboveground treatment plant using a continuous, multi-step process that involves reduction of Cr(VI) to Cr(III); precipitation and removal of precipitate solids by clarification and microfiltration; and lowering the naturally-occurring TDS using reverse osmosis. Similar to *in-situ* treatment, the *ex-situ* process converts Cr(VI) to Cr(III), thereby reducing the toxicity and mobility of the site contaminants. **Degree Treatment is Irreversible.** The Cr(VI) reduction reaction is not reversible. The Cr(VI) is removed from the groundwater through chemical reduction by ferrous iron compounds followed by alkaline precipitation and filtration. The resulting sludge is transported offsite to an appropriate permitted disposal facility for long-term management. The reversibility of the Cr(VI) reduction reaction depends on the geochemical conditions in the offsite permitted disposal facility. **Type and Quantity of Residual Remaining After Treatment.** Cr(III) resulting from the treatment process is removed from the site and disposed of in an offsite, permitted disposal facility.	**Protection of the Community During Remedial Action.** The community would be protected during this period by prohibiting the use of the groundwater for drinking water through institutional controls. Monitoring would be ongoing to verify the effectiveness of the fluvial sediments provide a natural geochemical barrier to the Colorado River. The community would face limited disturbance from construction noise, and physical hazards such as traffic related to material transport. Risks can be reduced through proper controls during construction and operation. **Protection of Workers During Remedial Action.** Workers would face general site hazards including heavy equipment, occupational noise exposure, slip and fall, and so on. General site hazards would be reduced by site-specific health and safety plans and safety equipment. Workers would be required to wear appropriate personal protective equipment and use best management practices to minimize exposure. **Protection of the Environment During Remedial Action.** This alternative would not require the installation of any additional extraction, injection, or monitoring wells. Operation of the *ex-situ* system would result in environmental impacts because a substantial amount of electrical power would be required, as well as trucking requirements for delivery of treatment chemicals and disposal of wastes, with associated energy use and traffic hazards. Residuals would consist of sludge containing Cr(III) and iron, and brine or concentrate from the reverse osmosis process. Operation and maintenance of the aboveground treatment plant would include periodic sample collection, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Measures will be taken during construction, sampling, and operational activities to minimize environmental disturbance. Additional protections to the environment and community will be through compliance with ARARs such as for floodplain and wetland protection and stormwater requirements. **Time Until RAOs are Achieved.** It is estimated that between 100 and 960	**Technical Feasibility.** Alternative I is technically implementable. Implementation of the IM has shown that extraction, treatment, and injection are technically implementable at this site. However, there is some amount of uncertainty about the overall ability to remove contaminants relying on flushing technology. Operation of the *ex-situ* treatment system will require some oversight during implementation to ensure that the system is operating correctly, but this alternative would not include changes to the number, location, and configuration of remedial systems over time to optimize and enhance the performance of the alternative to meet changing conditions or to enhance performance of the remedy to attain the cleanup goals. **Administrative Feasibility** Alternative I is administratively implementable. No offsite actions would be associated with Alternative I that would require permits from other agencies. Since the remedial facilities for Alternative I are already in place, there would be no new construction for Alternative I; however, operation and maintenance (that may require construction to replace system components) would need to be coordinated with and approved by the respective landowners. There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. Administration of an institutional control to prohibit use of groundwater within the plume until attainment of cleanup goals would be required. The institutional control would need to be coordinated with the various landowners that overlie the plume. **Availability of Services and Materials.** Some specialized services may be needed for operation of certain treatment components in the *ex-situ* treatment plant; however, these services can be made available. Treatment byproducts would need to be disposed of at an offsite, licensed disposal facility; although not widely available or close to the site, there are available disposal facilities elsewhere in California, Nevada, and/or Arizona. Offsite disposal facilities for drill cuttings or development water generated from the well replacement, development, and sampling are widely available.	$186,000,000 - $398,000,000

TABLE 5-5
Individual Detailed Analysis of Remedial Alternatives against Seven Criteria
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Protect Human Health and the Environment Attain Media Cleanup Goals and Control Source of Releases	Comply with ARARs	Long-term Effectiveness, Permanence and Reliability	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-term Effectiveness	Implementability	Cost Net Present Value
	Control Sources of Releases. The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have been eliminated; therefore, sources of wastewater discharge and hexavalent chromium have been controlled. However, the historic source of contaminated groundwater in bedrock at AOC 10 has not yet been determined, and the evaluation of whether leaching of soil contamination to groundwater represents a significant transport pathway has not yet been completed.	As a threshold matter, this alternative cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision, and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation Officers, and others to identify potential effects on cultural resources and evaluate and implement reasonable and prudent mitigation measures, thereby ensuring that the selected remedy attains these ARARs. **Action-specific ARARs, including standards for management of wastes generated by the remedial action.** This alternative can be designed and implemented to attain action-specific requirements. Injection of treated groundwater will be performed in a manner that meets Federal Underground Injection Control requirements (40 CFR Parts 144-148). There will be no discharge of fill to wetlands or waterways (40 CFR 230.10), point source discharge of pollutants to waters of the United States (40 CFR Parts 122, 125), or other activities that alter the course, condition, or capacity of navigable waters (33 USC § 401 and 403). Remedial activities will comply with applicable NPDES construction stormwater requirements (40 CFR 122.26). Remedial activities will not emit regulated hazardous air pollutants (40 CFR Parts 61, 63). Wells, piping, and the *ex-situ* treatment plant already exist, and were constructed in a manner that did not result in a "take" of threatened or endangered species, damage their critical habitat (50 CFR part 402), or impact migratory birds (15 USC § 703-712). Waste generated during remedial activities will be handled in compliance with hazardous waste generator requirements (22 CCR Division 4.5, Chapters 11, 12, 18). The treatment system was constructed and is operated in compliance with requirements for hazardous waste tank systems (22 CCR Div. 4.5, Ch. 14, Articles 2, 10); regulated waste piles, landfills, and miscellaneous units will not be constructed. Monitoring will be performed in accordance with RCRA (22 CCR Division 4.5, Ch. 14, Article 6) and California Water Code (23 CCR Div. 3, Chapter 15; 27 CCR Div. 2, Subdivision 1; Calif. Water Code Section 13801(c)) monitoring requirements. Because RAOs will achieve background levels for chromium, this alternative is consistent with the substantive provisions of SWRCB Resolution 68-16 that requires maintenance of the highest water quality consistent with maximum benefit to the people of the State. It will also result in achieving Basin Plan water quality objectives for chromium in groundwater. This alternative will not comply with California State Water Board Resolution 92-49. Appropriate land use covenants will be implemented (22 CCR 67391.1).			years would be required to achieve the RAOs for this alternative. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.		

Note: Refer to Appendices D and F for assumptions supporting conceptual design of the alternatives.

Proposed Plan. Figure 5-12 presents the comparison of the alternatives against these seven criteria. In general terms, the comparative analysis is a qualitative review of how each alternative achieves the RAOs described in Section 3.0, how each reflects various risks and benefits to its implementation, and the associated tradeoffs.

5.5.1 Protect Human Health and the Environment, Attain Media Cleanup Goals, and Control Sources of Releases

This criterion is summarized by addressing the following factors:

- Protect human health and the environment
- Attain media cleanup goals
- Control sources of releases

The following subsections address each of these factors.

5.5.1.1 Protect Human Health and the Environment

As concluded in the groundwater risk assessment, there are no current direct or indirect complete exposure pathways for contact with site groundwater, and there are no human or ecological populations currently at risk of adverse health effects due to groundwater at the Topock site (ARCADIS, 2009). All alternatives will need to rely on institutional controls until their completion to ensure that exposure pathways are not created during the remedial process. Alternative A does not include institutional controls and therefore provides the possibility of future exposure to human populations in residential setting prior to attainment of cleanup goals. Alternatives B through I include an institutional control that would prohibit use of the groundwater as a potable water supply/drinking water source until the cleanup goals are attained, thereby eliminating the potential future pathway for human health risk from direct exposure to groundwater. Alternatives B and I are considered less protective than Alternatives C, D, E, F, G, and H because of the considerably longer time that an institutional control would need to be maintained to prohibit use of the groundwater as a potable water supply/drinking water source. Alternatives C through G are all considered equally protective in this regard.

With regard to verifiable river protection, Alternatives C, D, E, F, G and H are considered equally protective. Alternative I ranks lower than Alternatives C through H because of the considerably longer time until cleanup goals are achieved. Existing data show that concentrations in surface water collected from the Colorado River, both upgradient and downgradient of the site, both before and after implementation of the interim measure, are below water quality standards that support the designated uses of the Colorado River (CH2M HILL, 2009a), and the groundwater risk assessment concluded that the potential transport of constituents in groundwater to the Colorado River represents an insignificant transport pathway (ARCADIS, 2009). The two alternatives that rely on natural processes to convert Cr(VI) to Cr(III) (Alternatives A and B) have some uncertainty about protection of the river in the long term because there is no way to prove that the reducing conditions exist everywhere, and over the centuries that would be required for natural processes to reach cleanup goals, it is possible that the geochemistry or groundwater flow directions, or even the location of the Colorado River channel, could change significantly. Further studies to assess the effectiveness of long-term natural attenuation in the East Ravine will continue during remedial design.

Alternatives C, D, E, and G include floodplain cleanup (mass removal and establishment of geochemical barriers in the floodplain) as the initial step in the implementation. Alternatives E, F, G, H, and I include extraction and, thereby, hydraulic control, providing additional certainty of river protection. Alternatives C through H also include extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. For Alternative I, uncertainty exists regarding the flow direction of groundwater in bedrock at East Ravine.

These two approaches (mass removal/establishment of geochemical barrier in floodplain and hydraulic containment) both will require a high level of management to ensure that the natural reducing conditions in the floodplain are not damaged or otherwise altered in a manner that diminishes the natural reductive capacity of the floodplain. Management of reducing conditions will involve regular sampling of groundwater to monitor redox conditions and possibly dosing with organic carbon to restore floodplain reducing capacity if it becomes depleted.

5.5.1.2 Attain Media Cleanup Goals

All of the remedial alternatives would attain the media (groundwater) cleanup goals, although the time to achieve the goals would vary depending upon the type of treatment. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.

Alternatives A, B, and I would require the longest time to attain the media cleanup goals. It is estimated that Alternatives C, D, E, F, G, and H would attain the cleanup goals sooner through induced treatment, either *in-situ*, *ex-situ*, or both, with Alternative D likely requiring the least time because of the localized, intensive nature of the *in-situ* treatment activities.

By attaining the cleanup goals, the alternatives would reduce the potential human health risk from exposure to Cr(VI) and Cr(T) through the hypothetical future use of groundwater as a potable water supply/drinking water source in the long term (after cleanup goals have been attained). As discussed in Section 3.3.1, the preliminary cleanup goal for Cr(VI) (32 µg/L) is lower than the calculated noncancer risk-based remediation goal for Cr(VI) (46 µg/L), assuming future hypothetical human groundwater users that may be exposed to site groundwater in a residential setting.

5.5.1.3 Control Sources of Releases

The historic practice of wastewater discharge to Bat Cave Wash and the use of hexavalent chromium at the site have been eliminated. Therefore, sources of wastewater discharge and hexavalent chromium have been controlled. However, the historical source of contaminated groundwater in bedrock at AOC 10 has not yet been determined, and the evaluation of whether leaching of Cr(VI) from contaminated soils represents a significant transport pathway to groundwater has not yet been completed. There is no distinction between the alternatives with respect to this criterion.

5.5.1.4 Overall Ranking for Protect Human Health and the Environment, Attain Media Cleanup Goals, and Control Sources of Releases

In summary, Alternative A does not meet the threshold criteria for protecting human health and the environment because there would be no institutional controls imposed to restrict use of groundwater in locations where Cr(VI) concentrations exceed the cleanup goals, and there would be no monitoring to evaluate changes in geochemical conditions near the river over the long time period required to reach the cleanup goals. Alternatives B through I are all considered to meet the threshold criteria of protecting human health and the environment. Alternatives C, D, E, F, G, and H were ranked high for this criterion; these alternatives would all provide for protection of human health from exposure due to use of groundwater as a drinking water supply in both the short term and long term. These alternatives would also provide additional certainty for river protection as a result of floodplain cleanup (mass removal in the floodplain and establishment of a geochemical barrier) as the initial step in implementation and/or through hydraulic control. Alternatives B and I ranked medium for this criterion primarily because of the long time required to attain cleanup goals, which would require long-term use of institutional controls, as well as the uncertainty about the robustness of the natural geochemical conditions near the river over this relatively long time for Alternative B, and the high level of operation and maintenance for Alternative I.

5.5.2 Comply with Applicable or Relevant and Appropriate Requirements

The following paragraphs present the evaluation of compliance with ARARs (DOI, 2009e).This threshold criterion evaluates whether each alternative would attain the federal and state ARARs identified for the cleanup of Cr(VI) in the groundwater at the Topock site. An alternative must attain all identified ARARs, or provide grounds for invoking an ARAR waiver, in order to be eligible for selection. The ARARs for the Topock site are identified in Appendix B and have been determined to be ARARs for this site by the DOI. In addition, each alternative described in this CMS/FS has been evaluated by DOI in terms of its attainment of ARARs.

There are a number of cultural resource ARARs identified for the site. In general, they require that a federal agency identify and consider the effects of an undertaking on cultural resources and seek ways, through consultation, to avoid, minimize, or mitigate any adverse effects. As a threshold matter, none of the alternatives under consideration in this CMS/FS has been determined to fail to satisfy these cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision and a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation Officers, and others to identify potential effects on cultural resources and to seek ways to avoid, minimize, or mitigate any adverse effects, thereby ensuring that the selected remedy attains these ARARs.

In addition, with respect to any remedial action to be undertaken within the HNWR, the National Wildlife System Administration Act has been identified as an ARAR. This statute governs the use and management of National Wildlife Refuges, requiring that ongoing and proposed activities and uses on a Refuge are appropriate and compatible with both the mission of the National Wildlife Refuge System, as well as the specific purposes for which a Refuge was established. Prior to the selection of a remedial action by DOI/USFWS, that remedial action must be found by the HNWR Manager to be both an appropriate use of the Refuge and compatible with the mission of the Refuge and the Refuge System as a whole. Any remedial action proposed to be implemented on the HNWR that was not selected by DOI/USFWS would be subject to the formal appropriate use/compatibility determination process. As a threshold matter, none of the alternatives under consideration in this CMS/FS has been determined to fail to satisfy this ARAR. After a remedy is selected by DOI/ USFWS, USFWS will identify, during remedial design and implementation, those measures necessary to ensure that the selected remedy satisfies this ARAR.

Finally, based on the specific circumstances presented at the Topock site, Alternatives A, B, and I do not satisfy all identified ARARs. Specifically, these alternatives would not satisfy the "reasonable time frame" requirement established by the California State Water Resources Control Board Resolution 92-49. This Resolution requires that the selected remedy have "a substantial likelihood to achieve compliance, within a reasonable time frame, with the cleanup goals and objectives" established for a site. At DOI's request, the Water Board has interpreted this requirement in light of the specific alternatives under consideration at the Topock site. The Water Board is the state entity that originally identified this Resolution as a potential ARAR for this site, and it is the Water Board's responsibility to interpret and enforce this Resolution. In a letter, dated October 7, 2009, the DTSC as the lead State agency forwarded the recommendation from the Water Board stated that: "With respect to the nine alternatives and estimated cleanup time frames described in PG&E's draft Corrective Measures Study/Feasibility Study (CMS/FS), dated January 2009, Alternatives A, B, and I would not comply with the 'reasonable time frame' provision in Section III.A. of Resolution 92-49. Alternatives C through H would comply with this provision." Based on the analysis and supporting information provided by the Water Board, DOI concurs with the Water Board's interpretation of this Resolution as it pertains to the Topock site. In summary, alternatives C, D, E, F, G and H have been determined to comply with all ARARs. As a threshold matter, none of the alternatives under consideration in this CMS/FS has been determined to fail to satisfy cultural resource ARARs or the National Wildlife System Administration Act. Alternatives A, B, and I would not satisfy the ARAR requirements of the California State Water Resources Control Board Resolution 92-49, and thus fail to meet this threshold criterion.

5.5.3 Long-term Effectiveness, Permanence, and Reliability

This criterion is summarized by addressing the:

- Magnitude of residual risk remaining from untreated waste or treatment residuals at the conclusion of the remedial activities.
- Adequacy and reliability of controls such as containment systems and institutional controls that are necessary to manage the untreated waste or to manage treatment residuals that remain at the site.

The following subsections address these factors.

5.5.3.1 Magnitude of Residual Risk

All nine of the alternatives would reduce concentrations of Cr(VI) in groundwater at the site, either through natural reductive processes (Alternatives A and B), through *in-situ* treatment (Alternatives C, D, E, G, and H), and/or through *ex-situ* treatment (Alternatives F, G, H, and I). Alternatives C through H also include extraction within the East Ravine bedrock.

As such, the magnitude of residual risk from Cr(VI) remaining is comparable for all alternatives (after RAOs are met). Risk from residual contamination in groundwater would be reduced as Cr(VI) mass within the plume is treated.

5.5.3.2 Adequacy and Reliability of Controls

Alternatives that incorporate *ex-situ* treatment (Alternatives F, G, H, and I) will produce sludge as a treatment byproduct, and Alternative I will also produce a brine or concentrate from the reverse osmosis process. Long-term controls would be required for the treatment byproducts. Disposal in a permitted, offsite facility is assumed to provide reliable long-term containment for the byproducts.

With the exception of Alternative A, all the alternatives would include 5-year reviews to evaluate the effectiveness of the remedy to attain RAOs, as well as the adequacy and reliability of controls. Because Alternative A would not include monitoring or 5-year reviews, future changes in geochemistry or hydrogeologic characteristics would not be identified.

With regard to the degree of certainty that the alternative will be successful, there are uncertainties associated with all nine alternatives. Alternatives A and B only rely on natural attenuation to convert Cr(VI) to Cr(III). While the reducing conditions have been shown to be robust, there is no way to prove that these conditions exist everywhere, and over the centuries that would be required for MNA to reach cleanup goals, it is possible that the geochemistry or groundwater flow directions, or even the location of the Colorado River channel, could change significantly.

Alternatives C, D, E, G, and H include *in-situ* treatment, and there is uncertainty associated with distribution of carbon source substrates across this large of an area. It is possible that these uncertainties can be overcome by achieving sufficient coverage to allow natural transport of the residual chromium (that is not treated directly) to contact the treatment zones created. This concern is also addressed through optimization of the remedy during implementation and is expected to be more challenging in alternatives that target the whole plume for distribution of substrates (Alternatives C and D), in comparison to alternatives where *in-situ* treatment is limited to establishment of a geochemical barrier in the floodplain.

Alternatives E, F, G, and H rely on flushing technology. Many sites that rely on flushing to remove contaminants have reached a limit where concentrations are no longer being reduced effectively, but cleanup goals have not been met, and it is not possible to predict what the limit of concentration reduction might be for flushing technology at the Topock site. Maintaining hydraulic control through pumping or injection can be accomplished at the Topock site due to the flat groundwater gradients and lack of extensive aquitards within the Alluvial Aquifer. Alternatives C, D, E, F, G, and H include provisions for optimization of the remedy during or after the active phase. These provisions for optimization are not included with Alternative I.

Alternatives C through H include pumping within the East Ravine bedrock to ensure hydraulic control of East Ravine groundwater.

5.5.3.3 Overall Ranking for Long-term Protectiveness, Permanence, and Reliability

In summary, Alternative A (No Action) ranked the lowest of all alternatives because this alternative does not include monitoring to verify the effectiveness of natural recovery processes and to determine when the RAOs have been achieved. Any future changes in site conditions that may cause undesirable impacts to the Colorado River or unacceptable exposures to other receptors would not be detected under Alternative A. Alternative B ranked medium because, in contrast to Alternative A, Alternative B would include monitoring and institutional controls; however, this alternative relies on natural attenuation to convert Cr(VI) to Cr(III), and while the reducing conditions have been shown to be robust, there is no way to prove that these conditions exist everywhere. Over the centuries that would be required for MNA to reach cleanup goals, it is possible that the geochemistry or groundwater flow directions, or even the location of the Colorado River channel, could change significantly.

Alternatives F, G, H, and I all ranked medium for long-term effectiveness, permanence, and reliability. These alternatives include *ex-situ* treatment; the resulting waste generation requiring land disposal of treatment residuals at an offsite, permitted landfill requires long-term containment, management, and monitoring that are not required by the alternatives that include *in-situ* treatment.

Alternatives C, D, and E ranked medium-high for this criterion. While there is uncertainty regarding the ability to distribute substrates across the targeted area, and Alternative E relies on flushing to remove contaminants from the upland portion of the aquifer, comparatively few long-term controls are expected for these alternatives following attainment of cleanup goals.

5.5.4 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion is summarized by addressing the:

- Amount of plume destroyed or treated.
- Degree of expected reduction in toxicity, mobility, and volume.
- Degree to which treatment is irreversible.
- Type and quantity of residual remaining after treatment.

The following subsections address each of these factors.

5.5.4.1 Amount of Plume Destroyed or Treated

All nine alternatives would address the entire area of groundwater within the Alluvial Aquifer where Cr(VI) concentrations are higher than 32 µg/L, either through natural reductive processes (Alternatives A and B), through *in-situ* treatment (Alternatives C, D, E, G, and H), and/or through *ex-situ* treatment (Alternatives F, G, H, and I).

Alternatives C through H also include extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater. If it is determined that additional remedial effort is needed to reach RAOs in East Ravine bedrock, other technologies could be applied to supplement the pumping wells. In addition to pumping for hydraulic control, technologies that may be applicable to East Ravine bedrock would include, but are not limited to, freshwater injection for flushing and injection of carbon amendments for insitu reduction of Cr(VI).

Because the mass of Cr(VI) in East Ravine bedrock is estimated to be less than one percent of the total Cr(VI) plume mass, the amount of the plume treated is considered comparable for all alternatives.

5.5.4.2 Degree of Expected Reduction in Toxicity, Mobility, and Volume

All nine alternatives involve reduction of Cr(VI) to Cr(III); Cr(III) is a less toxic and essentially immobile form of chromium.

Alternatives A and B rely on the natural reducing conditions in fluvial materials near the Colorado River to reduce Cr(VI) to Cr(III) through no active treatment, while the remaining alternatives involve active treatment to reduce Cr(VI) to Cr(III) either *in-situ* (Alternatives C, D, E, G, and H) and/or *ex-situ* (Alternatives F, G, H, and I). Alternatives C through H also include extraction within the East Ravine bedrock to provide hydraulic control of East Ravine groundwater.

The degree of treatment for Alternatives A and B is considered lower than for Alternatives C through I because the extent of reduction in toxicity, mobility, and volume of Cr(VI) in Alternative A and B is less certain, while the entire Alluvial Aquifer plume would be targeted by active treatment in Alternatives C through I. The intent of Alternatives C through I is reduction of Cr(VI) concentrations to 32 μg/L and, therefore, the reduction of the toxicity, mobility, and volume of Cr(VI) through treatment.

5.5.4.3 Degree to Which Treatment is Irreversible

Reduction of Cr(VI) in an *ex-situ* treatment process such as for Alternatives F, G, H and I is not reversible. The Cr(VI) is removed from the groundwater through chemical reduction by ferrous iron compounds followed by alkaline precipitation and filtration. The resulting sludge is transported offsite to an appropriate disposal facility for long-term management.

The degree to which the Cr(VI) reduction is irreversible is similar for the alternatives involving *in-situ* treatment (Alternatives A, B, C, D, E, G, and H). As discussed in Section 5.2.6, once reduced to Cr(III), chromium takes the form of the Cr^{3+} ion and forms very low solubility oxides under the neutral and alkaline pH encountered in site groundwater. Solubility of chromium oxide Cr_2O_3 and chromium hydroxide, $Cr(OH)_3$, are low enough to maintain the Cr^{3+} concentration below the detection limit of 0.2 μg/L (Brookins, 1988; Ball and Nordstrom, 1998). Once reduced, Cr(III) does not readily become reoxidized to Cr(VI); however, Cr(III) that comes into contact with manganese oxide (MnO_2) or dissolved oxygen can be re-oxidized to Cr(VI), leading to increased concentrations of Cr(VI) over time. Two key factors are expected to limit the reconversion of Cr(III) to Cr(VI) after *in-situ* reduction: the limited solubility of Cr(III) and the lack of availability and reactivity of an adequate oxidizer (MnO_2). Together these factors are expected to limit any reoxidized Cr(VI) concentrations to levels similar to ambient background.

5.5.4.4 Type and Quantity of Residual Remaining After Treatment

Alternatives C through I differ in the type and quantity of residual remaining after treatment. Alternatives C, D, E, G, and H include *in-situ* treatment, where iron, manganese, and arsenic are potential residual byproducts. Alternatives C and D include *in-situ* treatment throughout the plume, while Alternatives E, G, and H include more limited *in-situ* treatment either within the floodplain area (Alternatives E and G) or the upland areas (Alternative H). Alternatives F, G, H, and I involve *ex-situ* treatment that generates sludge as a treatment byproduct.

Manganese is present in the Alluvial Aquifer as Mn(IV) in solid manganese oxide, and in the fluvial aquifer found adjacent to the Colorado River, manganese is present in its reduced, soluble Mn(II) form. *In-situ* reduction locally transforms Mn(IV) to soluble Mn(II) and the oxide dissolves, leading to the temporary formation of a zone with soluble manganese. After the organic carbon in the IRZ is degraded, soluble manganese is reprecipitated in its oxidized Mn(IV) form.

Natural arsenic is present in the Alluvial Aquifer commonly in association with iron oxide minerals, as an adsorbed and/or coprecipitated phase. In the fluvial aquifer found adjacent to the Colorado River, arsenic is present in its reduced, soluble As(III) form. Under reducing conditions within the fluvial zone, the iron oxides dissolved as iron is reduced from Fe(III) to Fe(II), releasing the associated As(V) and partially reducing it to As(III). In a similar way, when an IRZ is formed by the injection of a carbon source, a zone with soluble arsenic is formed, though at a lower maximum concentration than the fluvial zone found adjacent to the Colorado River (see Appendix G).

Both Mn(II) and As(III) are attenuated by adsorption reactions and consequently do not transport rapidly through groundwater. They both are significantly attenuated within the anaerobic IRZ zone, generally with limited migration out of the reduced zone. Mn(II) and As(III) are also easily reoxidized and immobilized when they reach a more oxidizing environment.

It is expected that byproducts such as arsenic and manganese will exceed baseline and background concentrations during implementation of *in-situ* methods. Under ideal geochemical and hydrologic conditions described in Appendix G arsenic and manganese byproducts should not be a significant issue. However, because of uncertainty in the complexity of aquifer lithology and geochemistry, large-scale implementation of *in-situ* treatment could result in elevated concentrations of arsenic and manganese that persist for longer than expected periods of time in some portions of the aquifer. Careful monitoring during the initial phase(s) of *in-situ* operation will enable early detection of these conditions. Specific contingency measures will be available to address potential threat to the Colorado River or the aquifer.

Alternatives C and D are designed to produce reducing conditions in all portions of the plume and therefore would temporarily produce zones around the injection wells with the most manganese and arsenic. Depending on the resulting groundwater concentrations of these elements, some monitoring time may be required following the active treatment phase before they are naturally reprecipitated within the aquifer.

Alternatives E and G include an initial phase of floodplain cleanup using *in-situ* technology, and Alternative H includes *in-situ* treatment in the upland areas. Alternative E would also include *in-situ* application in a limited area around the upland injection wells but, unlike Alternatives C and D, would not result in producing reducing conditions throughout the upland. These alternatives affect a much smaller area with *in-situ* treatment than Alternatives C and D and therefore would be expected to require less monitoring following the active period of each alternative. Only those portions of the floodplain that are currently oxidizing will be treated by *in-situ*, and these zones will potentially have soluble manganese and arsenic which, in time, should return to the solid phase within the aquifer. Careful monitoring of potential byproducts both inside and outside the plume will be conducted. Naturally reduced areas of the floodplain adjacent to the Colorado River have high concentrations of solid phase organic carbon, which already have contributed to high concentrations of dissolved iron, manganese, and arsenic.

Alternatives F, G, and H involve *ex-situ* treatment that generates sludge as a treatment byproduct. Alternative I will also generate brine or concentrate from the reverse osmosis process. The sludge and/or brine would be managed by disposal at an offsite, permitted disposal facility.

5.5.4.5 Overall Ranking for Reduction of Toxicity, Mobility, or Volume through Treatment

In summary, Alternatives F, G, and I are ranked high because the toxicity, mobility, and volume of Cr(VI) is reduced throughout the plume. Byproducts from *in-situ* treatment are expected to be localized to the reducing zone formed by the IRZ and within the range of naturally occurring concentrations found at the site (Appendix G) but could remain temporarily elevated above baseline and background concentrations in some portions of the aquifer. If monitoring indicates that byproducts remain elevated for an extended period of time, appropriate actions will be taken. For these reasons, Alternatives C, D, E, and H are ranked medium high. Byproducts from *ex-situ* treatment would be managed through disposal at an offsite, permitted disposal facility. Alternatives A and B ranked medium because the amount of plume destroyed or treated is less certain due to the passive nature of treatment and the extent and average capacity of the floodplain area to naturally reduce Cr(VI) over time.

5.5.5 Short-term Effectiveness

This criterion addresses:

- Time until remedial action objectives are achieved.
- Protection of the community during remedial action.
- Protection of the workers during remedial action.
- Protection of the environment during remedial action.

The following subsections address each of these factors. Tables 5-6A and 5-6B summarize the estimated component quantities and various features discussed under this criterion for each alternative.

TABLE 5-6A
Remedial Alternative Component Summary for Short-term Effectiveness Evaluation
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

	Well Locations			*Ex-situ* Treatment	Pipelines, Utilities, Roads (Lengths in 1,000s of feet)						Extraction, Injection, and IRZ Well Locations by Area			
Alternative	**Remediation [b]**	**Monitoring**	**Total**	**Above ground Treatment Plant**	**Piping**	**Trenches**	**Electrical**	***In-Situ* Reduction Zone**	**Access Roads**	**Number Under Crossings**	**Upland**	**Floodplain**	**Bedrock (East Ravine)**	**Estimated Time to Cleanup (Years) [a]**
A - No Action	0	0	0	0	0	0	0	-	0	0	0	0	0	220-2,200
B - Monitored Natural Attenuation	0	28	28	0	0	0	0	-	0	0	0	0	0	220-2,200
C - High-volume *In-situ* Treatment	111	32	143	0	18.4	24.4	29.6	5.3	7.7	1	49	47	15	10-60
D - Sequential *In-situ* Treatment	87	40	127	0	26.2	31.2	55.3	25	8.0	2	62	10	15	10-20
E - *In-situ* Treatment with Fresh Water Flushing	51	28	79	0	23.8	21.0	23.6	2.9	3.0	0	12	24	15	10-110
F - Pump and Treat	26	24	50	1	16.9	13.0	12.7	0	3.0	2	11	0	15	15-150
G - Combined Floodplain *In-situ*/ Pump and Treat	59	30	89	1	18.0	16.6	20.3	5.3	6.0	2	11	33	15	10-90
H - Combined Upland *In-situ*/Pump and Treat	67	32	99	1	24.0	22.1	24.9	6.6	5.8	1	47	5	15	10-70
I - Continued Operation of Interim Measure	0	0	0	1	0	0	0	0	0	0	0	0	0	100-960

Notes: Quantities shown in this table were developed for conceptual cost estimating and alternative comparison purposes. Actual quantities and distances may change based on site-specific considerations, constraints, or future evaluation. Quantities are for initial construction and do not include subsequent construction associated with future optimization or replacement during the remedial implementation period.

[a] See Appendix D.

[b] – Remediation Well Locations include extraction wells, injection wells, and wells for IRZ system. There may be more than one well per location based on site conditions. For cost estimating purposes, the number of remediation wells (not well locations) is included in Appendix D, Table D-19A.

Note: Refer to Appendices D and F for assumptions supporting conceptual design of the alternatives.

TABLE 5-6B
Remedial Alternative Component Summary for Short-term Effectiveness Evaluation
Revised
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Alternative	Description	Extraction, gpm	Injection, gpm	Net Consumptive Use, gpm	Annual Energy Use, kW-hr/yr	Waste, Tons/Year	CO_2, Tons per Year[d]	Truck, Trips per Year [e]
A - No Action	No Action	N/A	N/A	N/A [a]	0	0	0	0
B - Monitored Natural Attenuation	Monitored Natural Attenuation	N/A	N/A	N/A	0	0 [b]	40	0
C - High-volume *In-situ* Treatment	High Volume *In-situ* Treatment	2,000	2,000	0 [b]	1,300,000	0 [b]	820	100
D - Sequential *In-situ* Treatment	Sequential *In-situ* Treatment	27-1,500	27-1,500	0 [b]	400,000	0 [b]	300	50
E - *In-situ* Treatment with Fresh Water Flushing	*In-situ* Treatment with Freshwater Flushing	1,140	1,140	0 [b]	800,000	0 [b]	500	20
F - Pump and Treat	Pump and Treat	1,280	1,280	0 [b]	5,400,000	3,100	3,100	180
G - Combined Floodplain *In-situ*/Pump and Treat	Combined Floodplain *In-situ*/Pump and Treat	1,230	1,230	0 [b]	5,400,000	3,100	3,200	200
H - Combined Upland *In-situ*/Pump and Treat	Combined Upland *In-situ*/Pump and Treat	500	500	0 [b]	3,800,000	650	2,200	150

I - Continued Operation of Interim Measure	Continued Operation of Interim Measure [c]	125-133	124-132	1-3	1,800,000	220 [f]	1,300	220

Notes:

Quantities shown in this table are estimates developed for conceptual cost estimating and alternative comparison purposes. Actual quantities and rates may change based on site-specific considerations, constraints, or future evaluation. Includes primary treatment elements of alternatives, and does not include activities such as construction or monitoring.

af-yr = acre-feet per year

[a] Not applicable as no pumping for extraction or injection is a part of the alternative.

[b] Minimal.

[c] Rates are based on recent plant performance (December 2008 to March 2009). Rates are adjusted to account for plant downtime. As described in Appendix F, extraction rate assumption and injection rate assumption for estimating cleanup time for Alternative I are 135 gpm and 120 gpm, respectively.

[d] Alternative specific assumptions regarding number of vehicle trips were developed. Vehicles trips include heavy truck, field vehicle (light truck) and personal vehicles for employees. Vehicle carbon dioxide emissions based on the following:

- 0.0016 CO_2 equivalents (tons/mile) for diesel heavy truck at 7 miles per gallon (mpg).
- 0.0008 CO_2 equivalents (tons/mile) for field vehicle at 15 mpg.
- 0.0006 CO_2 equivalents (tons/mile) for personal vehicle at 20 mpg.

CO_2 equivalents for diesel vehicles based on California Climate Action Registry General Reporting Protocol, March 2007: http://www.climateregistry.org/PROTOCOLS/grcp/.

CO_2 equivalents for gasoline vehicles based on USEPA Office of Transportation and Air Quality data: http://www.epa.gov/OMS/climate/420f05004.htm.

CO_2 emissions include those for electrical power generation at 0.00521 tons per kilowatt-hour. Average value for Natural Gas from Environmental Costs of Electricity, Pace University Center for Environmental and Legal Studies (Oceana Publications, 1990), which includes data (in pounds) from PLC Inc., and Oak Ridge National Laboratories for the United States Department of Energy.

[e] Does not include maintenance activities or pick-up trucks.

[f] Does not include brine waste.

5.5.5.1 Time Until Remedial Action Objectives are Achieved

Under Alternatives A and B, the time required for the natural recovery processes to achieve the RAOs is estimated to range from 220 to 2,200 years. Alternative I is estimated to require from 100 to 960 years to achieve the RAOs. The active remediation technologies associated with Alternatives C through H are designed to significantly shorten the time to achieve RAOs; therefore, all of these alternatives ranked higher than Alternatives A, B, and I for this aspect of short-term effectiveness. The ranges in times to cleanup for all alternatives are shown in Tables 5-6A and 5-6B. The estimated time to achieve the RAOs was based on the simulated time to remove 98 percent of the Cr(VI) mass within the plume. The amount of Cr(VI) mass within the East Ravine bedrock is estimated to be less than one percent of the total plume mass, and therefore does not significantly affect the simulated time to cleanup.

5.5.5.2 Protection of the Community During Remedial Action

Under Alternative A (No Action), no remedial action would occur; therefore, there would be no short-term disturbance to the community from construction activities. However, Cr(VI) in groundwater would not be addressed, the time for natural recovery processes to occur is estimated to be over 200 years, and performance monitoring would not be included in this alternative. Further, Alternative A would not include an institutional control to limit exposure from future development of a water supply within the plume prior to attainment of cleanup goals.

Alternatives B through I all include an institutional control to prohibit development of a water supply within the plume area prior to attainment of cleanup goals, thereby providing protection to the community from exposure via a hypothetical future drinking water source during the remediation period. When compared to Alternatives C through I, Alternative B would cause the least short-term disturbance to the community since minimal construction would occur to add groundwater monitoring wells to the existing network.

The four *ex-situ* treatment alternatives, Alternatives F, G, H and I, were ranked low with respect to effects to the community, workers and environment during implementation of the remedy from construction and operation of an aboveground treatment plant. Construction of an aboveground treatment plant (Alternatives F, G, and H) would include foundation, exterior structure, tanks, piping, pumps, equipment, controls and instrumentation. Operation and maintenance of the aboveground treatment plant would include periodic sample collection, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Construction and operation of the *ex-situ* system would result in greater environmental disturbance than the *in-situ* treatment alternatives due to the greater amount of construction, aboveground visual impact, worker/operator presence onsite, and electrical power that would be required for the building and operation of a treatment plant. Operation of the *ex-situ* system would result in greater trucking requirements for chemical delivery and waste disposal than the *in situ* treatment systems. Greater trucking requirements for chemical delivery and waste transportation and disposal would generate the greatest amount of waste. Alternative I does not require construction of a new treatment plant, but does include a high level of operation and maintenance for a substantially longer period than the treatment plant associated with Alternatives F, G, and H. With respect to effects to the community during implementation of the *in-situ* alternatives, Alternatives C and E were comparably ranked as high for short-term effectiveness because these alternatives would result in a similar and relatively limited amount of construction and operation of the remedial facilities. As shown in Table 5-6A, Alternative C would include installation of more wells than Alternative E; however, Alternative E would involve more piping and trenches than Alternative C. Operation and maintenance activities for Alternatives C, D and E are similar and include periodic well maintenance, sample collection, and refinement of the injection/recirculation systems; management of the reactant material; equipment inspections; and periodic replacement of wells and other structures that become clogged or damaged. Controls would be implemented during construction and operational phases to limit disturbance to the community during the remedial activities.

Alternative D involves implementation of *in-situ* treatment systems similar to Alternatives C and E. However, in contrast to Alternatives C and E, Alternative D does not minimize construction of remedial facilities in previously disturbed areas and would therefore result in more disruption to the community than Alternatives C and E. Alternative D, therefore, was ranked low for protection of the community during implementation of the remedy.

5.5.5.3 Protection of the Workers During Remedial Action

Under Alternative A (No Action), no remedial action would occur; therefore, there would be no short-term disturbance to workers from construction activities.

When compared to Alternatives C through I, Alternative B would cause the least short-term disturbance to construction workers since minimal construction would occur to add groundwater monitoring wells to the existing network (see Tables 5-6A and 5-6B). However, the monitoring effort that involves activity at the site and possible Cr(VI) exposure to workers would continue for centuries.

The four *ex-situ* treatment alternatives—Alternatives F, G, H, and I—are considered to rank lower than the other alternatives with respect to protection of workers due to construction and operation of the aboveground treatment plant associated with these alternatives. Construction of an aboveground treatment plant (Alternatives F, G, and H) would include foundation, exterior structure, tanks, piping, pumps, equipment, controls, and instrumentation. Operation and maintenance of the aboveground treatment plant would include periodic sample collection, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Construction and operation of the *ex-situ* system would result in greater presence of workers/operators onsite than the other alternatives. As shown in Table 5-6B, operation of the *ex-situ* system would result in greater trucking requirements for chemical delivery and waste disposal than the *in-situ* treatment systems. Alternative I does not require construction of a new treatment plant but does include a high level of operation and maintenance for a substantially longer period than the treatment plant associated with Alternatives F, G, and H.

With respect to effects to workers during implementation of the *in-situ* alternatives, Alternatives C and E were comparably ranked higher than the other active alternatives because these alternatives would result in a similar and limited amount of construction and operation of the remedial facilities. As shown in Table 5-6A, Alternative C would include installation of more wells than Alternative E; however, Alternative E would involve more piping and trenches than Alternative C. Operation and maintenance activities for

Alternatives C, D, and E are comparable and include periodic well maintenance, sample collection, and refinement of the injection/recirculation systems; management of the reactant material; equipment inspections; and periodic replacement of wells and other structures that become clogged or damaged. Controls would be implemented during construction and operational phases to protect workers during the remedial activities.

5.5.5.4 Protection of the Environment During Remedial Action

Under Alternative A (No Action), no remedial action would occur; therefore, there would be no short-term disturbance to the environment from construction activities.

When compared to Alternatives C through I, Alternative B would cause the least short-term disturbance to the environment since minimal construction would occur to add groundwater monitoring wells to the existing network (see Tables 5-6A and 5-6B). However, the monitoring effort that involves activity at the site and possible Cr(VI) exposure to workers or releases to the environment would continue for centuries under Alternative B.

Alternatives C through I address the second RAO stated in Section 3.0 (to ensure that concentrations of Cr(T) and Cr(VI) in groundwater at the site do not cause exceedances in water quality standards that support the designated uses of the Colorado River) in a comparable manner through floodplain cleanup, mass removal in the floodplain, establishment of a geochemical barrier (Alternatives C, D, E, and G), and/or hydraulic control (Alternatives E, F, G, H, and I) and are considered equally effective in protecting river water quality during the remediation period. As stated in the evaluation of long-term effectiveness, with the exception of Alternative I, these alternatives include provisions for optimization of the remedy during the implementation period.

The four *ex-situ* treatment alternatives, Alternatives F, G, H, and I, were ranked comparably low with respect to protection of the environment due to construction and operation of the aboveground treatment plant. Construction of an aboveground treatment plant (Alternatives F, G, and H) would include foundation, exterior structure, tanks, piping, pumps, equipment, controls, and instrumentation. Operation and maintenance of the aboveground treatment plant would include periodic sample collection, chemical controls, equipment maintenance and inspection, and process chemical and waste management. Construction and operation of the *ex-situ* system would result in greater environmental disturbance than the *in-situ* treatment alternatives due to the greater amount of construction, aboveground visual impact, and electrical power that would be required for the building and operation of a treatment plant. Operation of the *ex-situ* system would result in greater trucking requirements for chemical delivery and waste disposal than the *in-situ* treatment systems. Alternative I does not require construction of a new treatment plant but does include a high level of operation and maintenance for a substantially longer period than the treatment plant associated with Alternatives F, G, and H.

For those alternatives that include *in-situ* treatment (Alternatives C, D, E, G, and H), concentrations of byproducts such as manganese and arsenic are likely to temporarily increase within portions of the treatment zone. Although these elements are expected to naturally re-precipitate within the anaerobic zone (as part of sulfide or iron precipitates) or to become re-oxidized and attenuate through sorption and precipitation in the aerobic zones outside the treatment zone over time (Appendix G) because of uncertainty in the complexity of aquifer lithology and geochemistry, large-scale implementation of *in-situ* treatment could result in unacceptably high concentrations of arsenic and manganese that persist for longer than expected periods of time in some portions of the aquifer. For these alternatives, monitoring and continued enforcement of institutional controls may be required for some time period to assess *in-situ* treatment byproducts once the remedy is complete.

With respect to effects to the environment during implementation of the *in-situ* alternatives, Alternatives C and E were comparably ranked higher because these alternatives would result in a similar and limited amount of construction and operation of the remedial facilities. As shown in Table 5-6A, Alternative C would include installation of more wells than Alternative E; however, Alternative E would involve more piping and trenches than Alternative C. Operation and maintenance activities for Alternatives C, D, and E are comparable and include periodic well maintenance, sample collection, and refinement of the injection/recirculation systems; management of the reductant material; equipment inspections; and periodic replacement of wells and other structures that become clogged or damaged. Controls would be implemented during construction and operational phases to limit disturbance to the environment during the remedial activities.

Alternative D involves implementation of *in-situ* treatment systems similar to Alternatives C and E. However, in contrast to Alternatives C and E, Alternative D does not minimize construction of remedial facilities in previously disturbed areas and would therefore result in greater impacts to the environment than Alternatives C and E. Alternative D, therefore, was ranked low for protection of the environment during implementation of the remedy.

5.5.5.5 Overall Ranking for Short term Effectiveness

Taking all of these aspects of short-term effectiveness into consideration, Alternative B was ranked medium because of the minimal footprint but relatively long time to cleanup. Alternatives C and E were ranked medium-low because of the comparatively shorter remediation period and relatively limited construction and operational activities that would occur primarily in previously disturbed areas. Alternatives A, D, F, G, H, and I received a low ranking for short-term effectiveness. Alternative A was ranked low primarily because of the extensive time to cleanup with no controls during the remedial period. Alternatives F, G, H, and I were ranked low as a result of construction and operation of an aboveground treatment plant and the greater amount of construction, aboveground visual impact, worker/operator presence onsite, electrical power requirements, and trucking requirements for chemical delivery and waste transportation and disposal. Alternative D ranked low primarily because the location of remedial facilities would not be limited to previously disturbed areas and because of the need for subsequent additional disturbance from grading, road construction, facility construction, and operation and maintenance.

5.5.6 Implementability

This criterion is summarized by addressing the:

- Technical feasibility.
- Administrative feasibility.
- Availability of services and materials.

The following subsections address each of these factors.

5.5.6.1 Technical Feasibility

Alternative A is easily implementable because no remedial action would be taken. Alternatives B through I involve remedial technologies that are technically implementable to construct and consist of a combination of monitoring wells, extraction wells, injection wells, pipelines, utilities, and/or treatment facilities that have been constructed at a smaller scale at the Topock site during the IM, *in-situ* pilot studies, and RFI/RI site characterization. The more robust remedial alternatives involving *in-situ* or *ex-situ* treatment (Alternatives C through I) have greater technical implementability challenges than those alternatives that rely solely on natural attenuation in the fluvial sediments of the Colorado River for treatment. Alternatives C through I also would require a higher level of oversight during implementation to ensure that the systems are optimized and modified as remediation progresses. Alternative I has been in operation for a number of years and has been shown to be technically feasible, although it was designed for a different set of goals than this remedial action. Alternatives C and D have technical challenges associated with the ability to obtain complete distribution of substrates across a large area Alternatives E, F, G, H, and I have technical challenges associated with reliance on flushing to remove contaminants. Alternatives E, G, and H have fewer technical challenges associated with *in-situ* treatment than Alternatives C and D because the *in-situ* treatment is confined to portions of the site. Alternatives C, D, and H include construction of injection/extraction wells for *in-situ* treatment within Bat Cave Wash that presents challenges associated with maintaining protection against future damage or wash out. Alternative C includes the additional technical challenge of balancing reductant delivery throughout the plume while maintaining hydraulic containment.

Treatment byproducts would be generated by the *ex-situ* treatment process under Alternatives F, G, H, and I; the sludge (and brine for Alternative I) would require disposal at an offsite, licensed disposal facility. Wastes generated from installation, development, maintenance, and sampling of wells under Alternatives B through H would be characterized for disposal and transported to a licensed, offsite disposal facility as required.

5.5.6.2 Administrative Feasibility

Alternatives B through I would each include administration of an institutional control to prohibit use of groundwater associated with the plume until attainment of cleanup goals. The institutional control would need to be coordinated with the various landowners that overlie the plume. Alternatives B through I are considered equal in the administrative challenges associated with the institutional control, although the institutional control associated with Alternatives B and I would be in place considerably longer than the institutional control associated with Alternatives C, D, E, F, G, and H.

There may be challenges associated with administrative requirements of location-specific ARARs, such as archeological recordation. These administrative challenges increase for alternatives with the most infrastructure and highest level of operation and maintenance.

Alternative E is the only alternative that includes installation of a new water supply well, and a pipeline to transport the water. Approvals for the water supply well and pipelines would have to be obtained through the landowners and associated water agencies.

Each of the alternatives, with the exception of Alternative A, would require construction of remedial and/or monitoring facilities outside of PG&E property. Construction and operation of these facilities would need to be coordinated with and approved by the respective landowners, including Burlington Northern-Santa Fe and Caltrans for Alternatives C through H. Since the remedial facilities for Alternative I are already in place, there would be no new construction for Alternative I; however, operation and maintenance for this and other alternatives (that may require construction to replace system components due to equipment aging and breakdown) would need to be coordinated with and approved by the respective landowners.

5.5.6.3 Availability of Services and Materials

All alternatives consist of remedial technologies that are readily available in the marketplace. Some specialized services and equipment may be needed for construction and operation of the *ex-situ* treatment plant under Alternatives F, G, H, and I or for the optimization of the reactant mix and delivery systems in the *in-situ* treatment systems under Alternatives C, D, E, G, and H; however, these services can be made available. Offsite disposal facilities are available for the wastes expected to be generated from the *ex-situ* treatment in Alternatives F, G, H, and I.

5.5.6.4 Overall Ranking for Implementability

In summary, Alternatives A and B are ranked high for implementability because Alternative A involves no remedial action, and the only remedial activities associated with Alternative B are monitoring well construction and maintenance and administration of an institutional control. Alternative I also ranked high because the system has been shown to be technically implementable over the years it has operated. Alternatives D, E, F, G, and H were ranked medium because while these alternatives are administratively implementable, there will be technical challenges associated with the active treatment processes. Alternative E requires additional approvals from landowners and associated water agencies for the water supply well and pipeline. Alternative C was ranked low for this criterion because of the relatively more complex technical challenges associated with balancing reductant delivery and hydraulic containment of the plume, as well as construction within Bat Cave Wash.

5.5.7 Cost

The cost estimates for each alternative are located in Appendix D. Table 5-7 summarizes the estimated present value and nominal (total lifetime alternative) costs for the remedial alternatives. The costs for Alternatives A and B are the lowest; therefore, these alternatives are ranked high in cost-effectiveness. Alternatives C, D, E, and H are the next most costly; therefore, these alternatives are ranked medium in cost-effectiveness. Alternatives F, G, and I are the most expensive of the alternatives and are therefore ranked low in cost-effectiveness.

TABLE 5-7
Remedial Alternative Cost Summary
Final Groundwater Corrective Measures Study/Feasibility Study for SWMU 1/AOC 1 and AOC 10, PG&E Topock Compressor Station, Needles, California

Description	Net Present Value	Nominal Costs
Alternative A—No Action	$0	$0
Alternative B—Monitored Natural Attenuation	$25,000,000 - $54,000,000	$513,000,000
Alternative C—High Volume *In-situ* Treatment	$119,000,000 - $255,000,000	$206,000,000
Alternative D—Sequential *In-situ* Treatment	$118,000,000 - $254,000,000	$191,000,000
Alternative E—*In-situ* Treatment with Freshwater Flushing	$92,000,000 - $198,000,000	$184,000,000
Alternative F—Pump and Treat	$187,000,000 - $401,000,000	$443,000,000
Alternative G—Combined Floodplain *In-situ*/Pump and Treat	$177,000,000 - $380,000,000	$329,000,000
Alternative H—Combined Upland *In-situ*/Pump and Treat	$127,000,000 - $273,000,000	$225,000,000
Alternative I—Continued Operation of Interim Measure	$186,000,000 - $398,000,000	$2,030,000,000

Note:
See Appendix D for cost estimate assumptions.

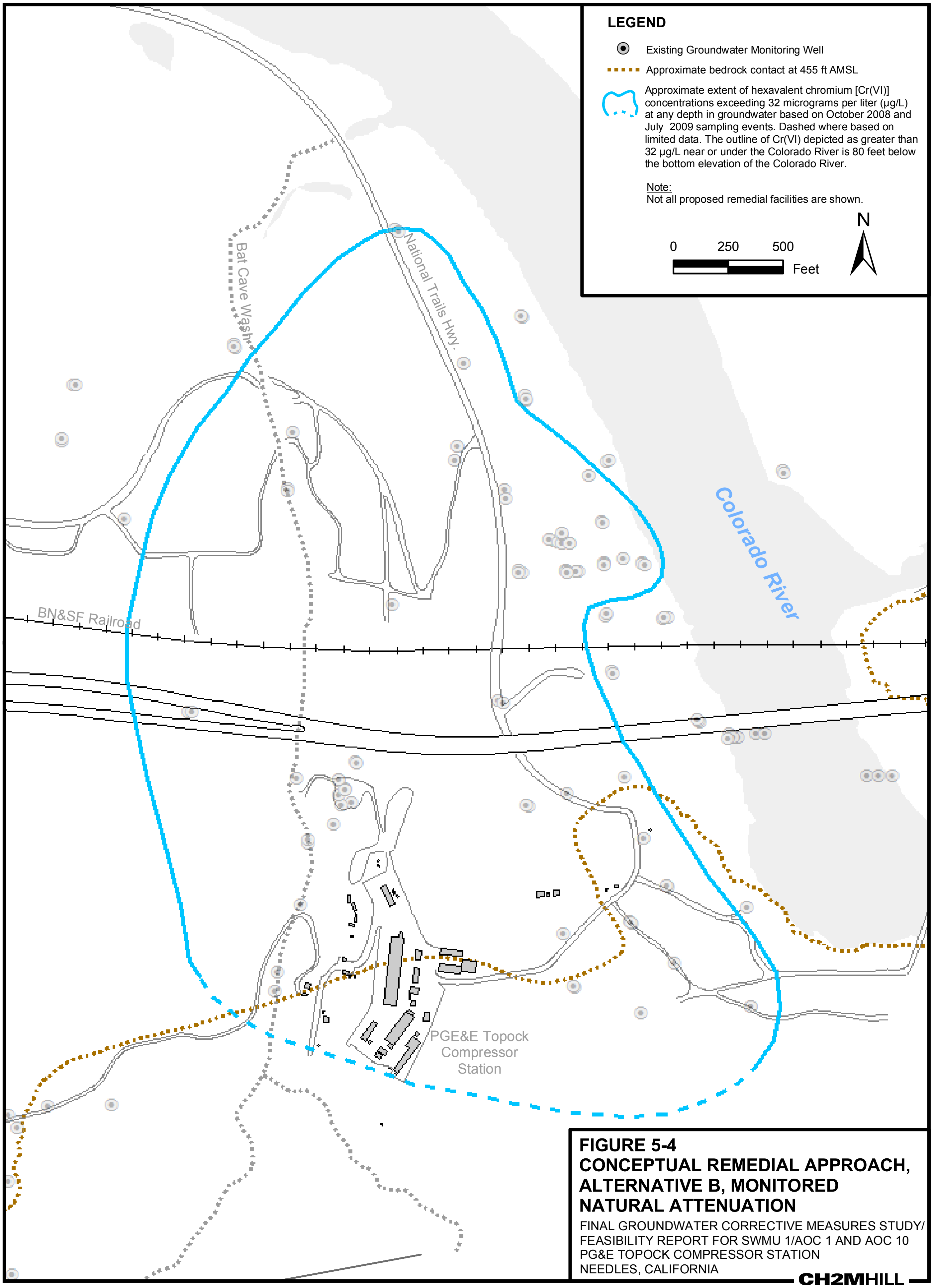

FIGURE 5-4
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE B, MONITORED NATURAL ATTENUATION

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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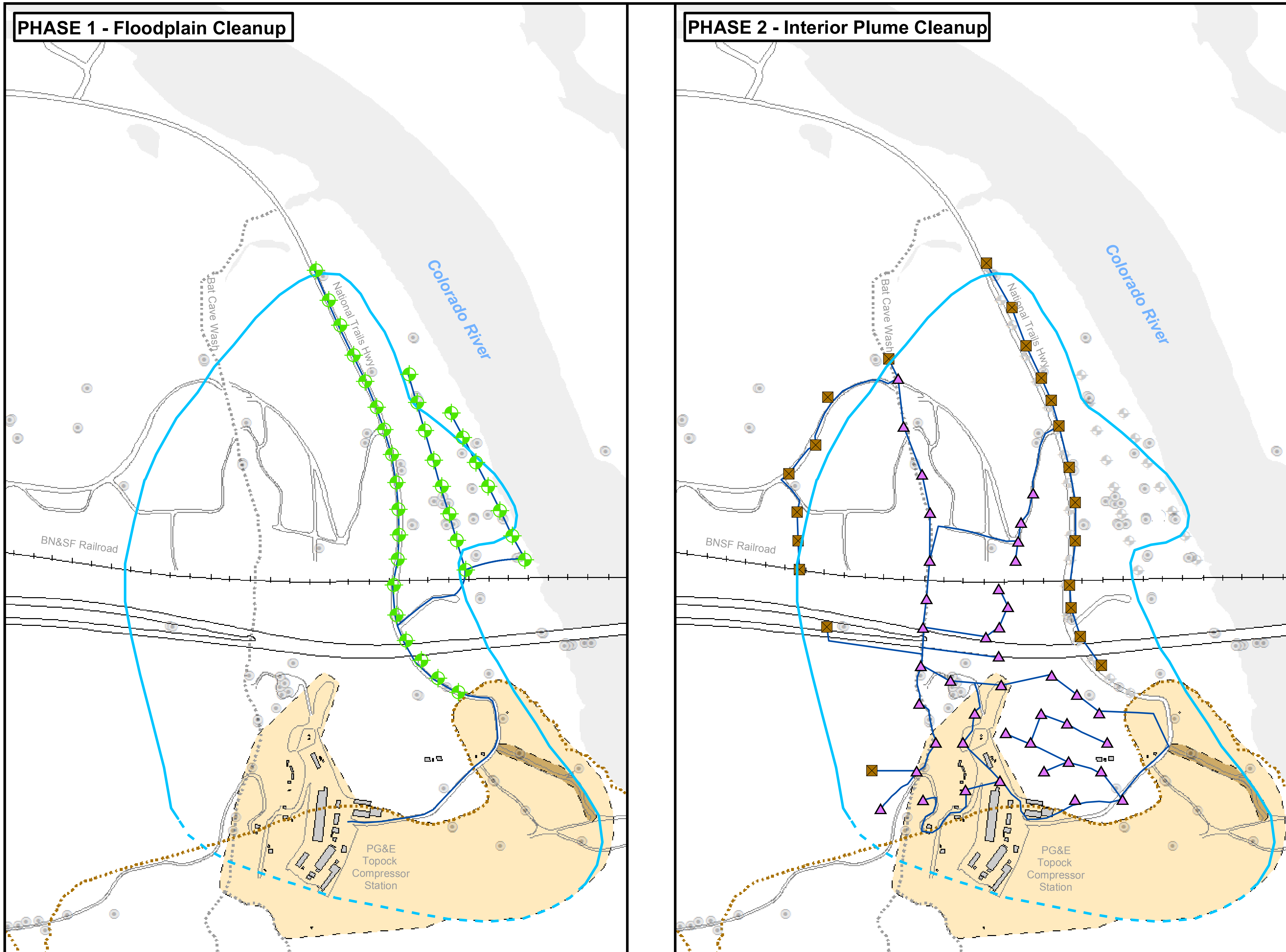

LEGEND

- Extraction Well
- Injection Well For Carbon-Amended Water
- IRZ Recirculation Wells
- Approximate area where additional infrastructure maybe necessary for bedrock remedial activities in the East Ravine.
- Approximately 15 bedrock wells for bedrock remedial activities in the East Ravine
- Existing Groundwater Monitoring Well
- Utility/Pipeline Trench
- Approximate bedrock contact at 455 ft MSL elevation
- 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.

Notes:

1. Required piping, wells and locations are approximate at this time. Multiple wells could be installed at each of the identified locations depending upon actual well performance.

2.Phase 1 features shown in grey on Phase 2 map for reference.

3.Not all proposed remedial facilities are shown.

FIGURE 5-5
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE C, HIGH VOLUME *IN-SITU* TREATMENT

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT
FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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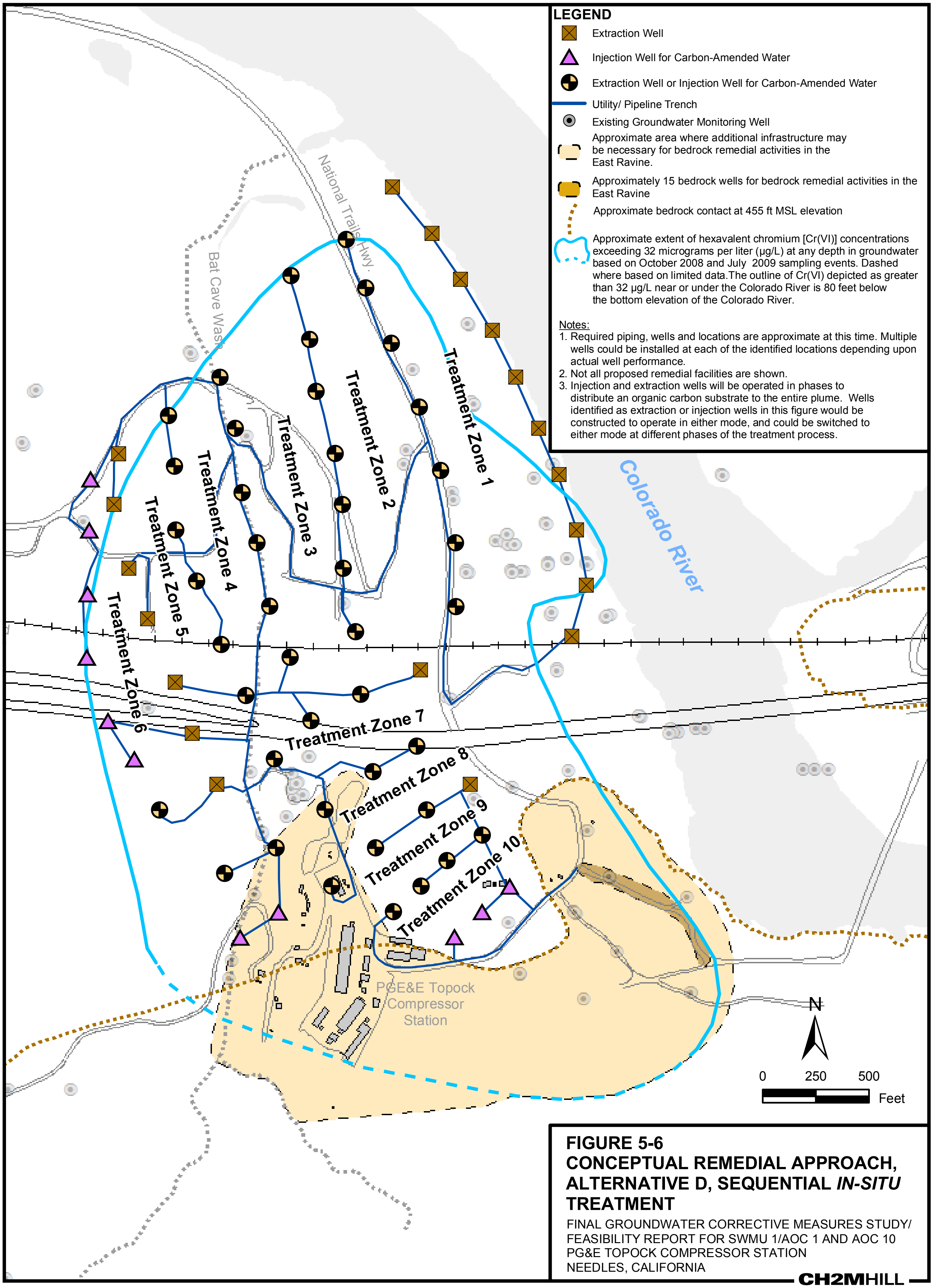

FIGURE 5-6
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE D, SEQUENTIAL *IN-SITU* TREATMENT

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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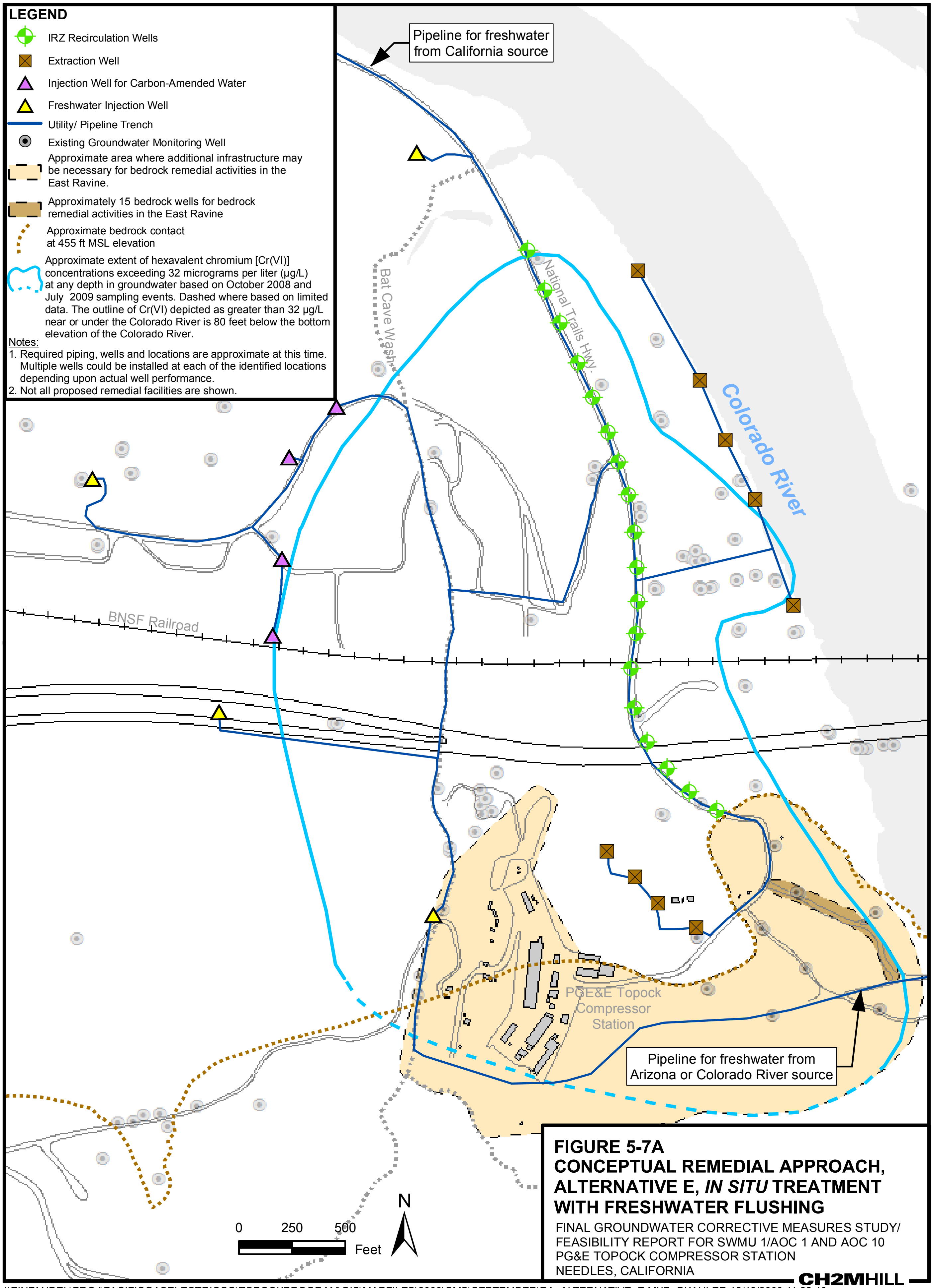

FIGURE 5-7A
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE E, *IN SITU* TREATMENT WITH FRESHWATER FLUSHING

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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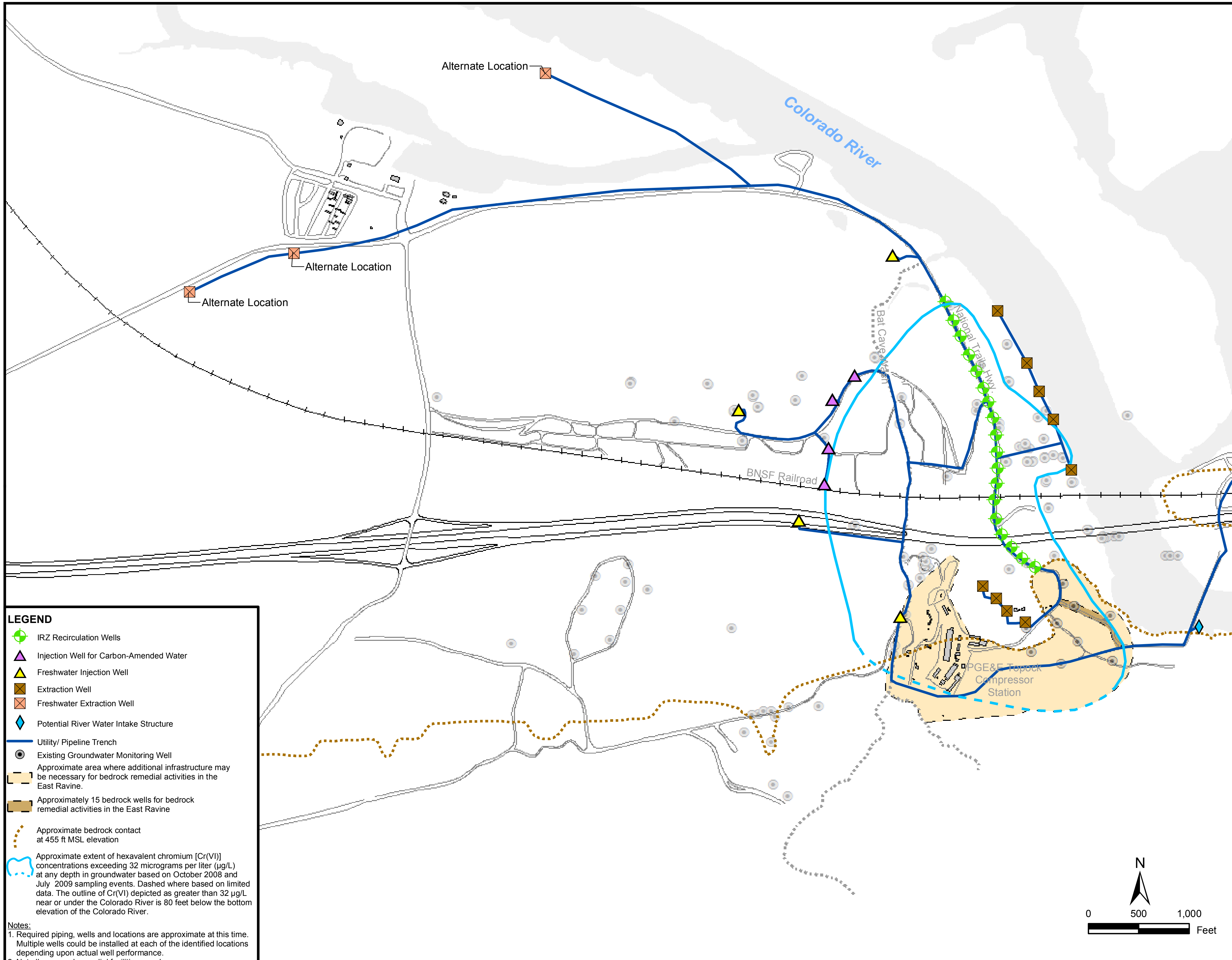

FIGURE 5-7B
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE E, *IN SITU* TREATMENT WITH FRESHWATER FLUSHING EXPANDED VIEW

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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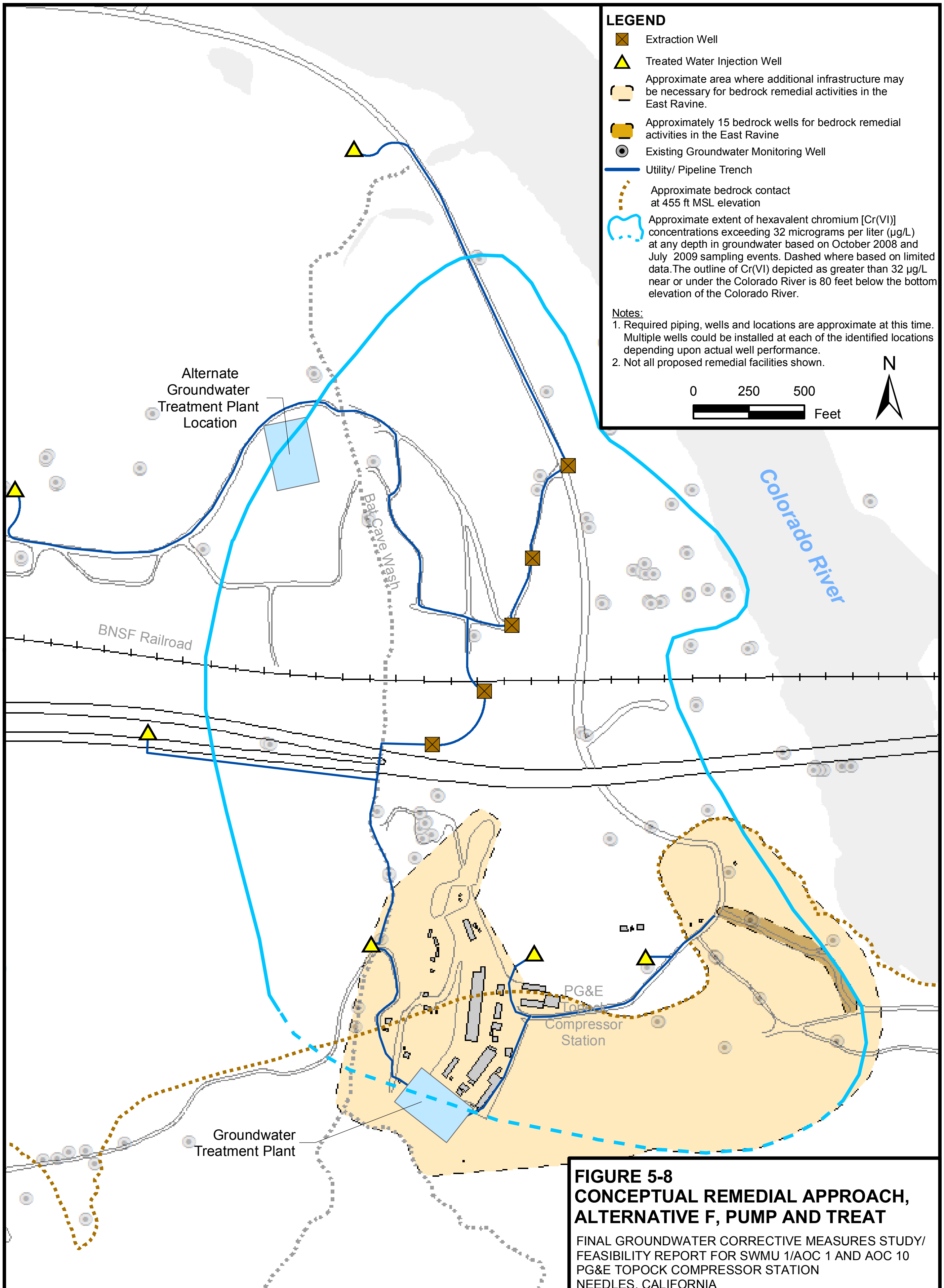

FIGURE 5-8
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE F, PUMP AND TREAT

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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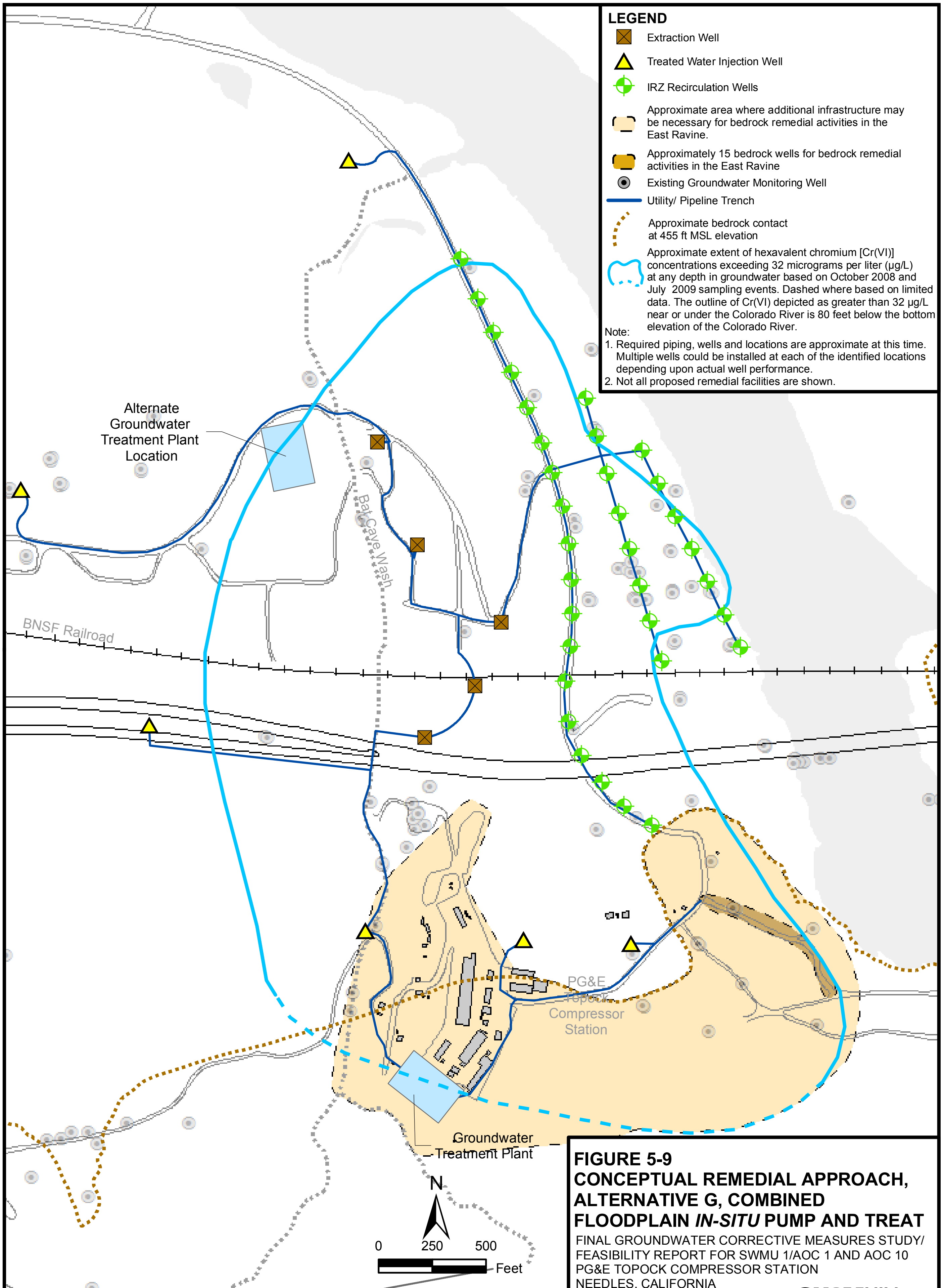

FIGURE 5-9
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE G, COMBINED FLOODPLAIN *IN-SITU* PUMP AND TREAT

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/ FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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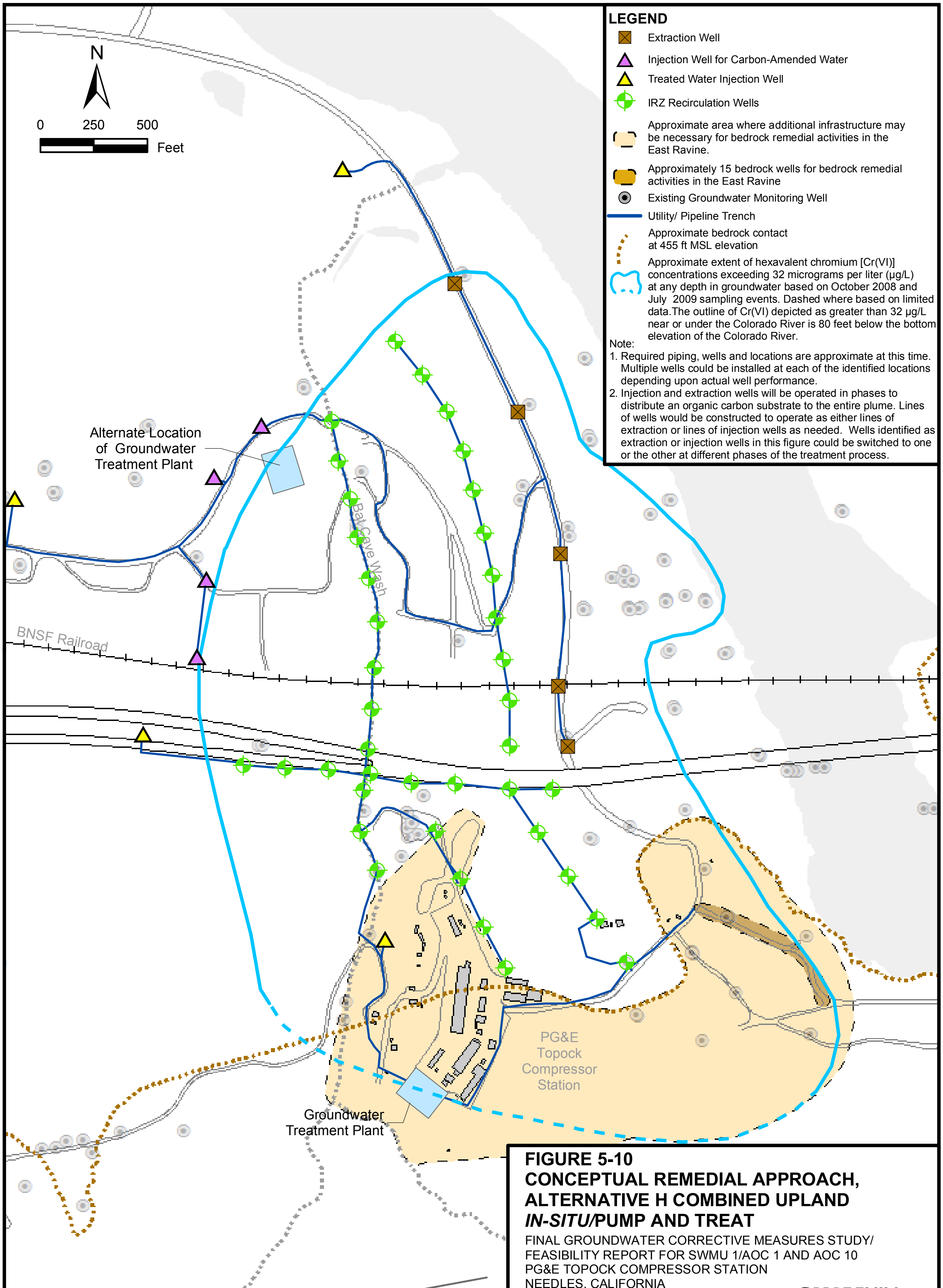

FIGURE 5-10
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE H COMBINED UPLAND *IN-SITU*/PUMP AND TREAT

FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/
FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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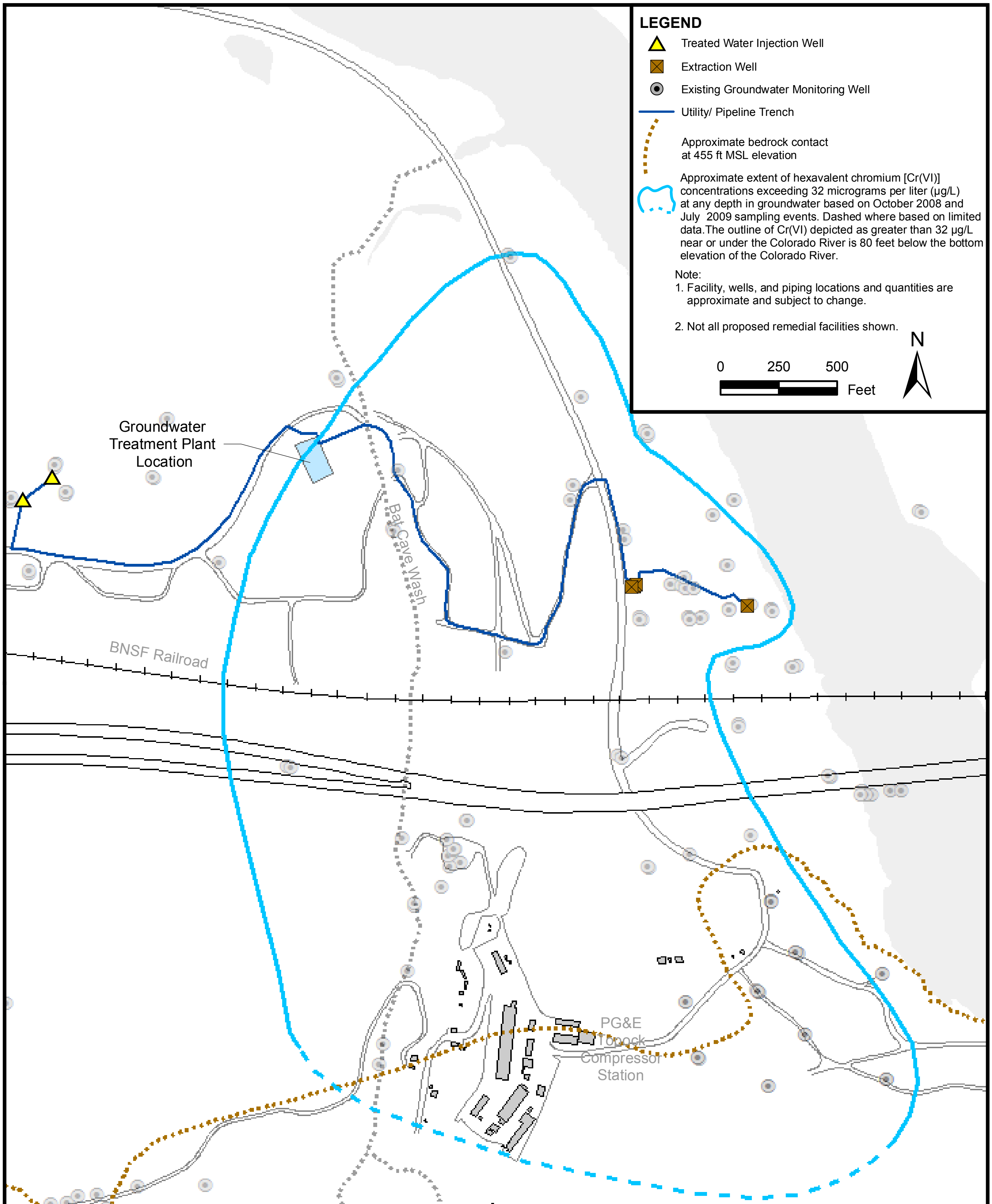

FIGURE 5-11
CONCEPTUAL REMEDIAL APPROACH, ALTERNATIVE I
CONTINUED OPERATION OF INTERIM MEASURE
FINAL GROUNDWATER CORRECTIVE MEASURES STUDY/
FEASIBILITY REPORT FOR SWMU 1/AOC 1 AND AOC 10
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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CRITERIA	ALTERNATIVE A No Action	ALTERNATIVE B Monitored Natural Attenuation	ALTERNATIVE C High Volume *In-Situ* Treatment	ALTERNATIVE D Sequential *In-Situ* Treatment	ALTERNATIVE E *In-Situ* Treatment with Fresh Water Flushing	ALTERNATIVE F Pump and Treat	ALTERNATIVE G Combined Floodplain *In-Situ* Treatment /Pump and Treat	ALTERNATIVE H Combined Upland *In-Situ* Treatment/ Pump and Treat	ALTERNATIVE I Continued Operation of Interim Measure	SUMMARY
Protect human health and the environment, attain media cleanup goals, and control source of releases • Protect human health and the environment • Attain media cleanup goals • Control sources of releases	Low	Medium	High	High	High	High	High	High	Medium	• Alternatives C, D, E, F, G, and H are ranked high because they would all provide for protection of human health from exposure due to use of groundwater as a drinking water supply in both the short term and long term and would protect the Colorado River as a result of floodplain cleanup and/or through hydraulic control. • Alternatives B and I ranked medium primarily because of the long time required to attain cleanup goals, long-term use of institutional controls, as well as the uncertainty about the robustness of the natural geochemical conditions near the river over this relatively long time for Alternative B, and the high level of operation and maintenance and potential for degradation of the natural reducing capacity in the floodplain due to flow of aerobic river water through the fluvial sediments from long-term extraction in the floodplain for Alternative I. • Alternative A ranked low because there would be no institutional controls imposed to restrict use of groundwater in locations where Cr(VI) concentrations exceed the cleanup goals and no monitoring to evaluate changes in geochemical conditions near the river over the long time period required until cleanup goals are attained.
Comply with ARARs • Chemical-specific ARARS • Location-specific ARARs • Action-specific ARARs, including standards for management of wastes generated by the remedial action	Low	Low	High	High	High	High	High	High	Low	• Alternatives C, D, E, F, G, and H ranked high because DOI has determined that as a threshold matter, none of these alternatives can be eliminated based on the alternative's inability to satisfy cultural resources ARARs or the National Wildlife System Administration Act. • Alternatives A, B, and I are ranked low because DOI has determined these alternatives would not satisfy the requirements of the California State Water Resources Control Board Resolution 92-49.
Long-term effectiveness, permanence and reliability • Magnitude of residual risk remaining from untreated waste or treatment residuals at the conclusion of the remedial activities • Adequacy and reliability of controls such as containment systems and institutional controls that are necessary to manage the untreated waste or to manage treatment residuals that remain at the site	Low	Medium	Medium-High	Medium-High	Medium-High	Medium	Medium	Medium	Medium	• Alternatives C, D, and E ranked medium-high because there is uncertainty regarding the ability to distribute substrates across the targeted area and Alternative E relies on flushing to remove contaminants from the upland portion of the aquifer; comparatively, few long-term controls are expected for these alternatives following attainment of cleanup goals. • Alternatives F, G, H, and I all ranked medium because the resulting waste byproducts from the ex-situ treatment process require long-term containment, management, and monitoring at an offsite disposal facility. • Alternative B ranked medium because it includes monitoring and institutional controls; however, the ability of the natural attenuation processes to convert Cr(VI) to Cr(III) is uncertain over the centuries that would be required for MNA to reach cleanup goals. • Alternative A (No Action) ranked the low because this alternative does not include monitoring to verify the effectiveness of natural recovery processes and to determine when the RAOs have been achieved. Any future changes in site conditions that may cause undesirable impacts to the Colorado River or unacceptable exposures to other receptors would not be detected under Alternative A.
Reduction of toxicity, mobility, or volume through treatment • Amount of plume destroyed or treated • Degree of expected reduction in toxicity, mobility, and volume • Degree treatment is irreversible • Type and quantity of residual remaining after treatment	Medium	Medium	Medium-High	Medium-High	Medium-High	High	High	Medium-High	High	• Alternatives C, D, E, F, G, H, and I ranked high because the toxicity, mobility, and volume of Cr(VI) is reduced throughout the plume. Byproducts from in-situ treatment are expected to be localized to the reducing zone formed by the IRZ and within the range of naturally occurring concentrations found at the site (Appendix G) but could remain temporarily elevated above baseline and background concentrations in some portions of the aquifer. Byproducts from ex-situ treatment would be managed through disposal at an offsite, permitted disposal facility. • Alternatives A and B ranked medium because the amount of plume destroyed or treated is less certain due to passive nature of treatment and the extent and average capacity of the floodplain area to naturally reduce Cr(VI) overtime.
Short term effectiveness • Time until remedial action objectives are achieved • Protection of the community during remedial actions • Protection of the workers during remedial actions • Protection of the environment during remedial actions	Low	Medium	Medium-Low	Low	Medium-Low	Low	Low	Low	Low	• Alternative B ranked medium because of the minimal footprint but relatively long time to cleanup. • Alternatives C and E ranked medium-low because of the comparatively shorter remediation period and relatively limited construction and operational activities that would occur primarily in previously disturbed areas. • Alternative A ranked low primarily because of the extensive time to cleanup with no controls during the remedial period. • Alternatives F, G, H, and I were ranked low as a result of construction and operation of an aboveground treatment plant and the greater amount of construction, aboveground visual impact, worker/operator presence onsite, and electrical power and trucking requirements for chemical delivery and waste transportation and disposal. • Alternative D ranked low primarily because the location of remedial facilities would not be limited to previously disturbed areas and because of the need for subsequent additional disturbance from grading, road construction, facility construction, and operation and maintenance.
Implementability • Technical feasibility • Administrative feasibility • Availability of services and materials	High	High	Low	Medium	Medium	Medium	Medium	Medium	High	• Alternatives A and B ranked high because Alternative A involves no remedial action, and the only remedial activities associated with Alternative B are monitoring well construction and maintenance and administration of an institutional control. • Alternative I ranked high because the system has been shown to be technically implementable over the years it has operated. • Alternatives D, E, F, G, and H ranked medium because while these alternatives are administratively implementable, there will be technical challenges associated with the active treatment processes. • Alternative C was ranked low for this criterion because of the relatively more complex technical challenges associated with balancing reductant delivery and hydraulic containment of the plume, as well as construction within Bat Cave Wash.
Cost effectiveness	High	High	Medium	Medium	Medium	Low	Low	Medium	Low	• See Table 5-7 for estimated costs.

Comparative Rating

Low · Medium-Low · Medium · Medium-High · High

Note:
The assessment of state and community acceptance is not completed until comments on the Proposed Plan are received after the public comment period.

FIGURE 5-12
Qualitative Comparison of Remedial Alternatives
Final Groundwater Corrective Measure Study/
Feasibility Study Report for SWMU 1/AOC 1 and AOC 10
PG&E Topock Compressor Station, Needles, California

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6.0 Recommended Remedial Action Alternative

This CMS/FS Report presents the identification and evaluation of various remedial alternatives to address the remedial action goals for groundwater contamination associated with SWMU 1/AOC1 and AOC 10 at the PG&E Topock Compressor Station.

Nine alternatives were identified:

- Alternative A - No Action
- Alternative B - Monitored Natural Attenuation
- Alternative C - High Volume *In-situ* Treatment
- Alternative D - Sequential *In-situ* Treatment
- Alternative E - *In-situ* Treatment with Fresh Water Flushing
- Alternative F - Pump and Treat
- Alternative G - Combined Floodplain *In-situ*/Pump and Treat
- Alternative H - Combined Upland *In-situ*/Pump and Treat
- Alternative I - Continued Operation of Interim Measure

The alternatives above were defined to a sufficient level of detail to develop remedial cost estimates in accordance with USEPA guidance for feasibility studies. The alternatives were evaluated against the threshold and balancing criteria of RCRA Corrective Action and CERCLA.

PG&E's recommendation for the preferred alternative, based on the conclusions of the comparative analysis in Section 5.5, is **Alternative E - *In-situ* Treatment with Fresh Water Flushing**. Alternative E provides the best balance of advantages and tradeoffs for the remedial action. This alternative involves flushing to push the plume through an IRZ barrier located along Park Moabi Road. Flushing would be accomplished through a combination of potable water injection and injection of carbon amended water in wells to the west of the plume. This alternative includes extraction wells near the Colorado River to provide hydraulic capture of the plume, accelerate cleanup of the floodplain, and help flush the groundwater with elevated Cr(VI) through the IRZ line. Alternative E also includes bedrock extraction wells in the eastern (downgradient) end of the East Ravine, with the water from the bedrock extraction wells managed within the active treatment system for the Alluvial Aquifer. Carbon amended water from injection wells, within and outside of the plume, will be monitored for potential byproducts migration and managed through careful design and operation. Additional extraction wells are located in an area northeast of the compressor station where the flushing efficiency from injection wells alone is relatively poor.

Alternative E meets both of the threshold criteria of (1) protecting human health and the environment, attaining media cleanup goals (over a reasonable timeframe), and controlling sources of releases; and (2) compliance with the identified chemical-, location-, and action-specific ARARs. As a threshold matter, Alternative E cannot be eliminated for an inability to attain the various cultural resource ARARs. As the remedy selection process continues through the issuance of a Proposed Plan and the Record of Decision, and as a remedy is designed and implemented, the federal agencies will continue to engage in consultation with tribes, State Historic Preservation Officers, and others to identify potential effects on cultural resources and will seek ways to avoid, minimize, or mitigate any adverse effects, thereby ensuring that the selected remedy attains these ARARs. The alternative also provides a sufficient degree of long-term effectiveness, permanence, and reliability; is implementable; is relatively cost-effective; and provides a sufficient degree of protectiveness to the community, workers, and environment during implementation.

Additional advantages of Alternative E include the following:

- In comparison to Alternative A (No Action), Alternative E includes active treatment of the Cr(VI) plume to address the RAOs, as well as monitoring and institutional controls, to limit exposure during the remediation period. Alternative A would leave the plume in place without controls or monitoring and would not comply with ARARs.
- In comparison to Alternative B (MNA), Alternative E would provide a higher degree of reliability in treatment and achieve the cleanup goals in substantially less time.
- Alternative C (High Volume *In-situ* Treatment) and Alternative D (Sequential *In-situ* Treatment) also rely on *in-situ* treatment technology. In contrast to Alternative E, however, the *in-situ* treatment concept for Alternatives C and D involves distributing carbon throughout the plume, while Alternative E involves flushing the plume toward an established *in-situ* reductive zone. Both concepts have technical challenges that can be overcome. Alternative E provides *in-situ* treatment with fewer wells but more pipelines than Alternatives C and D. Generation of *in-situ* treatment byproducts would be considerably less than with Alternatives C and D because the *in-situ* component of Alternative E would only be applied along National Trails Highway and in a limited area around each of the upland injection wells. Overall, a much smaller fraction of the aquifer would become reduced with Alternative E than with Alternatives C and D. In comparison to Alternative D, Alternative E would involve construction primarily in previously disturbed areas, thereby resulting in less grading and construction of fewer access roads.
- In comparison to Alternatives F, G, H, and I that include *ex-situ* treatment, Alternative E is substantially more cost-effective and would result in substantially fewer effects to the community, workers, and environment. Alternatives F, G, and H require the construction of a large aboveground treatment plant with a high level of energy requirements that would generate waste byproducts to be transported offsite with associated energy use and traffic hazards. Alternatives F, G, H, and I would generate waste byproducts from an *ex-situ* treatment plant that would require long-term monitoring and containment after the RAOs at the site are attained.

As discussed in Section 5.5, the comparative analysis did not consider the evaluation criteria of state and community acceptance. DTSC and DOI will formally address the modifying criteria of State Acceptance and Community Acceptance during the final remedy selection under the Record of Decision and DTSC's final remedy adoption. Following completion of this CMS/FS Report, DTSC will propose a remedy through a RCRA Statement of Basis, and DOI will issue a Proposed Plan identifying a preferred alternative for public comment. After evaluation and response to public comments, DTSC and DOI will select a final remedy through the preparation of the final Statement of Basis and a CERCLA Record of Decision, respectively. Following selection of the remedy by DTSC and DOI, the final remedy design and approval processes will begin, wherein additional detail on the implementation of the remedy will be developed and documentation required by various location- and action-specific ARARs will be prepared. As required by the CACA, PG&E will prepare a Corrective Measures Implementation Work Plan that more specifically describes the size, shape, form, and content of the selected remedy; describes the key components or elements needed; provides conceptual drawings and schematics; and includes procedures and schedules for implementing the selected remedy. Other operations and maintenance and construction plans may also be prepared prior to construction and operation of the selected remedy.

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