Draft Operations and Maintenance Manual
Volume 3

Contingency Plan Intermediate (60%) Design Submittal for the Final Groundwater Remedy PG&E Topock Compressor Station Needles, California

Prepared for

Pacific Gas and Electric Company

April 2013

CH2MHILL®

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Acronyms and Abbreviations

µg/L	micrograms per liter
ADEQ	Arizona Department of Environmental Quality
ARAR	Applicable Relevant and Appropriate Requirement
COC	chemical of concern
COPCs	chemicals of potential concern
Cr(III)	trivalent chromium
Cr(T)	total chromium
Cr(VI)	hexavalent chromium
EIR	Environmental Impact Report
FMEA	Failure Mode Effect Analysis
HNWR-1	Havasu National Wildlife Refuge Well No. 1
IRL	Inner Recirculation Loop
MCL	maximum contaminant level
MG	million gallons
MWD	Metropolitan Water District
NTH IRZ	National Trails Highway In-Situ Reactive Zone
O&M Manual	Operations and Maintenance Manual
PG&E	Pacific Gas and Electric Company
RAOs	Remedial Action Objectives
RD/RA	Remedial Design/Remedial Action
SCADA	Supervisory Control and Data Acquisition
UNLV	University of Las Vegas

1.0 Introduction

This volume of the Operation and Maintenance Manual presents the contingency plans for the groundwater remedy, as required by the 1996 Consent Agreement (DTSC 1996) and the 2013 Consent Decree (DOI 2013). Contingency planning is being conducted as a part of the final groundwater remedy design process to anticipate potential risks and organize plans to mitigate these risks. A contingency plan such as this one is typically used during the design phase as a tool to anticipate potential risks and to develop methods to mitigate these risks either within the design or as part of the future system operations. The contingency planning is done using a method termed Failure Mode Effect Analysis (FMEA). The FMEA tool provides an analytical and systematic approach to reviewing potential failure modes and their associated causes, and therefore helps to assess which risks pose the greatest concern and to prioritize risk management in order to prevent problems before they arise. The objective of the FMEA process is to outline possible failures that could cause unacceptable conditions in the groundwater remedy. Mitigation measures in design and operation are focused on these issues first and foremost. The FMEA also identifies conditions that, while not unacceptable, are issues that PG&E will strive to avoid or minimize. The following types of unacceptable conditions have been identified:

- **Category A: Unacceptable remedy performance** — The Remedial Action Objectives (RAOs) are not met. Specifically, this could include migration of unacceptable concentrations of constituents of concern to the Colorado River, permanent expansion of the target remediation area, or not achieving the numeric cleanup goals of the RAOs.
- **Category B: Schedule** — Failures that cause the schedule to achieving the groundwater remedy RAOs to be extended by more than 5 to 15 years.
- **Category C: Cost** — Failures that cause the cost of achieving the groundwater remedy RAOs to be increased by more than $10,000,000 to $50,000,000.
- **Category D: Significant change to impact** — Changes (such as visual impact) that necessitate re-opening the EIR process.
- **Category E: Significant H&S or compliance incident** — A health and safety incident that results in lost work time for remedy or Compressor Station staff or the public; an environmental compliance Notice of Violation (other than related to remedy performance); or violation of the requirements in the ARARs.

The mitigation measures described in the FMEA tables are taken to minimize or eliminate the likelihood, or severity, of these unacceptable conditions. The FMEA also identifies potential failures that could cause conditions that, while not unacceptable as defined above, should be prevented or minimized.

Causes of potential failures are mitigated in the design process (e.g., select equipment to accommodate a range of anticipated operational conditions), in adaptive operations (e.g., adjusting flow rates and/or carbon substrate dosing, installation of future provisional remediation, freshwater supply, and/or monitoring wells, etc.), and/or in corrective action/contingency response planning (e.g., installing additional wells). Operational mitigation descriptions include the condition that an operator would observe and the action he/she would take. A preventative maintenance schedule is/will be proposed as an overall mitigation step to minimize risk of unexpected failures.

Contingency planning has been prepared for five key elements of the groundwater remedy:

- In-Situ Remediation System (Section 2.1)
- Remedy-produced Water Management System (Section 2.2)
- Freshwater Supply including pre-injection treatment (Section 2.3)
- Power Supply (Section 2.4)
- Supervisory Control and Data Acquisition (SCADA), Control Systems, and Instrumentation (Section 2.5)

Each system's analysis in this FMEA includes an evaluation of the likelihood and severity of each type of potential failure to help prioritize mitigation. The severity scoring is shown in Table 1.0-1 (tables presented at the end of this document). It should be noted that the "Severity of Effect" column denotes the implication of the effect if it were to occur, which should be unlikely since the mitigation measures are being taken. The likelihood score is relative, with 5 being the highest likelihood, though not necessarily highly likely.

The RAOs for the final groundwater remedy are to:

1. Prevent ingestion of groundwater as a potable water source having hexavalent chromium (Cr[VI]) in excess of the regional background concentration of 32 micrograms per liter (µg/L).
2. Prevent or minimize migration of total chromium (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.

Compliance monitoring will include groundwater and surface water sampling and will focus on confirming that the final groundwater remedy will/is achieving these RAOs. Compliance monitoring is primarily designed to ensure that the remedy is meeting RAOs 2, 3, and 4, relating to controlling migration and reducing mass to an adequate degree.

The contingency plan anticipates potential issues that may occur with the remedy and identifies design and adaptive operations elements to mitigate those issues, which have been incorporated into the 60% Design Submittal. The adaptive operations framework is presented in data quality objectives in the Sampling and Monitoring Plan in Volume 2 of this Operations and Maintenance Manual (O&M Manual) (see also Figures 2.2-2 to 2.2-9 in Volume 2) and is referenced in the FMEAs. Additional mitigations identified in the FMEA that may be required and are not covered by design or adaptive operations constitute contingency actions, as outlined in this plan.

2.0 Contingency Planning

2.1 In-Situ Remediation System

The in-situ remediation system includes the following components, as described above and in Section 3.2 of the Revised Basis of Design Report:

- National Trails Highway In-Situ Reactive Zone (NTH IRZ): line of wells that may be used as both injection and extraction wells to circulate groundwater and distribute an organic carbon source to promote reduction of the Cr(VI) to trivalent chromium (Cr[III]).
- Inner Recirculation Loop (IRL):
  - River Bank extraction wells along the Colorado River to provide hydraulic capture of Cr(VI) groundwater concentrations, accelerate cleanup of the floodplain, enhance the flow of contaminated groundwater through the NTH IRZ line, and control migration of IRZ-generated by-products toward the Colorado River in the deeper part of the aquifer.
  - IRL injection wells to re-inject groundwater extracted from the River Bank extraction wells (which may be amended with an organic carbon source) and/or fresh water into wells in the upgradient portion of the Cr(VI) plume to flush the plume through the NTH IRZ.
- Freshwater injection wells to inject freshwater into wells upgradient of the Cr(VI) plume to flush the plume through the NTH IRZ.
- TCS Recirculation Loop:
  - East Ravine extraction wells in the eastern (downgradient) end of the East Ravine to provide hydraulic capture of contaminated groundwater in bedrock.
  - TCS injection wells located upgradient of the TCS for the re-injection of groundwater extracted from the East Ravine extraction wells and Transwestern Bench extraction wells, which will be amended with an organic carbon source, to promote reduction of the Cr(VI) to Cr(III) and remove elevated Cr(VI) groundwater concentrations from the alluvial aquifer in the vicinity of the TCS.

Table 2.1-1 presents the results of the FMEA for the in-situ remediation system.

Potential failures identified include possible ways in which the remedy may not perform per the original intent. This risk is mitigated through design (including pilot testing, predictive simulations/modeling, additional design efforts, and designing in flexibility) and operational flexibility (as described in the Decision Rules/Operational Framework section of this O&M Manual). The FMEA includes references to elements of the 60% design submittal that provide additional details on how remedy risks are being mitigated in the design and operational strategy. Other potential failures include operational and safety issues involved with mechanical equipment and chemicals for which PG&E has set as a design criteria that two levels of protection would have to fail simultaneously for a failure to be considered significant enough to be included in the FMEA.

2.2 Remedy-produced Water Management System

The final groundwater remedy is reliant on several dozen wells used for the IRZ, freshwater and carbon-amended injection, and groundwater extraction. For all wells, especially the injection and IRZ wells, regular maintenance such as backwashing and rehabilitation is vital to ensure efficient and effective operations during the 30-year projected life of the remedy. Well maintenance will also prevent or reduce the need for drilling new replacement wells. These maintenance activities will produce an ongoing water stream that must be managed as part of the remedial action. Other types of produced water with smaller volumes will also need to be managed, such as monitoring well sampling purge water, equipment decontamination wastewater, and rainfall that collects in remedy facility secondary containment. Providing a reliable means of managing this wastewater is a necessary supporting component of the overall remedy.

The Remedy-produced Water system includes the generation, transportation, conditioning, reuseand disposal of conditioned water. The system is described in Section 2.3 of Volume 1, Operations and Maintenance Manual.

Table 2.2-1 presents the FMEA matrix for the Remedy-produced Water Management System. Two main failure types were identified. The first type of failure is the system a) not having capacity to condition the produced water due to produced water flow being greater than forecasted, or b) experiences downtime which could be caused by a range of events (vandalism, acts of God, equipment failure, etc). This would result in having to truck some or all produced water off-site for management. This would increase costs and traffic-related impacts of the remedy. However, it would not impact remedy performance. To mitigate this risk, the conditioning system has been conservatively sized and space has been reserved for build-out of additional equipment if needed. Also, multiple disposal/reuse options are being established to reduce the risk of disposal/reuse limiting produced water management.

The second type of failure is the conditioning system effluent causing performance problems with wells used for re-injecting the water. Problems could range up to the possibility of well fouling or scaling forcing replacement of the wells. Water quality issues that could hurt well performance include high suspended solids, high pH, or constituents that precipitate out and scale the well. Loss of wells due to fouling or scaling could slow the remedy performance, until the wells are rehabilitated or replaced. This risk is mitigated by designing in fine-particle filtration and in-line monitoring of pH and turbidity. Operational mitigations will include frequent monitoring of the conditioning system performance and of the injectivity of the wells used for re-injecting treated water.

2.3 Freshwater Supply

The Freshwater Supply Water System will provide water for the freshwater injection wells used in the groundwater remedy. The freshwater injection is to assist with flushing the chromium plume through the IRZ located along the NTH. The objective of the Freshwater Supply is to provide sufficient water of acceptable quantity and quality for successful implementation of the remedy. The quantity and quality requirements are defined in Section 3.3 of the Basis of Design Report. It is assumed that fresh water for the remedy will be supplied from well HNWR-1 located in Arizona. For well quality protection, Volume 2 of the O&M Manual discusses in detail the proposed monitoring plan for the HNWR-1 well and results of a recent source assessment. Table 2.3-1 presents the FMEA matrix for the supply of fresh water.

In addition, per DTSC's direction in a letter dated December 31, 2012 (DTSC 2012), the 60% design includes a pre-treatment system to polish Arizona groundwater to California standards prior to injection. The decision by the State Water Resources Control Board (State Board) is anticipated to guide further direction from DTSC regarding the ultimate use of the freshwater source and what level of treatment, if any, will be required for various constituents. As such guidance is still forthcoming; in the 60% design, PG&E has made the conservative assumption for freshwater pre-injection treatment goals, specifically that arsenic treatment goal is to below the federal/state maximum contaminant level (MCL) of 10 µg/L and fluoride treatment goal is to below the state MCL of 2 milligrams per liter (mg/L). The freshwater source details will be included in an addendum to the Intermediate (60%) Design, after such requirements are determined and completion of planned source water studies. The 60% design information is based on ongoing bench scale studies and the experience in designing and operating arsenic and fluoride groundwater treatment systems on non-Topock projects. Additional engineering efforts are being conducted to complete the detailed design of the Freshwater Pre-Injection Treatment System and to optimize the system from a physical footprint perspective (system layout, building design including coordination of facilities with the adjacent remedy-produced water conditioning building, etc.) and a long-term operational footprint perspective (waste generation, management of waste including coordination with the remedy-produced water conditioning operation, etc.). The design information will be updated as additional bench-scale testing results become available, and as the detailed design/optimization efforts progresses (target completion in summer 2013). The goal is to include the additional design information in the 60% addendum. An

FMEA matrix will be prepared for the freshwater pre-injection treatment system for submittal in the 60% design addendum.

2.4 Power Supply

The power supply system will provide electricity for the groundwater remedy. The design objective of the system is to reliably provide sufficient electricity to power the groundwater remedy's electrically driven components such as pumps, controls, and lighting.

The primary power supply source for the remedy facilities in California will be power generated by the PG&E Topock Compressor Station and/or supplied from the City of Needles. For the freshwater supply well (HNWR-1) in Arizona, the power supply source will be power provided by Mohave Electric Cooperative. Secondary power supply will be power generated from small photovoltaic solar panels at various locations such as at the Central Maintenance Facility at the Transwestern Bench and at select remote well locations.

A potential failure is the temporary loss of power to the groundwater remedy infrastructure such as pumps and control systems. This could be caused by damage to the power generation equipment or transmission system. The failure modes anticipated would all be repairable in a period of days to weeks. Because the remedy performance is not anticipated to be affected by equipment outages of that duration, the power supply failure modes evaluated are not anticipated to significantly affect remedy schedule or performance.

To mitigate the risk of even temporary power outages, the electrical equipment used in the remedy will be designed for the site conditions, site security will be provided to minimize risk of vandalism, and an uninterruptible power supply (UPS) will be provided for key equipment such as control systems.

Table 2.4-1 presents the FMEA matrix for the power supply system.

2.5 SCADA, Control Systems, and Instrumentation

The SCADA system provides operator control, remote access, data logging, and alarm notification for the groundwater remedy. Field instrumentation measures various process data and transmits these data to local programmable logic controllers (PLCs). PLCs are industrial computerized controllers that gather this process data and use process-specific algorithms to provide automated control of the groundwater remedy system. Additionally PLCs are used to concentrate hardwired data signals and transmit to the central SCADA control center via communications network links. The Human/Machine Interfaces (HMI) provides graphical displays representing current and historical process data, and provides for operator interaction with the process, adjustment to the automation system, and trending of historical data. The final remedy will contain field instrumentation and local PLCs for each process area or well site tied together via fiber optic cabling, and multiple HMIs to allow operators to interact with various aspects of the groundwater remedy system .

The design objectives of the SCADA, instrumentation and control systems are to reliably provide automatic and remote control/monitoring of the groundwater remedy system components, and reliably record data that are needed for operations and compliance reporting.

A potential failure evaluated is damage to the SCADA system that causes temporarily losing the ability to view system performance, send/receive control signals from the control room, and log system data. This could have various causes such as hardware or software failures due to site environmental conditions or vandalism, power outages, or damage to communication wiring. These are not anticipated to significantly affect remedy schedule or performance.

To mitigate the risk of even temporary loss of control from the central control area, the SCADA and instrumentation equipment used in the remedy will be designed for the site conditions, equipment spares will be stocked on-site for critical control equipment, site security to protect against vandalism will be provided, and externally powered instruments will be connected to UPS-fed circuits.

Table 2.5-1 presents the FMEA matrix for the SCADA system.

3.0 References

California Department of Toxic Substances Control (DTSC). 1996. *Corrective Action Consent Agreement (Revised), Pacific Gas and Electric Company's Topock Compressor Station, Needles, California.* EPA ID No. CAT080011729. February 2.

_______. 2011. *Final Environmental Impact Report for the Topock Compressor Station Groundwater Remediation Project*. January 31.

_______.2012. Letter from Ms. Karen Baker/DTSC to Yvonne Meeks/PG&E. Subject: *Second Extension Request for Intermediate (60%) Design at Pacific Gas and Electric Company (PG&E), Topock Compressor Station, Needles, California (EPA ID No. CAT080011729)*. December 31.

U.S. Department of the Interior (DOI). 2013. Remedial Action/Remedial Design Consent Decree (CD) between the United States of America and Pacific Gas & Electric Company. Case 5:13-cv-00074-VAP-OP, Document 5-1. Filed January 15.

Tables

TABLE 1.0-1
Severity Scoring Used in Failure Mode and Effects Analysis
Groundwater Remedy Draft Operation and Maintenance Manual
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PG&E Topock Compressor Station, Needles, California

	Category				
Severity of Effect	**A - Unacceptable Remedy Performance**	**B - Schedule**	**C - Cost**	**D - Change to Impact**	**E - H&S or Compliance**
Unacceptable Conditions					
5	Remedy does not meet RAOs, cleanup goals, design objectives, or otherwise perform as required.	Very significant schedule increase more than 15 years	Very significant cost increase more than $50M	Environmental Impact Report (EIR) process required to be re-opened	• Serious H&S incident • ARARs, mitigation measures, or other compliance Notice of Violation event
4	Not defined	Schedule increase more than 5 years	Cost increase more than $10M	Not defined	Not defined
Other Conditions					
3	Remedy performance, operational, or other issue that prompts remedy (or portions thereof) to be temporarily shut down, but does not constitute unacceptable condition as defined above	Schedule increase 1-5 years	Cost increase $1M - $10M	See A.	See A.
2	Less significant/nuisance issues with remedy	Schedule increase 6 mo. - 1 year	Cost increase $0.5M - $1M	See A	See A
1	An incident that has an impact in one or more of the five categories, but less than defined above.				

TABLE 2.1-1

Failure Mode Effect Analysis Matrix - In-Situ Remediation System

Groundwater Remedy Draft Operation and Maintenance Manual

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PG&E Topock Compressor Station, Needles, California

Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations				Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition					Notes
			Mitigation	Observable Condition - PLC	Observable Condition - Human	Action if Cause Occurs				A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	
Conveyance (General)															
Release from conveyance pipeline. <u>Effect Without Mitigation:</u> Potential release of water with Cr(VI), carbon substrate, and/or well/pipeline maintenance chemicals.	Differential thermal expansion or settlement, deterioration, vandalism, puncture; pressure exceedance; fabrication failure.	Overall pipeline design for durability over project lifetime; secondary containment (double-wall pipe or concrete trench box); redundant/spare pipe installed (or spare space provided for additional pipe); pipe installed within concrete trench box or direct buried without stacking to facilitate access.		Alarm conditions - secondary containment sump alarms; out-of-range process alarms (i.e., pipeline flows or pressures)	Observe leak	Stop pipeline operation, switch to spare pipeline and/or repair /replace pipeline, resume operation.	4	1	4					X	Type E unacceptable condition associated with potential environmental release. Type A through D unacceptable conditions unlikely.
Conveyance fouling/clogging. <u>Effect without Mitigation:</u> Potentially insufficient capacity to support remedy.	Solids buildup (i.e., scaling, biofouling).	Overall system/pipeline design to mimize solids buildup; clean-in-place system and cleanouts for pipeline maintenance (see Operations and Maintenance Plan, Section 5 - Pipeline Maintenance); redundant/spare pipe installed (or spare space provided for additional pipe); pipe installed within concrete trench box or direct buried without stacking to facilitate access.	Pipeline pressure/flow monitoring	Pipeline pressure/flow monitoring and data-logging	Significant increase in pipeline pressure or decrease in flow; observed clogging	Stop pipeline operation, switch to spare pipeline and/or clean/repair /replace pipeline, resume operation.	2	3	6						
Pipeline maintenance chemical/fluid release to wells. <u>Effect without Mitigation:</u> Release of chemicals, solids, etc. into wells and groundwater.	Valving between wells and conveyance not closed during pipeline maintenance.	Clean-in-place system programmed to require automated wellhead valves to be closed prior to operation.	Operator training; wellhead/pipeline inspection during maintenance	Well pressure/flow monitoring and data-logging; wellhead valve position monitoring	Loss of pipeline maintenance solution; observed well flows during pipeline maintenance	Well rehab (Operations and Maintenance Plan, Section 4 - Well Maintenance)	2	2	4						

TABLE 2.1-1

Failure Mode Effect Analysis Matrix - In-Situ Remediation System

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Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations				Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition					Notes
			Mitigation	Observable Condition		Action if Cause Occurs				A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	
				PLC	Human										
Remediation Wells (General)															
Extraction well failure. <u>Effect without Mitigation:</u> The well will not be able to contribute to meeting extraction rate/remedy goals.	Capacity declines over time due to fouling or other well issues.	See Appendix C - Design Criteria (Remediation Well Design and Field Construction Approach) and Operations and Maintenance Plan, Section 4 - Well Maintenance - Extraction wells designed to optimize performance - Extraction wells designed to facilitate periodic well rehab - Remedy operations to minimize substrate and remedial by-product concentrations at extraction wells to minimize fouling	Remediation/monitoring well performance monitoring; periodic well rehab (Operations and Maintenance Plan, Section 4 - Well Maintenance)	Well water level/flow monitoring and data-logging	Insufficient capacity of produced water based on remediation/ monitoring well performance monitoring and evaluation	If well maintenance efforts ineffective - stop well operation, repair or replace, resume operation.	2	3	6						Unacceptable conditions unlikely due to individual extraction well failure.
	Well collapse or casing/screen failure (from deterioration, corrosion, etc.), vandalism, accidental damage, etc.	See Appendix C - Design Criteria (Remediation Well Design and Field Construction Approach) - Overall well design for durability over project llifetime - materials selection for resistance against corrosion, deterioration, and damage during routine operation and well rehab - Wells secured within vaults for protection	Visual well inspections	Alarm condition - out-of-range well operation	Observe damage	Stop well operation, repair or replace, resume operation.	2	1	2						
Injection well failure. <u>Effect without Mitigation</u>: The well will not be able to contribute to meeting injection rate/remedy goals.	Capacity declines over time.	See Appendix C - Design Criteria (Remediation Well Design and Field Construction Approach) and Operations and Maintenance Plan, Section 4 - Well Maintenance - Injection wells designed to optimize performance - drop tubes to minimize air entrainment - Injection wells designed to facilitate routine backwashing and periodic well rehab	Remediation/monitoring well performance monitoring; periodic well backwashing and rehab (Operations and Maintenance Plan, Section 4 - Well Maintenance)	Well water level/pressure/flow monitoring and data-logging	Insufficient capacity of injected water based on remediation/ monitoring well performance monitoring and evaluation	If well maintenance efforts ineffective - stop well operation, repair or replace, resume operation.	2	3	6						Unacceptable conditions unlikely due to individual injection well failure.
	Well collapse or casing/screen failure (from deterioration, corrosion, etc.), vandalism, accidental damage, etc.	See Appendix C - Design Criteria (Remediation Well Design and Field Construction Approach) - Overall well design for durability over project llifetime - materials selection for resistance against corrosion, deterioration, and damage during routine operation and well rehab - Wells secured within vaults for protection	Visual well inspections	Alarm condition - out-of-range well operation	Observe damage	Stop well operation, repair or replace, resume operation.	2	1	2						
Release from wellhead, piping, or vault. <u>Effect Without Mitigation:</u> Potential release of water with Cr(VI), carbon substrate, and/or well/pipeline maintenance chemicals.	Differential thermal expansion, deterioration, vandalism, puncture; pressure exceedance; fabrication failure.	Overall wellhead design for durability over project lifetime; wells secured within vaults for protection; leak detection level switch in vault sump to alarm/stop well operation	Visual well/vault inspections	Alarm condition - well vault sump level switch; out-of-range well operation	Observe leak	Stop well operation, repair, resume operation.	4	1	4					X	Type E unacceptable condition associated with potential environmental release. Type A through D unacceptable conditions unlikely.
	Injection well overflows.	Downwell pressure transducer to shut off well if excessive water level/pressure increase; leak detection level switch in vault sump to alarm/stop well operation; overall injection system designed for flow/pressure balancing across network to minimize potential for well overflow	Visual well/vault inspections; preventative well maintenance (Operations and Maintenance Plan, Section 4 - Well Maintenance)	Alarm condition - well vault sump level switch; out-of-range well operation	Observe leak	Stop well operation, make repairs (as necessary), troubleshoot injection well capacity issues, as necessary - rehab/redevelop well (Operations and Maintenance Plan, Section 4 - Well Maintenance)	4	1	4					X	

TABLE 2.1-1
Failure Mode Effect Analysis Matrix - In-Situ Remediation System
Groundwater Remedy Draft Operation and Maintenance Manual
Volume 3: Contigency Plan
PG&E Topock Compressor Station, Needles, California

Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations				Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition					Notes
			Mitigation	Observable Condition		Action if Cause Occurs				A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	
				PLC	Human										
Remediation well equipment, valving, instrumentation failure (other than above). Effect without Mitigation: Potential well damage or undesired operation.	Mechanical or electrical failure; general wear and tear; temperature.	Valves/instruments designed to fail in safest position; redundant controls/alarms; well casing relief valves to protect injection wells in case of excess pressure; common equipment/onsite spares for wells to facilitate troubleshooting	Preventative maintenance schedule; visual well/vault inspections	Alarm condition - well vault sump level switch; out-of-range well operation	Observe leak or out-of-range well operation	Stop well operation, repair, resume operation.	2	2	4						Unacceptable conditions unlikely due to individual well failure.

TABLE 2.1-1
Failure Mode Effect Analysis Matrix - In-Situ Remediation System
Groundwater Remedy Draft Operation and Maintenance Manual
Volume 3: Contigency Plan
PG&E Topock Compressor Station, Needles, California

Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations: Mitigation	Observable Condition: PLC	Observable Condition: Human	Action if Cause Occurs	Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
Carbon Amendment Systems (MW-20 and TW Benches)															
General carbon amendment system failure. Effect without Mitigation: Unable to operate parts or all of groundwater recirculation and carbon amendment systems to support remedy.	Equipment, valving, instrumentation failure	Valves/instruments that can result in a release if a fail-safe return is not provided are designed to fail in safest position; redundant controls/alarms; common equipment/onsite spares to facilitate troubleshooting; secondary containment at bench systems.	Visual inspections and preventative maintenance schedule	Alarm condition - out-of-range system operation; sump level alarm	Observed failure condition	Stop system operation, repair, resume operation.	3	2	6						Unacceptable conditions unlikely due to general carbon amendment system failure.
Carbon substrate storage and/or feed system failure. Effect without Mitigation: Potential release of flammable liquid; unable to amend recirculated groundwater with carbon substrate; potential over-dosing of carbon substrate to injection wells.	Human error Physical impact from vehicles Equipment, valving, instrument failue Corrosion, puncture, deterioration, accidental damage Vandalism	See Appendix C - Design Criteria, C.4.6 - Fire Protection Equipment and Draft Basis of Design Report, Section 3.2.1.1 - Description - NTH IRZ (Organic Carbon Substrate Amendment System [MW-20 Bench]) and Section 3.2.3.1 - Description - TCS Recirculation Loop (Organic Carbon Substrate Amendment System [Transwestern Meter Station]) - System designed in accordance with all applicable codes for flammable liquids - Overall system design for durability over project lifetime, including materials selection for compatibility, corrosion control, impact/damage protection - Storage tank has impact-resistant construction and double-wall construction with integral interstitial zone for leak detection monitoring - Instrumentation to include: tank interstitial space fluid level sensors, primary tank level transmitter with manual gauging port for operator verification, primary tank fluid temperature sensor, visible beacon/audible alarm within bench areas to notify operators of high level during tank filling, pipeline secondary containment leak detection system - Double-wall tank and piping systems with additional secondary containment in process/filling area - Valves/instruments designed to fail in safest position - Redundant controls/alarms - Fire extinguishers to be located at bench systems in accordance with applicable codes - Security fencing/traffic bollards	Visual inspections and preventative maintenance schedule; operator training	Alarm condition - leak detection/ secondary containment alarm; tank overfill alarm; out-of-range system operation (i.e., over- or under-dosing)	Observe failure condition	Stop system operation, repair, replace, or otherwise resolve failure, resume system operation; manual carbon substrate dosing at system or individual wells, if necessary	5	2	10			X		X	Type C/E unacceptable conditions associated with potential cost/H&S issues with flammable liquid storage and handling. Type A/B/D unacceptable conditions due to potential carbon substrate and/or feed system failure unlikely.

TABLE 2.1-1

Failure Mode Effect Analysis Matrix - In-Situ Remediation System

Groundwater Remedy Draft Operation and Maintenance Manual

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PG&E Topock Compressor Station, Needles, California

Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations				Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition					Notes
			Mitigation	Observable Condition		Action if Cause Occurs				A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	
				PLC	Human										
NTH IRZ															
IRZ is not effective at removing Cr(VI) from groundwater as designed. <u>Effect without Mitigation:</u> Potential schedule/cost increase or other issues with achieving RAOs as designed.	More rapid utilization of carbon substrate after injection than anticipated.	Design included pilot testing, predictive simulations/modeling, and additional design efforts; system designed with flexibility for range of operating flow rates and carbon substrate types and dosing strategies; future provisional wells have been included in the design, if needed; manual carbon substrate dosing can target individual wells if needed to supplement IRZ-wide dosing; River Bank extraction wells are designed to capture downgradient Cr(VI), TOC, and/or byproducts, as needed.	See Sampling and Monitoring Plan, Decision Rules/Operational Framework (Figures 2.2-2 and 2.2-3) for IRZ performance troubleshooting and operational adaptability philosophy to be conducted based on remedial performance monitoring/evaluation and using the designed system flexibility - operational adjustments may include flow rates, carbon substrate type and dosing strategy, number and location of operating wells, etc. River Bank extraction, Inner Recirculation Loop extraction, and Freshwater injection wells may be slowed or shut down to slow groundwater flow rate during NTH IRZ troubleshooting.		See Sampling and Monitoring Plan and Operations and Maintenance Plan for summary of remedy monitoring and how data will be evaluated/applied to remedy system optimization	If operational adjustments outlined in Sampling and Monitoring Plan, Decision Rules/Operational Framework (Figures 2.2-2 and 2.2-3) are not succesful in establishing IRZ effectiveness - additional extraction/injection wells or water sources (if system is flow limited) will be considered	4	2	8	X	X	X	X		Unacceptable conditions associated with potential increased level of effort required to achieve RAOs; however, inability to effectively operate IRZs within design/future provisional flexibility of remedy system as designed considered unlikely based on pilot testing, predictive simulations/modeling, and additional design efforts.
	Well spacing or screen placement is inadequate.						4	2	8	X	X	X	X		
	Recalcitrant mass in immobile porespace						4	2	8	X	X	X	X		
	Unexpected hydrogeologic conditions (e.g., preferential flow paths allow water to pass through IRZ without adequate treatment)						4	3	12	X	X	X	X		
	Extraction/injection flow limited						4	2	8	X	X	X	X		
Extraction of organic carbon and/or significant byproducts. <u>Effect without Mitigation:</u> Potential to increase well/pipeline maintenance required to meet remedy goals.	Carbon substrate dosing greater than required.					If operational adjustments outlined in Sampling and Monitoring Plan, Decision Rules/Operational Framework (Figures 2.2-2 and 2.2-3) are not succesful in managing organic carbon or by-product concentrations at extraction wells - additional wells or water sources (if system is flow limited) will be considered; treatment of River Bank extracted groundwater prior to re-injection will be considered.	4	2	8			X			
	By-product generation greater than expected/attenuation slower than expected						4	2	8			X			

TABLE 2.1-1

Failure Mode Effect Analysis Matrix - In-Situ Remediation System

Groundwater Remedy Draft Operation and Maintenance Manual

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PG&E Topock Compressor Station, Needles, California

Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations: Mitigation	Mitigation - Operations: Observable Condition: PLC	Mitigation - Operations: Observable Condition: Human	Mitigation - Operations: Action if Cause Occurs	Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition: A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
Inner Recirculation Loop															
Unacceptable migration of Cr(VI) or byproducts. Effect without Mitigation: Potential for Cr(VI) or byproducts to enter the Colorado River; potential plume expansion.	Unexpected hydrogeologic conditions.	Design included pilot testing, predictive simulations/modeling, and additional design efforts; system designed with flexibility for range of operating flow rates and carbon substrate type and dosing strategy; IRL injection wells designed for flexibility to inject freshwater and/or River Bank extracted groundwater; future provisional wells have been included in the design, if needed	See Sampling and Monitoring Plan, Decision Rules/Operational Framework (Figures 2.2-4 and 2.2-5) for IRL performance troubleshooting and operational adaptability philosophy to be conducted based on remedial performance monitoring/evaluation and using the designed system flexibility - operational adjustments may include flow rates, carbon substrate type and dosing strategy, number and location of operating wells, injection of freshwater and/or River Bank extracted groundwater into IRL injection wells, etc.		See Sampling and Monitoring Plan and Operations and Maintenance Plan for summary of remedy monitoring and how data will be evaluated/applied to remedy system optimization	If operational adjustments outlined in Sampling and Monitoring Plan, Decision Rules/Operational Framework (Figures 2.2-4 and 2.2-5) are not succesful in establishing adequate plume control or plume flushing - additional extraction/injection wells, River Bank extraction well pumping from shallow zones (for Cr[VI]) plume control in the shallow zones only), or additional water sources (if system is flow limited) will be considered; institutional controls will be considered, as needed, to limit new large-capacity extraction wells; additional mitigation measures, including potential treatment of River Bank extracted groundwater prior to re-injection, will be considered	4	3	12	X		X	X		Unacceptable conditions associated with potential increased level of effort required to achieve RAOs; however, inability to effectively operate the Inner Recirculation Loop within design/future provisional flexibility of remedy system as designed considered unlikely based on pilot testing, predictive simulations/modeling, and additional design efforts.
	Well spacing or screen placement is inadequate.						4	2	8	X		X	X		
	New large-capacity wells (e.g., water supply wells) are installed near the site (e.g., at Park Moabi or elsewhere along the Colorado River).						4	2	8	X		X	X		
Flushing of plume through NTH IRZ not as effective as designed. Effect without Mitigation: Potential schedule delay.	Unexpected hydrogeologic conditions.						4	3	12		X	X	X		
	Lack of adequate supply of injection water (e.g., reduced freshwater supply, River Bank Extraction Well produced water contains unacceptably high concentrations of byproducts/other constituents).						4	2	8		X	X	X		
Natural reducing rind near river is negatively-impacted by pumping resulting in inadequate reducing buffer in floodplain. Effect without Mitigation: Could affect ability to rely on MNA for residual contamination when active remediation ends.	Oxic water from the river being pulled into floodplain by extraction wells near the river	Design included pilot testing, predictive simulations/modeling, and additional design efforts; system designed with flexibility for range of operating flow rates; River Bank extraction well pumping planned for deeper zones only				If operational adjustments are not successful in adequately maintaining the natural reducing rind - assess potentially required remedy modifications	2	2	4						

TABLE 2.1-1

Failure Mode Effect Analysis Matrix - In-Situ Remediation System

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Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations: Mitigation	Mitigation - Operations: Observable Condition: PLC	Mitigation - Operations: Observable Condition: Human	Mitigation - Operations: Action if Cause Occurs	Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition: A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
TCS Recirculation Loop															
TW Bench extraction well network does not provide adequate volume or mass removal. Effect without Mitigation: Potential schedule delay as impacted water near TCS not treated as rapidly as planned.	Unexpected hydrogeologic conditions.	Design included pilot testing, predictive simulations/modeling, and additional design efforts; system designed with flexibility for range of operating flow rates and carbon substrate type and dosing strategy; TCS injection wells designed for flexibility to inject freshwater and/or extracted groundwater; future provisional wells have been included in the design, if needed; River Bank extraction wells are designed to capture downgradient Cr(VI), TOC, and/or byproducts, as needed.	See Sampling and Monitoring Plan, Decision Rules/Operational Framework (Figures 2.2-6 to 2.2-8) for TCS Recirculation Loop performance troubleshooting and operational adaptability philosophy to be conducted based on remedial performance monitoring/evaluation and using the designed system flexibility - operational adjustments may include flow rates, carbon substrate type and dosing strategy, number and location of operating wells, etc.; TW Bench and East Ravine extracted groundwater may be injected into NTH IRZ, if needed.		See Sampling and Monitoring Plan and Operations and Maintenance Plan for summary of remedy monitoring and how data will be evaluated/applied to remedy system optimization	If operational adjustments outlined in Sampling and Monitoring Plan, Decision Rules/Operational Framework (Figures 2.2-6 to 2.2-8) are not successful in achieving design objectives - additional extraction/injection wells will be considered.	4	3	12		X	X	X		Unacceptable conditions associated with potential increased level of effort required to achieve RAOs; however, inability to effectively operate the TCS Recirculation Loop within design/future provisional flexibility of remedy system as designed considered unlikely based on pilot testing, predictive simulations/modeling, and additional design efforts.
	Well spacing or screen placement is inadequate.						4	2	8		X	X	X		
East Ravine extraction well network does not provide capture of targeted groundwater, as designed. Effect without Mitigation: Potential expansion of plume or Cr(VI) release to Colorado River.	Unexpected hydrogeologic conditions.						4	3	12	X	X	X	X		
	Well spacing or screen placement is inadequate.						4	2	8	X	X	X	X		
Cr(VI) treatment by TCS injection well network not as effective as designed. Effect without Mitigation: Potential schedule delay.	Unexpected hydrogeologic conditions.						4	3	12		X	X	X		
	More rapid utilization of carbon substrate after injection than anticipated.						4	2	8		X	X	X		
	Well spacing or screen placement is inadequate.						4	2	8		X	X	X		
	Lack of adequate supply of injection water.						4	2	8		X	X	X		

TABLE 2.1-1

Failure Mode Effect Analysis Matrix - In-Situ Remediation System

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Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations				Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition					Notes
			Mitigation	Observable Condition		Action if Cause Occurs				A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	
				PLC	Human										
Freshwater Injection System															
Flushing of plume through NTH IRZ not as effective as designed. Effect without Mitigation: Potential schedule delay.	Unexpected hydrogeologic conditions.	Design included pilot testing, predictive simulations/modeling, and additional design efforts; system designed with flexibility for range of operating flow rates	See Sampling and Monitoring Plan, Figure 2.2-9 Freshwater Injection System Decision Rules/Operational Framework for freshwater injection performance troubleshooting and operational adaptability philosophy to be conducted based on remedial performance monitoring/evaluation and using the designed system flexibility - operational adjustments may include flow rates, number and location of operating wells, etc.; TCS injections may be adjusted or shut down if FW-02 is not operating as intended		See Sampling and Monitoring Plan and Operations and Maintenance Plan for summary of remedy monitoring and how data will be evaluated/applied to remedy system optimization	If operational adjustments outlined in Sampling and Monitoring Plan, Figure 2.2-9 Freshwater Injection System Decision Rules/Operational Framework are not succesful in achieving design objectives - additional injection wells and/or freshwater source will be considered	4	3	12		X	X	X		Unacceptable conditions associated with potential increased level of effort required to achieve RAOs; however, inability to effectively operate the Freshwater Injection System within design/future provisional flexibility of remedy system as designed considered unlikely based on pilot testing, predictive simulations/modeling, and additional design efforts.
	Well or screen placement is inadequate.						4	2	8		X	X	X		
	Lack of adequate supply of injection water.						4	2	8		X	X	X		
Insufficient FW-02 performance to maintain control of southwestern plume margin. Effect without Mitigation: Potential plume expansion.	Unexpected hydrogeologic conditions.						4	3	12	X					
	Well or screen placement is inadequate.						4	2	8	X					
	Lack of adequate supply of injection water.						4	2	8	X					

TABLE 2.1-1

Failure Mode Effect Analysis Matrix - In-Situ Remediation System

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Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations				Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition					Notes
			Mitigation	Observable Condition		Action if Cause Occurs				A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	
				PLC	Human										
In-Situ Remediation System (General)															
Aerial or vertical extent of Cr(VI) plume greater than currently defined. <u>Effect without Mitigation</u>: Potential expansion of remedy footprint.	Inadequate characterization of Cr(VI) in groundwater	Groundwater characterization efforts to date indicate it is unlikely that significant Cr(VI) concentrations exist outside of currently-defined plume footprint. Remedy system design includes some flexibility to expand outside of planned footprint, if needed.	Installation of remediation and monitoring wells will be conducted in a step-wise manner with a focus on first gathering lithologic data, then water quality data, before finalizing well screen locations and installing wells. Well construction will also consider previous well data to ensure the latest data is used in the well installation process.		See Sampling and Monitoring Plan and Operations and Maintenance Plan for summary of remedy monitoring and how data will be evaluated/applied to remedy system optimization	Assess potentially required remedy modifications, including system expansion	4	2	8			X	X		Unacceptable conditions associated with potential cost increase/re-opening of EIR due to expansion of remedy footprint. Other unacceptable conditions unlikely.
Cr(III) re-oxidation to Cr(VI) after in-situ treatment. <u>Effect without Mitigation:</u> Potential issues with achieving RAOs as designed.	Unexpected high availability of reactive MnO_2 surfaces along groundwater flow path.	Design included pilot testing, predictive simulations/modeling, and additional design efforts that indicated significant re-oxidation of Cr(III) to Cr(VI) is unlikely	See Sampling and Monitoring Plan, Decision Rules/Operational Framework (Figures 2.2-2 to 2.2-9) for remedy performance troubleshooting and operational adaptability philosophy to be conducted based on remedial performance monitoring/evaluation and using the designed system flexibility such as adjusting operational flow rates, organic carbon dosing strategy, etc.			Assess potentially required remedy modifications	1 to 4	1	1 to 4	X	X	X	X		Unacceptable conditions associated with potential increased level of effort required to achieve RAOs.
In-situ remedy byproduct (arsenic) concentrations do not sufficiently attenuate. <u>Effect without Mitigation</u>: Potential issues with achieving RAOs as designed.	Inadequate groundwater and/or biogeochemical characterization	Design included pilot testing, predictive simulations/modeling, and additional design efforts that indicate sufficient byproduct attenuation following remedy operation				Assess potentially required remedy modifications	1 to 3	1	1 to 3						
In-situ remedy byproduct (manganese) concentrations do not sufficiently attenuate. <u>Effect without Mitigation</u>: Potential issues with achieving RAOs as designed.							1 to 3	1	1 to 3						
In-situ remedy byproduct (iron) concentrations do not sufficiently attenuate. <u>Effect without Mitigation</u>: Potential issues with achieving RAOs as designed.							1 to 3	1	1 to 3						

TABLE 2.1-1

Failure Mode Effect Analysis Matrix - In-Situ Remediation System

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Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations				Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity x Likelihood	Type of Unacceptable Condition					Notes
			Mitigation	Observable Condition		Action if Cause Occurs				A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	
				PLC	Human										
Natural Disaster															
Seismic damage. <u>Effect without Mitigation</u>: Damage to remedy infrastructure may cause shutdown of parts or all of remedy.	Earthquake	See Appendix C - Design Criteria, C.2.5 - Seismic Loads - Structures will be designed in accordance with applicable seismic codes		Alarm conditions will shut system down if significant damage	Observed failure condition		varies	1	varies		X	X			
Flooding. <u>Effect without Mitigation</u>: Damage to remedy infrastructure may cause shutdown of parts or all of remedy; potential loss of access.	Rising water levels in Colorado River	Remedy infrastructure located outside of ordinary high water mark and 100-year floodplain to the extent possible; system can be operated/shutdown remotely if access limited	Preventative system shutdown or other action if flood conditions predicted	Alarm conditions will shut system down if significant flooding (sump levels)/ damage	Observed failure condition		varies	1	varies		X	X			
Fire damage. <u>Effect without Mitigation</u>: Damage to remedy infrastructure may cause shutdown of parts or all of remedy.	Wildfires/vegetation fires; Compressor station or gas pipeline explosion	System can be operated/shutdown remotely if access limited	Routine vegetation clearing/housekeeping in remedy facility areas; preventative system shutdown or other actions if fires in area	Alarm conditions will shut system down if significant damage	Observed failure condition	Stop system operation, inspect system, repair/replace system infrastructure (as needed), resume system operation	varies	1	varies		X	X			
Freezing conditions. <u>Effect without Mitigation</u>: Potential damage to remedy infrastructure may cause shutdown of parts or all of remedy.	Cold temperatures	Site conditions/temperatures unlikely to be cold enough to cause issues.	Preventative system shutdown and system/pipeline draining if freezing temperatures predicted	Alarm conditions will shut system down if significant freezing/ damage	Observed failure condition		1	1	1						
Wind-blow dust damage. <u>Effect without Mitigation</u>: Potential damage to remedy infrastructure may cause shutdown of parts or all of remedy.	Dust, sands, etc. blown by high desert winds	Most remedy infrastructure located within enclosed buildings or vaults.	Preventative maintenance and visual inspection schedule to observe damage	Alarm conditions will shut system down if equipment failure due to dust damage	Observed damage or failure condition		1	2	2						

Abbreviations:

PLC - process logic controller
EIR - environmental impact report
H&S - health and safety
NOV - notice of violation
RAO - remedial action objective
TW - Transwestern
IRZ - In-Situ Reactive Zone
NTH - National Trails Highway
TCS - Topock Compressor Station
IRL - Inner Recirculation Loop
MNA - monitored natural attenuation
Cr(VI) - hexavalent chromium
Cr(III) - trivalent chromium
MnO_2 - manganese dioxide
P/V - pressure/vacuum
TOC - total organic carbon

TABLE 2.2-1
Failure Mode Effect Analysis Matrix — Remedy-produced Water Management System
Groundwater Remedy Draft Operation and Maintenance Manual
Volume 3: Contingency Plan
PG&E Topock Compressor Station, Needles, California

Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations: Mitigation	Observable Condition: PLC	Observable Condition: Human	Action if Cause Occurs	Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity * Likelihood	A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, ARARs, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
1. Conditioning System Capacity Insufficient [2,3] Effect without Mitigation: Some water will not be able to be conditioned or re-used/ disposed on-site	a. Generate more water that must be managed in a single backwash event – Short- term capacity condition	Plant designed for 35 gpm capacity and safety factor applied in sizing storage tanks	Temporarily decrease backwash frequency which would cause an increase in water level in the injection well	Influent flow measurements	N/A	Adjust operations to reduce backwash Investigate root cause and re-evaluate well ops/ maintenance procedures	1	1	1						In cases resulting in loss of well performance, see the SOPs in the O&M Manual for diagnostic and maintenance procedures.[4]
	b. Wells need more maintenance then anticipated – Long-term capacity condition	Plant designed for 35 gpm capacity and safety factor applied in sizing storage tanks. Process is divided into 2 sides (Remedy A-side and Freshwater B-side) to allow for flexibility in managing conditioned water.	Investigate root cause, re-evaluate well operations, and maintenance procedures (see Section 4) If needed, evaluate the need and methods to increase plant capacity.	Flow transmitters, High well operating level	N/A	Adjust operations to reduce backwash Investigate root cause and re-evaluate well ops/ maintenance procedures	3	2	6						See Note [1]. Severity depends on downtime and cost.
	c. Excessive load of solids on filters. Frequent filter change-outs	Install tanks to settle solids and turbidity analyzers on conditioned water tanks. Design coarse, then fine filter and standby filters on each train and instrumentation to measure pressure across the filters.	Conduct jar testing for alternative coagulants, to improve settling in tanks. Normal operation is flow through 2-stage filters. Standby filters put into service if operating filter is fouled. Stock spare filters on site	Quick increase in differential pressure across cartridge filters. Alarms	Scheduled inspections, check water chemistry for scaling conditions	Well sampling to evaluate influent solids concentrations; Replace cartridges. If scaling, change pH target or add antiscalant	2	1	2						In cases resulting in loss of well performance, see the O&M Manual for diagnostic and maintenance procedures.[4]
	d. Grit build-up in tank	Design capability to pump solids from these tanks to phase separators. Design capability to use vac truck to remove solids.	Operators to monitor solids level	N/A	Operators to monitor solids level	Operators to hose down solids so they'll pump out, or remove by vac. truck	1	1	1						
	e. Phase separator bins cannot be removed due to problems with hauling contractor and solids fill up in system. Plant capacity limited or stopped.	N/A	Have backup destination for disposal planned	N/A	N/A	Store full bins on site or at other PG&E facilities	1	1	1						

TABLE 2.2-1
Failure Mode Effect Analysis Matrix — Remedy-produced Water Management System
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PG&E Topock Compressor Station, Needles, California

			Mitigation - Operations							Type of Unacceptable Condition					
				Observable Condition											
Potential Failure and Effect without Mitigation	**Potential Cause**	**Mitigation - Design**	**Mitigation**	**PLC**	**Human**	**Action if Cause Occurs**	**Severity (1 Low - 5 High)**	**Likelihood (1 Low - 5 High)**	**Severity * Likelihood**	**A. Unacceptable Remedy Performance**	**B. Significant Schedule Increase**	**C. Significant Cost Increase**	**D. Re-Opening EIR, ARARs, etc.**	**E. H&S or Compliance NOV (other than related to remedy performance)**	**Notes**
	f. IRZ and other on-site reuse/disposal options do not have the capacity to take all treated water – Short term condition	N/A	Storage	N/A	N/A	Adjust operations	2	1	2						
	g. IRZ and other on-site reuse/disposal options do not have the capacity to take all treated water – Long term condition	N/A	Evaluate alternative re-use options.	N/A	N/A	Trucking	3	1	3						.
	h. More wells or higher flow rates are needed to achieve RAOs, which produces more water to manage.	Reserve space for additional storage and/or conditioning equipment	N/A	N/A	N/A	N/A	2	1	2						See Note 3.
2. Poor Quality Water to Wells: High or low pH Effect without Mitigation: Out of Spec Water may cause increased well or formation fouling or geochemical changes releasing minerals which could affect IRZ performance or plume composition. Excessive pH either high or low could reduce or change microorganism populations, which in turn could also reduce IRZ performance.	a. Tank eductor failure, and poor mixing of conditioning chemicals	Install redundant tank eductors	N/A	N/A	If chemical addition loses effectiveness at altering pH. Will do periodic visual inspections of educators	Repair or replace	1	1	1						
	b. pH Analyzer Failure	Install analyzers on influent and conditioned water tanks	Periodic calibration and system inspections	High and low alarm	Scheduled inspections and monitoring with handheld meter	N/A	1	1	1						
3. Poor Quality Water to Wells: High Suspended Solids Effect without Mitigation: Increase potential for well fouling which could result in increased well maintenance	Cartridge filter rupture or operator not install cartridge	Install turbidity analyzers on conditioned water tanks	Injection well performance monitoring SOP and RPWC System SOPs.[4] Normal operation is flow through 2-stage filters. Standby filter put into service if operating filter is fouled	Alarms on analyzers	Equipment inspections	Follow well maintenance procedures (Section 4), replace cartridges	2	1	2						

TABLE 2.2-1
Failure Mode Effect Analysis Matrix — Remedy-produced Water Management System
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Volume 3: Contingency Plan
PG&E Topock Compressor Station, Needles, California

			Mitigation - Operations							Type of Unacceptable Condition					
				Observable Condition											
Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation	PLC	Human	Action if Cause Occurs	Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity * Likelihood	A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, ARARs, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
4. Poor Quality Water to Wells: Presence of scaling ions: (Ca, Mg, Mn, Fe, etc) or high pH water Effect without Mitigation: Scaling in pipelines and wells	Presence of ions in well water	Reserve space to add conditioning units, if needed. Pigging stations or cleanouts are included in the pipelines. May need to add anti-scalants continuously or use other chemical cleaners.	Monitor effluent quality and injection well performance (see additional information in the Notes column).	N/A	N/A	Follow well maintenance procedures (Section 4)	2	2	4						System is not designed for removing dissolved metals. Modify conditioning process if dissolved ions and metals pose or are causing declining well performance. Addition of conditioning methods may be required if pH increase is not effective in removing constituents. More frequent rehabs or backwash at wells that are fouling due to poor effluent water quality.
5. Equipment Failure Effect Without Mitigation: Leak, contamination, personnel exposure	a. Pipe rupture	Select piping material that is appropriate for the liquid being conveyed and is rated for the anticipated operating pressure.	N/A	N/A	Visual	Follow SOPs,[4] and perform repair	2	1	2						
	b. Tank Failure	Install tank vents, barriers to prevent vehicle impact, seismic supports, coatings, corrosion protection system, and secondary containment for tanks	Preventive maintenance	N/A	Visual	Follow SOPs,[4] and perform repair	2	1	2						
	c. Pump Failure	Mech. seals, drainage for leaks and drips, evaluate seal flush system destination, evaluate cavitation potential on low suction head pumps.	Preventive maintenance	Run fail indication	N/A	Follow SOPs[4] for pump and seals, and perform repair	1	1	1						
	d. Filter failure	Install instrumentation to measure pressure across the filters and alarm. Install 2 stages filters (coarse and fine). Set vessel pressure rating to contain "deadhead" pump condition.	Preventive maintenance	Increased pressure across filters	N/A	Follow SOPs,[4] and perform repair/ replace cartridges	1	1	1						
	e. Eductor failure	Install multiple tank eductors. Monitor vacuum on educator to evaluate erosion or fouling.	Preventive maintenance and inspection. Do routine maintenance and adjust procedures and equipment accordingly.	N/A	Visual inspections/ maintenance	Follow SOPs[4] and perform repair/ replace educators.	1	1	1						

TABLE 2.2-1
Failure Mode Effect Analysis Matrix — Remedy-produced Water Management System
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			Mitigation - Operations							Type of Unacceptable Condition					
				Observable Condition											
Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation	PLC	Human	Action if Cause Occurs	Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity * Likelihood	A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, ARARs, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
6. Freezing Effect without mitigation: No fluid flow	Low ambient temperature	Install heat trace for some chemical piping and storage tanks.	Drain system. Other responses include heat tape, wrapping lines with cloth or rags, or placing heat lamps.	N/A	Weather forecast and anticipated outage schedule.	Upgrade freeze protection or change chemical strength or type	2	1	2						Not been a problem historically at TCS or IM-3
7. Spills Effect without Mitigation: Exposure and contamination of soil	Equipment or pipe failure.	Provide adequate secondary containment	SOP[4] and training and alarms (also in HMBP, BMPs, SWPPP)	SCADA alarm for pump running and no flow. Secondary containment level alarms	Visual, inspections	Drain system, pump to influent storage tanks. Repair leak.	2	1	2						
8. Unexpected constituents/ material by-product in conditioned water Effect without Mitigation: Carry over contaminant to cooling tower or injection wells	a. Not following RPWC SOPs[4]	N/A	Follow the Operation and Maintenance Manual and SOPs	N/A	N/A	Reinforce/training	1	1	1						Examples include, iron, manganese, silica, calcium, magnesium, and biological materials
	b. Unexpected material enters system	N/A	Investigate root cause, re-evaluate well operations, and maintenance procedures (see Section 4)	N/A	N/A	Revise SOPs[4] or process as needed, could modify monitoring procedures.	2	1	2						
9. Lightning Strike Effect without mitigation: Damage to plant may cause shutdown of system. May cause release of produced water or conditioning chemicals	Lightning	Provide lightning protection and adequate secondary containment for tanks and equipment	Maintain appropriate spare parts to minimize downtime. If necessary, can truck offsite or stop backwashing to mitigate downtime of conditioning system.	N/A	Add inspections into SOPs[4] to watch for leaks or overfilling after a strike	Inspect and assess site for damage / mechanical integrity or repair. If necessary, can truck offsite or stop backwashing until repair is done.	2	1	2						
10. Seismic Damage Effect without Mitigation: Damage to plant may cause shutdown of system	Earthquake	Design in accordance with structural design criteria in 60% Design, Appendix C. Provide adequate secondary containment for tanks and equipment	If necessary, can truck offsite or stop backwashing to mitigate downtime of conditioning system.	N/A	N/A	Inspect and assess site for damage / mechanical integrity or repair. If necessary, can truck offsite or stop backwashing until repair is done.	3	1	3						
11. Fire Effect without Mitigation: Damage to plant may cause shutdown of system	Fire	Fire hydrant in proximity of building. Provide adequate secondary containment for equipment and tanks.	Fire water/pumps at station. If necessary, can truck offsite or stop backwashing to mitigate downtime of conditioning system.	N/A	N/A	Contact Fire Dept. Inspect, assess damage, begin repairs, startup. If necessary, can truck offsite or stop backwashing until repair is done.	2	1	2						

TABLE 2.2-1
Failure Mode Effect Analysis Matrix — Remedy-produced Water Management System
Groundwater Remedy Draft Operation and Maintenance Manual
Volume 3: Contingency Plan
PG&E Topock Compressor Station, Needles, California

Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations: Mitigation	Mitigation - Operations: Observable Condition: PLC	Mitigation - Operations: Observable Condition: Human	Mitigation - Operations: Action if Cause Occurs	Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity * Likelihood	Type of Unacceptable Condition: A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, ARARs, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
12. System is damaged due to vandalism Effect without Mitigation: Damage to wells could result in increased trucking or well repair/ replacement. Plant is off-line for weeks to months while being re-built.	Vandalism	Facilities within the TCS will be secured by current TCS security system. Controls built into the system (alarms, containment, automatic cutoffs and shutdowns) are designed to help mitigate uncontrolled releases or discharges following several types of due to vandalism	Periodic inspections of all equipment inside and outside conditioning system and wells. TCS access control and security will help protect plant.	N/A	N/A	Inspect and assess site for damage / mechanical integrity or repair.	2	1	2						

Notes:

[1] Anticipated annual remedy-produced water volume (backwash and rehab) is 7.6 million gallons (MG) per year (625,000 gallons per month). The cost of transport and disposal of this water per month off-site (assuming $0.30/gal) would be $187,500. With provisional wells could be 10 MG/yr (833,000 gallons per month), which would be $250,000 per month. Assuming a truck volume of 6,500 gallons, 90 trucks per month would be needed to haul this monthly production. The Environmental Impact Report (EIR; DTSC 2011) states 100 vehicles per year for regular maintenance, up to 10 additional vehicles per year for non-routine maintenance, 1 pump rig for 1 to 4 months per year for well maintenance, 10 delivery trucks or sampling vehicles per monitoring event. Depending on how long the treatment and on-site reuse/disposal system is out of service will determine the cost and severity on trucking relative to EIR.

[2] Current estimated annual flow is 7.6 MG; with provisional wells could be 10 MG/yr. Peak design flow is 35 gpm (18.4 MG/yr).

[3] Space is reserved to allow for increase storage and system conditioning capacity if needed.

[4] Standard Operating Procedures are from Volume 1, Operations and Maintenance Plan, Appendix C (to be defined in 90% design).

Acronyms and Abbreviations:

ARAR	Applicable or Relevant and Appropriate Requirements	PLC	Programmable Logic Controller
BMP	Best Management Practices	RAO	Remedial Action Objective
EIR	Environmental Impact Report	RPWC	Remedy-Produced Water Conditioning
H&S	Health & Safety	SCADA	Supervisory Control and Data Acquisition
HMBP	Hazardous Materials Business Plan	SOP	Standard Operating Procedure
NOV	Notice of Violation	SWPPP	Storm Water Pollution Prevention Plan
N/A	Not Applicable	TCS	Topock Compressor Station
O&M	Operations and Maintenance		

TABLE 2.3-1
Failure Mode Effect Analysis Matrix — Freshwater Supply
Groundwater Remedy Draft Operation and Maintenance Manual
Volume 3: Contingency Plan
PG&E Topock Compressor Station, Needles, California

	Failure Mode	Likely Causes for Failure	Effects of Failure	Operational Actions	Possible Contingency Measures
Failure Modes Associated with HNWR-1 Source	Well yield declines below the minimum required for optimal remedy operation	• Pump failure • Extraction well fouling • Excessive drawdown due to competing water users	• Delay in reaching RAOs	• Replace pump • Rehab well • Replace well • Install contingent well (the proposed location of this future provisional well is shown in Figure 3.0-1)	• Seek other location for well(s) • Seek alternative freshwater supply to augment or replace primary supply • Establish institutional control to prevent excessive drawdown from competing water users
	Quality of water in freshwater well declines over time	• Pumping draws in saline water from below or geochemically reduced water containing iron and manganese	• Could result in shutting down remedial action if water quality is not suitable for injection	• Add additional pre-treatment within footprint of the Fresh Water Pre-Injection Treatment system	• Seek other sources of fresh water or other locations for well(s)
	Freshwater pumping causes adverse effects on water quality or capacity in nearby wells	• Over pumping of aquifer in areas with marginal groundwater quality / transmissivity	• Could result in shutting down remedial action if affected water users cannot be made whole	• None	• Seek other sources of fresh water or other locations for well(s) • Provide alternate water supply for affected water users

TABLE 2.4-1
Failure Mode Effect Analysis Matrix—Power Supply
Groundwater Remedy Draft Operation and Maintenance Manual
Volume 3: Contingency Plan
PG&E Topock Compressor Station, Needles, California

Potential Failure and Effect without Mitigation	Potential Cause	Mitigation – Design	Mitigation - Operations			Action if Cause Occurs	Severity (1 Low - 5 High)	Likelihood (1 Low - 5 High)	Severity * Likelihood	Type of Unacceptable Condition					Notes
			Mitigation	Observable Condition: PLC	Observable Condition: Human					A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, ARARs, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	
1. Utility or generated power supply failure Effect Without Mitigation: Loss of equipment function and eventual loss of control system functionality. May prohibit systematic shutdown of processes	Raptor entanglement, lightning strike on line, high wind, post insulator destroyed by gunshot, traffic collision with pole, or external customer causes distribution circuit trip	Uninterruptible Power Supplies (UPS) for control circuits	Maintain site security.	N/A	N/A	Repair, replace	1	2	2						
	Generator mechanical, electrical, or controller failure	Interconnection to other source(s) of generated electrical power, connection point for portable generator.	N/A	N/A	N/A	Repair, replace	2	1	2						
2. Electrical distribution equipment failure Effect Without Mitigation: Loss of power downstream of failed equipment. May prohibit systematic shutdown of processes	Manufacturing defects, age, and heat exposure, or ingress of dirt/sand into electrical equipment	Use utility-grade equipment, rated for installation environment. Utilize common equipment styles for quick replacement	Periodic electrical testing, including transformer dissolved gas analysis	N/A	N/A	Repair, replace	3	1	3						
3. Damage from direct or nearby lightning strikes Effect Without Mitigation: Loss of power downstream of failed equipment. May prohibit systematic shutdown of processes	If power is from utility: Connection to utility overhead lines which attract lightning	Use of Surge Protective Devices	Periodic inspection of SPD indicators	N/A	N/A	Repair, replace	3	1	3						
	Direct strike on equipment	None	None	Loss of Power Detected	Charred Enclosure	Repair, replace	3	2	6						
4, Cable damage/fault/failure Effect Without Mitigation: Loss of power downstream of failed equipment. May prohibit systematic shutdown of processes	Digging near underground lines, rodents in termination cabinets, over temperature leading to insulation failure	Protect power cabling in raceway and enclosures. Minimize sun exposure to insulation systems and size circuits conservatively	Keep enclosure doors closed, use proper bolt torques	Loss of Power Detected	N/A	Repair, replace	3	1	3						
5. Externally caused equipment failure Effect Without Mitigation: Loss of power downstream of failed equipment. May prohibit systematic shutdown of processes	Vandalism, theft, force majeure	Provide secure, robust, and lockable system enclosures	Inspect accessible equipment for damage	N/A	Inspect accessible equipment for damage	Repair, replace	3	1	3						

Note:
N/A = not applicable.

TABLE 2.5-1
Failure Mode Effect Analysis Matrix—SCADA, Control Systems, and Instruments
Groundwater Remedy Draft Operation and Maintenance Manual
Volume 3: Contingency Plan
PG&E Topock Compressor Station, Needles, California

			Mitigation - Operations							Type of Unacceptable Condition					
				Observable Condition											
Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation	PLC	Human	Action if Cause Occurs	Severity (1 Low – 5 High)	Likelihood (1 Low – 5 High)	Severity * Likelihood	A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, ARARs, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
1. PLC hardware failure Effect Without Mitigation: Lose ability to send/receive control signals from control room. Lose ability to collect data.	a. Over-temperature	Keep cooled, design includes shade or active cooling where required for equipment longevity.	Keep spares on-site in stock	SCADA monitors communication and PLC health, and alarms in failure event	Failure may result in unchanged or frozen process variable	Repair, replace	1	3	3						Would be fixed before would cause RAO or schedule issues
	b. Dust/Rainfall/Spray from washdown or pipe break	Design utilizes industrial-grade equipment, housing in National Electrical Manufacturers Association (NEMA)-rated enclosures appropriate for environment. For open enclosures include filters.													Would be fixed before would cause RAO or schedule issues
	c. Power supply irregularity (lightning, shifting generator power, utility's overvoltage, harmonics, temporary power loss)	UPS provided for each PLC.													Would be fixed before would cause RAO or schedule issues
2. Cabling or termination damage/failure Effect Without Mitigation: Lose ability to send/receive control signals from control room. Lose ability to collect data.	Mechanical damage by backhoe or shovel for underground circuits, traffic or vandalism for above-ground circuits, or temperature changes loosen terminations	Provide conduit for mechanical protection of circuits, route fiber optic cables in protected areas of panels, monitor communications, detection tape, rigid conduit, concrete cap, pipe markers.	Use proper torque on cable terminations	SCADA monitors communications network, alarms in failure event	Routine patrols of utility corridors and facilities	Repair, replace	1	2	2						
3. Field instrumentation damage/failure Effect Without Mitigation: Lose ability to receive accurate control signals from control room or at local controllers. Diminished process data accuracy.	a. Thermal or physical damage to instrument or aging of internal parts or circuits, drifting of instrument output signal(s)	Provide sun protection and mechanical protection where instruments are vulnerable to damage	Calibrate instruments according to manufacturer's recommended schedules	Reduced control system and process performance	Test critical alarms as part of O&M procedure and field verification (e.g., water levels)	Adjust, repair, replace	1	1	1						For severities upon loss of critical instrumentation, see Process FMEAs.
	b. Power supply irregularity (lightning, shifting generator power, utility's overvoltage, harmonics, temporary power loss)	Connect externally powered instruments to UPS-fed circuits	Routine testing of battery capacity or regular replacement	Erroneous alarms, reduced control system and process performance	N/A	Repair, replace	1	1	1						

TABLE 2.5-1
Failure Mode Effect Analysis Matrix—SCADA, Control Systems, and Instruments
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Potential Failure and Effect without Mitigation	Potential Cause	Mitigation - Design	Mitigation - Operations: Mitigation	Mitigation - Operations: Observable Condition: PLC	Mitigation - Operations: Observable Condition: Human	Mitigation - Operations: Action if Cause Occurs	Severity (1 Low – 5 High)	Likelihood (1 Low – 5 High)	Severity * Likelihood	Type of Unacceptable Condition: A. Unacceptable Remedy Performance	B. Significant Schedule Increase	C. Significant Cost Increase	D. Re-Opening EIR, ARARs, etc.	E. H&S or Compliance NOV (other than related to remedy performance)	Notes
4. SCADA controls software failure: Effect without Mitigation: Control system commands lock themselves into last state	Software bug, OS or applications software	Use HMI software suited for size of system, rigorous testing of applications software prior to and during startup	Keep backup files onsite and offsite for all OS and application software programs	N/A	Loss of real-time monitoring and/or control	Reboot system, potential reload of software	2	2	4						
5. Valve fails in non-safe state. Effect without Mitigation: Water or chemical may flow not per design.	a. Power failure	Valves that are important to fail in safe position will be designed or configured with a fail safe mode or passive valves (checks), alarm at PLC	N/A	Detection of undesirable process condition	N/A	Repair, replace	2	2	4						
	b. Electrically actuated valves - power loss at valve	Program to fail to safe position	N/A	Objectionable flow condition	N/A	Repair, replace	2	2	4						
6. Radio Communication interruption Effect Without Mitigation: Lose ability to send/receive control signals from control room. Lose ability to collect data.	Vegetation or other obstruction in radio path	Antennas on towers with clear line of sight, use appropriate carrier frequency for link, program comms heartbeat	Vegetation management	Communication loss for radio link	N/A	Clear obstruction	1	2	2						
7. Externally caused SCADA equipment failure Effect Without Mitigation: Lose ability to send/receive control signals from control room. Lose ability to collect data.	Vandalism, theft, force majeure	Provide secure and robust system enclosures, bollards where required, installations above flood plain	Periodic inspections of all equipment inside and outside conditioning system and wells. TCS access control will help protect plant.	Loss of equipment functionality	Visibly damaged or missing equipment	Repair, replace	1	1	1						

TABLE 2.5-1
Failure Mode Effect Analysis Matrix—SCADA, Control Systems, and Instruments
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8. pH probe or other analytical probe/device fouling <u>Effect Without Mitigation:</u> Lose ability to monitor pH/parameter. Lose ability to collect data.	Contact with process liquid over time	Make pH probes or other devices accessible to operators	Routine inspection of cleaning of pH probes or devices	N/A	Rapid loss of calibration, visual fouling	Clean and re-calibrate	1	1	1						
9. Cyber-security: Software security, remote access security, or operating system update errors. <u>Effect Without Mitigation:</u> Lose ability to send/receive control signals from control room. Lose ability to collect data.	Not keeping software up to date, remote hack	Design in site access security, and remote access security, password protected access	Maintain software license, password protection	N/A	N/A		2	1	2						