FEASIBILITY STUDY
CHLOR-ALKALI
REMEDIAL ACTION UNIT

Vol. 2b of RI/FS, Georgia-Pacific West Site
Bellingham, Washington

Prepared for: Port of Bellingham

Project No. 070188-001-21 • June 2018
Final

Aspect
CONSULTING

earth + water

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Acronym and Abbreviation List

AOC	area of contamination
ASB	aerated stabilized basin
AKART	all known available and reasonable methods of treatment
ARAR	applicable or relevant and appropriate requirement
Aspect	Aspect Consulting, LLC
BBAT	Bellingham Bay Action Team
bgs	below ground surface
BNSF	BNSF Railway Company
CAMU	corrective action management unit
CAP	Cleanup Action Plan
CCMP	Cleanup Construction Management Plan
CFH	Caustic Filter House
cis-1,2-DCE	cis-1,2 dichloroethene
City	City of Bellingham
cm	centimeter
CNF	confined nearshore fill
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSM	conceptual site model
DCA	disproportionate cost analysis
DEIS	draft environmental impact statement
DNR	Washington State Department of Natural Resources
DOC	dissolved organic carbon
DOE	U.S. Department of Energy
DOH	Washington State Department of Health
Ecology	Washington State Department of Ecology
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ERH	electrical resistance heating
FEIS	final environmental impact statement
FS	feasibility study
ft	feet (or foot)
GP	Georgia-Pacific Corporation
gpd	gallons per day
gpm	gallons per minute

GRA	General Response Action
Hg	mercury
[Hg]	mercury concentration
Hg(II)	divalent mercury
HgS	mercury sulfide
ISCO	*in-situ* chemical oxidation
ISS	*in-situ* solidification/stabilization
ISTD	*in-situ* thermal desorption
LDR	land disposal restriction
LNAPL	light non-aqueous phase liquid
MEBA	Mercury Export Ban Act
MG	Million Gallon Tanks
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
µg/L	micrograms per liter
$\mu g/m^3$	micrograms per cubic meter
MLLW	mean lower low water
MNA	monitored natural attenuation
MRU	Mercury Recovery Unit
MTCA	Model Toxics Control Act (Chapter 173-340 WAC)
MTR	minimum technology requirement
mV	millivolt
MW	monitoring well
NAPL	non-aqueous phase liquid
NOM	natural organic matter
NTR	National Toxics Rule
NPDES	National Pollutant Discharge Elimination System
NWCAA	Northwest Clean Air Agency
OH-	hydroxide ion
O&M	operation and maintenance
ORC	Oxygen-Releasing Compound®
ORP	oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
pH	negative logarithm of hydrogen ion concentration

Port	Port of Bellingham
PMA	Port Management Agreement
PRB	permeable reactive barrier
QA	quality assurance
QC	quality control
PSE	Puget Sound Energy
RAO	Remedial Action Objective
RAU	remedial action unit
RCRA	Resource, Conservation, and Recovery Act
RCW	Revised Code of Washington
Remerc	Mercury Extraction and Recovery System
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
SEPA	State Environmental Policy Act
Site	Georgia-Pacific West Site
SMP	Shoreline Master Program
SU	standard unit for measurement of pH
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TCH	thermal conductive heating
TCLP	toxicity characteristic leaching procedure
TEF	toxicity equivalency factor
TEQ	toxic equivalent concentration
TPH	total petroleum hydrocarbon
TSCA	Toxic Substances Control Act
UCS	unconfined compressive strength
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UTS	Universal Treatment Standards
VI	vapor intrusion
VOC	volatile organic compound
WAC	Washington Administrative Code
WIPP	Waste Isolation Pilot Plant (Carlsbad, New Mexico)
ZVI	zero-valent iron

1 Introduction and Background

This document presents the Feasibility Study (FS) for the portion of the Georgia-Pacific (GP) West Site (Site) referred to as the Chlor-Alkali Remedial Action Unit (RAU).

Agreed Order No. DE 6834 (Order), entered into by the Washington State Department of Ecology (Ecology) and the Port of Bellingham (Port) in August 2009, requires the Port to perform a Remedial Investigation/Feasibility Study (RI/FS) for the Site in accordance with WAC 173-340-350 and pursuant to the Scope of Work and Schedule of the Order as amended.

The First Amendment to the Order, executed in August 2011, required that the Port perform an interim action to remove mercury-contaminated soils and building materials from the Caustic Plume subarea and remove petroleum-contaminated soils from the Bunker C subarea of the Site. The First Amendment also contemplated additional interim actions and set out a process for approval of interim actions proposed by the Port. The Second Amendment to the Order, executed in August 2013, separated the Site into the Pulp/Tissue Mill RAU and the Chlor-Alkali RAU. Figure 1-1 shows the Site and boundaries of the two RAUs.[1]

Remediation of contamination in the 36-acre Chlor-Alkali RAU is considerably more complex than that in the Pulp/Tissue Mill RAU. Division of the Site into two RAUs allows expediting remedial action at the Pulp/Tissue Mill RAU and, thus, putting it back into productive use more quickly.

Under the Order and its two Amendments, the Port is required to perform a Remedial Investigation (RI) for the entire Site (Volume 1 of the RI/FS; completed in August 2013 [Aspect, 2013f]), and prepare a separate FS for the Pulp/Tissue Mill RAU and for the Chlor-Alkali RAU (Volumes 2a and 2b, respectively, of the RI/FS). The FS for the Pulp/Tissue Mill RAU was completed in October 2014 (Aspect, 2014c). This document is the FS for the Chlor-Alkali RAU (Volume 2b of the required RI/FS for the Site).

The Site and its history are described in detail in Sections 1 and 2 of the RI (Aspect, 2013f), and that information is not reiterated here. Note that, as shown on Figure 1-2, the southeastern[2] portion of the Chlor-Alkali RAU includes a narrow strip of property owned by BNSF Railway Company (BNSF), which is occupied by an operating rail line, including

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[1] The boundary between the two RAUs has been modified since the Second Amendment to the Order was executed in August 2013. The Site includes property owned by BNSF Railway Company (BNSF), which originally occupied both RAUs. As described in Section 7.3 of the RI, the BNSF property encompassing the former Chlorine Plant stormwater swale contains mercury contamination associated with the Chlor-Alkali RAU. To further expedite remedial action at the Pulp/Tissue Mill RAU, the RAU boundary was redrawn such that the entire BNSF property (and BNSF's easement on the Port's property) within the Site now falls within the Chlor-Alkali RAU. This boundary revision does not impact the work elements of the FS and results in minor shifts in the FS schedule of deliverables for the portion of the Site that is now in the Chlor-Alkali RAU.

[2] For ease of discussion, and consistency with previous Site reports, this document uses "Mill north" as its directional reference ("Mill north" axis approximately 45 degrees west of true north). In the "Mill north" reference, the Whatcom Waterway is oriented east-west on the north side of the Site.

the mainline tracks that connect Seattle, Washington and Vancouver, British Columbia. The rail line also crosses property within the RAU owned by the Port, for which BNSF has an easement.

1.1 Purpose of Feasibility Study

This FS develops and evaluates remedial alternatives for soil and groundwater at the Chlor-Alkali RAU in accordance with WAC 173-340-350(8), to enable Ecology to select a cleanup action for the RAU. The FS process includes identifying applicable or relevant and appropriate requirements (ARARs) for cleanup, establishing cleanup standards that are protective of human health and the environment, identifying extents of contaminated media where remedial action is needed, identifying and evaluating potentially applicable remedial technologies for those media, and assembling remedial technologies into remedial alternatives to address Site contamination. The remedial alternatives are then evaluated against specific Model Toxics Control Act (MTCA) criteria (protectiveness, effectiveness, permanence, implementability, cost, and consideration of public concerns) to inform selection of a preferred remedial alternative. Each step in the FS process involves consideration of site-specific data and planned future land use.

1.2 Document Organization

This FS is prepared as Volume 2b of the RI/FS for the Site. It is intended to supplement the findings of the RI (Aspect, 2013f), which is Volume 1 of the RI/FS. The RI and FS documents have been prepared in general accordance with the Ecology approved RI/FS Work Plan for the Site (Aspect, 2009).

Following this introductory Section 1, the remaining sections of this FS document are organized as follows:

- Section 2, Related Documents, Adjacent Cleanup Sites, and Redevelopment Planning describes feasibility studies performed by GP prior to the Port's acquisition of the Site, environmental cleanups in progress at adjacent sites, and waterfront redevelopment planning activities;
- Section 3, Prior Cleanup Actions describes the independent cleanup actions performed by GP prior to the Port's acquisition of the Site;
- Section 4, Post-RI Investigations and Update/Recap of Conceptual Site Model (CSM) summarizes investigations and evaluations conducted after finalization of the Site RI, and provides subarea-specific CSMs that include integration of the new information;
- Section 5, Cleanup Requirements describes the RAU's land use, potentially complete contaminant exposure pathways, cleanup standards, remedial action objectives (RAOs), and ARARs for the remedial action;
- Section 6, Screening of Remedial Technologies identifies and evaluates a range of potentially applicable remedial technologies for the RAU contaminants and media, evaluates them with respect to applicability to the RAU, and retains the best technologies for possible incorporation into remedial alternatives for the RAU;

- Section 7, Description of Remedial Alternatives describes the remedial alternatives developed in consideration of the RAOs;
- Section 8, Detailed Evaluation of Remedial Alternatives compares the remedial alternatives relative to MTCA evaluation criteria, including a disproportionate cost analysis (DCA);
- Section 9, Evaluation of Groundwater Point of Compliance Under Alternative 4 considers alternative point-of-compliance scenarios for the remedial alternative determined by the DCA to be permanent to the maximum extent practicable; and
- Section 10, Preferred Alternative describes in greater detail the remedial alternative that the DCA determined to be permanent to the maximum extent practicable and is recommended for implementation.

2 Related Documents, Adjacent Cleanup Sites, and Redevelopment Planning

2.1 Prior Feasibility Studies by GP

2.1.1 1994 Feasibility Study (ENSR, 1994b)

Following completion of a RI (ENSR, 1994a), ENSR prepared a FS to evaluate remedial alternatives for mercury-impacted soil, groundwater, and stormwater at the Chlor-Alkali site (ENSR, 1994b). The FS delineated four operable units at the site, and, for each, evaluated a range of remedial alternatives relative to MTCA cleanup criteria. Technologies included in the remedial alternatives included:

- Enhanced inspection and recordkeeping program to address potential releases of waste material from the Chlorine Plant;
- Soil excavation with off-site disposal;
- Soil capping;
- Groundwater extraction and treatment using GP's existing on-site treatment systems;
- Groundwater monitoring; and
- Site grading and construction of new stormwater collection and conveyance system to control stormwater drainage.

2.1.2 2004 Draft Feasibility Study (Aspect, 2004)

Under the terms of Agreed Order DE 02 TCPIS-472, an updated FS was prepared, incorporating the results from GP's independent cleanup actions and additional Site characterization activities completed since the 1994 FS (Aspect, 2004a). The 2004 FS evaluated remedial alternatives assuming continued industrial use of the Site (thus industrial soil cleanup levels), and was intended to provide sufficient analysis to enable Ecology to select a cleanup action alternative that is protective of human health and the environment for that site use. The FS identified three areas (Areas 1, 2, 3) requiring cleanup of mercury-impacted media to achieve protectiveness for a future industrial site use. Area 1 is the area of elevated mercury and pH in soil and groundwater at and downgradient of the former Chlorine Plant (Caustic Plume). Area 2 is mercury-containing subsurface soils within the Laurel Street Pipe Rack area. Area 3 is mercury-containing surface soils within the Stormwater Swale that runs along the BNSF railroad tracks on the south side of the Site.

The FS evaluated the following remedial technologies for mercury-impacted soil and groundwater:

- Soil excavation and off-site disposal;
- Soil treatment using the Mercury Extraction and Recovery System (Remerc) process;
- Soil stabilization using the Chemfix process;

- Soil capping;
- Groundwater extraction and treatment;
- Groundwater containment using sheet pile walls;
- *In-situ* neutralization/stabilization;
- Groundwater treatment using permeable reactive barriers (PRBs); and
- Electrochemical remediation.

2.2 Pulp/Tissue Mill RAU Cleanup

The Chlor-Alkali RAU is adjacent to the Pulp/Tissue Mill RAU (Figure 1-1), which is being cleaned up under the terms of Consent Decree No. 14207008 between the Port and Ecology. Contamination within the two RAUs does not comingle, and they were therefore segregated administratively for cleanup.

Ecology's CAP for the Pulp/Tissue Mill RAU includes an RAU-wide cap that will need to be integrated into design of the cleanup remedy for the Chlor-Alkali RAU.

2.3 Whatcom Waterway Cleanup

The Chlor-Alkali RAU is also adjacent to the Whatcom Waterway cleanup site, which has a cleanup remedy and schedule defined under a Consent Decree between the Port and Ecology. Phase 1 of the Whatcom Waterway cleanup, including capping of the Log Pond bordering the north side of the RAU, was completed in 2016. The preferred alternative for the Chlor-Alkali RAU must be compatible with the Whatcom Waterway cleanup; this compatibility principally involves integrating with the existing capping of the Waterway's south bank including the Log Pond.

2.4 Redevelopment Planning

Future anticipated land uses and use designations at the RAU have been established as part of the Bellingham Waterfront District planning effort that was performed under an inter-local agreement between the Port and the City of Bellingham (City). Planning details are included in *The Waterfront District Draft Sub-Area Plan (Port/City, 2012)*. Plans are being coordinated between the Port and the City, and are expected to result in a rezoning of the RAU to include a mix of industrial, commercial, and institutional designations (depicted on Figure 4-8 of the RI [Aspect, 2013f]).

The *Draft Environmental Impact Statement* (DEIS) for the Port's Waterfront District redevelopment was prepared in January 2008, and was subsequently revised to include a *Supplemental DEIS* in October 2008, an *EIS Addendum* in February 2010 (Port of Bellingham, 2008a; 2008b; and 2010a), a *Final EIS* (Port of Bellingham, 2010b), and a subsequent Addendum to the final EIS in December 2012 (Port of Bellingham, 2012). These documents were prepared under the State Environmental Policy Act (SEPA) to coordinate redevelopment activities consistent with the cleanup, address potential impacts resulting from the proposed redevelopment alternatives, and discuss the need for imposing cleanup-related institutional controls within the context of redevelopment.

Institutional controls would be implemented for contaminated areas of the Site as needed to prohibit or limit activities that could potentially interfere with the long-term integrity of cleanup actions. The institutional controls required as a component of the Chlor-Alkali RAU cleanup remedy will be defined in the CAP and Consent Decree for the RAU. Environmental covenant(s) will be established once remediation construction is complete. The long-term integrity of remediation elements will be ensured by implementing inspection and maintenance of remedy components, Ecology notification and materials management protocols for subsurface activities, and/or land use restrictions in accordance with the environmental covenant(s) and dependent on the scope of the selected remedy.

In addition, a separate SEPA environmental review for the Chlor-Alkali RAU cleanup action will be conducted prior to Ecology finalizing the cleanup decision.

3 Prior Cleanup Actions

Starting in the early 1990s, GP and the Port conducted a series of independent cleanup actions for the Chlor-Alkali RAU, which are described below by subarea.

3.1 Caustic Plume Subarea

3.1.1 72 Catch Basin Soil Removal Action (1993)

In April 1993, prior to construction of the Remerc facility as part of the Chlorine Plant, GP directed removal and off-site disposal of approximately 217 cubic yards of mercury-contaminated soils from the 72 Catch Basin area, and from along the east and south walls of the Cell Building (ENSR, 1993). Following soil removal, detected residual soil mercury concentrations within the excavations ranged up to 100 milligrams per kilogram (mg/kg) within the 72 Catch Basin area and up to 65 mg/kg adjacent to the Cell Building. Based on the available information, it appears that soils with higher concentrations located around and beneath the excavation area were not fully removed. RI boring CP-MW13 did not confirm the very high soil mercury concentrations reported for this area by ENSR (1993).

3.1.2 Independent Remedial Actions during Infrastructure Improvements (1999 to 2002)

Over the period from 1999 through 2002, GP performed infrastructure improvements within the Chlor-Alkali RAU that included soil excavation and off-site disposal. The infrastructure excavations included the following:

1. **Fire Main and Parking Lot Excavations (1999).** The fire main (FM) excavation was required for emergency repair of a failed fire main on the east side of the former Cell Building. The parking lot (PL) excavation, south of the Chlorine Plant, was required for the installation of a fiber optic cable in the former plant parking lot.

2. **Beer Well Excavation (December 1999).** An undocumented quantity of soil was excavated during installation of a large beer well near the Laurel Street Pipe Rack. Five soil samples were collected from the excavation, and composited for toxicity characteristic leaching procedure (TCLP) mercury analysis. TCLP-leachable mercury was not detected (<1 microgram per liter [μg/L]) in the composite sample. The soil samples were not analyzed for total mercury.

3. **Post-Demolition Chlorine Plant Sewer Installation (December 2000).** The excavation for a new sewer extended down the old roadway north and west of the former Cell Building. The excavation soils were sampled at five different locations and tested for both total and TCLP mercury. The highest total mercury detected was 120 mg/kg, though its location from within the excavation is not certain. The majority of the soil came from the excavation along the west side of the Cell Building.

3.1.3 Chlorine Plant Decommissioning (2000)

In accordance with Agreed Order DE TC99 I035, in 2000, GP conducted decommissioning and demolition of the Chlorine Plant, reportedly including removal of mercury process materials, equipment, and debris from the Mercury Cell Building and ancillary infrastructure. A demolition plan was developed, and was approved by Ecology prior to demolition activities (Foster Wheeler, 2000a). A portion of the stack wood and concrete columns/pillars in the building designated as characteristic dangerous waste, and those materials were managed as such during decommissioning (Foster Wheeler, 2000b). The process materials within the Cell Building were removed during the 2000 decommissioning; however, the Cell Building shell and floor slab remained in place until demolished and removed during the Port's Caustic Plume-Cell Building interim action (described in Section 4.1.1 of this FS).

3.1.4 Caustic Plume-Cell Building Interim Action (2013 to 2014)

The First Amendment to Agreed Order No. DE 6834 required that the Port perform an interim action to remove mercury-contaminated soils and building materials from the Caustic Plume subarea. The goal of the interim action was to permanently control substantial sources of mercury contamination to groundwater, surface water, and air. The Caustic Plume-Cell Building interim action removed the highest concentrations of mercury detected in Site soil (soil containing visible elemental mercury), and elevated mercury concentrations in building materials not removed during the 2000 decommissioning of the Chlor-Alkali Plant.

Within the caustic plume source area, two localized occurrences of visible elemental mercury had been identified in subsurface soils:

- At the former Caustic Filter House (CFH), where mercury was filtered from the caustic produced in the chlor-alkali process; and
- At the former Mercury Recovery Unit (MRU), where mercury was recovered from the brine used in the electrolysis process.

The high soil concentrations of elemental mercury (volatile form of mercury) in these two locations represented substantial sources of mercury to soil vapor and groundwater within the Caustic Plume subarea. A goal of the interim action was to remove the soil with high mercury concentrations and thereby reduce the source of mercury to soil vapor and groundwater.

Some of the remaining structural building materials within the Cell Building contained elevated total mercury concentrations, and a small percentage of the structural concrete contained mercury leachable in the TCLP above the toxicity characteristic criterion for hazardous waste (waste code D009). Portions of the structural building materials also contained high levels of lead in paint. The building also contained regulated building materials including asbestos-containing material, fluorescent light bulbs, etc. The regulated building materials were properly abated prior to demolition. The interim action goal was to completely remove the Cell Building structure, including its floor slab and its appurtenances, with disposal of the demolition debris waste in accordance with applicable laws and regulations.

This interim action was not intended as final cleanup for mercury soil contamination throughout the Caustic Plume subarea. Rather, it was intended to permanently remove known sources of mercury, including the highest mercury soil concentrations detected on-site.

Prior to developing construction plans and specifications for the soil cleanup portion of the interim action, Aspect prepared and submitted for Ecology review and approval a plan for conducting the work (Aspect, 2012c), which included general approaches for excavating soil and designating it for off-site disposal, performance monitoring and over-excavation, soil stabilization and designation of the stabilized soil for off-site disposal, air monitoring, and excavation backfill. Ecology also reviewed the construction technical specifications used to solicit competitive bids for the cleanup construction, as well as the Cleanup Construction Management Plan (CCMP; Aspect, 2013a) that outlined the construction management and monitoring procedures implemented during the cleanup construction.

The mercury source control involved complete removal of the mercury-contaminated Cell Building, and removal of mercury-contaminated soil to meet the following interim action soil remediation levels defined in Aspect (2011):

- Lateral Remediation Level = 2,100 mg/kg. The interim action excavation sidewalls were expanded laterally as needed to remove soil containing visible mercury and with total mercury concentrations exceeding a lateral remediation level of 2,100 mg/kg, which is twice the 1,050 mg/kg industrial soil cleanup level based on direct contact, and was anticipated to remove visible liquid elemental mercury and be protective of both groundwater and vapor intrusion (VI).
- Vertical Remediation Level = 24 mg/kg. The excavation was extended vertically to a maximum depth of 15 feet to achieve a vertical remediation level of 24 mg/kg total mercury, which was anticipated to be protective of all exposure pathways, including direct contact exposure under an unrestricted land use.
    - The interim action is briefly outlined below, and is described in more detail in the Interim Action Report for this area (Aspect, 2014b).

3.1.4.1 Excavation and Waste Treatment/Disposal

The extent of interim action excavations expanded substantially beyond the originally defined MRU and CFH excavation areas, largely as a result of “chasing” and removing visible mercury encountered in and around buried infrastructure from the former Chlorine Plant. Figure 3-1 depicts the expanded excavation areas. Beyond the planned minimum CFH and MRU excavation areas, visible mercury was observed and removed from the following areas:

- A soil-filled trench and vault system north of the MRU, and a small concrete pipe adjacent to the vault system, using methods proposed to Ecology (Aspect, 2013d) and approved by Ecology.
- Around the former caustic tank foundations west/northwest of the CFH.
- Within decommissioned Type 2 catch basins[3] of a former stormwater collection system connecting to the MRU (Figure 3-1; referred to on GP plant drawings as the Oak Street sewer system). The conveyance piping between the catch basins was also cleaned out using methods proposed to Ecology (Aspect, 2013e) and approved by Ecology, but the piping did not contain visible mercury.

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[3] Catch basins were filled with pea gravel.

Based on verification soil sampling in accordance with the CCMP, the excavations in the CFH and MRU areas, as expanded, met soil remediation levels except at two sample locations (refer to Figure 3-1):

- Verification bottom soil sample CB6-B-6.5, collected at the former Oak Street sewer alignment, contained 2,389 mg/kg total mercury. The soil represented by that sample was left in place due to the significant groundwater inflow and associated collapse of the excavation, which threatened to undermine the adjacent operational stormwater infrastructure.
- Verification bottom soil sample CTB2-8, located at the north side of the MRU area, contained 480 mg/kg total mercury. That area was at the northern reach of the Lower Sand depressurization wells' hydraulic influence; therefore, soil represented by that sample was left in place due to concern for aquitard breach if not installing more depressurization wells, and the presence of comparable soil mercury concentrations in adjacent soils outside the scope of the interim action (e.g., 560 mg/kg mercury at adjacent boring CP-SB03), with the understanding that, after the interim action, this whole area will be addressed in the FS.

The backfill in each interim action excavation area was compacted and paved with 4 inches of asphalt.

Waste Disposal

In total, the completed interim action achieved permanent removal of approximately 6,880 tons of mercury-contaminated soil and debris from the mercury source area within the Chlor-Alkali RAU. The Port, as waste generator, managed the materials excavated during the interim action in the following waste categories, in accordance with Resource Conservation and Recovery Act (RCRA) as described in Aspect (2012c):

- **Non-Hazardous.** Material containing TCLP mercury concentrations less than 0.2 milligram per liter (mg/L) and total mercury concentrations less than 1,000 mg/kg. These excavated soils were properly disposed of in a permitted Subtitle D Landfill.
- **WT02.** Material with TCLP mercury concentrations less than 0.2 mg/L but with total mercury concentrations greater than 1,000 mg/kg, thus designating as State-only toxic dangerous waste (WT02).[4] These excavated soils were properly disposed of in a permitted Subtitle C Landfill (Waste Management's Chemical Waste Management Subtitle C Landfill in Arlington, Oregon).
- **Stabilization-Required.** Soil containing TCLP mercury concentrations greater than or equal to 0.2 mg/L (i.e., exhibiting the toxicity characteristic under RCRA), and total mercury concentrations greater than 1,000 mg/kg. These soils were stabilized on-site (described below) to meet applicable RCRA land disposal restrictions (LDRs) prior to Subtitle C Landfill.
- **D009 Debris (Macroencapsulated).** Debris too large to be included in the chemical stabilization process and containing TCLP mercury concentrations greater than or equal to 0.2 mg/L. This included oversize debris containing visible

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[4] Refer to derivation of the 1,000 mg/kg total mercury threshold concentration for WT02 provided to Ecology on June 22, 2011.

elemental mercury. The D009 debris was treated using macroencapsulation to meet LDRs for debris prior to Subtitle C landfill disposal. The macroencapsulation treatment and landfill disposal occurred at the Chemical Waste Management facility in Arlington, Oregon.

The approximately 6,880 tons of contaminated material included the following approximate quantities of each waste type: 640 tons of non-hazardous soil, 2,460 tons of non-hazardous debris, 700 tons of WT02 soil that was not stabilized, 2,190 tons of WT02 waste following its on-site chemical stabilization, and 890 tons of hazardous debris (D009) which was macroencapsulated.

Chemical Stabilization

The goal for on-site soil stabilization was to achieve the alternative LDR treatment standards for the mercury-contaminated soils (remediation waste), in accordance with 40 CFR 268.49,[5] so that the stabilized soil could be land disposed at a Subtitle C landfill. Based on bench-scale treatability studies (Anchor QEA, 2012), chemical stabilization was accomplished by mixing 45 units of Portland cement (by weight) and 5 units elemental sulfur with 100 units of contaminated soil and 15 to 20 units water (or as required to generate a mixable and flowable mixture). The proportions of amendments (cement and sulfur) used included a factor of safety to increase the likelihood that the stabilization would achieve the alternate UTS.

To control air emissions, stabilization was performed inside the Cell Building prior to its demolition. In the chemical stabilization process, excavated material was first physically screened to remove particles larger than 4 inches in any dimension, and the larger particles were disposed of as D009 oversize debris; the D009 oversize debris was macroencapsulated to meet LDRs for hazardous debris prior to Subtitle C disposal, as described in Aspect (2012c). The screened soil was then combined with the specified quantities of amendments (sulfur then cement then water) and thoroughly mixed in a high-shear paddle mixer. The mixture was then dispensed in approximately 1-cubic-yard increments into polypropylene bulk sacks ("Super Sacks"), and allowed to cure for several days.

Soil was stabilized in treatment "batches" having a typical amended weight of 15 to 16 tons, and each batch was divided approximately equally into 10 Super Sacks. Prior to beginning full-scale stabilization of contaminated soil, a two-step stabilization process test run was conducted to verify that performance standards would be achieved.

Robust compliance monitoring demonstrated that each of the 165 treatment batches achieved a TCLP mercury concentration below 0.2 mg/L, and thus removed the hazardous waste characteristic and met the alternative UTS. Consistent with the CCMP, total mercury concentrations of the stabilized soil were not tested, since they were assumed to still exceed 1,000 mg/kg mercury; therefore, designating as WT02, not D009, waste. Each batch of stabilized soil was transported off-site and disposed of as WT02 waste in the Chemical Waste Management Subtitle C Landfill in Arlington, Oregon.

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[5] Reduce TCLP mercury concentrations by at least 90% <u>or</u> to 10 times the universal treatment standard (UTS) in 40 CFR 268.48, whichever is less stringent. For mercury, 10 x 0.025 mg/L TCLP mercury (UTS under 40 CFR 268.48) = 0.25 mg/L TCLP mercury as the alternate LDR treatment standard.

3.1.4.2 Dewatering and Depressurization

During the interim action, the Contractor pumped groundwater from the shallow Fill Unit aquifer to facilitate excavation and handling of contaminated soil, and pumped groundwater from the deeper, confined, Lower Sand aquifer to depressurize it and thus prevent breach of the aquitard underlying the excavations and hydraulically separating the Fill Unit and Lower Sand aquifer units. The groundwater extracted from both aquifers was treated and discharged to the Port's ASB. A total of approximately 1,100,000 gallons of groundwater were pumped and disposed of to the ASB during the project, with Ecology approval (Ecology, 2012b).

An aquitard breach was encountered near the MRU during drilling for installation of a Lower Sand depressurization well. The situation was communicated to (Aspect, 2013b) and discussed with Ecology immediately after the breach was encountered. Aspect (2013b) provided a recommended approach for depressurization and excavation of the MRU Area, which was approved by Ecology and implemented by the interim action contractor. Refer to Section 4.1.2.2 for additional information on the aquitard breach.

3.1.4.3 Siderite-Amended Backfill of CFH Excavation

In accordance with Aspect (2012c), the interim action excavation encompassing the former CFH footprint was backfilled using imported gravel borrow amended with 3 wt% siderite (iron carbonate), with the intent to help buffer (decrease) the very high pH groundwater in that source area. While the excavation expanded well beyond the anticipated extents, the siderite-amended backfill was generally limited to the location of the CFH as originally planned (refer to Figure 3-1). During RI sampling and analysis, groundwater pH was below 8.5 in the vicinity of the MRU excavation; therefore, backfill for excavations in that area was not chemically amended.

The impact of the siderite-amended backfill on downgradient groundwater quality is discussed in Section 4.3.

3.1.4.4 Cell Building Demolition

The Caustic Plume-Cell Building interim action also included demolition and off-site disposal of the remaining Cell Building structure (building shell and floor slab), which contained mercury concentrations representing a source of mercury to air. Prior to demolition, a regulated materials survey was conducted, and abatement of such materials was conducted in accordance with applicable state and federal requirements. In addition, the Cell Building demolition waste (concrete and wood) was pre-characterized for disposal, in consultation with Ecology. The above-grade structure, and the upper (vintage 2000) floor slab, was demolished and properly disposed of without issue.

Following removal of the upper concrete floor slab, visible mercury was observed within the original (1960s-vintage) floor troughs and soil-filled floor sump into which the troughs drained (Figure 3-2). These features were constructed into the Cell Building's original floor slab, which was paved over by a newer floor slab during the 2000 decommissioning of the Chlorine Plant conducted under Agreed Order DE TC99 I035; the floor troughs and sump were, therefore, not visible until the upper floor slab was removed during demolition.

The floor troughs were individually saw-cut (more than 1,000 linear feet) to segregate them from the remaining floor slab which did not contain visible mercury. The floor trough concrete debris and the sump debris was removed and transported to the Chemical Waste

Management facility in Arlington, Oregon, for treatment by macroencapsulation prior to Subtitle C disposal.

3.1.4.5 Visible Mercury Observed beneath Cell Building Floor Slab

Despite having soil data (ENSR [1994a] data) and soil gas data (2011) collected beneath the floor slab that indicated low mercury concentrations beneath the Cell Building (described in Aspect, 2013f), substantial quantities of visible mercury were encountered in subsurface soil beneath the Cell Building floor slab near the former floor troughs and sump during the interim action. In September-October 2014, a test pit exploration program was conducted to investigate the extent of mercury-impacted materials across the entire area of the former Chlorine Plant (results are summarized in Section 4.4).

Removing additional soils containing visible mercury from the Cell Building footprint would be challenging due to the dense array of building foundation components present (Figure 3-2). Because the scope and cost of the interim action had already grown substantially beyond initial expectations, Ecology and the Port agreed to terminate the interim action without further soil removal, and to address the Cell Building area residual mercury as part of the FS and CAP/Consent Decree for final cleanup of the Chlor-Alkali RAU. Nineteen steel road plates (generally 20 feet by 8 feet and 1-inch thick) were placed across remaining grade beams to cover open excavation areas. An estimated 430 cubic yards of mercury-impacted soil and debris occupied the northern portion of the Cell Building footprint (location shown on Figure 3-1). Crushed brick generated from demolition of the former pulp mill was placed and graded to generally level the remainder of the footprint. The entire footprint was then secured beneath a heavy-gage, impervious and ultraviolet-resistant polyethylene cover pending the final cleanup action.

3.1.5 2017 Removal of Mercury-Contaminated Soil and Debris at Cell Building

Due to a number of factors, it became apparent in 2016 that completion of this FS and development of the final cleanup action for the RAU would take longer than expected. Therefore, Ecology required the Port to remove the estimated 430 cubic yards of mercury-impacted material within the Cell Building footprint prior to the final cleanup action. This removal was conducted in Fall 2017 as a separate interim action.

Prior to developing construction plans and specifications for the interim action, Aspect prepared and submitted for Ecology review and approval a plan for conducting the work (Aspect, 2016), which included general approaches for soil treatment, waste designation, control of air emissions, and compliance monitoring. Ecology also reviewed the construction technical specifications used to solicit competitive bids for the cleanup construction, as well as the Compliance Monitoring Plan (CMP; Aspect, 2017b), which described the construction management and monitoring procedures implemented during the interim action.

The soil was chemically stabilized in an on-site treatment process similar to that used in the 2013–2014 interim action. However, additional pilot testing was first conducted to re-evaluate the amendment dosage requirements. As noted in Section 3.1.4.1, the dosages used in the 2013-2014 interim action were intentionally conservative because the cost of treatment failure was exceptionally high. During full-scale application, TCLP results for batches of treated soil were typically two orders of magnitude below the treatment objective (0.25 mg/L TCLP), confirming the conservatism in treatment design.

Based on pilot test results (Aspect, 2017a), the Portland cement dosage (per 100 units of contaminated soil) was reduced from 45 to 25 units (by weight), and the elemental sulfur dosage was reduced from 5 to 2 units. There was also a corresponding reduction in the amount of water that needed to be added to generate a mixable and flowable mixture, to approximately 10 units. As a result, both the amendment costs and the cost to dispose of the treated soil were significantly lower (per ton of soil treated) than in the 2013-2014 interim action.

To control air emissions, stabilization was performed inside a treatment enclosure (tent) erected by the construction contractor. The material was first physically screened to remove particles larger than 3 inches in any dimension. The screened soil, in treatment batches of 0.7 to 0.8 tons each, was then combined with amendments at the dosages specified above and thoroughly mixed in an Enterra BMX-600 cement mixer. The treated soil was dispensed into Super Sacks, which were arranged into “treatment lots” weighing roughly 31 tons each. Aspect collected one representative 10-point composite sample from each treatment lot in accordance with the CMP. After curing for a minimum of 5 days, the composite sample was submitted for laboratory analysis of TCLP mercury.

A total of 533 tons of contaminated soil was treated in 28 treatment lots. All but one of the lots achieved the TCLP mercury treatment objective of 0.25 mg/L. The TCLP mercury results for the 27 treatment lots that passed were significantly higher than those achieved in the 2013-2014 interim action (which used higher amendment dosages), but were still more than an order of magnitude below the treatment objective. Successfully treated soil was disposed of as WT02 waste. The treatment lot that failed (33 tons) and the oversize debris generated in the pretreatment screening process (181 tons) were disposed of as D009 waste via macroencapsulation to meet LDRs for hazardous debris prior to Subtitle C disposal. All hazardous waste generated during the interim action was disposed of at the Chemical Waste Management Subtitle C Landfill in Arlington, Oregon.

After soil treatment was completed, the steel road plates that covered open excavation areas within the Cell Building footprint were removed, and the voids were backfilled with the crushed brick and soils generated during the Bellingham Shipping Terminal (BST) Phase 1 stormwater improvements project[6]. The Cell Building footprint was then paved with a 3-inch thickness of hot mix asphalt. Prior to paving, the steel road plates were placed on the ground surface in the northern portion of the footprint to help stabilize the saturated soils in this area, which were extremely soft and mushy. A geotextile was then placed over the entire Cell Building footprint, followed by a thick layer of crushed surfacing base course (also for the purpose of stabilizing the ground surface to facilitate paving). Figure 3-3 shows the approximate extent of the pavement and location of the underlying road plates.

The 2017 interim action is described in more detail in the Interim Action Report, Mercury Soil Treatment and Disposal Project (Aspect, 2018).

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[6] The Port provided soil sampling results to Ecology in a letter proposing that a portion of the stockpiled BST soils be used for this purpose (Port, 2017).

3.2 Confined Nearshore Fill/Chemfix Subarea

3.2.1 Settling Basin Cleanup Using Chemfix Process (1976-1977)

In 1976, GP removed mercury-contaminated sludge from the wastewater settling basin, and treated the solids by a proprietary process (Chemfix) using 2.4 percent by volume sodium silicate and 1.7 percent by volume Portland cement. Approximately 8,000 cubic yards of this material were contained within an approximately 2-acre area within this subarea (Chemfix Area on Figure 4-1). The solidified Chemfix material reportedly extends to a depth of approximately 4 to 5 feet below current grade, and is covered with (from bottom up) a layer of bank run fill; a geotextile membrane (DuPont Typar®, lapped and glued, and extending beyond the lateral extent of Chemfix); a 6-inch layer of sand; and two layers of asphalt totaling 5 to 6 inches in thickness.

An Ecology Order (DE-3677) specifies the following cap maintenance requirements for the Chemfix area:

> "The completed project shall be continually maintained as required to retain the impervious condition of the covering. No future project involving excavation or degradation of the covering shall be undertaken without written approval of the Department of Ecology."

3.2.2 Residual Sludge Removal during Settling Basin Closure (1980)

The wastewater settling basin was closed in 1980. Residual sludge was removed from the earthen wastewater settling basin and transported to the Chem Security (now Chemical Waste Management) Subtitle C Landfill in Arlington, Oregon for disposal. The wastewater settling basin was then filled with clean upland material. The Chlorine Plant wastewater was modified by constructing a wastewater collection sump and a surge storage tank near the southern boundary of the former wastewater setting basin. Chlorine Plant wastewater was then conveyed through the collection sump and surge storage tank to the Aerated Stabilization Basin (ASB) on the north side of the Whatcom Waterway for treatment and discharge under a National Pollutant Discharge Elimination System (NPDES) permit. Outfall 7 which discharged from the wastewater settling basin to the Log Pond was later plugged.

3.2.3 Chlor-Alkali Facility Spill Independent Remedial Action (1997)

Following a 1997 spill of sludge from the surge storage tank, GP performed an independent remedial action involving removal and off-site disposal of materials containing elevated mercury concentrations (GP, 1998). A total of 957 tons of mercury-impacted soil were excavated to depths of up to 18 inches, and properly disposed of off-site. Eight post-excavation verification soil samples indicated residual total mercury concentrations ranging from 1 to 119 mg/kg, and leachable (TCLP) mercury concentrations below 0.0005 mg/L.

3.3 Laurel Street Pipe Rack Subarea Soil Removal (1993)

Removal of mercury-impacted soil from the Laurel Street Pipe Rack Subarea is documented in Law/Crandall (1993). During the 1992 construction of aboveground utility pipelines between the cogeneration power plant and GP's mill, the construction contractor encountered demolition debris within a footing excavation at the Laurel Street Pipe Rack, just west of the main facility gate. The debris was suspected as discarded from the Chlorine

Plant. Soil containing the debris was stockpiled separately from other excavated soils, and construction was halted. Six samples were collected from stockpiled soil and analyzed for total mercury and leachable mercury by the TCLP. Based on where the debris was observed, Law/Crandall collected 33 soil samples within two excavations (pipe rack and underground steam pipeline trench) for mercury, and conducted air quality monitoring for mercury to assess worker safety.

The six soil samples collected from the excavated soil stockpile had total mercury concentrations ranging from 16 to 100 mg/kg, but no detectable (<0.0005 mg/L) leachable mercury by TCLP.

Four of the 16 soil samples collected within the pipe rack excavation had total mercury concentrations above 24 mg/kg (maximum of 14,000 mg/kg), all of which were reportedly in shallow soil along the western sidewall. Samples collected below the bottom of the 4- to 7-foot-deep excavation contained mercury concentrations up to 0.4 mg/kg. Of the 17 soil samples collected within the underground pipeline excavation, six samples clustered near the excavation’s northeast corner exceeded 24 mg/kg total mercury; the maximum detected concentration of 1,100 mg/kg was detected approximately 1 foot below the bottom of the 5-foot-deep excavation.

The dimensions and location of the excavation, and the quantity of soil removed is not clearly documented in Law/Crandall (1993). As discussed in Section 4.4 below, RI soil sampling did not corroborate the highest reported soil concentrations (14,000 mg/kg), indicating that the higher concentration soils may have been removed during the construction project.

3.4 Million Gallon Tanks Subarea Soil Removal (2006)

GP conducted an independent cleanup action in November and December 2006 prior to demolition of the Million Gallon Tanks (RETEC, 2007). Approximately 31 tons of grossly petroleum-contaminated soil was excavated on the mill-north side of Tank 2 to an average depth of the about 2 feet and disposed of as State-only dangerous waste at the Chemical Waste Management Subtitle C landfill in Arlington, Oregon.

Following soil removal, four of the five excavation verification soil samples had detected petroleum concentrations below the 2,000 mg/kg unrestricted soil screening level for diesel- and oil-range petroleum. One confirmation soil sample, SS-2-1.5, contained 2,105 mg/kg total petroleum hydrocarbons (TPH). The excavation was lined with plastic and backfilled with clean gravel to grade.

4 Post-RI Investigations and Update/Recap of Conceptual Site Model (CSM)

A CSM describes the contaminants of concern (COCs) and their historical source(s), nature and extent of contamination, contaminant fate and transport, and environmental exposure pathways and receptors. Section 7 of the RI presents the CSMs for each of the GP West Site subareas, and for areas outside the defined subareas, based on information available at the time of the RI. Additional investigations were conducted in the western portion of the Chlor-Alkali RAU after the RI was completed. These investigations are described in Sections 4.1 through 4.5. Sections 4.6 and 4.7 then provide updated CSMs for the Caustic Plume subarea and the Confined Nearshore Fill/Chemfix subarea, respectively, incorporating the results of the post-RI investigations. Finally, Sections 4.8 through 4.11 provide brief CSM recaps for the other defined subareas in the Chlor-Alkali RAU (Figure 1-2), and for screening level exceedances in soil and groundwater outside the defined subareas. This provides the basis for defining RAOs in Section 5.

4.1 Aquitard Breach and Lower Sand Groundwater Quality, MRU Area

As discussed in Section 3.1.4.2, the Caustic Plume-Cell Building interim action included extraction of groundwater from the Lower Sand aquifer. During drilling for installation of Lower Sand depressurization well CP-DW2, located immediately mill-northeast of the MRU excavation area (Figure 3-1), the aquitard was not observed when drilling to a total depth of 26 feet. This is distinctly different than subsurface conditions observed in the other Caustic Plume subarea borings, including adjacent Lower Sand wells CP-DW1 and CP-DW3 (Figure 3-1), in which the aquitard was encountered at depths between 15 feet and 19 feet. In the boring for CP-DW2, artificial fill (including crushed rock and concrete debris) was encountered to a depth of 26 feet, underlain by the Lower Sand. The aquitard may have been excavated and artificial fill material placed at that location during the mid-1900s construction of a former Log Pond bulkhead or revetment there (prior to the mid-1970s filling of the Log Pond).

Depressurization well CP-DW2's well screen was placed completely within the Lower Sand aquifer, but water level and water quality measurements from it suggest that the Fill Unit is in direct hydraulic communication with the Lower Sand at the aquitard breach location. Where the aquitard is present, groundwater levels in the Fill Unit are several feet higher than those in the Lower Sand, as described in Section 4.2 of the RI. However, the water level measured in CP-DW2 was intermediate between that of the Fill Unit and Lower Sand, indicating hydraulic communication between the two water bearing units at that location. After completion of well CP-DW2, Aspect installed a new Fill Unit monitoring well (CP-MW22; Figure 3-1) adjacent to CP-DW2 to allow monitoring of Fill Unit water levels and groundwater quality above the aquitard breach.

Following excavation in the MRU area, a new Lower Sand monitoring well (CP-MW23) was installed approximately 100 feet downgradient (mill-northwest) of well CP-DW2. The aquitard was observed during drilling of the new well, consistent with all Lower Sand wells in the RAU except CP-DW2. Following well installation (in late July 2013), groundwater samples were collected for analysis of dissolved mercury and field parameters (including pH) from the following Lower Sand wells located at and downgradient of the MRU excavation area: CP-DW1, CP-DW2, CP-DW3, CP-MW04, CP-MW05,[7] and CP-MW23. Groundwater samples were also collected from Fill Unit wells CP-MW13 and CP-MW22 located at the MRU area. The July 2013 monitoring results are presented in Table 4-1, and the detected dissolved mercury concentrations are depicted in plan view on Figure 4-1.

The July 2013 data demonstrated MRU-area Lower Sand dissolved mercury concentrations below the conservative 0.059 µg/L groundwater cleanup level[8] except at CP-DW2 (0.41 µg/L) located within the aquitard breach and well CP-MW23 located downgradient of it (0.13 µg/L). As expected, higher dissolved mercury concentrations were detected at the Fill Unit wells in the MRU area (5.8 µg/L at CP-MW13; 3.5 µg/L at CP-MW22) (Figure 4-1).

A substantial reduction in dissolved mercury concentrations is observed with distance along the inferred groundwater flow path from the Fill Unit at the aquitard breach location (3.5 µg/L at CP-MW22), into the Lower Sand at the breach (0.41 µg/L at CP-DW2), and then downgradient from the breach within the Lower Sand (0.13 µg/L at CP-MW23). Figure 4-2 depicts the dissolved mercury groundwater concentrations as function of distance down the groundwater flow path from the Fill Unit at the aquitard breach (well CP-MW22) to Lower Sand well CP-MW23. An exponential regression through the data provides a near-perfect fit ($R^2 = 0.999$), consistent with contaminant transport theory for an attenuating plume. Based on extrapolation of the exponential trend to distance downgradient of CP-MW23, the downgradient dissolved mercury concentration is estimated to meet the 0.059 µg/L groundwater cleanup level within about 320 feet of well CP-DW2, several hundred feet from the marine environment (Figure 4-2). The estimated downgradient extent of Lower Sand dissolved mercury exceedance is shown in plan view on Figure 4-1.

Approximately 250 feet mill-north of the aquitard breach, the dissolved mercury concentration at Lower Sand well CP-MW05 (0.0019 µg/L) was well below the cleanup level, consistent with data collected during the RI. This well is located cross gradient, not downgradient, of the aquitard breach (Figure 4-1).

Because the aquitard breach has existed for decades, we expect that the July 2013 Lower Sand data represent a steady state condition prior to the interim action source removal. The interim action achieved substantial removal of mercury mass from the Fill Unit in the MRU area (removal of both soil and groundwater), indicating that groundwater mercury concentrations should only improve over time. As an early indication of the source control achieved, the dissolved mercury concentration at Fill Unit well CP-MW22, located at the aquitard breach, showed a substantial decline from the time it was installed in March 2013 (23 µg/L), prior to soil removal, to July 2013 (3.5 µg/L), after soil removal with associated dewatering. The lower detected dissolved mercury concentrations at Lower Sand well CP-DW2 (at aquitard breach) were comparable between February and July of 2013 (0.31 and 0.41 µg/L, respectively) (Table 4-1).

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[7] Located mill-north of the MRU, within the former wastewater settling basin footprint.

[8] Cleanup level based on protection of marine sediment.

4.2 Supplemental Groundwater and Porewater Sampling, Summer 2015

A round of supplemental groundwater and porewater sampling was conducted on August 31 and September 1, 2015, in the Caustic Plume subarea, the former wastewater settling basin area, and the Law-1 area. Sampling was conducted to provide an up-to-date snapshot of groundwater quality (pH and dissolved mercury), since groundwater at many well locations had not been sampled since early 2010. In addition, porewater samples were collected from four intertidal sediment locations to directly measure dissolved mercury concentrations at the point of benthic exposure, which is the basis for the 0.059 µg/L groundwater cleanup level. Sampling results are summarized on Figure 4-3, and have been incorporated into this FS evaluation. Sampling procedures and a detailed discussion of results are provided in Aspect (2015b).

4.3 Fill Unit Groundwater Quality Downgradient of Siderite-Amended Backfill, CFH Area

As noted in Section 3.1.4.3, the interim action excavation encompassing the former CFH footprint was backfilled (in spring 2013) using imported gravel borrow amended with 3 weight percent siderite (iron carbonate). Siderite can reduce caustic groundwater pH through the following chemical reactions (S.S. Papadopoulos and Associates, 2010):

1. Dissolution of siderite releases iron and carbonate ions into solution; and
2. The iron ions react with hydroxyl ions (OH-) to precipitate hydrous iron oxide (goethite), thus lowering the pH of the groundwater by removing OH- from solution.

Prior to the interim action, the CFH area contained a substantial mass of elemental mercury in soil and the highest groundwater pH observed within the RAU (from historical releases of caustic). Mercury mobility is increased in caustic conditions. The combination of substantial mercury mass with highly caustic groundwater in the CFH area produced the highest measured dissolved mercury concentrations within the RAU (at well CP-MW15,[9] which was removed during the interim action excavation; see Figure 3-1). Because the CFH excavation extended well below the water table, amending its backfill provided a cost-effective opportunity to evaluate siderite's ability to buffer (decrease) high-pH groundwater and thus reduce the mobility of dissolved-phase mercury.

Wells AMW-02, EMW-19S, and CP-MW24, situated approximately downgradient and within 200 feet of the CFH excavation (Figure 4-3), were monitored to evaluate the impact of the siderite on downgradient Fill Unit groundwater quality. Wells AMW-02 and EMW-19S were installed in 2009 and had been sampled on two occasions prior to siderite placement, whereas CP-MW24 was installed just after siderite placement, in July 2013. The well was intentionally installed outside of excavation backfill material to assess conditions within the Fill Unit material (expecting that the imported backfill material may generate notably different groundwater quality). Well CP-MW24 was sampled just after it

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[9] Groundwater at well CP-MW15 had the highest mercury concentrations and pH when sampled in December 2010 (619 µg/L mercury, pH 11.2), February 2011 (232 µg/L mercury, pH 11.0), and February 2013 (146 µg/L mercury, pH 11.7).

was installed, and all three wells were subsequently sampled in August 2014 and September 2015. Sampling results, which are depicted on Figure 4-3, indicate the following:

- Groundwater at EMW-19S experienced a large reduction in dissolved mercury and a small reduction in pH. An average mercury concentration of 23.5 µg/L and a pH of 11.0 were measured in the two sampling rounds prior to siderite placement, versus 7.8 µg/L mercury and 10.5 pH average measurements after placement;
- Groundwater mercury concentration and pH did not change significantly at AMW-02, the furthest-downgradient well, in "before" versus "after" sampling rounds. Average values of 33.3 µg/L mercury and 9.8 pH were measured over the four rounds; and
- Groundwater at CP-MW24 had both the lowest pH and the lowest mercury concentration among these three wells. Average values of 1.1 µg/L mercury and 9.3 pH were measured over the three sampling rounds (all post-siderite placement). Judging from measurements in surrounding wells (EMW-19S, AMW-02, and former well CP-MW15), both the mercury concentration and the pH of groundwater at CP-MW24 were likely considerably higher prior to siderite placement.

Unfortunately (from the standpoint of evaluating siderite treatment effectiveness), highly impacted soils were removed from the CFH area just prior to siderite placement, which would also be expected to reduce mercury concentrations and pH in downgradient groundwater. So, while conditions improved at EMW-19S and likely at CP-MW24 as well following siderite placement, the contribution of the siderite versus impacted soil removal cannot be determined.

4.4 Delineation of Residual Soils Containing Visible Elemental Mercury

As noted in Section 3.1.4.5, soils containing visible elemental mercury were encountered unexpectedly beneath the Cell Building during the Caustic Plume-Cell Building interim action. A test pit exploration program was conducted in February 2014 to investigate the extent of impacted material within and in the immediate vicinity of the Cell Building footprint. A total of 30 test pits were dug to depths up to approximately 13 feet. Field observations indicated a heterogeneous distribution of visible mercury beneath most of the Cell Building footprint within the extent of the former floor troughs/sump (southern portion), but no visible mercury within the northern portion adjacent to the former Shop Annex. Visible mercury was observed in soils adjacent to the former floor troughs to depths of approximately 13 feet, where a layer of organic-rich (woody) fill was observed, resting on top of the Tidal Flat Aquitard. In addition, subsurface visible mercury was observed outside the Cell Building footprint—east of it about 15 feet, and west of it at least 25 feet and approaching the CFH excavation area. The February 2014 test pit investigation is described in more detail in the Caustic Plume/Cell Building Interim Action Report (Aspect, 2014b).

In September-October 2014, a more expansive follow-up test pit exploration program was conducted outside the Cell Building footprint, in the portion of the Caustic Plume subarea known as the Chlorine Plant Area (refer to Figure 5-1). The primary purpose of the investigation was to further delineate the extent of residual soils containing visible elemental mercury. Fifty-four test pits were excavated for this purpose. Visible mercury was observed in soil at four distinct locations north and northwest of the Cell Building. A total of 93 soil samples were collected from the test pits. All soil samples were analyzed for total mercury. In addition, six soil samples collected from intervals where elemental mercury was present were also analyzed for TCLP mercury. Sampling results and details of the September/October 2014 test pit investigation are documented in the Test Pit Investigation Results memorandum (Aspect, 2014d). Figure 5-1 depicts the lateral extent of residual soil containing visible mercury inferred from the two test pit investigations.

4.5 Chlorine Plant Area Soils Impacted by TPH

During the February 2014 test pit investigation, petroleum hydrocarbons were observed on shallow groundwater in the vicinity of former electrical rectifiers[10] (part of the electrical substation for the Cell Building) near the southeast corner of the Cell Building footprint. Therefore, a secondary goal of the September/October 2014 test pit investigation was to delineate the extent of petroleum hydrocarbon impacts in the Chlorine Plant Area. Five test pits were excavated primarily for this purpose. As depicted on Figure 5-1, TPH-impacted soils were observed at three distinct locations in the Chlorine Plant Area: two locations within the electrical substation area along the Cell Building’s southeast corner, and a minor occurrence in the northwest former of the Chlorine Plant Area. In each location, observed petroleum impacts were relatively shallow (not exceeding 5-foot depth) since the shallow groundwater table precludes further downward migration of separate-phase oil. Soil samples collected from the test pits were analyzed for diesel- and oil-range TPH, polychlorinated biphenyls (PCBs), and RCRA 8 metals. Total PCB concentrations detected in each soil sample were below the 1 mg/kg soil screening level for unrestricted use, indicating the petroleum (oil) is not PCB-containing (would not be regulated under the Toxic Substances Control Act [TSCA] if excavated). Sampling results and details of the petroleum hydrocarbon investigation are documented in the Test Pit Investigation Results memorandum (Aspect, 2014d).

4.6 Updated CSM – Caustic Plume Subarea

The Caustic Plume subarea, which encompasses the Chlorine Plant Area, contains the highest concentrations of mercury in soil and groundwater, as well as the most alkaline (highest pH) groundwater, within the Chlor-Alkali RAU. The conditions documented in the RI for this subarea have changed following completion of the Caustic Plume-Cell Building interim action described in Section 3.1.4. The updated CSM for this subarea is discussed below.

4.6.1 Soil in Chlorine Plant Area

Over the course of the interim action, visible mercury was encountered within and around buried infrastructure of the former Chlorine Plant, and thus in locations not anticipated

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[10] A rectifier is an electrical device that converts alternating current (AC) to direct current (DC). Like electrical transformers, they contain mineral oil for heat dissipation.

based on the collective RI data. While the extent of visible mercury is greater than anticipated in the RI, the interim action also confirmed that, in areas of visible mercury, soil mercury concentrations decline substantially over distances of only a few feet from the visible mercury occurrence.

Based on the observations from the interim action, we assume for purposes of this FS that there is a moderate probability for the presence of visible elemental mercury anywhere within the footprint of the former Chlorine Plant. If the elemental mercury occurs in soil above the water table, it can create mercury soil vapor concentrations above indoor air screening levels, as was observed around the interim action areas. Within the interim action excavation footprints, soils met soil screening levels for unrestricted land use (24 mg/kg mercury), with the two exceptions noted in Section 3.1.4.1.

4.6.2 Soil outside Chlorine Plant Area

Outside of the Chlorine Plant Area, the RI data indicate areas of soil containing mercury concentrations greater than the 24 mg/kg unrestricted soil screening level within the Caustic Plume subarea. The assumed area of potential elemental mercury (with associated mercury soil vapor exceedances), and other areas exceeding the unrestricted soil screening level, are depicted on Figure 5-1.

West of the former Chlorine Plant Area, within the groundwater mercury plume, mercury concentrations in subsurface soil (aquifer matrix) are below 1 mg/kg.

4.6.3 Fill Unit Groundwater

The highest groundwater mercury concentrations are detected in association with the very high groundwater pH near the former CFH, termed the “Caustic Core.” The highly alkaline, highly reducing geochemical conditions within the Caustic Core increase the mobility of mercury in the aquifer, in part by also liberating into solution higher concentrations of dissolved organic carbon (DOC) and sulfide, as discussed Section 7.1.3 and Appendix C of the RI. These unique groundwater geochemical conditions do not occur anywhere else within the RAU.

In addition, higher dissolved mercury concentrations are generally observed only where caustic groundwater occurs in combination with a substantial source of mercury in soil. This is illustrated by comparing conditions at the CFH area versus the MRU area, both of which contained extensive visible elemental mercury prior to the interim action. The CFH area had groundwater pH exceeding 10 and corresponding dissolved mercury concentrations up to 620 µg/L. Conversely, at the MRU area, the groundwater pH was below 10 with dissolved mercury concentrations below 5 µg/L. The RI data indicate there were separate but overlapping release areas for the caustic and the mercury in the subarea.

Groundwater quality data for this subarea indicate variable results from one monitoring round to the next, but a clear overall trend of declining dissolved mercury concentrations over time. This is especially apparent at EMW-19S, the well within the Caustic Core with the longest sampling record. Measured concentrations at EMW-19S fell from 460 µg/L in 1993 to 28.5 µg/L in April 2010 (prior to removal of upgradient source soils in the Caustic Plume-Cell Building interim action), and to 8.6 µg/L in August 2015, the most recent sampling event.

Based on the RI data and results of groundwater monitoring conducted after completion of the RI, groundwater pH and mercury concentrations decline rapidly with distance downgradient of the Caustic Core. Groundwater pH is attenuated to less than the pH 8.5 screening level more than 200 feet upgradient from the Bellingham Bay shoreline.

4.6.3.1 Intertidal Porewater Data

Dissolved mercury concentrations exceed the stringent 0.059 µg/L screening level at well CP-MWB3, one of five monitoring wells installed along the shoreline on the west edge of the Caustic Plume subarea. However, mercury concentrations detected in porewater samples collected from two locations in the Bellingham Bay intertidal zone downgradient of CP-MWB3 in August 2015 were more than two orders of magnitude below the screening level (measured porewater concentrations up to 0.00048 µg/L; Figure 4-3). The porewater samplers were deployed during a lower low-tide event, and were positioned a few feet inland of the water's edge at the time of deployment. They were buried 15 to 18 centimeters (cm) below the sediment mudline, which was below saturation at the time of deployment. This ensured that the samplers would remain in saturated conditions throughout the period of deployment. Assuming the bioactive zone (0 to 12 cm below the sediment mudline) contains a mixture of upwelling groundwater at lower tides and surface water intrusion at higher tides, a sampling depth of 15 to 18 cm is expected to provide a conservative representation of porewater quality in the shallower bioactive zone. Details of that sampling event are described in Aspect (2015b).

A mercury concentration attenuation greater than 500-fold was indicated between well CP-MWB3 and the downgradient porewater sampling locations, based on the August 2015 data.

4.6.3.2 Modeling of Fill Unit Groundwater Contaminant Attenuation at Western Edge of Caustic Plume (Shoreline)

A groundwater modeling assessment of Fill Unit contaminant concentrations attenuation in response to tidally-induced physical mixing—ignoring chemical transformation—was performed for the Caustic Plume subarea and the Law-1 area (described below) within the Chlor-Alkali RAU. The modeling assessment (Aspect, 2012b) was reviewed and the results, incorporating a factor of safety, were approved by Ecology.

The modeling indicates that, under current conditions for the Caustic Plume subarea, groundwater contaminant concentrations are reduced about 130-fold[11] between an upland shoreline monitoring well (CP-MWB3) and the downgradient bioactive sediment zone, which is the point of exposure for which the 0.059 µg/L mercury groundwater screening level was developed. There is no active sediment remediation planned offshore of the caustic plume's western edge as part of the Whatcom Waterway cleanup; therefore, the modeled attenuation factor of 130 is assumed to apply for the future condition of this subarea as well.

The attenuation factor predicted by the model is significantly lower than that indicated empirically by the August 2015 sampling results described above (500-fold attenuation), suggesting that the modeling result is conservative. Ecology agreed that an attenuation factor could be used to establish groundwater remediation levels at upland shoreline wells

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[11] With a safety factor applied, as agreed to with Ecology (refer to Aspect, 2012b).

if a groundwater conditional point of compliance within the sediment bioactive zone (point of exposure) were approved by Ecology. In that case, a groundwater cleanup level based on marine protection (0.059 µg/L mercury) would still apply at the conditional point of compliance within the bioactive zone (point of exposure).

For the Caustic Plume subarea, a 0.059 µg/L mercury groundwater cleanup level applied within the sediment bioactive zone multiplied by a conservative 130-fold attenuation factor equals a 7.6 µg/L mercury groundwater remediation level at the upland shoreline wells (e.g., CP-MWB3). Concentrations detected at well CP-MWB3 have consistently been more than an order of magnitude below that level (Figure 4-3).

The empirical porewater data, supplemented by the contaminant transport modeling, indicate that the current Fill Unit groundwater quality within the Caustic Plume subarea is protective of the marine environment.

4.6.4 Lower Sand Groundwater

Within the Lower Sand, groundwater mercury concentrations exceed the 0.059 µg/L groundwater screening level downgradient of the aquitard breach observed immediately northeast of the MRU (at well CP-DW2). As described above, the available data indicate that the Lower Sand mercury plume remains hundreds of feet from the area of groundwater discharge to the Bellingham Bay.

4.6.5 Soil Vapor

As discussed in Section 7.1.2.4 of the RI, elemental mercury is the source of mercury to soil vapor, but only when it occurs in unsaturated soil conditions (vadose zone). Elemental mercury's relatively low solubility in water inhibits the formation of mercury vapor under saturated conditions; conversely, divalent mercury may dissolve in caustic water, but does not have a high enough vapor pressure to generate significant mercury vapor.

Prior to the Caustic Plume-Cell Building interim action, mercury was detected in soil vapor at concentrations above the soil gas screening level for unrestricted land use within the CFH and MRU areas. The interim action removed soils containing visible elemental mercury from those areas but, as discussed above, soils containing visible elemental mercury remain at other locations within the Chorine Plant Area. The potential for mercury in soil vapor to exceed the soil gas screening level is assumed to exist wherever soils containing elemental mercury are present at or above the water table.

4.7 Updated CSM – Confined Nearshore Fill/Chemfix Subarea

This subarea includes the former wastewater settling basin, hydraulic fill used to partially fill the inland portion of the former Log Pond, and Chemfix-stabilized waste removed from the former wastewater settling basin. Outside the wastewater settling basin and Chemfix areas, soil mercury concentrations within the dredge fill are below 24 mg/kg.[12]

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[12] A mercury concentration of 39 mg/kg was detected at boring STB-03 located west of the Chemfix area and north of the former Cell Building. The RI report included this boring location in the Confined Nearshore Fill/Chemfix subarea. However, as shown on Figure 5-1, it is situated within the Chlorine

4.7.1 Former Wastewater Settling Basin Area

Within the footprint of the former wastewater settling basin, the highest residual soil mercury concentrations were detected in silty gravel soil at depths ranging between about 8 and 15 feet below ground surface (bgs) (shallower on north end). Within this layer of material, soil mercury concentrations were detected up to 1,760 mg/kg. Fill soils on top of the deep layer have much lower soil mercury concentrations, but concentrations greater than 24 mg/kg were commonly detected.

Results of the TCLP mercury testing of soils, including testing of the 1,760 mg/kg sample, met the 0.2 mg/L toxicity characteristic criterion, indicating the impacted material at depth should not be designated as characteristic hazardous waste if excavated.

The former wastewater settling basin remains unpaved, and it is an area of concentrated groundwater recharge to the Fill Unit (creating groundwater mounding with semi-radial groundwater flow). Seasonal recharge events, therefore, cause temporary changes in the local groundwater flow directions.

Groundwater quality within the southern portion of the former wastewater settling basin is impacted by caustic and mercury associated with the Caustic Plume subarea and is addressed as part of that subarea.

Within the northern portion of the former wastewater settling basin and in the Law-1 area discussed in Section 4.7.2, dissolved mercury concentrations in Fill Unit groundwater were highly variable, likely due to the changing local groundwater flow conditions caused by concentrated recharge events through this unpaved area (refer to Section 7.2.2.2 of the RI). Within the footprint of the former wastewater settling basin, elevated dissolved mercury concentrations were measured in wells screened across the soil layer with the higher mercury concentrations at depth (e.g., 83 µg/L at well L1-MW05 and 17.6 µg/L at well EMW-14S, measured in August 2015) in spite of the fact that the groundwater was only slightly alkaline (pH 7.6 and 8.5, respectively; Figure 4-3). As illustrated on RI Figures 4-4 and 4-5, the water table elevation in the wastewater basin footprint is significantly higher during the wet season (about 1.8 feet higher at CP-MW03 and EMW-14S in March 2010 compared to September 2009). Relative to the August 2015 sampling event that occurred during the summer of an unusually dry year, the historically lowest mercury concentrations at both L1-MW05 and EMW-14S were detected during wet-season (December) sampling events.[13] It is likely that the wet-season recharge of precipitation into the basin footprint results in lower mercury concentrations in groundwater there. Absent the recharge, higher concentrations likely occur in samples collected during the dry season (e.g., August 2015 data).

While the collective groundwater data for the Caustic Plume subarea demonstrate gradually attenuating dissolved mercury concentrations over time, the available data from wells within the footprint of the former wastewater settling basin are not adequate to demonstrate that natural attenuation of dissolved mercury is occurring there.

Plant Area as defined in this FS evaluation and is, therefore, considered as part of the Caustic Plume subarea.

[13] For well EMW-14S, a mercury concentration of 0.96 µg/L was detected in December 1993; that historical detection is not displayed on Figure 4-3 but is presented in Table 7-2 of the RI.

Lower Sand groundwater immediately beneath the former wastewater settling basin footprint meets screening levels for mercury and pH, indicating negligible vertical transport of contaminants through the aquitard within this area.

4.7.2 Law-1 Area

The Law-1 area is named for the 1992-vintage monitoring well Law-1, located between the north end of the former wastewater settling basin and the shoreline of the Log Pond (Figure 4-3). During the RI, the Law-1 area was called out individually within this subarea because of the relatively high dissolved mercury concentrations (up to 33 µg/L) and elevated pH (up to 10.2) detected in the Law-1 well. As noted above, relatively high dissolved mercury concentrations were also measured at the north end of the basin itself, but monitoring indicates that the groundwater there is only slightly alkaline. During additional exploration drilling at and around the Law-1 well, no elevated mercury was detected in soil, and no obvious source of alkaline pH was observed. Detected mercury concentrations in soil within the Law-1 area were below 24 mg/kg, except in one sample from the base of the fill located next to the Law-1 well.

4.7.2.1 Intertidal Well Point and Porewater Data

GP initially capped the Log Pond with clean sand and gravel to isolate mercury-impacted sediments as an interim cleanup measure completed in 2001. The 2001 cap was 2 to 3 feet thick within the intertidal zone immediately offshore of the Law-1 area. In 2016, the final cap for the Log Pond was constructed as part of the Whatcom Waterway Phase 1 cleanup. Just offshore of the Law-1 area, the additional cap material that was placed consisted of approximately 3 feet of sand overlain by approximately 3 feet of armor gravel/rock, providing a total cap thickness of 5 to 6 feet of sand beneath the armor layer.

Groundwater samples were collected on two occasions from the Log Pond intertidal zone downgradient of the Law-1 area prior to placement of the final cap. In 2012, three intertidal well points (L1-WP1 through L1-WP3), each with a 3-foot screen that extended to approximately 4.5 feet below sediment mudline, were installed at the locations shown on Figure 4-3. The well points were, therefore, screened across both the 2001 cap material and the underlying contaminated sediment. Relative to groundwater quality at the Law-1 upland area, substantially lower dissolved mercury concentrations (below 0.2 µg/L) and pH (at or below 8.5) were detected in groundwater samples collected from these well points. While there was variability in the detected dissolved mercury concentrations from both upland wells and intertidal well points over the period of monitoring, the combined shoreline well-well point data indicated substantial concentration attenuation (roughly 50-fold) in the tidally influenced nearshore environment. Furthermore, the intertidal well points extended into mercury-contaminated Log Pond sediment, suggesting that the dissolved-phase mercury concentrations measured in the well point groundwater samples could be partially derived from the contaminated sediment beneath the interim action cap. As such, the degree of concentration attenuation occurring between the upland shoreline wells and the intertidal well points could be greater than that indicated by the measured data.

Porewater samples L1-PW-01 and L1-PW-02 were later collected (August 2015) from farther-downgradient Log Pond locations, within the 2001 cap material, shown on Figure 4-3. The porewater samplers were deployed in the same manner and at the same sampling depth interval as the porewater samplers for the Caustic Plume subarea (Section 4.6.3.1). Since the sampling depth interval (15 to 18 cm below sediment mudline) was much closer to the bioactive zone interval (0 to 12 cm below mudline) compared to that of the 2012 well point samples (approximately 1.5 to 4.5 feet below mudline), these samples are expected to more closely (but still conservatively) represent water quality in the bioactive zone. Dissolved mercury concentrations detected in both porewater samples were well below the 0.059 µg/L groundwater screening level (0.00978 and 0.0125 µg/L). A mercury concentration attenuation of 490-fold occurring during transport between upland shoreline groundwater and the bioactive zone is indicated based on the August 2015 data from shoreline well Law-1 and the average of the two porewater sampling results (0.011 µg/L).

4.7.2.2 Modeling of Groundwater Contaminant Attenuation in Law-1 Area (Shoreline)

Similar to the modeling described for the Caustic Plume subarea, modeling of nearshore groundwater contaminant concentration attenuation was also performed for the Law-1 area (Aspect, 2012b). The modeling simulated attenuation occurring under both then-current conditions (prior to the final [2016] Log Pond capping) and conditions with the final Log Pond cap in place.

The modeling for the Law-1 area indicates that, without the final Log Pond cap in place, contaminant concentrations are reduced about 50-fold[14] between the upland shoreline monitoring wells (e.g., Law-1) and the downgradient bioactive sediment zone. The attenuation factor predicted by the model is an order of magnitude lower than that indicated empirically by the 2015 porewater sampling results described in Section 4.7.2.1, suggesting that the modeling result is conservative.

With the final Log Pond sediment cap in place, the model-predicted attenuation increases nearly 9 times, to approximately 440-fold due to a substantially lengthened groundwater flow path distance (Aspect, 2012b).

Ecology agreed that an attenuation factor could be used to establish groundwater remediation levels at upland shoreline wells if a groundwater conditional point of compliance within the sediment bioactive zone (point of exposure) was approved by Ecology. For the Law-1 area, a 0.059 µg/L mercury cleanup level applied within the sediment bioactive zone multiplied by the 440-fold attenuation factor for the final-capped Log Pond condition equals a 26 µg/L mercury groundwater remediation level at the upland shoreline wells. Dissolved mercury concentrations detected at the Law-1 well during four of five sampling events since 2009, and the average concentration from those five events (15.5 µg/L), are below 26 µg/L (Figure 4-3).

The empirical porewater data, supplemented by the contaminant transport modeling, indicate that the current groundwater quality within the Law-1 area is protective of the marine environment following installation of the final Log Pond cap (now-current condition).

4.7.3 Chemfix Area

As detailed in Section 3.2.1, GP removed accumulated solids from the wastewater settling basin and chemically stabilized the solids using the Chemfix process. The treated materials were contained within a bermed area of approximately 2 acres, which was then capped

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[14] With a safety factor applied, as agreed to with Ecology (refer to Aspect, 2012b).

("Chemfix" area as shown on Figure 5-1). The capped Chemfix-treated material remains in place, and a 1977 Ecology Order prohibits disturbance of the cap.

The Chemfix material (chemically stabilized sludge) contains total mercury concentrations detected up to 5,800 mg/kg. Because the material contains greater than 1,000 mg/kg total mercury, it would be designated as State-only toxic dangerous waste (WT02) if excavated. Two samples of Chemfix material with total mercury concentrations of 2,500 and 5,800 mg/kg had TCLP-leachable mercury concentrations well below the 0.2 mg/L characteristic waste criterion, indicating that the Chemfix material would not designate as characteristic hazardous waste if excavated. Because the treated material is a State-only dangerous waste but not a federal hazardous waste, if excavated, it would not require pre-treatment to meet the federal universal treatment standards prior to Subtitle C disposal (although the existing TCLP data indicate it would still meet the 0.25 mg/L universal treatment standard).

Dissolved mercury concentrations immediately downgradient of the Chemfix material are less than the stringent groundwater screening level of 0.059 µg/L. In addition, soil vapor sampling on top of the placed Chemfix material demonstrates mercury soil vapor concentrations less than the soil gas screening level for unrestricted land use.

The collective data indicate that, while the Chemfix material contains very high total mercury concentrations, the mercury has been chemically stabilized such that it is protective of groundwater quality and potential VI to future structures within the RAU.

4.8 CSM Recap – Stormwater Swale Subarea

Soil mercury concentrations within the stormwater swale footprint are greater than the 24 mg/kg unrestricted cleanup level, but less than the 1,050 mg/kg industrial cleanup level; the detected mercury soil contamination is limited to the top 1 foot of soil throughout most of the swale footprint. Groundwater downgradient of the swale has near-neutral pH and dissolved mercury concentrations below the 0.059 µg/L screening level, indicating the soil mercury concentrations are protective of groundwater.

The swale is bisected by the (fenced) property boundary between the Port and BNSF. Any active remedial action for the swale would therefore require coordination with BNSF and accommodate access issues within the railroad right-of-way.

4.9 CSM Recap – Laurel Street Pipe Rack Subarea

This subarea is defined based on mercury contamination associated with spent anodes and other waste materials suspected from the Chlorine Plant encountered during the 1992 excavation for footings to construct an above-grade pipe rack. Soils removed and stockpiled, and in the construction trenches, were characterized and an undocumented quantity of soil was removed and disposed of off-site during the construction project.

Based on data collected to date, soils containing mercury concentrations greater than the 24/mg unrestricted soil screening level encompass an approximately 50-foot by 100-foot area, and extend to a depth of approximately 13 feet bgs. The water table is approximately 3 to 6 feet bgs in this area.

The collective information indicates that soil mercury concentrations exceeding the 1,050 mg/kg industrial soil cleanup level are restricted to the location of the AS-10 boring completed during the Anchor Environmental (2003) sampling and analysis. Law/Crandall

(1993) also reports soil mercury concentrations exceeding the soil cleanup level at two locations (1,100 mg/kg at WLSS-16 and 14,000 mg/kg at PLHA-9) within the construction trench. However, it is uncertain from the documentation whether those soils remained in place once the construction was completed. Detailed RI sampling and analysis (five soil samples) conducted at the highest concentration location (PLHA-9) detected a maximum soil mercury concentration of only 234 mg/kg. The relatively low detected concentrations from the RI data indicate that the higher soil mercury concentrations detected in the excavation during construction were actually removed in that project, without clear documentation in Law/Crandall (1993).

To profile stockpiled soil for off-site disposal, Law/Crandall (1993) conducted TCLP mercury analyses for six samples of stockpiled soil with total mercury concentrations ranging from 16 to 100 mg/kg. TCLP-leachable mercury was not detected (<0.005 mg/L) in the six samples. During the fall 2009 RI field program, TCLP mercury analyses were conducted for the two soil samples with the highest detectable soil mercury (up to 219 mg/kg). TCLP-leachable mercury was not detected (<0.001 mg/L) in either sample. Based on the TCLP data, the mercury-contaminated soil in the Laurel Street Pipe Rack subarea would not designate as characteristic dangerous waste if excavated.

The extent of groundwater dissolved mercury exceeding the 0.059 µg/L marine-based screening level is extremely limited within the Laurel Street Pipe Rack subarea. Dissolved mercury is present at a concentration roughly four times the 0.059 µg/L screening level in one well within the high-concentration soils (0.21 µg/L at well PR-MW03), but it attenuates to below the screening level less than 15 feet downgradient (0.0067 to 0.012 µg/L at well EMW-13S). In addition, a 17-year record of groundwater quality monitoring at well EMW-13S within the mercury-impacted area demonstrates substantial natural attenuation of groundwater pH and mercury in this subarea. At well EMW-13S, groundwater conditions improved from pH greater than about 10 and dissolved mercury up to 180 µg/L in 1993-1994 to a pH of about 7.7 and dissolved mercury of about 0.01 µg/L in 2009- 2010.

Groundwater mercury concentrations in the subarea are below the 0.89 µg/L VI screening level for unrestricted use, and the 2003 vapor monitoring data indicate vapor-phase mercury concentrations below the 1.4 micrograms per cubic meter (µg/m^3) unrestricted screening level in this subarea, as discussed in Section 7.4.2.3 of the RI.

The collective data indicate that residual soil mercury concentrations in the Laurel Street Pipe Rack subarea are not a source of mercury to air or to the marine environment via groundwater transport.

4.10 CSM Recap – Million Gallon Tanks Subarea

Seven of the eight “million gallon tanks” were used for storage of lignin-related products, and one tank, Tank 2, was used for storage of fuel oil. In addition, a fueling area was located immediately east of the tanks. GP excavated and disposed of off-site approximately 30 tons of petroleum-contaminated shallow soil located adjacent to Tank 2 in 2006, prior to demolition of the tanks (described in Section 3.4.1).

4.10.1 Soil

Based on subarea-specific data and analysis, the following subarea-specific TPH soil screening levels were calculated in accordance with MTCA:

- Method B level (unrestricted use) of 4,000 mg/kg based on direct contact as the most restrictive exposure pathway; and
- 10,000 mg/kg, based on residual saturation (non-aqueous-phase liquid [NAPL] mobility).

Following GP's independent cleanup, soils containing TPH concentrations greater than the unrestricted soil screening level occur in locations north of the 2006 cleanup area and in the fueling area immediately east of the tanks. Applying the MTCA 3-fold compliance criteria[15] to the current data set (described in RI Section 7.5.2.1) indicates that compliance with the 4,000 mg/kg Method B soil screening level could be achieved through removal of soil from the two identified locations with soil TPH exceeding two times the screening level (greater than 8,000 mg/kg TPH at MG-SB07 and MG-SB09).

One of those locations (MG-SB09) contained a 10,400 mg/kg TPH concentration, slightly exceeding the 10,000 mg/kg residual saturation screening level based on NAPL mobility; however, no separate-phase product was observed at that location during drilling or in the completed monitoring well, empirically indicating that the residual soil TPH is not generating mobile NAPL in this location. An area of soil encompassing Tank 2 and east and north of it contains naphthalene concentrations greater than the 0.17 mg/kg soil screening level based on leaching to groundwater for marine protection (irrespective of land use).

4.10.2 Groundwater

Groundwater TPH concentrations exceed the 500 µg/L screening level in monitoring wells adjacent to the former Tank 2 and downgradient. TPH was not detected in intertidal sediment porewater samples collected at the downgradient edge of the subarea, indicating that TPH from the Million Gallon Tanks subarea is not reaching the marine environment.

Groundwater concentrations of naphthalene exceeding the 8.9 µg/L screening level (based on VI for unrestricted use) are interpreted to extend roughly 500 feet downgradient of the former tanks. Groundwater concentrations of naphthalene exceeding an 83 µg/L screening level based on marine protection extend roughly 250 feet downgradient of the former tanks—remaining more than 400 feet upgradient of the Log Pond shoreline. Based on data collected in 2004 and 2009-2010 from well MG-MW01, located adjacent to former Tank 2, the naphthalene in subarea groundwater is attenuating naturally (refer to Section 7.5.2.2 of RI).

Groundwater containing carcinogenic polycyclic aromatic hydrocarbons (cPAHs) above the stringent marine-based screening level of 0.02 µg/L toxic equivalent concentration (TEQ; equal to the analytical reporting limit) extends roughly 500 feet downgradient of the former tanks—remaining more than 200 feet upgradient of the Log Pond shoreline. The detected groundwater cPAH concentrations show poor correlation with groundwater TPH

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[15] WAC 173-340-740(7)(d).

concentrations. Given the low solubility of cPAHs in water, the groundwater cPAH concentrations are likely partly attributable to suspended solids in the groundwater samples.

The collective RI groundwater data indicate that residual petroleum-related contamination at the Million Gallon Tanks subarea is not adversely impacting the marine environment.

4.10.3 Soil Vapor

Empirical soil vapor data indicate that the residual TPH concentrations in soil and groundwater are protective of the VI pathway for unrestricted use, in accordance with WAC 173-340-740(3)(b)(iii)(C)(III). Naphthalene was not detected in any of the four soil gas samples collected within the petroleum-impacted area. At the time of the soil gas sampling in 2010, the analytical reporting limit for naphthalene met the soil gas screening level for unrestricted use. However, the soil gas screening level for naphthalene subsequently decreased in 2015, and the reporting limit for the 2010 results is greater than the new screening level. Therefore, naphthalene in the Million Gallon Tanks subarea remains a potential concern with respect to the VI exposure pathway.

4.11 CSM Recap – Screening Level Exceedances outside Defined Subareas

4.11.1 Exceedances for Total cPAHs in Lignin Warehouse B Soil

In July 2004, GP advanced five soil borings and collected surface soil samples from four other locations north and west of Lignin Warehouse B to evaluate potential impacts associated with the spillage of dry lignin products and waste liquor. A total of fourteen soil samples were analyzed for total metals, hexavalent chromium, PAHs, and semivolatile organic compounds (SVOCs). Most of the soil samples submitted for analysis contained detectable concentrations of one or more cPAHs, and the 0.14 mg/kg TEQ screening level for total cPAHs (unrestricted direct contact) was exceeded in four samples collected from between the warehouse and the rail line to the north. The two highest exceedances (3.19 and 29.4 mg/kg) were surface samples collected along a rail spur, and creosote-treated railroad ties may have contributed to those results. The other exceedances (0.83 and 1.03 mg/kg) were collected from a boring along the north side of the warehouse at depth intervals of 0 to 4 and 4 to 8 feet, respectively).

The inferred lateral extent of soil screening level exceedances for total cPAHs is depicted on Figure 5-1. No other soil screening level exceedances were detected in the vicinity of Lignin Warehouse B.

4.11.2 Exceedances for Miscellaneous Dissolved Metals in Fill Unit Groundwater

In addition to groundwater mercury exceedances, concentrations of other dissolved metals in Fill Unit groundwater within the Chlor-Alkali RAU may exceed marine-based screening levels. These exceedances occur at monitoring wells located away from obvious sources for metals contamination—as was also observed within the Pulp/Tissue Mill RAU (Section 7.9.1 of the RI). The RI data indicate that these dissolved metals concentrations are attributable to Site-wide geochemically reducing groundwater conditions that enhance mobility of naturally occurring metals in the Fill Unit aquifer. The reducing groundwater conditions are attributable to the prevalence of organic-rich dredge fill with abundant wood that comprises the Fill Unit; such conditions are typical of man-made (filled) lands throughout the developed shorelines of Puget Sound.

Concentrations of dissolved arsenic, chromium, copper, and nickel exceeded screening levels in summer 2004 at monitoring wells EMW-12S and EMW-16S, located within the area of groundwater petroleum contamination associated with the Million Gallon Tanks subarea, and at monitoring well LW-MW01, located north of the Lignin Warehouse B (see Figure 5-1 for well locations). Figure 4-4 depicts the time trends (2004-2010) for these dissolved metals at those three wells. With the exception of chromium at LW-MW01, concentrations of these metals were below the respective cleanup levels in the spring 2010 monitoring round at all three wells. The chromium concentration detected at LW-MW01 increased from 633 µg/L in fall 2009 to 792 µg/L in spring 2010. Both results are below the concentration detected in summer 2004 (1,170 µg/L) but above the groundwater cleanup level of 260 µg/L for chromium.

The data collected between 2004 and 2010 indicate that natural attenuation is generally reducing dissolved metals concentrations at these wells, which are located greater than 500 feet from the shoreline. However, there were no RI groundwater metals data collected from wells downgradient of well of EMW-16S to document the downgradient extent of metals exceedances in that area of the RAU.

5 Cleanup Requirements

5.1 Land Use

In accordance with the Port and City's Waterfront District Subarea Plan (Port/City, 2012), the proposed land use in the Chlor-Alkali Mill RAU is predominantly of commercial and industrial mixed use, as depicted on Figure 4-8 of the RI.

Under MTCA, sites may be remediated to either unrestricted or industrial cleanup levels. Industrial cleanup levels are developed based on an adult occupational lifetime exposure scenario, which results in higher cleanup levels for the soil direct contact and groundwater VI pathways, relative to unrestricted cleanup levels that are based on a child's lifetime exposure (residential). Assumptions and limitations of industrial properties are defined in WAC 173-340-200 and -745. Industrial properties are often, but not always, covered by buildings, structures, access roads, and parking lots that minimize potential exposure to soil. Access to industrial property by the general public is typically not allowed or, when allowed, is usually highly controlled due to safety or security considerations. Restaurants and other commercial operations are allowed under the MTCA definition of industrial property as long as they are primarily serving the industrial facility employees and not the general public.

For purposes of this FS, and to maintain maximum flexibility for future redevelopment, this FS assumes remediation of the Chlor-Alkali RAU to meet unrestricted cleanup levels.

5.2 Exposure Pathways

Section 5 of the RI (Aspect, 2013f) provides a detailed description of environmental exposure pathways that are applicable for establishment of Site soil and groundwater cleanup levels. As described in Section 5.1 of the RI, the following potential exposures to groundwater and soil do not represent complete exposure pathways for the Site:

- Potable use of Site groundwater. As described in Section 5.2.1.1 of the RI, Ecology has determined that groundwater at the Site is classified as nonpotable in accordance with WAC 173-340-720(2). Therefore, groundwater cleanup levels are not established specific to this exposure pathway; and
- Terrestrial ecological receptor contact with soil, and soil erosion to marine sediment. The Chlor-Alkali RAU is currently covered predominantly with pavement and/or foundations of former structures, and these 'paved' conditions will remain in the future, which would prevent terrestrial species exposure to contaminated soil and prevent erosion and transport of contaminated soil. Therefore, soil cleanup levels are not established specific to these exposure pathways.

As discussed in Section 5.1.1 of the RI, potentially complete groundwater exposure pathways that will be addressed by groundwater cleanup levels in this FS include the following:

- Residents, workers, and patrons in buildings inhaling indoor air contaminated (via VI) by the volatilization of contaminants from shallow groundwater;

- Workers contacting contaminated groundwater during excavation or other construction-related activities, if no worker protection controls are in place;
- Direct exposure for benthic and aquatic organisms in Bellingham Bay and Whatcom Waterway, if groundwater contaminants migrate and discharge to marine sediment and surface water;[16] and
- Humans consuming organisms contaminated by discharges of contaminated groundwater to marine sediment and surface water.

As discussed in Section 5.1.2 of the RI, potentially complete soil exposure pathways that will be addressed by soil cleanup levels in this FS include:

- Workers contacting contaminated soils (skin contact and incidental ingestion) and/or inhaling contaminated dust or vapors from soil during excavation or other construction-related activities, if no worker protection controls are in place; and
- Residents/visitors contacting contaminated soils and/or inhaling contaminated dust or vapors from soil in the future, if no controls are in place to restrict use of the Site.

In addition, contaminants in soil can leach to groundwater and be released to air through VI of volatile contaminants. Therefore, the soil-to-groundwater and soil-to-groundwater-to-air exposure pathways are also considered in establishing cleanup levels. The soil-to-groundwater pathway provides protection of the most stringent groundwater cleanup levels protective of the multiple exposure pathways described above. Figure 7-11 of the RI provides a graphical illustration of the relevant exposure pathways considered for cleanup level development in this FS.

5.3 Cleanup Standards

A cleanup standard includes both a cleanup level (chemical- and media-specific concentration of a contaminant that is protective of human health and the environment via all exposure pathways) and a point of compliance (the location where the cleanup level must be attained to achieve protectiveness). The proposed cleanup levels and points of compliance for the Chlor-Alkali RAU are described in the following subsections.

5.3.1 Cleanup Levels

The approach for developing screening levels in the RI is consistent with MTCA protocols for cleanup level establishment, and the approach has been consistently applied across cleanup sites throughout Bellingham Bay, in close consultation with Ecology. As such, proposed soil and groundwater cleanup levels addressing potentially complete exposure pathways are consistent with the respective screening levels applied in the RI. There are no soil cleanup levels based on a soil-volatilization-to-air (via soil vapor) pathway, which is limited to vadose zone soil since saturated soil is addressed through the groundwater-to-

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[16] The aquitard breach discussed in Section 4.1 was discovered after completion of the RI. However, this exposure pathway applies to groundwater contamination in the Lower Sand unit resulting from the aquifer breach as well as to contamination in the Fill Unit.

vapor-intrusion pathway. Ecology (2009) guidance recommends evaluating VI from vadose zone soil using empirical soil vapor data, which was collected from selected areas in the RI.

Tables 5-1 and 5-2 present the proposed cleanup levels for RAU groundwater and soil, respectively, consistent with the potentially complete exposure pathways identified in Section 5.2. Table 5-2 includes the soil screening levels for direct contact and soil-to-groundwater leaching pathways, since remediation levels (less stringent than cleanup levels) can be established to address a specific pathway.

5.3.1.1 Mercury Soil Concentrations Protective of Groundwater

As described in Section 5.2.2.1 of the RI, generic soil mercury screening levels for the soil-to-groundwater pathway were derived using Ecology's three-phase partitioning model (WAC 173-340-747[5]) with the 0.059 µg/L groundwater mercury screening level. Separate screening levels were developed for mercury in saturated soil (0.1 mg/kg) versus unsaturated soil (2 mg/kg), applying default dilution/attenuation factors of 1 and 20, respectively, and assuming a standard point of compliance, in accordance with MTCA. The generic soil screening levels are intentionally conservative, and the resulting 0.1 mg/kg soil mercury screening level is marginally above a natural background concentration (0.07 mg/kg) and is likely at or below area background concentrations for downtown Bellingham, as stated in Section 5.2.2.1 of the RI. As an indication of the conservatism, detected soil mercury concentrations at numerous locations within the RAU exceed these generic screening levels without corresponding exceedances of the groundwater screening level. In areas where groundwater quality meets screening levels, the corresponding soil concentrations are determined empirically to be protective of groundwater in accordance with MTCA (WAC 173-340-747[9]).

For a more realistic assessment of the soil-to-groundwater pathway, Aspect (2015a) evaluated RAU-specific TCLP data and relationships of measured soil and groundwater concentrations in areas with groundwater exceedances (empirical evaluation). The assessment was limited to areas with near-neutral-pH groundwater outside of the caustic plume. Following discussion with Ecology, it was agreed to not apply the TCLP data in the assessment since the TCLP test conditions do not represent environmental conditions within the RAU.

Based on regression analysis of measured mercury concentrations in collocated or nearly collocated soil and groundwater samples, average soil mercury concentrations of 160 mg/kg in the Confined Nearshore Fill subarea and 560 mg/kg in the Laurel Street Pipe Rack subarea equate to an average groundwater mercury concentration of 0.059 µg/L; therefore, they can be considered protective of groundwater for those areas.

No collocated data are available for the Stormwater Swale subarea, but groundwater data are available from two monitoring wells just downgradient of the swale. Within the swale, the maximum detected soil mercury concentration is 530 mg/kg, and the average concentration is 18 mg/kg. No groundwater mercury exceedances were detected at the downgradient wells, despite decades of stormwater infiltration through the swale, suggesting the soil mercury concentrations in the swale are protective of groundwater.

Based on the collective empirical data from the RAU, 100 mg/kg is considered a reasonable and conservative soil mercury concentration that is protective of near-neutral-pH groundwater, assuming a standard point of compliance for groundwater. For unrestricted land use, a soil concentration of 24 mg/kg mercury is protective of direct contact; therefore, 100 mg/kg could not be a soil cleanup level (protective of all exposure pathways) but is applied in this FS as a soil remediation level based on groundwater protection.

5.3.1.2 Oil-Range TPH in Million Gallon Tanks Subarea Soil

Section 7.5.2.1 of the RI presents derivation of screening levels for oil-range TPH specific to the Million Gallon Tanks subarea. On this basis, a soil cleanup level of 4,000 mg/kg is proposed for oil-range TPH in the Million Gallon Tanks subarea, versus 2,000 mg/kg in the rest of the RAU. In addition, a subarea-specific soil remediation level of 10,000 mg/kg is proposed as protective of the soil-to-groundwater pathway (protective of both dissolved phase leachability and NAPL accumulation). This concentration is not protective of the soil direct-contact pathway for unrestricted (residential) use; therefore, this concentration is not a cleanup level.

As described in the RI, 10,000 mg/kg oil-range TPH is a conservative estimate of residual saturation for weathered oil-range TPH in this subarea. If it is deemed impracticable to remove or treat residual oil-range TPH concentrations above 10,000 mg/kg TPH, more refined subarea-specific analysis (e.g., centrifuge testing for NAPL migration; empirical groundwater monitoring for dissolved-phase migration) may be conducted to evaluate an alternate remediation level as part of remedial design or cleanup action implementation.

5.3.1.3 Potential Groundwater Remediation Levels at Shoreline

Substantial natural attenuation of groundwater contaminant concentrations can occur within the hydraulically and geochemically dynamic nearshore portions of an aquifer. Site-specific contaminant transport modeling for two areas within the Chlor-Alkali RAU indicate concentration reductions (attenuation factors) ranging from about 50 to 130 times between an upland shoreline well and the sediment bioactive zone under current conditions (Aspect, 2012b). That modeling accounted only for physical attenuation of contaminants through hydrodynamic mixing within the groundwater system. The physical mixing is independent of any chemical-specific properties; as such the attenuation factors would be applicable to any contaminants in the RAU. Additional attenuation processes, such as biodegradation of organic constituents or irreversible precipitation of metals, would result in additional attenuation beyond the modeled results; therefore, the modeled attenuation factors are considered conservative. The model conservatism is borne out by empirically measured attenuation factors on the order of 500 for that nearshore transport pathway, as described in Sections 4.6.3.2 and 4.7.2.2.

In discussions with Ecology during that modeling exercise, it was agreed that, if a conditional point of compliance[17] for marine-based groundwater cleanup levels were applied in the sediment bioactive zone (point of exposure) in accordance with MTCA requirements, attenuation factors could be used to establish groundwater remediation levels at shoreline monitoring wells. The groundwater cleanup levels would remain unchanged and apply at the conditional point of compliance. The groundwater remediation levels would apply at shoreline well(s) and be equal to the cleanup level multiplied by the attenuation factor (between the shoreline well and bioactive zone).

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[17] Refer to Section 5.3.2.1 and Section 9 for discussion of standard versus conditional point of compliance for groundwater.

5.3.2 Points of Compliance

5.3.2.1 Groundwater

Under MTCA, the standard point of compliance for groundwater cleanup levels is throughout site groundwater, regardless of whether groundwater is potable (WAC 173-340-720(8)(b)). If it is not practicable to meet groundwater cleanup levels throughout the site within a reasonable restoration time frame, Ecology may approve a conditional point of compliance (WAC 173-340-720(8)(c)). Remedial alternatives are developed and evaluated in this FS assuming the standard point of compliance for groundwater. Then, after the alternative that is permanent to the maximum extent practicable has been identified, the practicability of meeting groundwater cleanup levels throughout the RAU within a reasonable restoration time frame is evaluated, and conditional points of compliance are considered (in Section 9).

For volatile groundwater contaminants that can pose a risk via VI, protectiveness is achieved by meeting VI-based groundwater cleanup levels throughout RAU groundwater, or wherever structures would be built on grade in the future. Therefore, the point of compliance for RAU groundwater cleanup levels based on VI protection is throughout the shallowest aquifer (Fill Unit). Elemental mercury and naphthalene are volatile contaminants within this RAU.

5.3.2.2 Soil

In accordance with MTCA, the point of compliance for direct contact with soil extends to 15 feet bgs, based on a reasonable maximum depth of excavation and assumed placement of excavated soils at the surface where contact occurs.

For soil cleanup levels or remediation levels based on groundwater protection (i.e., leaching to groundwater or NAPL accumulation), the soil point of compliance is all depths, above and below the water table.

5.4 Area/Volume Estimates for Contaminated Media

Based on the CSM for the Chlor-Alkali RAU discussed in Section 4, this section describes the estimated extents of contaminated soil, groundwater, and soil vapor with contaminant concentrations that exceed cleanup levels and potential remediation levels under current conditions (post-interim action). Figure 5-1 depicts the inferred areas of the RAU with contaminant concentrations exceeding the levels discussed in this section.

5.4.1 Contaminant Concentrations in Soil Exceeding Cleanup Levels and Potential Remediation Levels

5.4.1.1 Soil with Mercury Exceeding Cleanup Level

Light blue shading on Figure 5-1 represents estimated areas of the RAU where Fill Unit soil concentrations exceed the unrestricted cleanup level for mercury (24 mg/kg). Volumes of soil with contaminants concentrations exceeding cleanup levels are roughly estimated as follows:

- **Chlorine Plant Area and Vicinity**. Based on an assumed average impacted-soil thickness of 14 feet in this area, a cleanup-level-exceedance volume of roughly 74,000 cubic yards is estimated.

- **Chemfix Area**. As described in Section 3.2.1, approximately 8,000 cubic yards of stabilized mercury-contaminated sludge from the former wastewater settling basin was placed in the fill area shown on Figure 5-1 in 1976. All of this stabilized sludge is assumed to exceed the unrestricted cleanup level for mercury.
- **Wastewater Settling Basin and Vicinity**. Based on an assumed average impacted-soil thickness of 15 feet in this area, a cleanup-level-exceedance volume of roughly 20,000 cubic yards is estimated.
- **Stormwater Swale**. This area exhibited only near-surface soil impacts, to an average depth of roughly 1.5 feet. On this basis, a cleanup-level-exceedance volume of approximately 1,400 cubic yards is estimated.
- **Laurel Street Pipe Rack Subarea.** This small subarea exhibited soil impacts to an average depth of roughly 12 feet. On this basis, a cleanup-level-exceedance volume of approximately 1,600 cubic yards is estimated.

Therefore, an RAU-wide total of roughly 110,000 cubic yards of Fill Unit soil is estimated to exceed the unrestricted cleanup level for mercury.

5.4.1.2 Soil with TPH and/or PAHs Exceeding Cleanup Levels

Orange shading on Figure 5-1 represents estimated areas of the RAU where Fill Unit soil concentrations exceed the unrestricted cleanup levels for TPH and/or PAHs. Cleanup-level-exceedance volumes are roughly estimated as follows:

- **Chlorine Plant Area.** Based on an assumed average impacted-soil thickness of 5 feet in this area, a cleanup-level-exceedance volume of roughly 1,500 cubic yards is estimated for the three discrete areas within the Chlorine Plant Area.
- **Million Gallon Tanks Subarea.** Based on an assumed average impacted-soil thickness of 9 feet in this area, a cleanup-level-exceedance volume of roughly 6,000 cubic yards is estimated. This soil may also contain naphthalene concentrations that are high enough to be of concern with respect to groundwater protection and/or VI.
- **Lignin Warehouse B.** Based on an assumed average impacted-soil thickness of 4 feet, a cleanup-level-exceedance volume of roughly 2,500 cubic yards is estimated along the north side of Lignin Warehouse B.

Therefore, an RAU-wide total of roughly 10,000 cubic yards of Fill Unit soil is estimated to exceed the unrestricted cleanup levels for TPH and/or PAHs.

5.4.1.3 Soil Exceeding Levels of Concern for Groundwater Protection

A portion of the soils with mercury and naphthalene concentrations that exceed the unrestricted cleanup levels are also of concern with respect to groundwater protection. Those soils are discussed separately in this section.

Mercury

Estimated areas of soils with mercury concentrations exceeding the level of concern for groundwater protection (100 mg/kg) are shaded medium blue on Figure 5-1. Exceedance volumes are roughly estimated as follows:

- **Chlorine Plant Area**. Based on an assumed average impacted-soil thickness of 14 feet in this area, an exceedance volume of roughly 28,000 cubic yards is estimated.
- **Chemfix Area**. All of the stabilized sludge in this area (estimated at 8,000 cubic yards) is assumed to exceed the groundwater protection cleanup level for mercury.
- **Wastewater Settling Basin and Vicinity**. Based on an assumed average impacted-soil thickness of 15 feet in this area, an exceedance volume of roughly 14,000 cubic yards is estimated.
- **Stormwater Swale**. Based on an assumed average impacted-soil thickness of 1.5 feet in this area, an exceedance volume of approximately 80 cubic yards is estimated.
- **Laurel Street Pipe Rack Subarea.** Based on an assumed average impacted-soil thickness of 12 feet in this area, an exceedance volume of approximately 800 cubic yards is estimated.

Therefore, an RAU-wide total of roughly 51,000 cubic yards of Fill Unit soil is estimated to exceed the groundwater protection cleanup level for mercury. However, it is important to note that the sludge in the Chemfix area has been treated to effectively limit the amount of mercury leaching to groundwater. Excluding Chemfix area soils, an RAU-wide total of roughly 43,000 cubic yards of Fill Unit soil is estimated to have the potential to leach mercury at concentrations exceeding the groundwater cleanup level.

Naphthalene

Soil in the Million Gallon Tanks subarea with TPH and PAH concentrations that exceed the respective unrestricted cleanup levels (refer to Section 5.4.1.2) may also contain naphthalene concentrations that are high enough to be of concern with respect to groundwater protection.

5.4.1.4 Mercury-Impacted Soil Posing Short-Term Threat to Sediment Bioactive Zone

The majority of soils with mercury concentrations exceeding 100 mg/kg are not located close to a shoreline and, therefore, do not represent a short-term concern with respect to leaching to the sediment bioactive zone via groundwater transport. The one exception is in the northern portion of the former wastewater settling basin. As discussed in Section 4.7.1, the available groundwater data from within the former wastewater settling basin footprint are not adequate to demonstrate that natural attenuation of dissolved mercury is occurring. Dissolved mercury concentrations have been detected above the 26 µg/L remediation level (derived in Section 4.7.2) at shoreline wells on the downgradient edge of this area during the RI/FS data collection.

Figure 5-2 shows soil sampling locations in and around the wastewater settling basin, with soil mercury concentrations ([Hg]) color-coded in the following ranges:

- [Hg] ≤100 mg/kg (green)
- 100< [Hg] ≤300 mg/kg (yellow)
- [Hg] >300 mg/kg (orange)

Following discussions between the Port and Ecology, Ecology agreed that a soil mercury concentration of 300 mg/kg is an appropriate remediation level to be evaluated in this FS for soils close to a shoreline. Specifically, nearshore soils with mercury concentrations exceeding 300 mg/kg require removal or active treatment for groundwater protection. Figure 5-2 shows the estimated area of soils in the northern portion of the wastewater settling basin (close to the Log Pond shoreline) with concentrations that exceed this remediation level. This area of mercury-impacted soil is also depicted on Figure 5-1.

For the purposes of this FS and based on RI data, it is assumed that soils in the wastewater settling basin with mercury concentrations exceeding 300 mg/kg are present only within the 8- to 15-foot depth interval. On this basis, an exceedance volume of roughly 2,200 cubic yards is estimated for this area.

5.4.1.5 Residual Soil with Potential Visible Elemental Mercury

"Soil containing visible elemental mercury" is another remediation level evaluated in this FS. As discussed in Section 3.1.4, the Caustic Plume-Cell Building interim action removed soils in the Chlorine Plant Area with high concentrations of mercury, including soils containing visible elemental mercury. Figure 5-1 depicts the lateral extent of residual soils containing visible elemental mercury, as inferred from the two test pit investigations conducted after completion of the interim action (described in Section 4.4). For the purposes of this FS, it is assumed that the entire Fill Unit soil column (roughly 14 feet thick) may contain visible elemental mercury within the five discrete areas shown on Figure 5-1. On this basis, a total of roughly 15,000 cubic yards of Fill Unit soil is estimated to potentially contain visible elemental mercury.[18]

5.4.2 Contaminant Concentrations in Groundwater Exceeding Cleanup Levels and Potential Remediation Levels

5.4.2.1 Groundwater with Concentrations Exceeding Cleanup Levels

Cleanup level exceedances have been detected in Fill Unit groundwater for mercury, PAHs, naphthalene, and miscellaneous dissolved metals, including arsenic, chromium, copper, and nickel. In addition, exceedances of the mercury cleanup level have been detected in Lower Sand groundwater. Estimated exceedance areas are depicted on Figure 5-1. RAU-wide exceedance areas are estimated as follows:

- Fill Unit groundwater is estimated to exceed the mercury cleanup level over an area of approximately 12 acres.
- Lower Sand groundwater is estimated to exceed the mercury cleanup level over an area of approximately 0.8 acre.
- Fill Unit groundwater is estimated to exceed the cleanup levels for PAHs (cPAHs and/or naphthalene) over an area of approximately 2.4 acres.
- Fill Unit groundwater is estimated to exceed the cleanup levels for miscellaneous dissolved metals over a total area of approximately 1.0 acre.

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[18] This is the estimated volume remaining after completion of the interim action planned for 2017 (discussed in Section 3.1.5).

5.4.2.2 Groundwater with Elevated pH

Green hatching on Figure 5-1 bounds the area in the western portion of the RAU where the pH of Fill Unit groundwater is elevated. The thick green hatching, which encompasses an area of approximately 1.8 acres, bounds the Caustic Core, where groundwater pH is greater than 10. A groundwater pH of 10 represents another remediation level to be evaluated in this FS.

The thin green hatching on Figure 5-1 bounds the estimated areas where Fill Unit groundwater pH exceeds the cleanup level (pH 8.5). It encompasses a total area (including the Caustic Core) of approximately 6.8 acres. Lower Sand groundwater pH is below the pH 8.5 cleanup level.

5.4.3 Areas of Potential Concern with Respect to Soil Vapor Intrusion

As noted in Section 5.3.2.1, elemental mercury and naphthalene are volatile contaminants within the RAU. According to Ecology guidance for evaluating soil VI (Ecology, 2016a), buildings located more than 100 horizontal feet from the edge of subsurface contamination are unlikely to experience unacceptable VI impacts. This distance would apply to residual soil with potential visible elemental mercury in the Chlorine Plant Area. More recently, Ecology issued an Implementation Memorandum (Ecology, 2016b) providing guidance on how to initially assess the potential for petroleum VI that states:

> *If the degree and extent of contamination is well-defined and the dissolved-phase plume is stable or receding, then a horizontal separation distance of 30 feet would generally be appropriate for establishing a lateral exclusion zone.*

This distance is potentially applicable to naphthalene-impacted soil and groundwater in the Million Gallon Tanks subarea.

5.5 Remedial Action Objectives (RAOs)

RAOs are specific goals to be achieved by remedial alternatives that meet cleanup standards and provide adequate protection of human health and the environment under a specified land use. The RAOs for soil and groundwater consider the applicable exposure pathways for those media (Section 5.2) and provide acceptable concentrations for COCs that are protective of all potential exposure pathways.

Based on the CSM for the Chlor-Alkali RAU (Sections 4.5 through 4.10), RAOs to be addressed in this FS are as follows:

- Prevent direct contact with and erosion of mercury-contaminated soils within the Caustic Plume, Confined Nearshore Fill/Chemfix, Stormwater Swale, and Laurel Street Pipe Rack subareas;
- Prevent VI from elemental-mercury-contaminated unsaturated soils or groundwater within the Caustic Plume subarea;
- Prevent leaching to groundwater of mercury-contaminated soils and prevent discharge to the Whatcom Waterway of pH- and mercury-contaminated groundwater from the Caustic Plume subarea and Confined Nearshore Fill/Chemfix subarea (Law-1 area);

- Prevent direct contact with TPH/PAH-contaminated soils within the Caustic Plume and Million Gallon Tanks subareas and along the north side of Lignin Warehouse B;
- Prevent discharge to the Whatcom Waterway of cPAH/naphthalene-contaminated groundwater from within the Million Gallon Tanks subarea;
- Prevent VI from naphthalene-contaminated unsaturated soils or groundwater within the Million Gallon Tanks subarea; and
- Prevent discharge to the Whatcom Waterway of metals-contaminated groundwater from the Miscellaneous Dissolved Metals Exceedances areas.

Each RAO will be achieved by terminating the associated exposure pathway. This can be done through contaminant removal or treatment to meet chemical- and media-specific cleanup standards (cleanup levels at points of compliance; Section 5.3) that are based on the specific exposure pathways, and/or otherwise preventing exposure through containment with associated institutional controls.

5.6 Applicable or Relevant and Appropriate Requirements (ARARs)

Cleanup standards represent chemical-specific requirements for a cleanup action under MTCA. As described in Section 5.3, cleanup levels for the Chlor-Alkali RAU were developed in accordance with MTCA protocols, including incorporating chemical criteria from applicable state and federal laws.

In addition to cleanup standards, there may be location- and action-specific requirements for completing a cleanup action, and potentially additional off-site requirements for elemental mercury storage and recycling. It is anticipated that the Chlor-Alkali RAU cleanup action will be conducted under a Consent Decree entered into by Ecology and the Port. In performing the cleanup action under a Consent Decree, the Port would be exempt from the procedural requirements of Chapters 70.94, 70.95, 70.105, 77.55, 90.48, and 90.58 RCW, and of any laws requiring or authorizing local government permits or approvals. However, the Port must still comply with the substantive requirements of such permits or approvals (WAC 173-340-520).

The following sections identify the permits or specific federal, state, or local requirements deemed applicable, and the applicable substantive requirements of those exempt permits or approvals.

5.6.1 Resource Conservation and Recovery Act (RCRA)

RCRA, as implemented through the Washington State Dangerous Waste Regulations (Chapter 173-303 WAC), has provisions for management of dangerous waste, including areas of contamination (AOCs) and corrective action management units (CAMUs), that may be applicable for cleanups that involve excavation, treatment, and disposal. These RCRA management units are discussed here because of their potential applicability to the consolidation, treatment, and placement or disposal of mercury-impacted soil designating as dangerous waste. Other RCRA provisions may also apply to the cleanup.

5.6.1.1 Areas of Contamination

RCRA allows remediation wastes to be managed within an AOC, without generating a dangerous waste. An AOC is limited to a contiguous area of contamination. Contaminated soil can be moved, consolidated, and capped within the AOC without triggering LDRs because these activities are performed before the point of generation. Hazardous waste determination is made only after a waste has been generated.

Treatment can be performed within an AOC, with some limitations. Contaminated soil cannot be consolidated from separate AOCs for treatment, and cannot be removed from an AOC for treatment and then returned to the AOC, because these actions involve waste generation. Soil cannot be excavated within the AOC, placed within a separate unit such as a tank (or undergo *ex situ* treatment) that is within the AOC, and then re-deposited into the same AOC. Soil treated within an AOC can be capped in place without generating remediation waste.

The Ecology Project manager approves an AOC at Ecology oversite cleanups (Agreed Order, Enforcement Order, and Consent Decree only).

5.6.2 NPDES Waste Discharge Permit

If construction-generated dewatering water or stormwater from the cleanup action is treated for discharge to waters of the State of Washington, such discharge would need to comply with requirements of a NPDES Construction Stormwater General permit.

5.6.3 State Environmental Policy Act (SEPA)

Compliance with SEPA, Chapter 43.21C RCW, would be achieved by conducting SEPA review in accordance with applicable regulatory requirements, including WAC 197-11-268, and Ecology guidance as presented in Ecology Policy 130A (Ecology, 2004). SEPA review will be conducted concurrent with public review of the cleanup action. The Port would act as the SEPA lead agency and would coordinate SEPA review. It is planned that public review for the Draft CAP and Consent Decree for the Chlor-Alkali RAU cleanup action would be conducted by Ecology concurrently with public review for the SEPA documentation.

5.6.4 Mercury Export Ban Act (MEBA)

The Mercury Export Ban Act (MEBA) would be applicable to remediation technologies that generate elemental mercury. MEBA (Public Law No. 110-414), which became law on October 14, 2008, is intended to reduce the availability of elemental mercury for domestic and international markets. MEBA prohibits the export of mercury from the United States after January 1, 2013, and requires the Department of Energy (DOE) to designate and operate a facility (or facilities) for the purpose of long-term management and storage of elemental mercury generated in the United States. Although MEBA does not preclude domestic recycling/reuse, it greatly reduces the market demand for mercury by eliminating international export.

MEBA requires that DOE’s long-term storage facility be operational by January 1, 2013. In the final EIS for the Long-Term Management and Storage of Elemental Mercury (DOE/EIS-0423, January 2011), the U.S. Department of Energy DOE identified seven potential locations, including Hanford, Washington, and stated that its preferred alternative is the Waste Control Specialists, LLC, site near Andrews, Texas. Subsequently, the DOE added three additional candidate sites near the Waste Isolation Pilot Plant (WIPP) at Carlsbad, New Mexico (Federal Register, Vol. 78, No. 76, pp. 23548-23550, April 19, 2013), and held public meetings in May 2013 as part of the Draft Mercury Storage EIS.

The DOE provided interim guidance (DOE, 2009) for the packing, transportation, receipt, management, and long-term storage of elemental mercury. Elemental mercury is required to be 99.5 percent pure for long-term storage, and mercury is categorized as a solid waste that is subject to RCRA and managed as hazardous waste. The generator is responsible for the cost of any required analyses, the cost for repackaging to meet the acceptance criteria, the preparation of the waste profile, the shipment to the DOE mercury storage facility, and the fee imposed for long-term storage and management. MEBA required the DOE to provide cost data for long-term storage by October 1, 2012.

5.6.5 Permit Exemptions and Applicable Substantive Requirements

The applicable substantive requirements of these permits or approvals are identified below. Substantive requirements may be further identified during remedial design, and their approval shall reflect Ecology's determination on what substantive requirements apply.

5.6.5.1 Shoreline Management Act; City of Bellingham Shoreline Permit

The Shoreline Management Act is implemented through the City's Shoreline Master Program (SMP). To comply with the SMP, the cleanup action must have no unreasonable adverse effects on the environment or other uses, no interference with public use of public shorelines, compatibility with surroundings, and no contradiction of purpose and intent of SMP designation. It is expected that the Chlor-Alkali RAU cleanup action would meet the conditions of the SMP's Waterfront District Shoreline Mixed Use designation and would be consistent with the SMP.

5.6.5.2 Major Grading Permit

Pursuant to the City Grading Ordinance (BMC 16.70), a Major Grading Permit is required from the City for grading projects that involve more than 500 cubic yards of grading. The City grading ordinance identifies a number of standards and requirements for obtaining a grading permit. The City standards and requirements will be integrated into the construction plans and specifications for the cleanup action to ensure that the cleanup action complies with the substantive requirements of the City Grading Ordinance. Those substantive requirements include: staking and flagging property corners and lines when near adjacent property, location and protection of potential underground hazards, proper vehicle access point to prevent transport of soil off-site, erosion control, work hours and methods compatible with weather conditions and surrounding property uses, prevention of damage or nuisance, maintaining a safe and stable work site, compliance with noise ordinances and zoning provisions, development of a traffic plan when using City streets, and written permission for grading from the legal property owner.

5.6.5.3 Critical Areas

City critical area substantive requirements will apply to the Chlor-Alkali RAU cleanup action. The cleanup action will occur partially on land designated as geologic hazard areas by BMC 16.55 Critical Areas: seismic hazard throughout the lateral extent of the Fill Unit, potential coal mine hazard in the southernmost portion of the RAU, and wave erosion hazard along the RAU's shoreline. The substantive requirements include an assessment or characterization of the hazard areas by a licensed professional, which will be conducted in consultation with the City.

5.6.5.4 Stormwater Requirements

Pursuant to the City Stormwater Management (BMC 15.42), the cleanup action would need to meet the substantive requirements of a City Stormwater Permit. The substantive requirements include preparation of a stormwater site plan, preparation of a construction stormwater pollution prevention plan, source control of pollution, preservation of natural drainage systems and outfalls, on-site stormwater management, runoff treatment, flow control, and system operations and maintenance.

5.6.5.5 Washington Clean Air Act

Cleanup actions would be regulated under the Washington Clean Air Act (Chapter 70.94 RCW) as implemented through Chapter 173-400 WAC and Chapter 173-460 WAC. The Regulation of the Northwest Clean Air Agency (NWCAA) would also be applicable. The substantive requirements would include not creating conditions that would significantly degrade the ambient air quality or cause exceedance of applicable air quality standards.

5.6.5.6 Other Requirements

Other local, state, and federal laws and requirements that potentially would apply to the cleanup action include the following:

- Solid Waste Disposal Act (40 CFR 257 and 258), as implemented through the state Solid Waste Handling Standards (Chapter 173-350 WAC) regulating any handling, treatment, or off-site disposal of non-hazardous solid waste;
- OSHA/WISHA Regulations (29 CFR 1910.120; Chapter 296-62 WAC) governing worker safety during cleanup action execution. Compliance would be achieved through preparation and implementation of site-specific health and safety plan(s) with appropriate controls, worker training and certifications, and occupational monitoring;
- Washington State Water Well Construction Regulations (Chapter 173-160 WAC) regulating groundwater well installation and decommissioning as part of the cleanup action; and
- USDOT/WSDOT Regulations regarding transport of hazardous materials (49 CFR Parts 171-180) if regulated material is transported off-site as part of the cleanup action.

6 Identification and Screening of Remedial Technologies

This section identifies and screens remedial technologies that may be effective in satisfying the RAOs for the Chlor-Alkali RAU defined in Section 5.5. The retained technologies are then used to assemble remedial alternatives for the RAU in Section 7.

6.1 General Response Actions

General Response Actions (GRAs) represent categories of remedial technologies that might be undertaken to satisfy the RAOs for a site and may involve, depending on site-specific circumstances, the complete elimination or destruction of hazardous substances at the site, the reduction of concentrations of hazardous substances via engineering or institutional controls, or some combination of the above. GRAs for the Site media are as follows:

- **Institutional Controls.** Institutional controls are measures undertaken to limit or prohibit activities that may interfere with a cleanup action or result in exposure to hazardous substances.
- **Monitored Natural Attenuation (MNA) of Groundwater.** Natural attenuation is the reduction of contaminant concentrations over time through natural processes, such as sedimentation, sorption, dispersion, and/or biodegradation. Monitoring documents that attenuation is occurring at a satisfactory rate.
- ***In-Situ* Containment.** *In-situ* containment involves confining hazardous substances in place through placement of physical barriers or hydraulic controls. Containment technologies can be designed to prevent contact with and/or migration of hazardous substances.
- ***In-Situ* Treatment.** *In-situ* treatment technologies can potentially reduce the concentration, mobility, and/or toxicity of COCs.
- **Source Soil Excavation.** Contaminated soils can be excavated and treated *ex situ*, consolidated on-site, and/or disposed of either on-site or at an off-site, permitted disposal facility. *Ex-situ* treatment technologies destroy or immobilize contaminants in excavated soils.
- **Groundwater Extraction.** Contaminated groundwater can be extracted (e.g., via extraction wells) and treated *ex situ* and/or discharged under permit to a sanitary sewer, to surface water, or reinjected to groundwater.

Each GRA listed above is discussed in the following sections.

6.2 Institutional Controls

Institutional controls are mechanisms for ensuring the long-term performance of cleanup actions. While not considered a stand-alone remedial technology, institutional controls would be an integral component of remedies where contaminants exceeding cleanup levels remain at the Site. Institutional controls involve administrative/legal tools to provide notification regarding the presence of contaminated materials, regulate the disturbance/management of these materials and the cleanup action components including prohibiting creation of preferential pathways for contaminant migration, and provide for long-term care of cleanup actions including long-term monitoring. Under MTCA, the legal instruments for applying institutional controls are termed environmental covenants, and are equivalent to restrictive covenants for a specific property or portion of a property.

The specifics of the institutional controls required as a component of the selected cleanup action for the Chlor-Alkali RAU will be developed by Ecology and the Port, in consultation with stakeholders including the City, during preparation of Ecology’s CAP and Consent Decree for the cleanup action.

The required institutional controls and their implementation will be legally defined in an environmental covenant specific to the Chlor-Alkali RAU cleanup action. The environmental covenant will define use limitations and/or specific worker protection standards applicable to specific areas of the RAU. Documents prepared in association with the environmental covenant (e.g., Cap Inspection and Maintenance Plan, Contaminated Materials Management Plan) will identify responsibilities for institutional controls implementation (including those of the Port, City, and future land owner), provisions for inspection and maintenance of engineering controls, and protocols for notification regarding the presence of the institutional controls (e.g., including notification triggered by utilities on-call requests).

The cleanup-required environmental covenant will be recorded by Whatcom County on property deeds for land owned within the RAU by the Port, City, or private land owners. To assist in information transfer, the environmental covenant and associated technical implementation documents will also be filed with Port property files and with the City building department. These documents will be reviewed as part of property sales, leases, or proposed development projects within the RAU. The cleanup-required institutional controls for the RAU will remain in place indefinitely unless and until removal is approved by Ecology.

6.3 Monitored Natural Attenuation of Groundwater

Groundwater contamination is of concern with respect to discharge to surface water and marine sediment, and potentially with respect to indoor air via contaminant volatilization and soil VI. Groundwater at the Site is a non-potable water source, and the groundwater ingestion exposure pathway is not complete.

Contaminants can naturally attenuate in groundwater via dispersion, speciation, sorption, volatilization, and bioattenuation. Longitudinal and transverse dispersion occur along the groundwater discharge path to surface water.

Mercury speciation impacts its phase, solubility, and volatility, which impacts its persistence and mobility in the environment. Mercury speciation is influenced by the pH and oxidation-reduction potential of groundwater, and the relative concentrations of ligands. Elemental mercury has been encountered in borings and excavations in the caustic plume source area and detected in soil gas samples. Elemental mercury is dense and insoluble, but can attenuate by volatilization and by transformation to mercury-ligand complexes. Elemental mercury speciation is generally favorable with high pH and low reducing conditions. Mercury sulfide precipitation becomes more favorable in anaerobic groundwater with less caustic pH and increased concentrations of sulfide and sulfate. Mercury sulfide has very low solubility (about 10^{-18} µg/L) and precipitates from groundwater. Mercury preferentially forms more mobile species as groundwater becomes more aerobic. Methyl mercury speciation is more toxic and typically more prevalent near surface waters. Soluble mercury species have varying adsorptive properties, and speciation and sorption are also influenced by tidal mixing in groundwater. Because mercury speciation reactions are reversible, changing groundwater conditions can stabilize and mobilize mercury.

The organic COCs, including cPAHs and naphthalene, are variably influenced by sorption and bioattenuation. The sorption of organic compounds is influenced by the chemical-specific octanol-to-water partitioning coefficient (Koc) and the fraction organic carbon (foc) in soil. For example, cPAHs are hydrophobic and tightly bound to soil, whereas naphthalene is more mobile in groundwater. In contrast, naphthalene is generally amenable to natural bioattenuation, whereas cPAH compounds have limited potential for natural bioattenuation. Hydrocarbons are preferentially bioattenuated under aerobic conditions. Although the groundwater at the Site is generally under strong reducing conditions, groundwater becomes more aerobic via tidal mixing near the waterfront.

MNA of contamination in groundwater is retained as a component for development of remedial alternatives.

6.4 *In-Situ* Containment Technologies

The following *in-situ* containment technologies are discussed in this section:

- Soil capping; and
- Physical containment of groundwater.

A recent review of former chlor-alkali plant sites in North America indicates that, although removal of mercury-impacted soils is commonly conducted, the main remediation remedy most often involves on-site containment, including capping and/or consolidation and on-site disposal (Golder, 2012).

6.4.1 Soil Capping

Capping in the form of clean soil cover and hard surfaces can be applied as surface barriers to prevent human and terrestrial ecological exposure to, and erosion of, contaminated soil. Capping with impervious materials can also be used to restrict surface water infiltration and contaminant leaching from the vadose zone to groundwater. Hard surfaces can include existing and future redevelopment pavement, building foundations, etc. A large portion of the Chlor-Alkali RAU is currently capped with pavement and building foundations which, subject to long-term inspection and maintenance, may provide sufficient isolation of underlying contaminated soil to achieve environmental protection. When redevelopment modifies these conditions, protectiveness would need to be reassessed.

This technology category also includes physical stabilization of the nearshore upland as needed to prevent erosion of contaminated soil into the Whatcom Waterway. The Whatcom Waterway cleanup is proceeding on a parallel track, and will likely include shoreline capping and stabilization. Upland capping within the Chlor-Alkali RAU would need to be integrated with that work to provide complete coverage and isolation of nearshore contaminated soil.

Capping to prevent soil direct contact and erosion is retained as a technology for development of remedial alternatives.

6.4.2 Physical Containment of Groundwater

Physical containment involves installing a structural barrier, such as a soil/bentonite slurry wall, to control the movement of groundwater. The barrier may be used to prevent off-site migration of contaminated groundwater or improve the performance of other technologies, including groundwater extraction and PRBs. Barriers installed in the Upper Fill Unit could be keyed into the underlying Tidal Flat Aquitard. Except when coupled with groundwater extraction, barriers generally retard and inhibit, but do not prevent, the flow of groundwater.

Physical containment of groundwater is retained as a technology for development of remedial alternatives.

6.5 *In-Situ* Treatment Technologies

The following *in-situ* treatment technologies are discussed in this section:

For mercury contamination:

- Chemically enhanced extraction/treatment;
- Solidification/stabilization;
- Electrochemical treatment;
- Thermal desorption;
- Vitrification;
- pH buffering/neutralization; and
- Mercury precipitation/immobilization.

For petroleum hydrocarbon contamination:

- Chemical oxidation; and
- Enhanced aerobic bioremediation.

Information on mercury speciation in Site soils is important for evaluating potential *in-situ* treatment technologies. In general, a high proportion of bioavailable mercury would favor the use of electrochemical treatment and phytoremediation. For soil with high elemental mercury content, solidification/stabilization and immobilization are potentially suitable technologies. For soil with high non-available mercury content, thermal desorption may be suitable (Wang et al., 2012).

6.5.1 Chemically Enhanced Extraction/Treatment

For the purpose of this FS evaluation, chemically enhanced extraction/treatment refers to the *in-situ* acidification/oxidation of groundwater with the intent of solubilizing and extracting mercury from the aquifer. Groundwater in mercury source areas would be oxidized and acidified to promote transformation of elemental mercury and mercury sulfide trapped in the soil to mercuric chloride dissolved in groundwater. This is how mercury was recovered from wastewater sludges in the Remerc process used at the former Chlorine Plant.

Chemically enhanced extraction/treatment could be applied in small batches by controlled injection, *in-situ* reaction, and extraction. Alternatively, it could be applied by passively treating a larger area and hydraulically capturing and extracting water from the treatment area. Groundwater pH would ideally be reduced to less than 6 SU to maximize the transformation of elemental mercury, and the ORP would ideally be increased to greater than 500 mV to maximize the oxidation of mercury sulfide. Acidification/oxidation could be achieved by injecting hydrochloric acid and hypochlorous acid to the treatment area. Hypochlorous acid is a strong oxidant that is unstable and must be produced on-site. Caution must be exercised because these two acids can react to generate chlorine gas. However, since this reaction is reversible, an alternate approach may be to inject chlorine gas (e.g., from cylinders) into groundwater using passive gas diffusers in treatment wells, which would react to form hydrochloric acid and hypochlorous acid.

Groundwater laden with dissolved mercuric chloride would be extracted, pretreated with sodium bisulfite to decrease the dissolved oxygen content, and then treated with zero-valent iron (ZVI) to recover mercury. Elemental mercury would coalescence at the bottom of the ZVI vessel, and the aqueous effluent from the vessel would contain reaction products that would require further treatment. The elemental mercury could be stabilized by sulfur-cement mixing and disposed of off-site along with depleted ZVI.

Chemically enhanced extraction/treatment has the potential to permanently remove mercury from the subsurface. However, *in-situ* application of this technology has not been demonstrated at full-scale for mercury remediation. It would require addition of a strong acid, a strong oxidizer, and/or a highly toxic gas to the subsurface, and mercury would be converted *in situ* to a more mobile form, which may be difficult to fully capture. For these reasons, chemically enhanced extraction/treatment is not retained as a technology for development of remedial alternatives.

6.5.2 Solidification/Stabilization

Solidification/stabilization involves physically binding or enclosing contaminants within a stabilized mass (solidification) and/or inducing chemical reactions between the stabilizing agent and the contaminants to reduce their mobility (stabilization). It does not reduce the total mercury content of the soil, but the hazard potential of the soil is reduced by converting the contaminants into less soluble, mobile, or toxic forms. The soil is mixed with binders such as Portland cement to create a slurry, paste, or other semi-liquid state, which is allowed time to cure into a solid form. The solidification/stabilization process may also include addition of pH adjustment agents, phosphates, or sulfur reagents to reduce the setting or curing time, increase the compressive strength, or reduce the leachability of contaminants. The soil volume would increase as a result of amendment addition and soil fluffing.

Ex-situ solidification/stabilization was successfully implemented to treat Chlorine Plant Area soils containing visible elemental mercury during the Caustic Plume-Cell Building interim action; as described in Section 3.1.3, Portland cement and elemental sulfur were mixed with excavated soils on-site prior to off-site disposal in a hazardous waste landfill.

In-situ solidification/stabilization (ISS) could be performed by several different means, depending on the delineated extent of contamination and other design factors such as area-specific physical conditions. For example, large-diameter augers could potentially be used to introduce and mix amendments into the soil. However, effective *in-situ* mixing would be limited by the presence of debris and/or other large objects in the soil. This would be a particular concern for impacted soils within the Cell Building footprint, with its high density of foundation piles. Augering with the piles left in place would leave a large portion of the soils untreated, along with the mercury-impacted piles themselves. On the other hand, removing the piles without compromising the underlying aquitard (which is penetrated by the piles) would likely require considerable soil excavation, in which case *ex-situ* soil treatment may be more cost-effective.

ISS is typically considered an innovative technology for remediation of soils containing visible elemental mercury. However, full-scale implementation of this technology was performed in summer/fall 2014 at the Mercury Refining Superfund Site in Albany County, New York. Roughly 13,000 cubic yards of soil containing beads of elemental mercury were treated *in situ* using an auger system to introduce and mix solidification agents (Portland cement and ground granulated blast furnace slag [GGBFS]) and stabilization agents (elemental sulfur and trihydrate sodium sulfide) into the soil to depths greater than 60 feet bgs. Performance criteria for the treated soil included achieving a minimum unconfined compressive strength (UCS) and a maximum hydraulic conductivity. Treatability studies were conducted during remedial design to evaluate the performance of various amendments, and a pilot study was completed at the start of full-scale construction (using the actual auger rig) to finalize the amendment mix and confirm *in-situ* treatment performance. Design details are provided in the Final Remedial Design Report (Brown and Caldwell, 2013), and remedial construction is documented in the Remedial Action Report (Brown and Caldwell, 2015).

ISS is retained as a technology for development of remedial alternatives.

6.5.3 Electrochemical Treatment

Electrochemical treatment is also referred to as electrochemical remediation or electro-kinetic remediation. In this technology, a low-intensity direct current is applied to the subsurface via electrodes placed in the soil (e.g., driven rods or sheet piles). Metals such as mercury are mobilized and travel to the electrodes, where they precipitate. The treatment process occurs in three stages (Sobolev et al., 1996). First, the metal must be transformed into a soluble form, with or without injection of solutions. Second, the electric current mobilizes the solubilized metal towards an electrode. Finally, the precipitated metal is recovered when the electrodes are removed. This technology is most effective in fine-grained soils, in which migration of charged and uncharged species may occur by electro-osmosis (Hempel and Thöming, 1999).

The material of the electrodes determines the contaminant subject to treatment. For mercury removal, the cathodes are made of iron or aluminum, and the anodes are made of carbon materials, titanium, or steel (Doering & Doering, 2006). Mercury can precipitate at both the anode and cathode as elemental mercury or as an insoluble compound.

Significant recovery of mercury was achieved in a laboratory bench-scale demonstration of this technology at Oak Ridge National Laboratory and in a field-scale pilot demonstration in Scotland. However, a field-scale pilot demonstration in Log Pond sediments did not result in a significant reduction in sediment mercury concentrations. Effectiveness appeared to have been hampered by corrosion of the electrodes. In upland areas, corrosion is generally expected to be less of an issue. However, the elevated pH and salinity found in mercury-impacted areas of the Chlor-Alkali RAU can accelerate corrosion.

The difficulty of electrochemical treatment of mercury-contaminated soil is the low solubility of mercury in most natural soils (Cox et al., 1996). It is not an efficient treatment technology for soil with a high proportion or elemental mercury (Thöming et al., 2000). For these reasons, as well as the poor performance of the Log Pond pilot demonstration, electrochemical treatment is not retained as a technology for development of remedial alternatives.

6.5.4 Thermal Desorption

In-situ thermal desorption (ISTD) involves the application of energy to the subsurface to heat impacted soils, promoting desorption and volatilization of mercury. Vapor extraction and control measures, including soil vapor extraction wells and a vapor cap at ground surface, can be used to capture mercury vapor for *ex-situ* treatment. The two most commonly applied ISTD technologies are electrical resistance heating (ERH) and thermal conductive heating (TCH). ERH would likely not be applicable due to insufficient heating capability; it relies on the electrical conductivity of the soil, which becomes negligible once the soil pore water has boiled off (at 100˚C). A minimum treatment temperature in the range of 300˚C to 350˚C would likely be required for desorption and volatilization of elemental and inorganic mercury (Golder, 2012). TCH has been used to treat SVOCs with relatively high boiling points, and would likely be applicable to treatment of mercury as well.

In its 2007 review of treatment technologies for mercury in soil, waste, and water, the U.S. Environmental Protection Agency (EPA) identified thermal desorption as an *ex-situ* treatment technology (EPA, 2007), and we are not aware that ISTD has been demonstrated commercially or at full-scale for mercury remediation. An *in-situ* application would have a very high potential for lateral and particularly vertical (downward) dispersal of elemental mercury at the outer edge of the heated zone (Golder, 2012). For these reasons, ISTD is not retained as a technology for development of remedial alternatives.

6.5.5 Vitrification

Vitrification is a high-temperature treatment technology designed to immobilize contaminants by incorporating them into a vitrified end product (“melt”) which is chemically durable and leach resistant. Due to its very high energy requirement, vitrification is a relatively high-cost technology that is mainly used at military installations to remediate soils contaminated with heavy metals mixed with radioactive elements (Wang et al., 2012). Metals retained in the melt must be dissolved to minimize formation of crystalline phases that can decrease the leach resistance of the vitrified product; high concentrations of mercury in soil may be difficult to treat because of mercury’s high volatility and low solubility in glass (EPA, 2007).

In-situ vitrification is not retained as a technology for development of remedial alternatives.

6.5.6 Buffering/Neutralization of pH and Precipitation/Immobilization of Mercury

For the purpose of this FS evaluation, pH buffering/neutralization and mercury precipitation/immobilization are inter-related technologies. Both refer to the addition of chemical amendments to the aquifer for the primary purpose of altering the speciation of mercury and enhancing its precipitation from groundwater. In high-pH areas, the amendments would also restore groundwater pH to more-neutral conditions (since those conditions are conducive to mercury precipitation/immobilization), thereby addressing both elevated pH and elevated mercury concentrations in groundwater. In more-neutral pH areas, pH buffers may need to be included in the amendment mix to moderate acidic conditions that could result from chemical reactions with sulfur-based amendments in the mix (e.g., ferrous sulfate or pyrite). Mercury sulfide precipitation is favored under anaerobic conditions, with increased favorability as the pH decreases.

Multiple *in-situ* implementation strategies are available for introducing chemical amendments to the aquifer, including PRB, trench backfill, area-wide application, groundwater recirculation, and liquid or gas direct injection. The optimum configuration depends on site-specific conditions, remedial objectives, and other factors.

The appropriate amendment mix would be determined during remedial design, which would likely include bench-scale and/or pilot testing. Potential amendments include, but are not limited to, the following:

- **Siderite.** Siderite (ferrous carbonate) amendment would lower and buffer the pH, where elemental mercury speciation is less favorable. The dissolution of siderite ($FeCO_{3(s)}$) enables the precipitation of goethite ($FeO(OH)_{(s)}$), which stoichiometrically removes three hydroxide ions per ferrous iron ion. Although the precipitation of goethite is an oxidation reaction, goethite is thermodynamically favored over siderite under the high-pH and low-ORP conditions encountered in the Caustic Core. Siderite provides a bicarbonate pH buffer between 4.8 and 6.3 SU, and the relatively fast weathering rates of carbonate provide quick buffering capacity (Wolkersdorfer, 2008). By reducing the pH, siderite would stimulate the precipitation of mercury as mercury sulfide. Mercury sulfide precipitation may be limited by the presence of other metals in the soil, which would also form sulfides at lower pH,
- **Ferrous Sulfate or Pyrite.** Ferrous sulfate or pyrite (ferrous sulfide) amendment would lower the groundwater pH without buffering and increase the concentrations of sulfate or sulfide to favor mercury sulfide speciation and precipitation. Ferrous sulfate and pyrite would be recommended for caustic areas of the plume where both pH neutralization and *in-situ* stabilization of mercury are the remedial goals. Ferrous sulfate and pyrite lower the pH of groundwater by oxidizing ferrous iron. Mercury immobilization is achieved by both mercury sulfide precipitation and by the adsorption of mercury in hydrous ferric iron oxide precipitates, which coat the soil particles. The latter mechanism is likely more reversible than the former. Pyrite amendment may be more effective than ferrous sulfate amendment because sulfate reduction is not necessary. Also, sulfide oxidation would further reduce the oxidation conditions, making mercury sulfide speciation more favorable. Ferrous sulfate

or pyrite amended soil could also be amended with siderite to provide a carbonate buffer to prevent acid leaching.

- **Sulfuric Acid.** Sulfuric acid would lower the pH of the caustic plume while also providing sulfate to stimulate mercury sulfide precipitation and immobilization. Sulfuric acid could be applied *in situ* by direct injection or gravity drainage. Direct injection would be performed at low injection pressure and flow rates, and the potential for permeability losses and exothermic reactions would need to be addressed. Gravity drainage could be applied using a network of shallow leachate piping. In either case, treatment involving the introduction of a strong acid to the subsurface would require careful design and implementation, with extensive controls and safeguards to ensure worker safety and protection of the environment.

- **Activated Carbon.** Activated carbon, which would not significantly reduce groundwater pH, could be used in areas where elevated pH is not a concern, or where application of the chemical amendments discussed above could result in unacceptably acidic groundwater. For example, a PRB containing activated carbon could potentially be installed at the western edge of the caustic plume to remove low concentrations of mercury from near-neutral-pH groundwater prior to discharge to surface water. Adsorption of dissolved mercury may be due to multiple mechanisms. Surface complexes may form between the mercury ion and the acidic surface functional groups on the activated carbon. Alternately, dissolved mercury may complex with dissolved organics which are adsorbed. Impregnating the carbon with sulfur compounds can greatly increase treatment effectiveness (Gomez, et.al., 1998). Spent carbon can be regenerated or disposed of at an appropriate facility.

- **Zero-Valent Iron**. ZVI has been demonstrated to be effective in removing a variety of dissolved metal contaminants from water. ZVI removal of mercury, which was successfully demonstrated in a field column study (Weisener et. al., 2005), occurs via reductive precipitation or co-precipitation reactions on the grain surfaces of the iron. The reaction kinetics are generally rapid over a wide range of water conditions. Similar to activated carbon, ZVI treatment would not significantly reduce groundwater pH.

- **Carbon Dioxide.** Injection of carbon dioxide (CO_2) gas into the caustic plume would lower pH and reduce mercury concentrations in groundwater, increase natural sulfate reduction, and enhance mercury sulfide precipitation and immobilization. Gaseous CO_2 would form carbonic acid and increase bicarbonate buffering in groundwater. Injection would need to be performed using high purity CO_2 to stimulate favorable anaerobic, neutral-pH conditions for mercury sulfide precipitation. The radius of influence for CO_2 injection would be limited by the shallow depth of the Tidal Flat Aquitard and the relatively low hydraulic conductivity of the Fill Unit. Injection could potentially be accomplished using CO_2 gas cylinders and passive gas diffusers with closely spaced injection points. By neutralizing and buffering groundwater without oxidation, CO_2 sparging is relatively safe compared to other acid neutralization options. However, it is also a less aggressive form of treatment, and may not be capable of achieving the groundwater cleanup level for mercury.

In-situ pH buffering/neutralization and mercury precipitation/immobilization are retained as technologies for development of remedial alternatives.

6.5.7 Chemical Oxidation

In-situ chemical oxidation (ISCO) is commonly applied to remediate petroleum hydrocarbon contamination in both soil and groundwater. (It is generally not effective for remediation of metals such as mercury.) Chemical oxidant in solution is injected into the subsurface to react with the organic contaminants. Oxidants most often used include hydrogen peroxide (with or without ferrous iron catalyst), potassium and sodium permanganate, sodium persulfate, and ozone. Among these, permanganate may be the most effective in oxidizing naphthalene and the higher-molecular-weight PAHs (IT&RC, 2005).

Application of ISCO generally requires careful site characterization and pilot testing. Effective delivery of the oxidant to the targeted treatment zone is critical; failure to account for subsurface heterogeneities or preferential flow paths can cause uneven distribution of the oxidant, resulting in pockets of untreated contamination. Since the oxidant also reacts with natural organic matter and other reductants in the soil and groundwater, the injection volume will typically be much greater than the stoichiometric requirement for contaminant oxidation. Multiple injections are often required to achieve remediation goals.

ISCO is retained as a technology for treatment of petroleum hydrocarbons, including naphthalene and cPAHs, in soil and groundwater.

6.5.8 Enhanced Aerobic Bioremediation

Bioremediation relies on microorganisms, typically those that occur naturally in the subsurface, to biodegrade contaminants, and is commonly applied to remediate petroleum hydrocarbon contamination in soil and groundwater. (It is not applicable to metals such as mercury.) Naphthalene is readily biodegraded under aerobic conditions. PAHs with higher molecular weights, including cPAHs, may also biodegrade under aerobic conditions, although their biodegradation rates are significantly lower. Microorganisms catalyze reactions between electron donors and electron acceptors in groundwater, where the petroleum hydrocarbons are the electron donors and oxygen is the electron acceptor.

The growth and activity of naturally occurring aerobic microorganisms in the subsurface can be enhanced using oxygen-releasing compounds, ambient air, pure oxygen, hydrogen peroxide, or ozone. Oxygen-releasing compounds include formulations of calcium and magnesium peroxide and calcium oxy-hydroxide, which dissolve and release oxygen at a controlled rate over prolonged periods. These compounds can be injected as a slurry solution, placed as a solid into excavations, or placed in wells as a solid in a retrievable sock. Atmospheric air can be injected into groundwater to increase the concentration of dissolved oxygen. Alternatively, pure oxygen can be injected using passive infusion technologies. Use of pure oxygen can super-saturated groundwater with 40 to 50 parts per million (ppm) dissolved oxygen, as opposed to 8 to 10 ppm dissolved oxygen using atmospheric air. High concentrations of dissolved oxygen can also be achieved by injecting ozone, which is typically produced on-site via an ozone generator.

Enhanced aerobic bioremediation is retained as a technology for treatment of petroleum hydrocarbons, including naphthalene and PAHs, in soil and groundwater.

6.6 Technologies Involving Source Soil Excavation

The following *ex-situ* technologies addressing soil contamination are discussed in this section:

- On-site soil consolidation;
- Off-site soil disposal in landfill;
- Physical particle size separation methods;
- On-site (*ex-situ*) solidification/stabilization;
- On-site (*ex-situ*) thermal desorption; and
- Acid extraction.

6.6.1 On-Site Soil Consolidation

Excavated contaminated soils may be placed on site with other contaminated soils. Consolidating contaminated soils in this manner can reduce the footprint for subsequent capping or application of *in situ* treatment technologies. When soil contamination extends onto an adjacent property (e.g., mercury-impacted soils on BNSF property in the Stormwater Swale), this technology can be used by the party conducting the cleanup to consolidate contamination onto its own property.

On-site soil consolidation is retained as a technology for development of remedial alternatives.

6.6.2 Off-Site Soil Disposal in Landfill

Excavated contaminated soils may be transported to an off-site, permitted disposal facility. Excavation and off-site disposal of impacted soil would address all exposure pathways by removing contaminant sources from the RAU.

Mercury-contaminated soils may need to be disposed of in a hazardous waste (Subtitle C) landfill, and may require on-site treatment prior to transport/disposal. Soil typically becomes a “solid waste” when it is excavated from the ground. Mercury-contaminated solid waste is potentially subject to Washington State Dangerous Waste Regulations and alternative LDRs for contaminated soil. Excavated soil becomes D009 characteristic waste when the concentration of mercury exceeds 0.2 mg/L in TCLP leachate. D009 contaminated soil must be treated to remove 90% of the mercury when a removal technology is implemented, or 90% of the mercury in TCLP leachate when a stabilization technology is implemented. The treatment requirement is capped at 10 times the UTS for mercury, which corresponds to 0.25 mg/L in the TCLP leachate. Additionally, excavated soil is State-only dangerous waste (WT02) when the concentration of mercury is greater than 1,000 mg/kg.

Excavated soil can be treated with Portland cement and sulfur to reduce the concentrations of mercury in TCLP leachate. Anchor QEA and ALS Environmental (formerly Columbia Analytical Services) conducted bench-scale tests to evaluate the capability of Portland cement, Portland cement and ferrous sulfate, and Portland cement and sulfur to stabilize mercury in representative Site soil samples with approximately 29,000 mg/kg of mercury (Anchor, 2012). The Portland cement-sulfur mixture provided the best stabilization results.

Addition of sulfur at a 1:1 stoichiometric ratio with mercury was ineffective, but the addition of sulfur with a 5:1 stoichiometric ratio with mercury reduced the concentration of mercury in TCLP leachate to below the detection limits. Anchor recommended that the excavated soil from the CFH and the MRU be stabilized with Portland cement and sulfur (with a 9:1 ratio of Portland cement to sulfur) at a 1:2 mix ratio of amendment to soil.

The interim action included the excavation of soil from the CFH and the MRU. Excavated soil was staged in the Mercury Cell Building and treated in batches using a large-scale industrial mixing plant. The treatment process included the mixing of sulfur into the soil (5 grams of granular sulfur per 100 grams of soil) and subsequently mixing in cement (45 grams of cement and 15 grams of water per original 100 grams of soil). The final mixture was discharged into one-cubic-yard Super Sacks and sampled to characterize the treated waste in accordance with the Ecology-approved Cleanup Compliance Monitoring Plan (Aspect, 2012c). Mercury concentrations were reduced to below the UTS (0.25 µg/L TCLP mercury) in all of treated waste samples, which allowed the waste to be transported to Waste Management's Chemical Waste Management Subtitle C landfill in Arlington, Oregon for disposal.

Off-site disposal in a landfill is also an option for RAU soils containing other contaminants. Based on the types and concentrations of other soil contaminants encountered during the RI, it is likely that non-mercury-impacted soils would require no on-site treatment (except possibly for pH adjustment or control of free liquids), and could be disposed of in a non-hazardous waste (Subtitle D) landfill.

Off-site soil disposal in a landfill is retained as a technology for development of remedial alternatives.

6.6.3 Physical Particle Size Separation Methods

Physical particle size separation methods have the potential to reduce disposal costs, typically by reducing the amount of soil requiring disposal as hazardous waste. Depending on site-specific soil cleanup requirements and technology effectiveness, they may also be used to reduce the amount of soil requiring off-site disposal. Physical particle size separation techniques are effective because most contaminants, including mercury, tend to bind to the finer soil particles (clay and silt); relatively clean larger particles are separated from the finer particles, thus concentrating the waste stream. Thus, these methods tend to be most effective for soils dominated by coarse materials (i.e., sands and gravels) with less than 20% fines (Hinton and Veiga, 2001).

Soil washing involves processing excavated soils with large volumes of water. Soils containing visible elemental mercury are often amenable to this technology because elemental mercury droplets behave as a separate liquid phase in the soil washing process and are concentrated into the fines fraction (Hinton and Veiga, 2001). Examples of full-scale implementation of soil washing at former chlor-alkali plant sites include the following:

- Approximately 20,000 cubic meters of soil were treated to remove elemental mercury at a former chlor-alkali plant site in the Netherlands in 2011;

- Over 7 tons of elemental mercury was recovered from soils treated at a former chlor-alkali plant site in New York (LCP Bridge Street, a sub-site of the Onondaga Lake Superfund Site; 2004 -2008 time frame); and
- Approximately 2,900 metric tons of soil were treated to remove elemental mercury at a former chlor-alkali plant at the Botany Industrial Park site in Australia. After recovering approximately 1,200 kg of mercury over 4 months of operation (April to August 2011), the plant was shut down because it was not able to sustain adequate reliable operation.

Disadvantages of soil washing include high water use, water treatment challenges (e.g., mercury complexes in the leachate), and potential difficulty treating soil with high clay or organic content.

“Dry” particle size separation methods such as soil sieving/screening are less costly and can also be effective (although generally much less so than soil washing) in some instances.

Physical particle size separation methods are retained as a technology for development of remedial alternatives.

6.6.4 On-Site (Ex-Situ) Solidification/Stabilization

As noted in Section 6.5.2, *ex-situ* solidification/stabilization was successfully implemented to treat Chlorine Plant Area soils containing visible elemental mercury during the Caustic Plume-Cell Building interim action; as described in Section 3.1.3, Portland cement and elemental sulfur were mixed with excavated soils on-site prior to off-site disposal in a hazardous waste landfill.

Ex-situ solidification/stabilization could be performed by various means, depending on the delineated extent of contamination and other design factors such as area-specific physical conditions. Treatment of excavated soil would be performed and properly disposed of in a permitted Subtitle C Landfill.

On-site *ex-situ* solidification/stabilization is retained as a technology for development of remedial alternatives.

6.6.5 On-Site (Ex-Situ) Thermal Desorption

Thermal desorption involves heating contaminated soil to volatilize and recover elemental mercury. Mercury is present in RAU soils almost exclusively in the elemental state or as mercury (II) compounds. When heated to 700ºC, mercury (II) compounds are converted to elemental mercury, which volatilizes. Mercury vapors are collected and cooled, resulting in a liquid elemental mercury product.

In-situ thermal desorption (ISTD) was discussed in Section 6.5.4. As noted in that section, we are not aware that ISTD has been demonstrated commercially or at full-scale for mercury remediation. However, Mercury Recovery Services (MRS) offers a mobile, trailer-mounted thermal desorption system for *ex-situ* treatment of mercury-contaminated soil on-site. MRS reports that this process:

- Consistently reduces the mercury content of the treated material to less than 1 mg/kg regardless of the level and form of mercury originally contained;
- Efficiently treats sand, clay, and loam with high moisture content;

- Produces 99% pure metallic mercury without generating any secondary liquid, solid, or gaseous secondary waste; and
- Prevents released sulfur and chlorine from entering the process waste and produces gaseous effluent that meets clean air standards.

In one commercial project, MRS used their 12-ton/day mobile unit to process more than 6,000 tons of soil over an 18-month period. Treatment consistently decreased the concentrations of mercury from 100 to 2,000 mg/kg in soil to less than 2 mg/kg in soil and to below the detection limits in TCLP leachate. This process generated about 3,500 pounds of metallic mercury. For larger projects, MRS offers a 2-ton/hour mobile unit.

Unlike the solidification/stabilization treatment technology discussed above, *ex-situ* thermal desorption would reduce the mercury concentration in the soil, not just convert the mercury into a less soluble, mobile, or toxic form. It may be capable of treating soils sufficiently to allow their unrestricted reuse on-site. Disadvantages include high energy costs and potentially onerous permitting requirements (e.g., obtaining necessary air emissions permits). In addition, the elemental mercury generated by the process would likely need to be stabilized with sulfur and then solidified with cement for disposal as hazardous waste, since the domestic demand for elemental mercury is extremely limited and its export is prohibited.

High-temperature thermal desorption can also adversely impact the physical properties of the soil. For example, heavy metals that are associated with iron and manganese oxides may transform and repartition to acid-extractable organic matter. High temperatures may also adversely impact soil nutrients, including nitrogen, phosphorus, and potassium. Alternately, mercury can be volatilized via thermal desorption at lower temperatures (as low as 100ºC) for longer duration, but with reduced removal efficiencies.

On-site *ex-situ* thermal desorption is not retained as a technology for development of remedial alternatives.

6.6.6 Acid Extraction

Acid extraction uses an aqueous solution to leach contaminants, including ionic metals, from soil. The typical goal of acid extraction is to treat contaminated soils to achieve cleanup levels, thereby allowing their reuse on-site. It is generally more effective for soils with low organic content because organic compounds tend to interfere with contaminant desorption (EPA, 2007). Solvents are selected based on their ability to solubilize specific contaminants, and on their environmental and health effects. Sodium thiosulfate ($Na_2S_2O_3$), thiosulfate, iodide (I_2), nitric acid (HNO_3), *aqua regia*, EDTA, hydrochloric acid (HCl), sodium hydroxide (NaOH), and potassium iodide (KI) have been tested for their ability to extract mercury from soil. I_2, EDTA, and thiosulfate may effectively remove about 30% of mercury from soil with limited impact on soil physical and chemical properties. KI and HCl (pH = 1.5) leach solutions have removed 77% of mercury from soil, but with detrimental impacts to soil. I_2 leach solutions have removed 98% of mercury from soil (Wang et al., 2012).

Disadvantages of acid extraction include complex chemical process application, high water requirements, treated soil quality concerns, and the potential for chemical exposures/releases during treatment. This technology is not retained for development of remedial alternatives.

6.7 Groundwater Extraction

Groundwater extraction (e.g., pumping from wells or trenches) can be performed to dewater excavations, to effect removal of dissolved contaminants, and/or to provide hydraulic containment of groundwater plumes. This technology can be implemented independently or in combination with excavation, *in-situ* treatment, or physical containment technologies.

Extracted groundwater would be re-injected on-site or discharged to the ASB, to a municipal wastewater treatment plant, or to the Whatcom Waterway under an NPDES permit. Each of these options may require different on-site water treatment requirements. Mercury-contaminated groundwater can be treated by various methods, including activated carbon, ZVI, sulfide precipitation, and lignin complexation. Groundwater extracted from the caustic plume area may require pH neutralization.

Groundwater pumping is retained as a technology for the development of remedial alternatives.

6.8 Summary of Retained Technologies

6.8.1 Mercury Exceedance and High pH Areas

The following technologies are retained for development of remedial alternatives for the mercury exceedance and high pH areas:

- Institutional controls;
- Groundwater MNA;
- Soil capping;
- Physical containment of groundwater;
- Soil solidification/stabilization (both *in situ* and *ex situ)*;
- *In-situ* pH buffering/neutralization and mercury precipitation/immobilization;
- On-site soil consolidation;
- Off-site soil disposal in landfills;
- Physical particle size separation methods; and
- Groundwater extraction.

6.8.2 Petroleum Hydrocarbon Exceedance Areas

The following technologies are retained for development of remedial alternatives for the petroleum hydrocarbon exceedance areas:

- Institutional controls;
- Groundwater MNA;
- Soil capping;

- Physical containment of groundwater;
- *In-situ* chemical oxidation;
- *In-situ* enhanced aerobic bioremediation;
- Off-site soil disposal in landfills; and
- Groundwater extraction.

6.8.3 Areas of Miscellaneous Dissolved Metals Exceedances in Groundwater

The following technologies are retained for development of remedial alternatives for areas of miscellaneous dissolved metals exceedances in groundwater:

- Institutional controls;
- Groundwater MNA;
- Physical containment of groundwater; and
- Groundwater extraction.

7 Description of Remedial Alternatives

In this section, the retained remedial technologies are assembled into eight remedial alternatives developed to achieve the RAOs for the RAU using a broad range of actions, including various levels of containment and treatment/disposal. This section describes the remedy components of each alternative and how the alternatives would be implemented.

The remedial alternatives, which are presented in order of increasing permanence and cost, have the following descriptive titles:

- Alternative 1 – Containment and *In-Situ* Treatment of Accessible Soils with Visible Elemental Mercury, Removal of Mercury-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA.
- Alternative 2 – Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Elemental Mercury, Removal of Mercury-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA.
- Alternative 3 – Removal of Soils with Visible Elemental Mercury and Mercury-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA.
- Alternative 4 – Neutralization of Caustic Core, Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Elemental Mercury, Removal of Mercury-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA.
- Alternative 5 – Neutralization of Groundwater with pH >8.5, Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Elemental Mercury, Removal of Mercury-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA.
- Alternative 6 – Neutralization of Groundwater with pH >8.5, Removal of Mercury-Impacted Soils to Achieve Groundwater Protection, Capping of Residual Impacted Soils, and Groundwater MNA.
- Alternative 7 – Removal of All Soils Exceeding Cleanup Levels, Neutralization of Groundwater with pH >8.5, and Groundwater MNA.
- Alternative 8 – Removal of All Soils Exceeding Cleanup Levels, Neutralization of Groundwater with pH >8.5, *In-Situ* Treatment of Fill Unit Groundwater Impacted by Mercury and PAHs, and MNA for Residual Impacted Groundwater.

The remedial technologies that make up each alternative (i.e., the remedy components) are summarized in Tables 7-1 and 7-2. Their areas of application within the RAU are depicted on Figure 7-1 (elements outside the Chlorine Plant Area for Alternatives 1 through 3) and Figures 7-2 through 7-9 (for Alternatives 1 through 8, respectively). All of the alternatives include the previously completed cleanup actions described in Section 3. Although the alternatives are independent of specific redevelopment actions, they may include components that are performed in conjunction with redevelopment actions as they occur.

Estimated construction quantities, construction duration, and restoration time frame (assuming a standard point of compliance for groundwater) for each remedial alternative are summarized in Table 7-3, and calculations for estimated quantities are provided in Appendix B. The construction quantities and design criteria presented in this FS are strictly conceptual in nature. They were developed using existing information, for the purpose of developing preliminary (FS-level) cost estimates and comparing remedial alternatives. Additional data will be collected as necessary after a remedy is selected by Ecology, in order to refine quantities, select the most appropriate process options, and further develop design details during the remedy design phase.

The following subsections describe the remedial alternatives in detail.

7.1 Common Elements

This section describes elements that are common to the alternatives. These include assumptions regarding property redevelopment (Section 7.1.1); assumptions regarding elevated mercury concentrations in nearshore groundwater (Section 7.1.2); a summary description of predictive modeling tools used to estimate restoration time frames (Section 7.1.3); construction monitoring (Section 7.1.4); and the basis and common assumptions used for developing FS-level cost estimates for the alternatives (Section 7.1.5).

7.1.1 Redevelopment of the Property

Anticipated land uses and use designations within the RAU are managed under a Sub-Area Plan and related documents adopted by the Port and City of Bellingham in 2013. The Waterfront District Sub-Area Plan covers over 200-acres, including the 36-acre Chlor-Alkali RAU, and anticipates the redevelopment of the former Georgia-Pacific mill and other properties into a mix of industrial, commercial, residential, and institutional designations with numerous areas of parks and public access.

The Waterfront District redevelopment will require coordination with remedial activities to accommodate planned land use and improvements to existing infrastructure within and adjacent to the RAU. The improvements include developing new and existing roads, rights-of-way, and stormwater conveyance and treatment systems. In addition, redevelopment plans call for increasing the Site elevation to mitigate the impact of potential sea level rise and to reduce the grade separation between the Site and the downtown Bellingham Central Business District. Redevelopment grading will be designed to maintain the required remediation performance standards, integrated with redevelopment aesthetics and drainage.

7.1.2 Elevated Mercury Concentrations in Nearshore Groundwater

There are two RAU locations where mercury concentrations in excess of the groundwater cleanup level have been measured in Fill Unit monitoring wells near the shoreline:

- Western edge of the caustic plume; and
- Law-1 area north of the wastewater settling basin.

Nearshore groundwater and intertidal porewater data for these two areas were evaluated in Sections 4.6.3 and 4.7.2, respectively. In both cases, the empirical porewater data, supplemented by contaminant transport modeling, indicate that current Fill Unit groundwater quality is protective of the marine environment.[19] Furthermore, mercury concentrations in nearshore groundwater are expected to naturally attenuate over time.

Based on those evaluation results, an active remedy to address elevated mercury concentrations in nearshore groundwater is not included in Alternatives 1 through 7. Monitoring would be conducted at both locations (potentially in combination with intertidal zone attenuation modeling, since concentrations in the sediment bioactive zone are difficult to measure directly) to demonstrate current and future compliance. Installation of a PRB along the shoreline for *in-situ* treatment of mercury in groundwater is the assumed contingent action in Alternatives 1 through 7 in the event that the MNA remedy is determined by monitoring to be insufficient.

As discussed in Section 7.9, Alternative 8 includes active measures implemented during the remedy construction phase to ensure compliance for groundwater within the sediment bioactive zone at both locations.

7.1.3 Estimation of Restoration Time Frame

A cleanup action is considered to have achieved restoration once cleanup standards have been met. Preliminary geochemical modeling was conducted for the purposes of estimating restoration time frames for the remedial alternatives, assuming the MTCA standard point of compliance for groundwater (i.e., meeting groundwater cleanup levels throughout the RAU). Given their vastly different transport behavior, separate models were used to estimate restoration time frames with respect to mercury/pH and naphthalene. Brief descriptions of the modeling efforts are provided in the following subsections, and detailed documentation is provided in Appendix C for mercury/pH modeling and in Appendix D for naphthalene modeling.

7.1.3.1 Mercury/pH Modeling

The mercury/pH modeling was performed using the U.S. Geological Survey's (USGS's) geochemical modeling software PHAST, which is a three-dimensional reaction-transport model based on the USGS codes PHREEQC and HST3D. The specific goal of the modeling was to estimate the time required to meet groundwater cleanup levels for pH and dissolved mercury throughout the Caustic Plume subarea and Law-1 area for each remedial alternative. Consistent with the assumed standard point of compliance, the modeling assumed worst-case groundwater quality conditions in each area specific to the alternative (thus the worst-case location changed between some alternatives). For alternatives leaving untreated elemental mercury in place, the restoration time frames were estimated qualitatively.

7.1.3.2 Naphthalene Modeling

The naphthalene plume in the Million Gallon Tanks subarea is assumed to naturally attenuate in Alternatives 1 through 7. Natural attenuation modeling of naphthalene concentrations in groundwater was performed using the BIOSCREEN model developed for EPA. BIOSCREEN assumes one-dimensional groundwater flow conditions along the centerline of a dissolved contaminant plume and is able to simulate contaminant advection, dispersion, adsorption, and aerobic/anaerobic decay reactions. First-order biodegradation

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[19] As discussed in Section 4.7.2.2, contaminant transport modeling in the Law-1 Area evaluation accounted for additional attenuation of groundwater contaminant concentrations resulting from placement of the final Log Pond cap (a component of a separate cleanup action) in 2016.

(decay) modeling was selected based on evaluation of groundwater monitoring data from the Million Gallon Tanks subarea.

7.1.4 Construction Monitoring

Construction monitoring would be conducted in all remedial alternatives to ensure that all construction components are completed in accordance with construction specifications and documented with an appropriate level of quality assurance and quality control. Construction monitoring requirements would be specified in a compliance monitoring plan to be prepared during the remedy design phase.

7.1.5 Cost Estimate Basis and Assumptions

Net present value costs in 2017 dollars were estimated for each of the remedial alternatives using a discount factor of 0.7 percent[20]. The estimates (Appendix A) include costs for remedy design, construction, and operation and maintenance (O&M), which includes long-term periodic inspection and monitoring. The net present value cost represents the dollar amount which, if invested in the initial year of the remedy and disbursed as needed, would be sufficient to cover all costs associated with the remedial action. O&M costs were evaluated over a 30-year period, consistent with EPA guidance. The FS estimates are order-of-magnitude, with an intended accuracy in the range of -30 to +50 percent. They include a sunk cost of $4.9 million, including $3.5 million for the 2013-2014 interim action described in Section 3.1.4 and $1.4 million for the 2017 interim action described in Section 3.1.5. Cost information was not available for the other (older) cleanup actions described in Section 3.

Capping is a component of all remedial alternatives except Alternatives 7 and 8. As noted in Section 6.4.1, a large portion of the RAU is currently covered with pavement and foundations of former buildings, and it is anticipated that many of these existing features will be incorporated into the cap for the final remedy. For the purpose of estimating capping costs in this FS, it is assumed that 50 percent of the area to be capped in each alternative would require new pavement (asphalt assumed), and 50 percent would be capped by existing building foundations and pavement.

Estimated costs for the remedial alternatives are summarized in Table 8-1.

7.2 Alternative 1 Description

Alternative 1 includes the following remedial components:

- Prior cleanup actions;
- Removal of wastewater settling basin soils near the Log Pond with mercury concentrations >300 mg/kg;
- Removal of TPH-impacted soils in southeast corner of Cell Building;
- *In-situ* treatment of readily accessible soils containing visible elemental mercury;

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[20] Discount factor based on real interest rate on US Treasury 30-year notes and bonds, Circular A-94 Appendix C, Office of Management and Budget (Revised November 2016).

- Physical containment of groundwater in contact with soils containing visible elemental mercury;
- Consolidation of mercury-impacted soils from BNSF property onto Port property;
- Capping of residual soils exceeding cleanup levels;
- Institutional controls; and
- Groundwater MNA, with contingency actions to be evaluated/implemented in the event that the remedy is not sufficiently protective of the marine environment.

Refer to Section 3 for descriptions of prior cleanup actions. The other components of Alternative 1 are depicted on Figures 7-1 and 7-2 and described in the following subsections.

7.2.1 Alternative 1 Removal of Wastewater Settling Basin Soils near the Log Pond with Mercury Concentrations >300 mg/kg

As noted in Section 5.4.1.4, a soil mercury concentration above 300 mg/kg in soils close to a shoreline requires removal or active treatment. In this alternative, soils in and around the northern portion of the wastewater settling basin with mercury concentrations greater than 300 mg/kg would be excavated, stabilized on-site (if required for disposal), and disposed of as hazardous waste. Based on existing data, these soils are estimated to be present in the depth range of 8 to 15 feet bgs. It is assumed that excavation would yield approximately 3,300 tons of soil requiring off-site disposal. It is further assumed for this FS that 50 percent of this soil would be disposed of as hazardous waste (with no on-site stabilization required), and 50 percent would be disposed of as non-hazardous waste. Overburden soils (total mercury concentrations less than 300 mg/kg) would be stockpiled and used as backfill for the excavation.

Investigation would first be required to determine the extent of soils to be removed and to allow profiling for waste designation purposes.

7.2.2 Alternative 1 Removal of TPH-Impacted Soils in Southeast Corner of Cell Building

Shallow TPH-impacted soils in and around the southeast corner of the Cell Building with concentrations exceeding soil cleanup levels for TPH would be excavated, characterized, and disposed of as non-hazardous waste. Based on existing data, these soils are not expected to extend below a 5-foot depth. As discussed in Section 7.2.3, surficial foundation components and debris would first be removed to access the TPH-impacted soils. It is assumed that excavation would yield approximately 1,900 tons of soil requiring off-site disposal. It is further assumed that mercury and PCB concentrations in this soil are low enough that all excavated soil would be eligible for disposal as non-hazardous waste.

Investigation would first be required to determine the extent of soils to be removed and to allow profiling for waste designation purposes.

7.2.3 Alternative 1 In-Situ Treatment of Readily Accessible Soils Containing Visible Elemental Mercury

The Caustic Plume-Cell Building interim action discussed in Section 3.1.4 removed mercury-contaminated soils from the Chlorine Plant Area, including a portion of soils containing visible elemental mercury. As discussed in Section 5.4.1.5, the volume of residual Chlorine Plant Area soils with potential visible elemental mercury has been estimated at roughly 15,000 cubic yards.[21] (Soils containing visible elemental mercury have not been observed outside the Chlorine Plant Area.) The intent of Alternative 1 is to treat as much of this soil as possible via ISS using large-diameter augers. At each boring location, the auger would be advanced to the aquitard underlying the impacted Fill Unit soils. Then, as the auger is retracted through the soil column, an amendment mix would be pumped through a central mixing shaft and out through jets at the bottom of the auger. Augering would be performed in an overlapping pattern.

A major disadvantage of this strategy is that, due to the presence of foundation piles and other structural objects in the subsurface, a large portion of the target soil would not be accessible to auger treatment. This is particularly true for impacted soils beneath the former Cell Building due to its dense array of foundation piles. And based on observations during the 2013-2014 interim action, the wood piles themselves may contain a significant amount of mercury. If maintaining the integrity of the aquitard were not a concern, these piles could be efficiently removed by pulling them out. In subsequent remedial alternatives (Alternatives 2 through 8), it is assumed that soil would be moved as needed to expose and cut off the piles at the base of the Fill Unit. However, removal of the upper portions of the piles by this method would be a very labor-intensive and potentially hazardous activity. Therefore, Alternative 1 considers the merits of treating impacted soils *in situ* to the extent possible while leaving the foundation piles in place. For this FS evaluation, it is assumed that this would be accomplished as follows:

- **Investigation to Determine Extent of Residual Soils Containing Visible Elemental Mercury.** As described in Section 4.4, test pits were excavated within the Chlorine Plant Area to evaluate the extent of soils containing visible elemental mercury during the Caustic Plume-Cell Building interim action. A similar test pit investigation would likely be carried out during the remedy design phase to supplement existing information and better delineate the extent of soils requiring ISS.
- **Testing to Determine Soil Amendment Mix**. As discussed in Sections 3.1.4 and 3.1.5, amendments were added (*ex situ*) to soils containing visible elemental mercury during the 2013-2014 and 2017 interim actions in order to reduce the leachability of mercury to less than the 0.25 mg/L TCLP limit for off-site disposal. A reduction in mercury leachability would also be the primary treatment objective for ISS. However, the proposed groundwater cleanup level for mercury (0.059 µg/L) is more than three orders of magnitude lower than the TCLP limit for off-site disposal. It is unknown whether any practical amendment dosages could reduce the leachability of the visible elemental

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[21] This is the estimated volume remaining after completion of the interim action planned for 2017 (discussed in Section 3.1.5).

mercury-containing soil enough to achieve such a low cleanup level.[22] In addition, the TCLP test is applicable only for a landfill disposal scenario and is not representative of leaching conditions for ISS-treated soil submerged in groundwater at the Site.[23]

Using Portland cement in ISS applications not only helps reduce contaminant leachability but also improves the physical ability of the treated soil to support redevelopment activities (i.e., it increases soil strength). However, the cement dosage is limited by the physical constraints of the ISS process. ISS using large-diameter augers requires that the auger holes be overlapped to provide complete treatment. The required overlapping can be accomplished only at relatively low cement dosages because the treated soil "sets up" too quickly when higher cement dosages are used.

The pilot test conducted in preparation for the 2017 interim action (Aspect, 2017a) also collected information potentially applicable to ISS in the final cleanup action. Mercury leachability was significantly reduced using a proprietary blend of amendments that did not include Portland cement. In addition, soil samples amended with Portland cement and sulfur were formed into cylinders, allowed time to cure, and then tested for UCS.

If ISS is a component of the selected remedy, the amendment mix would likely be finalized during the remedial design phase. Supplemental bench-scale testing will likely be required at that time to optimize the mix design.

- **Removal and Processing of Surficial Foundation Components and Debris Where *In-Situ* Auger Treatment Is Otherwise Feasible.** Concrete grade beams and pile caps would be removed to access impacted areas beneath the former Cell Building. Surficial foundation components and debris would be inspected for the presence of elemental mercury, tested for mercury content if visible mercury is absent (for waste designation), and profiled and disposed of at a permitted off-site landfill based on the test results. Materials containing visible mercury would be macroencapsulated to meet the LDR treatment standard for hazardous waste debris and disposed of in a RCRA Subtitle C (hazardous waste) landfill. All removed debris is assumed to be disposed of in an off-site landfill.
- **Field Demonstration**. A test would be conducted using the actual full-scale equipment proposed for the job and the amendment mix as determined above. This step is required because the thorough mixing of soil with amendment that is easily achieved at the bench scale may not be reproducible at full scale under actual field conditions. The stabilized test plot would be evaluated (e.g., via augering and testing the treated soil for mercury leachability and UCS) to determine stabilization performance.
- **Complete ISS**. For cost estimating purposes, the following assumptions were made:

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[22] If the groundwater cleanup level cannot be achieved throughout the aquifer, a conditional point of compliance for groundwater would be considered. Refer to Section 5.3.2.1.

[23] For example, the TCLP test uses a low-pH leachant, whereas groundwater in the Chlorine Plant Area has neutral to alkaline pH.

- Seventy-five percent of the elemental-mercury-containing soil is accessible for ISS (a smaller percentage would likely be accessible beneath the former Cell Building, but a larger percentage would be anticipated at other Chlorine Plant Area locations);
- Twenty-five percent auger overlap; and
- An amendment mix consisting of 25 parts (by weight) Portland cement and 2 parts elemental sulfur per 100 parts soil.

Accounting for the pre-treatment removal of surficial foundation elements, ISS at the assumed amendment dosages is expected to result in roughly a 3-foot increase in ground surface elevation. For cost estimating purposes it was assumed that 5,600 BCY of clean fill is imported to raise perimeter grades to match this elevation increase[24]. This will be a detail to evaluate as part of remedial design for the ISS program.

7.2.4 Alternative 1 Physical Containment of Groundwater in Contact with Soils Containing Visible Elemental Mercury

Alternative 1 includes physical containment of groundwater in contact with soils containing visible elemental mercury. Containment is included in this alternative because, as discussed above, only a portion of the target soil will be accessible for ISS due to the presence of foundation piles and other large objects in the subsurface. Untreated soils containing visible elemental mercury would provide a continuing source of mercury to groundwater.

For cost estimating purposes, it was assumed that groundwater containment is achieved by constructing soil/bentonite slurry walls around the perimeter of the stabilized soil areas using jet grouting. A total perimeter wall length of approximately 1,300 lineal feet was assumed (refer to Figure 7-2). The slurry walls would extend down to the underlying aquitard.

7.2.5 Alternative 1 Consolidation of Mercury-Impacted Soils from BNSF Property onto Port Property

Mercury-impacted soils in the BNSF portion of the Stormwater Swale would be excavated and placed on top of mercury-impacted soils on the Port side of the Stormwater Swale. The crushed concrete covering these soils (on both properties) would first be removed. The following construction sequence is assumed for cost-estimating purposes:

- Approximately 700 lineal feet of the existing chain link fence along the property boundary would be temporarily removed;
- The crushed concrete covering the impacted soils (volume estimated at 900 BCY) would be excavated and stockpiled on Port property;
- Soils on the BNSF side of the Stormwater Swale with mercury concentrations exceeding 24 mg/kg (volume estimated at 680 BCY) would be excavated and placed on top of mercury-impacted soils on the Port side of the Stormwater Swale;

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[24] The same assumption was made for the ISS component of Alternatives 2, 4, and 5. The cost of this amount of imported fill is negligible compared to the total cost of these alternatives.

- Clean fill would be imported to backfill the BNSF side to pre-existing grade; and
- The chain link fence would be replaced.

7.2.6 Alternative 1 Capping of Residual Soils Exceeding Cleanup Levels

Hard caps would be installed in Alternative 1 to limit stormwater infiltration and to control the human and terrestrial ecological exposure and soil erosion pathways for concentrations of contaminants exceeding soil cleanup levels. Figures 7-1 and 7-2 show the assumed areas where caps would be installed. Following the soil consolidation discussed above, these areas occur exclusively on Port property. The hard cap in the portion of the Chlorine Plant Area enclosed by the groundwater containment wall (Figure 7-2) would also serve to reduce potential mercury vapor emissions from untreated soil.

For the purposes of this FS, it is assumed that the design of the new caps would be consistent with Type 2 hard caps as described in Ecology's Tacoma Smelter Plume Model Remedies Guidance (Ecology, 2012a). Specifically, caps would be composed of a minimum 3-inch thickness of concrete, asphalt, paving blocks, or building foundations. Further details on cap design would be determined during the remedy design phase. Facilities for management of stormwater generated on the capped areas would be designed in accordance with applicable local development regulations and ordinances.

Refer to Section 7.1.5 for capping cost estimate assumptions.

7.2.7 Alternative 1 Institutional Controls

Alternative 1 includes application of institutional controls to provide notification regarding the presence of contaminated materials, regulate the disturbance/management of these materials and the cleanup action components, and provide for long-term monitoring and stewardship of the RAU's selected cleanup action. An institutional control would also be needed requiring that VI potential be evaluated and/or VI controls be constructed beneath future buildings in the following areas:

- The groundwater containment area (within the Chlorine Plant Area), where mercury may pose a VI concern; and
- The immediate vicinity and downgradient of the Million Gallon Tanks subarea, where naphthalene may pose a VI concern.

As described in Section 6.2, the Port and Ecology, in consultation with stakeholders including the City of Bellingham, would develop the environmental covenant and associated technical implementation documents for the RAU, which would identify the inspection and maintenance requirements for engineering controls (capping), use limitations, specific worker protection standards, VI evaluation/control requirements, and notification requirements.

The caps would be periodically inspected and maintained over the long term to prevent erosion and direct contact exposures. A Cap Inspection and Maintenance Plan would be developed to address inspection frequency, inspection and maintenance procedures, and documentation requirements. For the purposes of this FS, it is assumed that the caps would be inspected annually and after significant seismic events, and maintenance would be performed on an as-needed basis. The cost estimate includes a nominal annual allowance for long-term maintenance of the caps.

7.2.8 Alternative 1 Groundwater MNA and Contingency Actions

Groundwater MNA would be applied to address residual contamination in groundwater that exceeds applicable groundwater cleanup levels. Contaminants would continue to naturally attenuate in groundwater through a combination of sorption, bioattenuation, volatilization, dispersion, and tidal mixing. Based on the RI data, cleanup-level exceedances in Fill Unit groundwater include mercury, miscellaneous metals, naphthalene, and cPAH concentrations, as well as elevated pH. Mercury exceedances have also been identified in the underlying Lower Sand groundwater unit. Different natural attenuation mechanisms operate for the different contaminants, and RI data indicate that natural attenuation is effectively reducing contaminant concentrations in RAU groundwater and reducing the elevated pH.

It is anticipated that the Consent Decree and CAP for the RAU will require the development of a groundwater monitoring plan to evaluate the performance of groundwater MNA. The groundwater monitoring plan would present the locations of upland monitoring wells, sediment pore water samples, location-specific monitoring, analytes and analytical methods, including quality control, monitoring frequency, and a decision process for evaluating and adaptively managing the MNA remedy. For the purposes of this FS, it is assumed that monitoring of groundwater and sediment pore water COCs and pH would be conducted at a network of 15 wells (12 Fill Unit wells and 3 Lower Sand unit wells) and six sediment pore water locations quarterly for 2 years and semi-annually thereafter.

Contingency actions would be considered for implementation if MNA fails to achieve the expected continued groundwater restoration and is determined to be insufficiently protective of the marine environment (remedy failure). Depending on the COCs and associated conditions, the contingency actions could include enhanced source attenuation. For example, groundwater buffering/neutralization could be considered to immobilize mercury and/or reduce pH within the caustic plume source area, whereas chemical oxidation or biostimulation could be considered to enhance source attenuation in the Million Gallon Tanks subarea. Alternatively, groundwater containment could be applied to limit the migration of any contaminant. PRBs could potentially be used to treat contaminated groundwater *in situ*. ZVI would likely be considered for *in-situ* treatment of metals contamination, including mercury, whereas activated carbon could be considered for removal of organic contaminants. Migration of contaminated groundwater could also be controlled using physical containment methods such as slurry walls or by groundwater extraction and treatment (pump-and-treat).

The need for a contingency action would be evaluated if potential failure of MNA is indicated through monitoring, at which time substantial additional information would be available to determine the causes of failure and the most effective and practicable remedy. For the purposes of this FS evaluation, it is assumed that MNA would successfully achieve groundwater remediation goals for all groundwater COCs so that contingency actions would not be required.

7.2.9 Alternative 1 Implementation and Restoration Time Frames

The time frame for implementing Alternative 1 is expected to be in the range of 1 to 2 years. Further investigation in the Chlorine Plant Area, removal of TPH-impacted soils, and design and construction of ISS and groundwater containment would likely be performed concurrently with the removal of mercury-impacted soils and capping outside the Chlorine Plant Area.

Because some visible elemental mercury in the Chlorine Plant Area would remain untreated or incompletely treated, assuming a standard point of compliance for groundwater, a restoration time frame of greater than 100 years is estimated for Alternative 1. Modeling results indicate that mercury is the limiting contaminant (refer to Appendix C).

7.2.10 Alternative 1 Estimated Cost

The cost for Alternative 1 is estimated at approximately $12.2 million, including an estimated $11.6 million for remedy construction and $0.6 million for post-construction inspection, maintenance, and monitoring. Groundwater containment and ISS in the Chlorine Plant Area represent the largest construction component, estimated at approximately $4.4 million. Table A-2 in Appendix A includes the detailed cost estimate assumptions for Alternative 1.

7.3 Alternative 2 Description

Alternative 2 is similar to Alternative 1, except that *in-situ* treatment of soils containing visible elemental mercury would be much more effective because aggressive measures would be implemented to remove subsurface obstructions prior to ISS. It includes the following remedial components:

- Prior cleanup actions;
- Removal of wastewater settling basin soils near the Log Pond with mercury concentrations >300 mg/kg;
- Removal of TPH-impacted soils in southeast corner of Cell Building;
- Aggressive removal of obstructions and *in-situ* treatment of soils containing visible elemental mercury;
- Consolidation of mercury-impacted soils from BNSF property onto Port property;
- Capping of residual soils exceeding cleanup levels;
- Institutional controls; and
- Groundwater MNA, with contingency actions to be evaluated/implemented in the event that the remedy is not sufficiently protective of the marine environment.

Refer to Section 3 for descriptions of prior cleanup actions. The other components of Alternative 2 are depicted on Figures 7-1 and 7-3 and described in the following subsections.

7.3.1 Alternative 2 Removal of Wastewater Settling Basin Soils near the Log Pond with Mercury Concentrations >300 mg/kg

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.1).

7.3.2 Alternative 2 Removal of TPH-Impacted Soils in Southeast Corner of Cell Building

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.2).

7.3.3 Alternative 2 Aggressive Removal of Obstructions and In-Situ Treatment of Soils Containing Visible Elemental Mercury

Foundation components and large debris would be aggressively removed in areas where soils contain visible elemental mercury so that those soils can be effectively treated via ISS. Fill Unit soils would be moved as needed to expose foundation piles down to the aquitard so that they can be cut off at the Fill Unit/aquitard interface. Removing the piles in this manner would maintain the integrity of the aquitard. Removed debris would be managed as in Alternative 1 (refer to Section 7.2.3).

Note that the soil containing visible mercury could likely be more effectively and less expensively treated *ex situ* (using equipment similar to that used in the 2013-2014 interim action) and then used as backfill for the excavation, rather than removing all subsurface structures and then treating the soil *in situ* using large-diameter augers. However, placement of soil treated *ex situ* back in the ground would constitute a CAMU under RCRA. While the federal RCRA rules allow the use of CAMUs at Superfund sites and allow their approval at state-led cleanup sites, the state Dangerous Waste Regulation (Chapter 173-303 WAC) limits use of CAMUs to cleanup sites that are under a RCRA permit (Treatment, Storage, and Disposal Facilities [TSDFs]). Prior to the Port’s ownership of the Site, GP was a large-quantity generator of hazardous waste and applied for a RCRA permit for on-site treatment of hazardous waste. However, prior to finalizing the permit, GP and Ecology agreed to use the provisions of a recycling exemption to conduct mercury recovery activities that would have otherwise required a permit, and a RCRA permit was never issued. Ecology therefore determined that a CAMU cannot be used in the cleanup for this RAU.

Ecology agrees in principle that impacted soils may be moved within the treatment area (“area of contamination”) to the extent required for pile removal and subsequent *in-situ* treatment without generating a remediation waste under RCRA. Detailed construction procedures for pile removal would be developed (with Ecology input/approval) either during the remedial design phase or by the construction contractor.

Except as described above, the steps to be followed in Alternative 2 for addressing soils with elemental mercury would generally be similar to those described for Alternative 1 (refer to Section 7.2.3). It is assumed that, following aggressive removal of obstructions down to the aquitard, 100 percent of the elemental-mercury-containing soil would be accessible for ISS in this alternative.

The following assumptions were made for estimating the cost of obstruction removal and ISS in Alternative 2:

- Very steep side-slopes are achievable, and relatively low-cost dewatering methods (e.g., pumping from sumps within the excavation) are sufficient to maintain dry conditions during excavation to 14 feet bgs in the Chlorine Plant Area. (These assumptions are consistent with conditions observed during the Caustic Plume-Cell Building interim action.) Trench boxes or other temporary shoring methods would still be required for worker safety during obstruction removal.
- Accounting for the pre-treatment removal of surficial foundation components, piles, and large debris, ISS is expected to result in a 3- to 4-foot increase in ground surface elevation. As in Alternative 1, it was assumed clean fill is imported to raise perimeter grades to match this elevation increase.

7.3.4 Alternative 2 Consolidation of Mercury-Impacted Soils from BNSF Property onto Port Property

Consolidation of these soils would be the same as in Alternative 1 (refer to Section 7.2.5).

7.3.5 Alternative 2 Capping of Residual Soils Exceeding Cleanup Levels

Alternative 2 includes capping as described for Alternative 1 (refer to Section 7.2.6). Figures 7-1 and 7-3 show the assumed areas where caps would be installed.

7.3.6 Alternative 2 Institutional Controls

Institutional controls would be implemented as described for Alternative 1 (refer to Section 7.2.7). In this alternative, VI should not be a concern in the Chlorine Plant Area because elemental mercury should no longer be present.

7.3.7 Alternative 2 Groundwater MNA and Contingency Actions

Groundwater MNA would be conducted as described for Alternative 1 (refer to Section 7.2.8).

7.3.8 Alternative 2 Implementation and Restoration Time Frames

The time frame for implementing Alternative 2 is expected to be in the same range as that for Alternative 1 (1 to 2 years).

Assuming a standard point of compliance for groundwater, a restoration time frame of greater than 100 years is estimated for Alternative 2. Modeling results indicate that mercury is the limiting contaminant (refer to Appendix C).

7.3.9 Alternative 2 Estimated Cost

The cost for Alternative 2 is estimated at approximately \$16.2 million, including an estimated \$15.6 million for remedy construction and \$0.6 million for post-construction inspection, maintenance, and monitoring. Aggressive removal of subsurface obstructions and ISS in the Chlorine Plant Area represent the largest construction component, estimated at approximately \$8.0 million. Table A-3 in Appendix A includes the detailed cost estimate assumptions for Alternative 2.

7.4 Alternative 3 Description

Alternative 3 is similar to Alternative 2, except that soils containing visible elemental mercury would be treated on-site (*ex situ*) and then disposed of off-site rather than being treated *in situ*, thereby removing the contaminant (mercury) from the RAU rather than just reducing its mobility and hazard potential. It includes the following remedial components:

- Prior cleanup actions;
- Removal of wastewater settling basin soils near the Log Pond with mercury concentrations >300 mg/kg;
- Removal of TPH-impacted soils in southeast corner of Cell Building;
- *Ex-situ* treatment/removal of soils containing visible elemental mercury;
- Consolidation of mercury-impacted soils from BNSF property onto Port property;
- Capping of residual soils exceeding cleanup levels;
- Institutional controls; and
- Groundwater MNA, with contingency actions to be evaluated/implemented in the event that the remedy is not sufficiently protective of the marine environment.

Refer to Section 3 for descriptions of prior cleanup actions. The other components of Alternative 3 are depicted on Figures 7-1 and 7-4 and described in the following subsections.

7.4.1 Alternative 3 Removal of Wastewater Settling Basin Soils near the Log Pond with Mercury Concentrations >300 mg/kg

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.1).

7.4.2 Alternative 3 Removal of TPH-Impacted Soils in Southeast Corner of Cell Building

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.2).

7.4.3 Alternative 3 Ex-Situ Treatment/Removal of Soils Containing Visible Elemental Mercury

In this alternative, soils containing visible elemental mercury would be solidified/stabilized on-site (*ex situ*) and then disposed of in a RCRA Subtitle C (hazardous waste) landfill, and foundation components and debris would be managed as in Alternative 2 (refer to Section 7.3.3). Thus, excavated materials would be managed in a manner similar to that used during the 2013-2014 interim action. Excavation monitoring would be conducted to segregate impacted soils for treatment prior to disposal, and excavated soils that do not require solidification/stabilization would also be disposed of off-site. Clean fill would be imported and used as backfill for the excavations to restore grade.

As discussed in Section 3.1.5, the pilot test to be conducted in preparation for follow-up (2017) removal of mercury-contaminated soil at the Cell Building will reevaluate amendments and dosages to satisfy the requirements for off-site disposal. The pilot test may demonstrate that the addition of stabilization agent alone can sufficiently reduce mercury leachability (i.e., precluding the need to add Portland cement). However, for the purpose of estimating costs for Alternative 3, it is assumed that the amendments and dosages for *ex-situ* treatment are the same as for ISS in Alternatives 1 and 2 (i.e., 25 parts [by weight] Portland cement and 5 parts elemental sulfur per 100 parts soil). On this basis, it is estimated that approximately 26,000 tons of treated mix (soil and amendments) would be disposed of as hazardous waste.

7.4.4 Alternative 3 Consolidation of Mercury-Impacted Soils from BNSF Property onto Port Property

Consolidation of these soils would be the same as in Alternative 1 (refer to Section 7.2.5).

7.4.5 Alternative 3 Capping of Residual Soils Exceeding Cleanup Levels

Alternative 3 includes capping as described for Alternative 1 (refer to Section 7.2.6). Figures 7-1 and 7-4 show the assumed areas where caps would be installed.

7.4.6 Alternative 3 Institutional Controls

Institutional controls would be implemented as described for Alternative 1 (refer to Section 7.2.7). In this alternative, VI should not be a concern in the Chlorine Plant Area because elemental mercury should no longer be present.

7.4.7 Alternative 3 Groundwater MNA and Contingency Actions

Groundwater MNA would be conducted as described for Alternative 1 (refer to Section 7.2.8).

7.4.8 Alternative 3 Implementation and Restoration Time Frames

For Alternative 3, further investigation followed by design and construction of *ex-situ* soil stabilization in the Chlorine Plant Area would likely be performed concurrently with RAU-wide soil capping and would not increase the remedy implementation time frame. Therefore, the time frame for implementing Alternative 3 is expected to be in the same range as that for Alternatives 1 and 2 (1 to 2 years). As with those alternatives, some cleanup may be integrated with redevelopment, which could control the schedule.

Assuming a standard point of compliance for groundwater, a restoration time frame of greater than 100 years is estimated for Alternative 3. Modeling results indicate that mercury is the limiting contaminant in the restoration time frame (refer to Appendix C).

7.4.9 Alternative 3 Estimated Cost

The cost for Alternative 3 is estimated at approximately $22.8 million, including an estimated $22.2 million for remedy construction and $0.6 million for post-construction inspection, maintenance, and monitoring. *Ex-situ* treatment/removal of soils containing visible elemental mercury represents the largest construction component, estimated at approximately $14.5 million. Table A-4 in Appendix A includes the detailed cost estimate assumptions for Alternative 3.

7.5 Alternative 4 Description

Alternative 4 is similar to Alternative 2, with the addition of neutralization of groundwater in the Caustic Core. It includes the following remedial components:

- Prior cleanup actions;
- Removal of wastewater settling basin soils near the Log Pond with mercury concentrations >300 mg/kg;
- Removal of TPH-impacted soils in southeast corner of Cell Building;
- Aggressive removal of obstructions and *in-situ* treatment of soils containing visible elemental mercury;
- Neutralization of groundwater in the Caustic Core;
- Consolidation of mercury-impacted soils from BNSF property onto Port property;
- Capping of residual soils exceeding cleanup levels;
- Institutional controls; and
- Groundwater MNA, with contingency actions to be evaluated/implemented in the event that the remedy is insufficiently protective of the marine environment.

Refer to Section 3 for descriptions of prior cleanup actions. The other components of Alternative 4 are depicted on Figure 7-5 and described in the following subsections.

7.5.1 Alternative 4 Removal of Wastewater Settling Basin Soils near the Log Pond with Mercury Concentrations >300 mg/kg

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.1).

7.5.2 Alternative 4 Removal of TPH-Impacted Soils in Southeast Corner of Cell Building

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.2).

7.5.3 Alternative 4 Aggressive Removal of Obstructions and In-Situ Treatment of Soils Containing Visible Elemental Mercury

Removal of obstructions and *in-situ* treatment of these soils would be the same as in Alternative 2 (refer to Section 7.3.3).

7.5.4 Alternative 4 Neutralization of Groundwater in Caustic Core

As noted in Section 4.6.3, the Caustic Core is the area in the southwestern portion of the RAU where the pH in Fill Unit groundwater exceeds 10. Fill Unit groundwater in this area is not only the most caustic (pH measurements as high as 12.2) but also has the highest dissolved mercury concentrations; up to 619 µg/L was measured in monitoring well CP-MW15 installed in the southwest corner of the Chlorine Plant Area, where soil with visible elemental mercury was subsequently removed (see Figure 3-1 for well location). The goal of neutralization of the Caustic Core in this alternative is to actively reduce groundwater pH and thereby induce precipitation of dissolved mercury.[25]

For evaluation in this FS, neutralization of the Caustic Core is assumed to be accomplished by placing ferrous sulfate heptahydrate ($FeSO_4*7H_2O$) below the water table in trenches

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[25] Similar to Alternatives 1, 2, and 3, groundwater pH in the Law-1 area and in the area surrounding the Caustic Core where pH exceeds 8.5 is assumed to naturally attenuate over time to below pH 8.5.

excavated perpendicular to the groundwater flow direction. Ferrous sulfate was selected for evaluation for several reasons, including its high solubility in water and relatively low cost. Groundwater parameters measured at well CP-MW15, including a pH of 11.2 and alkalinity of 9,510 mg/L as calcium carbonate, were input to the hydrogeochemical model PHREEQC to estimate the ferrous sulfate requirement. Assuming that hydrous ferric oxide (HFO) precipitation will occur along with ferrous sulfate treatment, the model predicted the mass of ferrous sulfate heptahydrate needed to reduce the pH of Caustic Core groundwater to below 8.

As depicted schematically on Figure 7-5, the conceptual design calls for five trenches spaced at approximately 60 feet on-center, with a total trench length of approximately 1,000 feet. An average trench width of 3 feet and chemical-filled depth of 14 feet (e.g., 1 to 15 feet bgs) would accommodate 1,400 tons of ferrous sulfate heptahydrate.

Approximately 1,700 cubic yards of soil would be excavated during the trench construction. *In-situ* stabilization of Chlorine Plant Area soils containing elemental mercury would likely be conducted first, and trench locations would be adjusted to avoid stabilized soils. On this basis, it is assumed that all soil excavated from the trenches could be disposed of at a RCRA Subtitle D (non-hazardous waste) landfill.

A plan would be developed and implemented for monitoring the performance of the neutralization trenches. However, O&M costs associated with the trenches are assumed to be negligible.

7.5.5 Alternative 4 Consolidation of Mercury-Impacted Soils from BNSF Property onto Port Property

Consolidation of these soils would be the same as in Alternative 1 (refer to Section 7.2.5).

7.5.6 Alternative 4 Capping of Residual Soils Exceeding Cleanup Levels

Alternative 4 includes capping as described for Alternative 1 (refer to Section 7.2.6). Figure 7-5 shows the assumed areas where caps would be installed.

7.5.7 Alternative 4 Institutional Controls

Institutional controls would be implemented as described for Alternative 1 (refer to Section 7.2.7). In this alternative, VI should not be a concern in the Chlorine Plant Area because elemental mercury should no longer be present.

7.5.8 Alternative 4 Groundwater MNA and Contingency Actions

Groundwater MNA would be conducted as described for Alternative 1 (refer to Section 7.2.8).

7.5.9 Alternative 4 Implementation and Restoration Time Frames

As noted above, *in-situ* treatment of soils in the Chlorine Plant Area and construction associated with neutralization of “Caustic Core” groundwater would likely be completed sequentially, which could increase the overall time frame for remedy construction. For this reason, the implementation time frame of Alternative 4 is estimated at 2 to 3 years.

Assuming a standard point of compliance for groundwater, a restoration time frame of 74 years is estimated for Alternative 4. Modeling results indicate that mercury is the limiting contaminant (refer to Appendix C).

7.5.10 Alternative 4 Estimated Cost

The cost for Alternative 4 is estimated at approximately $18.4 million, including an estimated $17.7 million for remedy construction and $0.7 million for post-construction inspection, maintenance, and monitoring. As in Alternative 2, aggressive removal of subsurface obstructions and ISS in the Chlorine Plant Area represent the largest construction component, estimated at approximately $8.0 million. Neutralization of groundwater in the "Caustic Core" is estimated at approximately $2.1 million. Table A-5 in Appendix A includes the detailed cost estimate assumptions for Alternative 4.

7.6 Alternative 5 Description

Alternative 5 is similar to Alternative 4, except that neutralization of groundwater would be implemented not just in the "Caustic Core" (pH >10) but wherever groundwater pH exceeds 8.5. It includes the following remedial components:

- Prior cleanup actions;
- Removal of wastewater settling basin soils near the Log Pond with mercury concentrations >300 mg/kg;
- Removal of TPH-impacted soils in southeast corner of Cell Building;
- Aggressive removal of obstructions and *in-situ* treatment of soils containing visible elemental mercury;
- Neutralization of groundwater in areas where groundwater pH exceeds 8.5;
- Consolidation of mercury-impacted soils from BNSF property onto Port property;
- Capping of residual soils exceeding cleanup levels;
- Institutional controls; and
- Groundwater MNA, with contingency actions to be evaluated/implemented in the event that the remedy is insufficiently protective of the marine environment.

Refer to Section 3 for descriptions of prior cleanup actions. The other components of Alternative 5 are depicted on Figure 7-6 and described in the following subsections.

7.6.1 Alternative 5 Removal of Wastewater Settling Basin Soils near the Log Pond with Mercury Concentrations >300 mg/kg

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.1).

7.6.2 Alternative 5 Removal of TPH-Impacted Soils in Southeast Corner of Cell Building

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.2).

7.6.3 Alternative 5 Aggressive Removal of Obstructions and In-Situ Treatment of Soils Containing Visible Elemental Mercury

Removal of obstructions and *in-situ* treatment of these soils would be the same as in Alternative 2 (refer to Section 7.3.3).

7.6.4 Alternative 5 Neutralization of Groundwater in Areas Where Groundwater pH Exceeds 8.5

In this alternative, trenches similar to those described in Section 7.5.4 would be constructed to neutralize groundwater pH wherever it exceeds 8.5. Areas treated in this alternative that are not actively addressed in Alternative 4 (i.e., where groundwater pH is between 8.5 and 10) include the Law-1 area and the perimeter area surrounding the Caustic Core. Dissolved mercury concentrations are elevated in these areas, although not as high as in the Caustic Core itself. Similar to Alternative 4, the goal of the neutralization trenches in Alternative 5 is to reduce groundwater pH and thereby induce precipitation of dissolved mercury.

For the purposes of this FS evaluation, the neutralization trenches treating areas where groundwater pH is between 8.5 and 10 are assumed to have the same construction, spacing, and chemical loading as those treating the Caustic Core (refer to Section 7.5.4). As depicted schematically on Figure 7-6, the conceptual design calls for nine trenches, with a total trench length of approximately 4,700 feet. The trenches would accommodate roughly 6,400 tons of ferrous sulfate heptahydrate.

Approximately 7,800 cubic yards of soil would be excavated during the trench construction. *In-situ* stabilization of Chlorine Plant Area soils containing elemental mercury would likely be conducted first, and trench locations would be adjusted to avoid stabilized soils. On this basis, it is assumed that all soil excavated from the trenches could be disposed of at a RCRA Subtitle D (non-hazardous waste) landfill.

As in Alternative 4, a plan would be developed and implemented for monitoring the performance of the neutralization trenches; however, O&M costs associated with the trenches are assumed to be negligible.

7.6.5 Alternative 5 Consolidation of Mercury-Impacted Soils from BNSF Property onto Port Property

Consolidation of these soils would be the same as in Alternative 1 (refer to Section 7.2.5).

7.6.6 Alternative 5 Capping of Residual Soils Exceeding Cleanup Levels

Alternative 5 includes capping as described for Alternative 1 (refer to Section 7.2.6). Figure 7-6 shows the assumed areas where caps would be installed.

7.6.7 Alternative 5 Institutional Controls

Institutional controls would be implemented as described for Alternative 1 (refer to Section 7.2.7). In this alternative, VI should not be a concern in the Chlorine Plant Area because elemental mercury should no longer be present.

7.6.8 Alternative 5 Groundwater MNA and Contingency Actions

Groundwater MNA would be conducted as described for Alternative 1 (refer to Section 7.2.8).

7.6.9 Alternative 5 Implementation and Restoration Time Frames

Although this alternative includes much more extensive construction of neutralization trenches than Alternative 4, trench construction west of the Chlorine Plant Area could likely be conducted in parallel with the *in-situ* treatment of soils in that area. Therefore, the implementation time frame for Alternative 5 is assumed to be similar to that of Alternative 4 (2 to 3 years).

Assuming a standard point of compliance for groundwater, a restoration time frame of 34 years is estimated for Alternative 5. Modeling results indicate that naphthalene is the limiting contaminant (refer to Appendix D).

7.6.10 Alternative 5 Estimated Cost

The cost for Alternative 5 is estimated at approximately $24.2 million, including an estimated $23.3 million for remedy construction and $0.9 million for post-construction inspection, maintenance, and monitoring. As in Alternatives 2 and 4, aggressive removal of subsurface obstructions and ISS in the Chlorine Plant Area represent the largest construction component, estimated at approximately $8.0 million. Neutralization of groundwater in the “Caustic Core” is estimated at approximately $7.8 million. Table A-6 in Appendix A includes the detailed cost estimate assumptions for Alternative 5.

7.7 Alternative 6 Description

Alternative 6 is similar to Alternative 5 with respect to neutralization of groundwater with elevated pH. However, soils containing visible elemental mercury would be treated on-site and then disposed of off-site (as in Alternative 3). Soils with no visible elemental mercury but with mercury concentrations representing a leaching-to-groundwater concern would also be excavated and disposed of off-site. Alternative 6 includes the following remedial components:

- Prior cleanup actions;
- Removal of TPH-impacted soils in southeast corner of Cell Building;
- *Ex-situ* treatment/removal of soils containing visible elemental mercury;
- Removal of mercury-impacted soils to achieve groundwater protection;
- Neutralization of groundwater in areas where groundwater pH exceeds 8.5;
- Consolidation of mercury-impacted soils from BNSF property onto Port property;
- Capping of residual soils exceeding cleanup levels;
- Institutional controls; and
- Groundwater MNA, with contingency actions to be evaluated/implemented in the event that the remedy is not sufficiently protective of the marine environment.

Refer to Section 3 for descriptions of prior cleanup actions. The other components of Alternative 6 are depicted on Figure 7-7 and described in the following subsections.

7.7.1 Alternative 6 Removal of TPH-Impacted Soils in Southeast Corner of Cell Building

Removal of these soils would be the same as in Alternative 1 (refer to Section 7.2.2).

7.7.2 Alternative 6 Ex-Situ Treatment/Removal of Soils Containing Visible Elemental Mercury

Removal, *ex-situ* treatment, and off-site disposal of these soils would be the same as in Alternative 3 (refer to Section 7.4.3).

7.7.3 Alternative 6 Removal of Mercury-Impacted Soils to Achieve Groundwater Protection

As discussed in Section 5.3.1.1, a soil mercury concentration of 100 mg/kg is considered protective of near-neutral-pH groundwater. Alternative 6 evaluates this mercury concentration as a soil remediation level to achieve groundwater protection (assuming a standard point of compliance for groundwater). Soils with mercury concentrations exceeding 100 mg/kg would be excavated and disposed of off-site. An estimated 28,000 cubic yards of mercury-impacted soils would be removed from the Chlorine Plant Area,[26] the wastewater settling basin and vicinity, the Stormwater Swale, and the Laurel Street Pipe Rack subarea. Area-specific soil volumes are estimated in Section 5.4.1.3. Although the stabilized sludge in the Chemfix area contains mercury concentrations exceeding 100 mg/kg, it would not be removed in this alternative because, as noted in Section 5.4.1.3, it has been treated to effectively limit the amount of mercury leaching to groundwater.

For cost estimating purposes, it is assumed that approximately 6,700 tons of the excavated soil would be disposed of as hazardous waste (with no on-site stabilization required), and the remainder (approximately 36,000 tons) would be disposed of as non-hazardous waste. Refer to Sheet B-2 in Appendix B for additional detail.

Investigation would first be required to determine the extent of soils to be removed, particularly in the Chlorine Plant Area. Removal of building foundation elements and other large debris would be required in some areas for the purpose of accessing impacted soils and to achieve comprehensive removal of mercury.

7.7.4 Alternative 6 Neutralization of Groundwater in Areas Where Groundwater pH Exceeds 8.5

Groundwater neutralization would be conducted as described for Alternative 5 (refer to Section 7.6.4). However, as shown on Figure 7-7, neutralization trenches would not be needed in some areas where mercury-impacted soils are removed. A total trench length of approximately 4,100 feet is assumed in this alternative. Approximately 6,900 cubic yards of soil would be excavated during the trench construction, and the trenches would accommodate roughly 5,600 tons of ferrous sulfate heptahydrate.

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[26] Soils with visible elemental mercury are addressed separately and are not included in the total of 29,000 cubic yards.

7.7.5 Alternative 6 Consolidation of Mercury-Impacted Soils from BNSF Property onto Port Property

Consolidation of these soils would be the same as in Alternative 1 (refer to Section 7.2.5). The volume of soils requiring consolidation would be slightly less in this alternative because soils with mercury concentrations exceeding 100 mg/kg would have been previously removed from the Stormwater Swale to achieve groundwater protection (refer to Section 7.7.3).

7.7.6 Alternative 6 Capping of Residual Soils Exceeding Cleanup Levels

Alternative 6 includes capping as described for Alternative 1 (refer to Section 7.2.6). Figure 7-7 shows the assumed areas where caps would be installed.

7.7.7 Alternative 6 Institutional Controls

Institutional controls would be implemented as described for Alternative 1 (refer to Section 7.2.7). In this alternative, VI should not be a concern in the Chlorine Plant Area because elemental mercury should no longer be present.

7.7.8 Alternative 6 Groundwater MNA and Contingency Actions

Groundwater MNA would be conducted as described for Alternative 1 (refer to Section 7.2.8).

7.7.9 Alternative 6 Implementation and Restoration Time Frames

Although this alternative includes much more extensive soil excavation than Alternatives 1 through 5, much of the soil excavation can likely be performed in parallel with the construction of neutralization trenches. Therefore, the implementation time frame for Alternative 6 is assumed to be similar to that of Alternative 5 (2 to 3 years).

Assuming a standard point of compliance for groundwater, a restoration time frame of 34 years is estimated for Alternative 6. Modeling results indicate that naphthalene is the limiting contaminant (refer to Appendix D).

7.7.10 Alternative 6 Estimated Cost

The total cost for Alternative 6 is estimated at approximately $39 million. Major construction cost components include $14.5 million for *ex-situ* treatment/removal of soils containing visible elemental mercury, $10.2 million for removal of additional mercury-impacted soils to achieve groundwater protection, and $6.9 million for neutralization of groundwater. Table A-7 in Appendix A includes the detailed cost estimate assumptions for Alternative 6.

7.8 Alternative 7 Description

Alternative 7 includes the following remedial components:

- Prior cleanup actions;
- Removal of all soils exceeding cleanup levels;
- Neutralization of groundwater in areas where groundwater pH exceeds 8.5;

- Institutional controls; and
- Groundwater MNA, with contingency actions to be evaluated/implemented in the event that the remedy is insufficiently protective of the marine environment.

The soil removal associated with Alternative 7 is much more extensive than that in Alternatives 1 through 6, and capping would not be required because all soils exceeding cleanup levels would be removed. Refer to Section 3 for descriptions of prior cleanup actions. The other components of Alternative 7 are depicted on Figure 7-8 and described in the following subsections.

7.8.1 Alternative 7 Removal of All Soils Exceeding Cleanup Levels

Fill Unit soils with contaminant concentrations that exceed the corresponding soil cleanup levels would be excavated, characterized, and disposed of off-site in this alternative. This includes all soils removed in Alternative 6 plus the following:

- Soils in and around the Chlorine Plant Area, wastewater settling basin, Stormwater Swale, and Laurel Street Pipe Rack subarea with mercury concentrations above the cleanup level (24 mg/kg) but below the groundwater protection level (100 mg/kg);
- Mercury-impacted sludge that was stabilized in 1976 and placed in the Chemfix area; and
- Soils on the north side of the Lignin Warehouse B and in the Million Gallon Tanks subarea with TPH and/or PAH concentrations above the respective cleanup levels.

The incremental soil removal volume compared to Alternative 6 is estimated at 77,000 cubic yards. For cost estimating purposes, it is assumed that approximately 13,000 tons of this incremental soil would be disposed of as hazardous waste, and the remainder (approximately 100,000 tons) would be disposed of as non-hazardous waste. Removal, *ex-situ* treatment, and off-site disposal of Chlorine Plant Area soils containing visible elemental mercury would be the same as that in Alternatives 3 and 6. Refer to Sheet B-2 in Appendix B for additional cost estimate detail.

Investigation would first be required to determine the extent of soils to be removed. Removal of building foundation elements and other large debris would be required in some areas for the purpose of accessing impacted soils.

7.8.2 Alternative 7 Neutralization of Groundwater in Areas Where Groundwater pH Exceeds 8.5

Groundwater neutralization would be conducted as described for Alternative 5 (refer to Section 7.6.4). However, as shown on Figure 7-8, neutralization trenches would not be needed in some areas where mercury-impacted soils are removed. A total trench length of approximately 3,900 feet is assumed in this alternative. Approximately 6,500 cubic yards of soil would be excavated during the trench construction, and the trenches would accommodate roughly 5,300 tons of ferrous sulfate heptahydrate.

7.8.3 Alternative 7 Institutional Controls

Institutional controls would be implemented as described for Alternative 1 (refer to Section 7.2.7). Because all soils exceeding cleanup levels would be removed, a much smaller portion of the RAU would be subject to institutional controls relative to those in

Alternatives 1 through 6 (i.e., institutional controls would focus on groundwater exceedance areas).

7.8.4 Alternative 7 Groundwater MNA and Contingency Actions

Groundwater MNA would be conducted as described for Alternative 1 (refer to Section 7.2.8).

7.8.5 Alternative 7 Implementation and Restoration Time Frames

Removal of the very large volume of Fill Unit soils and import of a similar volume of clean backfill in this alternative is estimated to increase the remedy implementation time frame to the range of 3 to 4 years.

Assuming a standard point of compliance for groundwater, a restoration time frame of 34 years is estimated for Alternative 7. Modeling results indicate that naphthalene is the limiting contaminant (refer to Appendix D).

7.8.6 Alternative 7 Estimated Cost

The total cost for Alternative 7 is estimated at approximately $64 million. Major construction cost components include $14.5 million for *ex-situ* treatment/removal of soils containing visible elemental mercury, $37 million for removal of all other soils exceeding cleanup levels, and $6.5 million for neutralization of groundwater. Table A-8 in Appendix A includes the detailed cost estimate assumptions for Alternative 7.

7.9 Alternative 8 Description

Alternative 8, the most aggressive remedial alternative considered in this FS, is similar to Alternative 7, with the addition of active treatment of groundwater in selected areas of the RAU that were designated for MNA in Alternatives 1 through 7. The primary objective of considering active groundwater treatment in these areas is to reduce the cleanup's restoration time frame. Alternative 8 includes the following remedial components:

- Prior cleanup actions;
- Removal of all soils exceeding cleanup levels;
- Neutralization of groundwater in areas where groundwater pH exceeds 8.5;
- *In-situ* treatment of mercury-impacted Fill Unit groundwater outside the areas where groundwater pH exceeds 8.5;
- *In-situ* treatment of PAH-impacted groundwater;
- Institutional controls; and
- MNA for residual impacted groundwater, with contingency actions to be evaluated/implemented in the event that the remedy is insufficiently protective of the marine environment.

Refer to Section 3 for descriptions of prior cleanup actions. The other components of Alternative 8 are depicted on Figure 7-9 and described in the following subsections.

7.9.1 Alternative 8 Removal of All Soils Exceeding Cleanup Levels

Fill Unit soils with contaminant concentrations that exceed the corresponding soil cleanup levels would be excavated, characterized, and disposed of off-site as described for Alternative 7 (refer to Section 7.8.1).

7.9.2 Alternative 8 Neutralization of Groundwater in Areas Where Groundwater pH Exceeds 8.5

Groundwater neutralization would be conducted as described for Alternative 5 (refer to Section 7.6.4). The total neutralization trench length, volume of soil excavated during the trench construction, and amount of ferrous sulfate placed in the trenches are assumed to be the same as in Alternative 7 (refer to Section 7.8.2).

7.9.3 Alternative 8 In-Situ Treatment of Mercury-Impacted Fill Unit Groundwater Outside the Areas Where Groundwater pH Exceeds 8.5

Active treatment of dissolved mercury using an *in-situ* precipitation/immobilization technology would be applied in this alternative to Fill Unit groundwater exceedance areas (i.e., areas where the dissolved mercury concentration exceeds the groundwater cleanup level) located outside areas of soil removal and groundwater neutralization. For purposes of evaluation in this FS, a PRB filled with ZVI is the assumed specific technology option. Similar to the neutralization trenches installed in areas where groundwater pH exceeds 8.5, PRBs are assumed to be installed roughly perpendicular to the groundwater flow direction and spaced approximately 60 feet on-center. The total length of the PRB segments depicted on Figure 7-9 is approximately 3,100 feet. Assuming the PRBs are 2 feet wide and extend to the aquitard, with a ZVI/sand mixture (50/50 percent by weight) occupying the bottom 13 feet, their construction would involve excavating roughly 4,150 cubic yards of soil and placing 2,400 tons of ZVI. A portion of the excavated soil would be used as backfill above the ZVI/sand mixture, and residual soil would be disposed of off-site. Refer to Sheet B-4 in Appendix B for additional treatment design assumptions and calculations.

The assumed treatment design is expected to result in dissolved mercury exiting the PRBs at concentrations below the groundwater cleanup level. Further, the initial application of ZVI is assumed to be sufficient to achieve the cleanup level throughout the treatment area. However, pre-design testing would be required to confirm performance. A plan would be developed and implemented for monitoring the performance of the PRBs. O&M costs associated with the PRBs are assumed to be negligible.

7.9.4 Alternative 8 In-Situ Treatment of PAH-Impacted Groundwater

Active *in-situ* treatment of dissolved PAHs using enhanced aerobic bioremediation technology would be applied in this alternative to Fill Unit groundwater with PAH concentrations that exceed corresponding cleanup levels (for naphthalene and cPAHs). For purposes of evaluation in this FS, injection of Oxygen-Releasing Compound® (ORC) supplied by Regenesis is the assumed specific technology option. ORC would be pressure-injected within the PAH plume, which is estimated to cover an area of approximately 2.4 acres, using a direct-push probe rig. As shown on Figure 7-9, injections are assumed to occur at 20-foot spacing along rows that are oriented perpendicular to the groundwater flow direction and spaced at 60-foot intervals. On this basis, there would be a total of 91 injection locations, and 30 pounds of ORC is assumed to be injected at each location. Refer to Sheet B-5 in Appendix B for additional treatment design assumptions and calculations.

Prior to the injection, supplemental groundwater investigation would be required to better delineate the extent of the PAH plume. A single ORC injection event as outlined above is assumed to be sufficient to achieve PAH cleanup levels throughout the PAH plume. However, a plan would be developed and implemented for monitoring the performance of the injection, which would include contingency measures (e.g., follow-up injections) to be implemented in the event that the treatment objective is not achieved following the first injection event.

7.9.5 Alternative 8 Institutional Controls

Institutional controls would be implemented as described for Alternative 1 (refer to Section 7.2.7). Because all soils exceeding cleanup levels would be removed, a much smaller portion of the RAU would be subject to institutional controls compared to Alternatives 1 through 6 (i.e., institutional controls would focus on groundwater exceedance areas).

7.9.6 Alternative 8 Groundwater MNA and Contingency Actions

Groundwater MNA would be conducted in this alternative for Fill Unit groundwater with cleanup level exceedances for miscellaneous dissolved metals (including arsenic, chromium, copper, and nickel) and for mercury exceedances in Lower Sand groundwater. A groundwater monitoring plan would be prepared as described for Alternative 1 (refer to Section 7.2.3), which would include contingency actions to be considered for implementation if MNA fails to achieve the expected groundwater restoration and is determined to be insufficiently protective of the marine environment.

7.9.7 Alternative 8 Implementation and Restoration Time Frames

It is assumed that installation of the PRBs and neutralization trenches in this alternative could be completed simultaneously with removal of Fill Unit soils and import of clean backfill. Therefore, the remedy implementation time frame is expected to be in the same range as that for Alternative 7 (i.e., 3 to 4 years).

Assuming a standard point of compliance for groundwater, a restoration time frame of 10 years is estimated to achieve the groundwater cleanup level for mercury (refer to Appendix C). Active treatment of the PAH plume in this alternative was not modeled but was assumed to reduce naphthalene concentrations to below the groundwater cleanup level in less than 10 years.

7.9.8 Alternative 8 Estimated Cost

The total cost for Alternative 8 is estimated at approximately $70 million. Major construction cost components include $14.5 million for *ex-situ* treatment/removal of soils containing visible elemental mercury, $37 million for removal of all other soils exceeding cleanup levels, $6.5 million for neutralization of groundwater, and $6.4 million for treatment of mercury-impacted groundwater outside areas of soil removal and groundwater neutralization. Table A-9 in Appendix A includes the detailed cost estimate assumptions for Alternative 8.

8 Evaluation of Remedial Alternatives

The eight remedial alternatives described in Section 7 are evaluated with respect to MTCA criteria in this section.

8.1 Feasibility Study Evaluation Criteria

This section reviews the minimum requirements and procedures for selecting cleanup actions under MTCA (WAC 173-340-360).

8.1.1 MTCA Threshold Requirements

Cleanup actions selected under MTCA must meet four "threshold" requirements identified in WAC 173-340-360(2)(a) to be accepted by Ecology. All cleanup actions must:

- Protect human health and the environment;
- Comply with cleanup standards;
- Comply with applicable state and federal laws; and
- Provide for compliance monitoring.

8.1.2 MTCA Selection Criteria

When selecting from remedial alternatives that meet the threshold requirements, the following three criteria, identified in WAC 173-340-360(2)(b), must be evaluated:

- **Use permanent solutions to the maximum extent practicable.** A DCA is conducted to assess the extent to which each remedial alternative meets this criterion. The general procedure for conducting a DCA is described in Section 8.1.3.
- **Provide a reasonable restoration time frame.** MTCA places a preference on remedial alternatives that can be implemented in a shorter period of time. Factors to be considered in evaluating whether an alternative provides for a reasonable restoration time frame (per WAC 173-340-360(4)(b)) are listed in Table 9-1.
- **Consider public concerns.** Consideration of public concerns is an inherent part of the Site cleanup process under MTCA. This Draft FS report will be issued for public review and comment, and Ecology will determine whether changes to the report are needed in response to public comments.

8.1.3 MTCA Disproportionate Cost Analysis

A DCA is conducted to determine whether a cleanup action uses permanent solutions to the maximum extent practicable. It evaluates the relative benefits and costs of remedial alternatives. Seven criteria are considered in the evaluation as specified in WAC173-340-360(3)(f):

- **Protectiveness –** overall protectiveness of human health and the environment, including the degree to which existing site risks are reduced, time required to reduce the risks and attain cleanup standards, on-site and off-site risks during implementation, and improvement in overall environmental quality.

- **Permanence –** degree to which the alternative reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of destroying hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of treatment, and the characteristics and quantity of the treatment residuals.
- **Cost –** Remedy design, construction, and long-term O&M costs to implement the alternative.
- **Long-term effectiveness –** degree of certainty that the alternative will successfully and reliably address contamination that exceeds applicable cleanup levels until cleanup levels are attained, the magnitude of the residual risk with the alternative in place, and the effectiveness of controls to manage treatment residue and remaining wastes.
- **Short-term risk management –** risks to human health and the environment during construction and implementation of the alternative, and the effectiveness of measures that will be implemented to manage such risks.
- **Implementability –** technical feasibility of the alternative; availability of necessary off-site facilities, services, and materials; administrative and regulatory requirements; scheduling, size, and complexity of the alternative; monitoring requirements; access for construction, operations, and monitoring; and integration with existing facility operations and other current or potential remedial actions. This FS also considers the impact to and integration with future redevelopment planned under the Waterfront District Subarea Plan (Port/City, 2012).
- **Consideration of public concerns –** concerns of individuals, community groups, local governments, tribes, federal and state agencies, and other interested organizations are addressed by Ecology's responses to public comments on the Draft Final FS report and the subsequent Draft CAP.

The DCA is based on a comparative evaluation of an alternative's cost against the other six criteria (environmental benefits). Per WAC 173-340-360(3)(e)(i), cost is disproportionate to benefits if the incremental cost of an alternative over that of a lower cost alternative exceeds the incremental degree of benefits achieved by the alternative over that of the lower cost alternative.

8.2 Evaluation with Respect to MTCA Threshold Requirements

The remedial alternatives are evaluated for compliance with the MTCA threshold criteria in this section.

8.2.1 Protection of Human Health and the Environment

All eight alternatives would be protective of human health and the environment. All alternatives rely to some extent on MNA of groundwater contamination (with groundwater compliance monitoring and contingency actions included in case the MNA remedy is determined to be insufficiently protective) and institutional controls (described in Sections 6.2 and 7.2.6) to achieve protectiveness. In addition, Alternatives 1 through 6 rely to a greater or lesser extent on capping of contaminated soils. Active treatment/removal components are added in successive alternatives to remediate contaminated media in specific areas of the RAU so that there is less reliance on groundwater MNA, institutional controls, and capping to achieve protectiveness. Alternatives 1 through 3 include removal of TPH-impacted soils in the southeast corner of the Cell Building and soils in the northern portion of the wastewater settling basin with mercury concentrations above 300 mg/kg. Soils containing visible elemental mercury are also actively addressed, in ways that are progressively more aggressive (ISS of readily accessible soils in Alternative 1; ISS following aggressive removal of obstructions in Alternative 2; and full removal in Alternative 3). Alternatives 4 and 5 are similar to Alternative 2 but also include neutralization of groundwater with elevated pH (in areas of pH >10 in Alternative 4, and pH >8.5 in Alternative 5). Alternative 6 is similar to Alternative 5 but includes removal of all soils with mercury concentrations greater than 100 mg/kg (to prevent leaching to groundwater). All remaining soils with contaminant concentrations above cleanup levels are removed in Alternative 7 (so that capping is no longer required), and Alternative 8 adds active treatment of groundwater plumes for selected contaminants (PAHs and mercury without elevated pH in Fill Unit groundwater).

8.2.2 Compliance with Cleanup Standards

All eight alternatives would achieve compliance with cleanup standards. Compliance with the cleanup standards for soil, groundwater, and air is discussed separately in the following subsections.

8.2.2.1 Compliance with Soil Cleanup Standards

Alternatives 7 and 8 comply with soil cleanup standards by removing from the RAU all soils exceeding soil cleanup levels. Alternatives 1 through 6 comply by implementing a combination of containment and removal of soils exceeding cleanup levels. Previous solidification and capping of mercury-contaminated sludge in the Chemfix area, ISS of soils containing visible elemental mercury, and capping of other contaminated soils provide barriers against human direct contact and terrestrial ecological exposures and prevent release to the environment via soil erosion, thereby satisfying the MTCA definition of “containment.” Per WAC 173-340-355(2), a cleanup action involving containment of soils exceeding cleanup levels at the point of compliance may be determined to comply with cleanup standards, provided the requirements specified in WAC 173-340-740(6)(f) are met:[27]

- The selected remedy is permanent to the maximum extent practicable.
- The cleanup action is protective of human health and terrestrial ecological receptors.
- Institutional controls are put in place that prohibit or limit activities that could interfere with the long-term integrity of the containment system.
- Compliance monitoring and periodic reviews are designed to ensure the long-term integrity of the containment system.

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[27] The requirements of WAC 173-340-740(6)(f) are paraphrased here; refer to the MTCA regulation for the complete language.

- The types, levels, and amounts of hazardous substances remaining on-site and the measures that will be used to prevent migration and contact with those substances are specified in the Draft CAP.

Alternatives 1 through 6 would be designed and implemented such that the above requirements are met. Therefore, these alternatives would comply with soil cleanup standards upon completion of remedy construction.

8.2.2.2 Compliance with Groundwater Cleanup Standards

As listed in Table 7-3, time frames for achieving groundwater cleanup levels throughout the aquifer (the standard point of compliance) range from 10 years (Alternative 8) to greater than 100 years (Alternatives 1, 2, and 3). However, compliance with groundwater cleanup standards would be achieved in the interim by putting in place institutional controls addressing groundwater contamination. As described in Section 6.2, an environmental covenant will be prepared, likely as a component of the Consent Decree for the RAU cleanup. The institutional controls addressing groundwater contamination will remain in place indefinitely unless and until removal is approved by Ecology.

Conditional points of compliance for groundwater are evaluated in Section 9.

8.2.2.3 Compliance with Air Cleanup Standards

Elemental mercury and naphthalene are volatile contaminants within the RAU. For alternatives that do not fully treat (via ISS) or remove elemental mercury, or that leave naphthalene concentrations that exceed cleanup levels in soil or groundwater, compliance with air cleanup standards would be achieved by putting in place an institutional control requiring that VI potential be evaluated and/or VI controls be constructed beneath future buildings in the immediate vicinity of the affected areas. As described in Section 6.2, an environmental covenant will be prepared, likely as a component of the Consent Decree for the RAU cleanup. The institutional control requiring evaluation/control of VI will remain in place indefinitely unless and until removal is approved by Ecology.

8.2.3 Compliance with Applicable State and Federal Laws

The remedial alternatives were specifically developed to comply with the MTCA regulation. Other ARARs identified and discussed in Section 5.6 were considered in developing remedial alternatives. The eight alternatives are expected to comply with all ARARs because the required engineering design and agency review process would include steps to ensure compliance. The ARARs may affect implementation, but they would not have a significant effect on whether a remedial alternative is fundamentally viable. The means of compliance with ARARs would be documented in the remedial design, remedial action work plan components, and other preconstruction documentation to be prepared during design.

8.2.4 Provisions for Compliance Monitoring

All eight alternatives would provide for compliance monitoring. Health and safety protocols outlined in a site-specific health and safety plan (required in all alternatives) would provide protection monitoring. Alternatives involving soil excavation would also include soil quality monitoring to guide excavations and confirm that performance objectives associated with the soil removal actions were met. Periodic groundwater sampling and analysis would provide both performance and confirmation monitoring in all alternatives.

8.2.5 Conclusion Regarding Compliance with Threshold Requirements

Based on the above evaluation, Alternatives 1 through 8 are all expected to comply with the MTCA threshold criteria. Therefore, all eight alternatives were carried forward to the next stage of evaluation.

8.3 Disproportionate Cost Analysis

As described in Section 8.1.3, a DCA is performed to evaluate whether a cleanup action uses permanent solutions to the maximum extent practicable. The DCA quantifies the environmental benefits of each remedial alternative and then evaluates the alternative's benefits versus costs. Costs are disproportionate to benefits if the incremental cost of a more permanent alternative over that of a lower cost alternative exceeds the incremental benefits achieved by the alternative over that of the lower cost alternative. Alternatives that exhibit disproportionate costs are considered "impracticable" under MTCA.

The DCA is described in the following subsections and summarized in Table 8-1.

Environmental benefit is quantified by first rating the alternatives with respect to each of the six criteria discussed in Section 8.1.3. Rating values are assigned on a scale of 1 to 10, where 1 indicates the criterion is satisfied to a very low degree, and 10 indicates the criterion is satisfied to a very high degree. Ecology does not consider the criteria to be of equal importance; therefore, each criterion is assigned a "weighting factor." Consistent with FSs and CAPs conducted on other Bellingham Bay cleanup sites and on the Pulp/Tissue Mill RAU portion of this Site, weighting factors are assigned as follows:

- Overall protectiveness: 30 percent;
- Permanence: 20 percent;
- Long-term effectiveness: 20 percent;
- Short-term risk management: 10 percent;
- Implementability: 10 percent; and
- Consideration of public concerns: 10 percent.

A MTCA benefits ranking is then obtained for each alternative by multiplying the six rating values by their corresponding weighting factors and summing the weighted values. Finally, the benefits ranking of each alternative is divided by the alternative's estimated cost to obtain a benefit/cost ratio, which is a relative measure of the cost effectiveness of the alternative.

8.3.1 Overall Protectiveness

All of the remedial alternatives would be protective of human health and the environment, but they vary in terms of the technologies used to achieve that protectiveness. Alternative 1 would address the human direct contact and terrestrial ecological exposure pathways, as well as the potential for soil erosion, primarily through *in-situ* containment of contaminated soils (via capping) with institutional controls. *In-situ* treatment of soils containing elemental mercury, removal of TPH-impacted soils, and groundwater containment in the Chlorine Plant Area would reduce the potential for VI, groundwater plume migration, and direct contact exposure. However, only a portion of the impacted soils would be accessible for *in-situ* treatment, so concerns associated with elemental mercury would remain (but to a lesser degree).

Protection of the vapor inhalation pathway would be achieved by requiring that VI potential be evaluated and/or VI controls be constructed beneath future buildings in the immediate vicinity of the Chlorine Plant Area (for mercury vapor) and where soil and groundwater cleanup levels are exceeded for naphthalene. The potential for mercury-impacted groundwater to migrate to the former Log Pond would be reduced through removal of mercury-impacted soil from the northern portion of the wastewater settling basin. Protection of benthic and aquatic organisms in Bellingham Bay and Whatcom Waterway would be confirmed through confirmation monitoring at the shoreline, and the monitoring would be integrated with the confirmation monitoring associated with the Whatcom Waterway cleanup site (per Anchor QEA, 2013). If a cleanup level exceedance is detected, active remedial measures would be considered for implementation in accordance with a contingency plan.

Alternatives 2 through 6 would also rely on capping with institutional controls and groundwater compliance monitoring, but they would include additional remedial components that would increase overall protectiveness in various ways. In Alternatives 2, 4, and 5, elemental mercury would be more comprehensively treated *in situ* than in Alternative 1 because aggressive measures would be implemented to first remove subsurface obstructions (e.g., piles). As a result, institutional controls addressing VI may not be needed. In Alternatives 3 and 6 (as well as Alternatives 7 and 8), soils with elemental mercury would be treated *ex situ* and disposed of off-site. Off-site disposal of treated soil is not inherently more protective than *in-situ* treatment, but it provides a higher level of certainty that protectiveness will be maintained in the long term.

Beginning with Alternative 4, long-term reliance on institutional controls would be further reduced through neutralization of groundwater in areas of elevated pH (within the Caustic Core in Alternative 4, and within the larger area where groundwater pH exceeds 8.5 in Alternatives 5 through 8). Alternative 6 would achieve increased protectiveness relative to Alternative 5 because the scope of soil removal would be increased to include all soils with leachable mercury.

All contaminated Fill Unit soils would be removed from the RAU in Alternative 7 so that capping would not be necessary. This would increase protectiveness relative to Alternative 6 by eliminating exposure concerns with respect to direct contact. Protectiveness with respect to groundwater would also increase in Alternative 7 because soils with leachable naphthalene would be removed. The PAH plume and dissolved mercury in neutral-pH areas would be actively treated in Alternative 8. This would increase protectiveness relative to Alternative 7 by reducing reliance on MNA.

Based on these considerations, the remedial alternatives were given overall protectiveness ratings in the range of 2 (for Alternative 1) to 10 (for Alternative 8). Refer to Table 8-1 for the alternative-specific ratings and summary justifications.

8.3.2 Permanence

In Alternative 1, containment and partial soil treatment in the Chlorine Plant Area would reduce mercury mobility via both dissolution to groundwater and volatilization to soil vapor. Removal of mercury-impacted soil from the northern portion of the wastewater settling basin would reduce mercury leaching and remove mercury mass from the RAU.[28] Capping would reduce potential mobility of soil contamination via erosion. Natural attenuation would be relied upon to reduce groundwater pH in areas where it is currently elevated, which, in turn, would reduce mercury mobility (because dissolved mercury tends to precipitate as groundwater pH approaches more neutral conditions). Concentrations of organic contaminants (e.g., TPH in soil and naphthalene in soil and groundwater associated with the Million Gallon Tanks subarea) are also expected to attenuate naturally over time.

Alternatives 2, 4, and 5 would offer somewhat increased permanence in the Chlorine Plant Area relative to Alternative 1 because soils with visible elemental mercury would be more completely treated via ISS, thereby further reducing the potential for mercury mobility in groundwater and soil vapor. Alternatives 3, 6, 7, and 8 would be significantly more permanent, because soils with visible elemental mercury would be removed from the RAU rather than stabilized and left on-site. The benefit accrued through removal and off-site disposal of contaminated soils would be greater in Alternative 6 than in Alternative 3 due to removal of soils with leachable mercury. Likewise, Alternatives 7 and 8 are considered more permanent than Alternative 6 because all soils exceeding cleanup levels would be removed.

Beginning with Alternative 4, neutralization of groundwater would permanently reduce elevated groundwater pH, as well as mercury mobility in affected areas of the RAU. Alternatives 5 through 8 would offer a greater benefit in this regard than Alternative 4 due to the broader application of groundwater neutralization in those alternatives.

Based on these considerations, the remedial alternatives were given permanence ratings in the range of 1 (for Alternative 1) to 10 (for Alternative 8). Refer to Table 8-1 for the alternative-specific ratings and summary justifications.

8.3.3 Long-Term Effectiveness

The degree to which a remedial alternative relies on institutional controls to achieve protectiveness is an important factor in evaluating its long-term effectiveness. There are long-term challenges associated with ensuring that institutional controls are adequately implemented, monitored, and enforced at cleanup sites. These challenges may be accentuated within the RAU, where redevelopment plans call for constructing public roadways and utility infrastructure, subdividing the RAU into multiple parcels, and recording cleanup-required institutional controls on property deeds of the individual land owners. In general, alternatives that treat or remove contamination are considered more effective in the long term than those that rely on compliance with institutional controls to reduce the potential for long-term exposure. In this regard, long-term effectiveness increases with each successive alternative.

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[28] Contaminated soil removal with landfill disposal is considered a permanent solution with respect to remediating environmental conditions at a site. However, it does not reduce contaminant toxicity or volume (although some contaminants may continue to naturally attenuate in the landfill).

The degree to which an alternative relies on remedial components that isolate contaminants from the environment or from specific receptors is another important consideration in assessing its long-term effectiveness. These include caps (in Alternatives 1 through 6), *in-situ* treatment of soils containing elemental mercury (in Alternatives 1, 2, 4, and 5), and containment of mercury-impacted groundwater (in Alternative 1). The continued effectiveness of these components depends on their long-term integrity.

The long-term effectiveness of Alternative 1 is heavily dependent on the continued enforcement of institutional controls and the long-term integrity of the remedial components noted in the previous paragraph. Alternatives 2, 4, and 5 would have increased long-term effectiveness in the Chlorine Plant Area relative to Alternative 1 due to reduced concerns with respect to VI and mercury migration (because soils with visible elemental mercury are more completely treated via ISS). The long-term benefits of Alternatives 2 and 3 are expected to be similar, but Alternative 3 ranks higher because the long-term effectiveness of soil removal is more certain than leaving stabilized soils *in situ*. The benefit accrued through removal of contaminated soil is successively greater in Alternatives 3, 6, and 7 because the volumes of removed soil increase.

Alternatives 4 through 8 would have increased long-term effectiveness relative to Alternatives 1, 2, and 3 because active neutralization of groundwater would reduce long-term reliance on institutional controls (more so in Alternatives 5 through 8 than in Alternative 4). Similarly, Alternative 8 would be most effective in the long term with respect to groundwater remediation, due to its aggressive treatment of contaminated groundwater (versus MNA in the other alternatives).

Based on these considerations, the remedial alternatives were given long-term effectiveness ratings in the range of 1 (for Alternative 1) to 10 (for Alternative 8). Refer to Table 8-1 for the alternative-specific ratings and summary justifications.

8.3.4 Short-Term Risk Management

This criterion relates to the effects and potential risks associated with remedial alternative implementation, considering the protection of workers, protection of the community, and potential impacts on the environment. In general, short-term impacts increase with construction duration and the quantities of contaminated materials that are removed or handled. (Refer to Table 7-3 for estimates of construction quantities and duration for each remedial alternative.) Although many impacts can be adequately managed through standard construction practices such as health and safety programs and best management practices, the potential for worker injuries, human exposures, or releases to the environment would increase with longer construction periods and handling of greater volumes of contaminated materials. In addition, several impacts would be difficult to control, including the following:

- Mercury vapor emissions from disturbance of materials contaminated with visible elemental mercury during excavation and *in-situ* treatment of soils in the Chlorine Plant Area;
- Naphthalene vapor emissions during soil removal in the Million Gallon Tanks subarea (Alternatives 7 and 8); and

- Impacts on the local community due to construction noise, traffic, and degraded aesthetics.

Short-term risks associated with Alternative 1 are expected to be relatively minor and due primarily to large rotating equipment and other general construction hazards. Risks associated with work in the Chlorine Plant Area could increase significantly in Alternative 2 due to the labor-intensive process of removing obstructions (e.g., piles) to the depth of the aquitard prior to *in-situ* treatment of soils, an activity also common to Alternatives 4 and 5. Treating these soils *ex situ* would allow a more closely controlled process, thereby reducing the potential for worker exposure to contamination and physical hazards. Therefore, treatment of soils with visible elemental mercury in Alternatives 3, 6, 7, and 8 should carry less risk than in Alternatives 2, 4, and 5 (but more than in Alternative 1).

Compared to Alternative 2, Alternatives 4 and 5 would pose greater risk of contaminant exposure for construction workers, because the neutralization trenches would be constructed in an area where both groundwater pH and dissolved mercury concentrations are elevated. Because the total trench length is greater in Alternative 5, the risks would be greater than those in Alternative 4.

Short-term risks increase in going from Alternative 5 to Alternative 6 to Alternative 7 because successively larger volumes of contaminated soil would be excavated; the excavation volume in Alternative 7 would represent a major earthwork construction project. Risks would also be greater in Alternative 8 relative to Alternative 7 due to construction of PRBs in areas where groundwater is marginally impacted by mercury.

Based on these considerations, the remedial alternatives were given short-term risk management ratings in the range of 1 (for Alternative 8) to 9 (for Alternative 1). Refer to Table 8-1 for the alternative-specific ratings and summary justifications.

8.3.5 Implementability

In general, implementability decreases with increased complexity of the alternatives. Treatment of Chlorine Plant Area soils containing elemental mercury, along with the associated removal of obstructions (e.g., piles) in Alternatives 2 through 8, is expected to be the most technically challenging remedial component. Among the three treatment strategies proposed, *ex-situ* treatment of soils (Alternatives 3, 6, 7, and 8) was demonstrated in the 2013-2014 interim action and would likely be the most implementable; nonetheless, challenges associated with pile removal would be significant. *In-situ* treatment of accessible soils (Alternative 1) would likely be most difficult to implement due to challenges associated with advancing large-diameter augers between closely spaced piles. Removing the piles prior to *in-situ* soil treatment (Alternatives 2, 4, and 5) would improve the implementability, but, as previously noted, pile removal has its own challenges.

For these reasons, the three alternatives with the most modest scopes (i.e., Alternatives 1 through 3) are rated in reverse order with respect to implementability; that is, Alternative 3 is expected to be easier to implement than Alternative 2, which would be easier to implement than Alternative 1. Alternative 4 would have a somewhat lower implementability than Alternative 2 due to design challenges associated with neutralization of groundwater with elevated pH. The technical implementability of Alternative 5 would be similar to that of Alternative 4, but it would be more difficult to implement administratively because the neutralization trenches would extend onto property owned by the Washington

State Department of Natural Resources (DNR), west of the Inner Harbor Line (refer to Figure 7-6).

The implementability of Alternative 6 is expected to be similar to that of Alternative 5 because, although the volume of impacted soils to be removed is much larger, *ex-situ* treatment of soils containing elemental mercury in Alternative 6 is more straightforward than *in-situ* treatment in Alternative 5.

Alternatives 7 and 8 would be considerably more difficult to implement than Alternative 6 due to the large quantities of contaminated soils to be removed, including previously stabilized sludge from the Chemfix area. Alternative 8 would be somewhat more difficult to implement than Alternative 7 because it would use PRBs to treat mercury-impacted groundwater. In addition to technical challenges associated with PRB design, there would likely be increased administrative challenges associated with the much larger encroachment onto DNR property (refer to Figure 7-9).

Based on these considerations, the remedial alternatives were given implementability ratings in the range of 1 (for Alternative 8) to 8 (for Alternative 3). Refer to Table 8-1 for the alternative-specific ratings and summary justifications.

8.3.6 Consideration of Public Concerns

Ecology provided preliminary ratings for this criterion for the purpose of the DCA in the Draft Final FS, ranging from 2 (for Alternative 1) to 10 (for Alternative 8). Ecology subsequently considered and responded to all public comments received on the Draft Final FS. The ratings for consideration of public concerns, which are shown in Table 8-1, did not change based on those comments.

8.3.7 Benefits Rankings, Estimated Costs, and Benefit/Cost Ratios

The MTCA benefits rankings, estimated costs, and benefit/cost ratios for the eight remedial alternatives are presented at the bottom of Table 8-1 and graphically on Figure 8-1. As previously noted, the MTCA benefits ranking for each alternative is obtained by multiplying the rating values assigned for the six evaluation criteria by their corresponding weighting factors and summing the weighted values. The benefit rankings range from a low of 2.7 for Alternative 1 to a high of 8.2 for Alternative 8.

The estimated costs for Alternatives 1 through 5 range from $12.2 million (Alternative 1) to $24.2 million (Alternative 5). The estimated costs for alternatives 6 through 8 are markedly higher, primarily because they include excavation and off-site disposal of much greater quantities of contaminated soils. Alternative 6 ($39.1 million) includes soils with mercury concentrations greater than 100 mg/kg (except for treated sludge in the Chemfix area) and Alternative 7 ($63.8 million) includes all soils exceeding cleanup levels. The estimated cost for Alternative 8 is the highest ($69.8 million) because it includes the same soil removal as Alternative 7 plus *in-situ* treatment of Fill Unit groundwater impacted by mercury and PAHs.

The benefit/cost ratio, which is a relative measure of cost effectiveness, is obtained by dividing the benefits ranking for each alternative by its estimated cost. As listed in Table 8-1 and depicted on Figure 8-1, the calculated benefit/cost ratios range from a low of 0.12 for Alternatives 7 and 8 to a high of 0.28 for Alternative 4.

8.3.8 Disproportionate Cost Analysis Conclusion

Based on the results of the DCA provided in Section 8.3.7, Alternative 4 is the most cost effective of the eight remedial alternatives evaluated in this FS. Therefore, under MTCA, **Alternative 4 is identified as the alternative that is permanent to the maximum extent practicable.**

9 Evaluation of Groundwater Point of Compliance under Alternative 4

The remedial alternatives were developed and evaluated assuming the MTCA-default standard point of compliance for groundwater (i.e., groundwater cleanup levels based on marine protection must be achieved throughout the Chlor-Alkali RAU). However, per WAC 173-340-720(8)(c), Ecology may approve a conditional point of compliance for groundwater under the following conditions:

- All practicable methods of treatment are to be used in the site cleanup.
- It is not practicable to meet groundwater cleanup levels at the standard point of compliance within a reasonable restoration time frame.

This section evaluates the appropriateness of different point(s) of compliance for groundwater under Alternative 4 (the remedial alternative determined by the DCA to be permanent to the maximum extent practicable). The evaluation is performed by first demonstrating that Alternative 4 uses all practicable methods of treatment and then evaluating restoration time frames under alternative point-of-compliance scenarios. Based on the evaluation, the most appropriate groundwater point(s) of compliance are identified.

9.1 Demonstration that All Practicable Methods of Treatment are to be Used

The eight remedial alternatives developed and evaluated in this FS incorporate the applicable known, available, and reasonable methods of groundwater treatment for the COCs within the RAU. Based on the comparative evaluation of protectiveness, permanence, long-term effectiveness, short-term risk management, implementability, consideration of public concerns, and cost, the DCA determined that Alternative 4 would be permanent to the maximum extent practicable. Therefore, Alternative 4 meets the requirement that all practicable methods of treatment will be used in cleaning up the RAU. Under Alternative 4, substantial source control has been accomplished by the two interim actions, and substantial additional source control will be accomplished using a combination of treatment and removal of soil serving as a source of groundwater contamination.

9.2 Evaluation of Restoration Time Frame under Alternative Point-of-Compliance Scenarios

WAC 173-340-360(4)(b) provides a list of nine factors to be considered in determining whether a cleanup action provides for a reasonable restoration time frame. Table 9-1 lists those factors and provides a brief summary of current conditions in the RAU and anticipated future conditions under Alternative 4 with respect to the factors.

Neither the MTCA regulation nor Ecology written policy provides specific guidelines for rating the reasonableness of restoration time frames. Based on groundwater modeling performed during the FS for the Pulp/Tissue Mill RAU portion of this Site (Aspect, 2014c), the remedial alternative selected by Ecology and currently under construction was estimated to have a restoration time frame of up to 36 years.

Restoration time frames were estimated for Alternative 4 under the following point-of-compliance scenarios:

- Standard point of compliance;
- Conditional points of compliance at the property boundary; and
- Conditional points of compliance at the shoreline.

The estimated time frames for these scenarios are discussed in the following subsections.

9.2.1 Standard Point of Compliance

As stated in Section 7.5.8, a restoration time frame of 74 years is estimated for Alternative 4 when a standard point of compliance for groundwater is assumed, where achieving the groundwater cleanup level for mercury is limiting. Ecology is unlikely to consider this a reasonable restoration time frame. Therefore, per WAC 173-340-720(8)(c), Ecology may approve conditional point(s) of compliance for groundwater.

9.2.2 Conditional Points of Compliance at Property Boundary

This section considers establishing conditional points of compliance for groundwater at the downgradient boundaries of the Port's property. Groundwater plumes in the Chlor-Alkali RAU migrate in the northerly and westerly directions. The RAU abuts the Whatcom Waterway at the Log Pond to the north and Bellingham Bay to the west. The Port's property boundary corresponds with the RAU boundary to the north. Therefore, the northerly point of compliance under this scenario is the Log Pond shoreline. The point of exposure at the Log Pond shoreline (for which the marine-based groundwater cleanup levels are based) is the sediment bioactive zone[29] (i.e., upper 12 cm below sediment mudline, as defined for the Whatcom Waterway cleanup project).

To the west, property owned by the State of Washington lies between Port property and Bellingham Bay. The Inner Harbor Line (shown on Figure 7-5) represents the boundary between the Port- and state-owned properties and is, therefore, the westerly point of compliance under this scenario. DNR manages all state aquatic lands, including filled lands seaward of the Inner Harbor Line; the property west of the Inner Harbor Line is hereafter referred to as DNR property. The Port manages the DNR property under a Port Management Agreement (PMA) with DNR.

As detailed in Appendix C, a restoration time frame of 55 years is estimated for Alternative 4 under this scenario, where achieving the groundwater cleanup level for mercury in the caustic plume at the Inner Harbor Line is limiting. (Monitoring data indicate that groundwater cleanup levels are currently achieved in the sediment bioactive zone at the Log Pond shoreline; see Section 4.7.2.) Based on Ecology precedent, 55 years is unlikely to be considered a reasonable restoration time frame. Therefore, a scenario that moves the conditional point of compliance beyond the Inner Harbor Line (i.e., off Port property) is considered in Section 9.2.3.

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[29] The Whatcom Waterway Log Pond tidelands immediately offshore of the Law-1 area are owned by the Port; therefore, a groundwater conditional point of compliance established in the sediment bioactive zone would be on Port property.

9.2.3 Conditional Points of Compliance at Shoreline

Under this scenario, the northerly point of compliance (for Law-1 area) would be the same as that described in Section 9.2.2 (i.e., the sediment bioactive zone of the Log Pond shoreline, on Port property), but the westerly point of compliance (for the caustic plume) would be the sediment bioactive zone of the Bellingham Bay shoreline, which is DNR property managed by the Port under the PMA. As is the case at the Log Pond shoreline, monitoring data indicate that groundwater cleanup levels are currently being achieved in the sediment bioactive zone at the Bellingham Bay shoreline. Therefore, under this scenario, restoration with respect to mercury concentrations in groundwater would be achieved in Alternative 4 upon completion of remedy construction (estimated at 2 to 3 years). However, the proposed conditional points of compliance would not apply to naphthalene in the Million Gallon Tanks subarea because the groundwater cleanup level for naphthalene is based on VI risk, which is applicable throughout the RAU (i.e., standard point of compliance). Based on groundwater modeling documented in Appendix D, the restoration time frame for the naphthalene plume in the Million Gallon Tanks subarea is estimated at approximately 34 years. This is essentially the same as the estimated 36-year upper-end restoration time frame for the remedy currently being implemented at the Pulp/Tissue Mill RAU of this Site.

WAC 173-340-720(8)(d)(ii) allows the establishment of a conditional point of compliance on the adjacent DNR property because the contaminant source area of the caustic plume is located on Port-owned property near, but not abutting, surface water. The affected downgradient property owner must agree in writing to the use of a conditional point of compliance on its property.[30] In addition, the requirements of WAC 173-340-720(8)(d)(i) must be met. Those requirements are listed below, along with brief descriptions of how they are currently being met and/or will be met in the future for the caustic plume area:

A. **Contaminated groundwater is entering the surface water and will continue to enter it after implementation of the selected cleanup action.** Groundwater within the caustic plume discharges to Bellingham Bay surface water, and this condition would not change as a result of the remedial alternatives considered in this FS. The collective data indicate that contaminated groundwater has reached shoreline monitoring wells in the RAU but not the sediment bioactive zone or surface water.

B. **It is not practicable to meet the cleanup level at the standard point of compliance, or at a point within the groundwater before it enters surface water, within a reasonable restoration time frame.** Sections 9.1 and 9.2.1 describe why meeting the cleanup levels at the standard point of compliance within a reasonable restoration time frame is impracticable. Ultimately, there is negligible environmental benefit from meeting marine-based groundwater cleanup levels at upland locations; therefore, any incremental cost to remediate dissolved-phase mercury to achieve the stringent cleanup level throughout the mercury source area (hundreds of feet inland from the marine point of exposure) would be disproportionate to the incremental environmental benefit of doing so, relative to less-expensive alternatives. It would, therefore, not be practicable to meet the groundwater cleanup level at the standard point of compliance in any restoration time frame.

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[30] The Port is coordinating with DNR in this regard.

C. **Use of a mixing zone to demonstrate compliance with surface water cleanup levels is not allowed**. The groundwater cleanup levels are protective of marine sediment and surface water. No mixing zone was assumed in establishing the marine-based groundwater cleanup levels, and the cleanup levels would be applied at the proposed conditional point of compliance in the sediment bioactive zone, prior to discharge to surface water.

D. **Groundwater discharges shall be provided with all known available and reasonable methods of treatment (AKART) before being released into surface water.** MTCA equates AKART to "all practicable methods of treatment," i.e., technologies that are available, demonstrated, and applicable to the RAU at reasonable cost (WAC 173-340-200). The Chlor-Alkali RAU cleanup alternative selected by Ecology in accordance with MTCA criteria will be permanent to the maximum extent practicable as determined by means of the MTCA DCA—considering protectiveness, permanence, cost, long-term and short-term effectiveness, implementability, and consideration of public concerns. Therefore, the cleanup alternative selected for the Chlor-Alkali RAU will inherently meet this requirement.

E. **Groundwater discharges shall not result in violations of sediment quality values published in Chapter 173-204 WAC.** The groundwater cleanup levels are protective of marine sediment in addition to marine surface water (see Section 5.3). Therefore, groundwater concentrations meeting cleanup levels at the proposed conditional point of compliance within the sediment bioactive zone would meet this requirement.

F. **Groundwater and surface water monitoring will be conducted to assess long-term performance of the selected cleanup action**. After the FS has been completed and the CAP/Consent Decree for the Chlor-Alkali RAU cleanup action has been issued, a compliance monitoring program—including performance monitoring during the cleanup action and long-term confirmation monitoring after it—will be implemented. The confirmation monitoring approach for the Chlor-Alkali RAU will be integrated with the confirmation monitoring program for the Whatcom Waterway cleanup to ensure that applicable exposure pathways for groundwater discharge, including potential bioaccumulation in the marine environment, are addressed. The confirmation monitoring program for the Whatcom Waterway Phase 1 cleanup includes monitoring of surface and subsurface sediment quality, aquatic organism tissue quality, and sediment porewater quality (Anchor QEA, 2013).

G. **A notice of the proposed conditional point of compliance would be mailed to the natural resource trustees, DNR, and the U.S. Army Corps of Engineers (USACE).** The Port and Ecology are part of the Bellingham Bay Action Team (BBAT), which includes USACE, EPA, U.S. Fish and Wildlife Services, the Washington Department of Fish and Wildlife, DNR, Native American tribes (Lummi Nation and Nooksack Tribe), Whatcom County, City of Bellingham, and a local citizen environmental group. The BBAT meets regularly for stakeholder discussion of habitat projects and cleanup projects, including those related to this Site. The proposed conditional point of compliance would be a component of the

CAP for the Chlor-Alkali RAU, which would be provided to the BBAT for review and comment and also undergo formal public review.

9.3 Conclusion regarding Groundwater Point(s) of Compliance under Alternative 4

Based on the evaluation of the groundwater point of compliance, the proposed conditional points of compliance for the RAU are located in the sediment bioactive zones of the Log Pond to the north and Bellingham Bay to the west. This point-of-compliance scenario is appropriate because it is expected to allow for a reasonable restoration time frame, whereas the other scenarios considered (standard point of compliance and conditional points of compliance at the property boundary) would not. It also would apply the groundwater cleanup levels at the location for which they were specifically developed (point of marine exposure).

Monitoring data indicate that groundwater cleanup levels are currently being achieved in the sediment bioactive zone along both of these shorelines. A robust post-construction confirmation groundwater monitoring program, integrated with the Whatcom Waterway cleanup confirmation monitoring program, would be implemented under Alternative 4 to ensure continued compliance in the future.

10 Preferred Alternative

The RI defined the physical characteristics, source areas, nature and extent of impacted media, and potential contaminant migration pathways at the Site (Aspect, 2013f). Information from the RI and previous investigations was used in this FS to develop and evaluate eight remedial alternatives for the Chlor-Alkali RAU. The alternatives were evaluated with respect to criteria defined by MTCA, including a comparative analysis to determine the relative benefits of each alternative and an evaluation of benefits versus estimated costs to determine the solution that is permanent to the maximum extent practicable.

Alternative 4 was selected as the preferred alternative based on these evaluations. It is described in the following subsections, which also discuss how it will be compatible with the Whatcom Waterway remedial activities.

10.1 Description of Preferred Alternative

The preferred alternative (Alternative 4) includes the following remedial components:

- Prior cleanup actions;
- Removal of wastewater settling basin soils near the Log Pond with mercury concentrations >300 mg/kg;
- Removal of TPH-impacted soils in southeast corner of the Cell Building;
- Aggressive removal of obstructions and *in-situ* treatment of soils containing visible elemental mercury;
- Neutralization of groundwater in the Caustic Core;
- Capping of residual soils exceeding cleanup levels;
- Institutional controls; and
- Groundwater MNA, with contingency actions to be evaluated/implemented in the event that the remedy is insufficiently protective of the marine environment.

The prior cleanup actions are described in Section 3. The other components of the preferred alternative are depicted on Figure 7-5.

It is anticipated that the preferred alternative will cost roughly $18.4 million, $4.9 million of which is sunk cost,[31] and will have an implementation time frame of 2 to 3 years.

10.2 Conditional Points of Compliance for Groundwater

For Alternative 4, the proposed conditional points of compliance for groundwater are located in the sediment bioactive zones of the Log Pond north of the RAU and Bellingham Bay west of the RAU. This point-of-compliance scenario is considered appropriate because it is expected to allow for a reasonable restoration time frame (estimated at approximately

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[31] Assumes the planned early-2017 interim action costs are sunk costs (see Section 7.1.5).

34 years for restoration of the naphthalene plume in the Million Gallon Tanks subarea[32]). A robust post-construction confirmation groundwater monitoring program, integrated with the Whatcom Waterway cleanup confirmation monitoring program, would be conducted to ensure continued compliance in the future.

10.3 Application of Groundwater Remediation Levels at Shoreline Wells

As described in Section 5.3.1.3, a confirmation groundwater monitoring program for the RAU may include use of groundwater remediation levels applied at shoreline monitoring wells along with direct measurement of groundwater concentrations at the conditional point of compliance (porewater in sediment bioactive zone). The groundwater cleanup levels would remain unchanged and would apply at the conditional point of compliance. The groundwater remediation levels applied at shoreline well(s) would be equal to the cleanup level multiplied by the concentration attenuation factor between the shoreline well and the bioactive zone.

Within the Law-1 area, empirical measurements of shoreline groundwater and porewater quality collected in 2015 indicated an attenuation of approximately 500-fold between shoreline wells and the sediment bioactive zone (see Section 4.7.2.1). The measured data represent conditions prior to the 2016 placement of the thick sediment cap along the Log Pond shoreline as part of the Whatcom Waterway Phase 1 cleanup. Contaminant transport modeling of that pre-capped condition indicated only a 50-fold attenuation, demonstrating the conservatism inherent in the modeling. The modeling indicated an attenuation of approximately 440-fold under the current capped condition (see Section 4.7.2.2).

On the downgradient edge of the caustic plume, empirical measurements of shoreline groundwater and porewater quality collected in 2015 also indicated an attenuation of approximately 500-fold between the shoreline wells and the sediment bioactive zone (see Section 4.6.3.1). Contaminant transport modeling of that area indicated only a 130-fold attenuation, demonstrating the conservatism inherent in the modeling (see Section 4.6.3.2).

The details of a confirmation groundwater monitoring program, including use of remediation levels, will be determined as part of a Compliance Monitoring Plan prepared during remedial design, following approval of the CAP for the RAU.

10.4 Compatibility with Whatcom Waterway Remedial Activities

The Chlor-Alkali RAU is adjacent to the Whatcom Waterway cleanup site, which has a cleanup remedy and schedule defined under a Consent Decree with Ecology. Remedy construction for the preferred alternative for the Chlor-Alkali RAU overlaps with that of the Whatcom Waterway site, in terms of integration of the soil capping in the southwest corner of the Log Pond with the capping of the south bank of the Whatcom Waterway. The preferred alternative for the Chlor-Alkali RAU is compatible with the Whatcom Waterway cleanup.

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[32] The standard point of compliance would still apply to the achievement of the groundwater cleanup level for naphthalene because it is based on protection from VI.

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TABLES

Table 4-1 - Groundwater Data Collected during Caustic Plume-Cell Building Interim Action

Project No. 070188, Chlor-Alkali RAU, GP West Site, Bellingham, Washington

Chemical Name	Groundwater Screening Level for Unrestricted Land Use	CP-DW01	CP-DW02		CP-DW03	CP-MW04	CP-MW05
		7/30/2013	3/6/2013	7/30/2013	7/30/2013	7/30/2013	7/30/2013
Metals							
Dissolved Mercury in ug/L	0.059	0.0239	0.312	0.406	0.0544	0.0251	0.0019
Field Parameters							
Dissolved Oxygen in mg/L		1.98	5.97	2.03	2.69	2.57	4.63
ORP in mVolts		-334	27.9	-71	-251	-281	33
pH in pH Units	6.2 - 8.5	7.54	8.48	8.26	6.94	6.93	7.41
Specific Conductance in us/cm		37,339	2,162	2,486	25,953	68,877	23,220
Temperature in deg C		17.1	13.2	17.1	18.1	16.8	14
Turbidity in NTU		4.1	673	4.9	5.7	2.9	31

Chemical Name	Groundwater Screening Level for Unrestricted Land Use	CP-MW13		CP-MW15	CP-MW22		CP-MW23	CP-MW24
		2/13/2013	7/31/2013	2/13/2013	3/7/2013	7/30/2013	7/31/2013	7/31/2013
Metals								
Dissolved Mercury in ug/L	0.059	0.179	5.84	146	7.75	3.54	0.129	1.3
Field Parameters								
Dissolved Oxygen in mg/L		1.03	0.84	0.92	2.43	1.55	1.31	0.88
ORP in mVolts		-117	-79	-266	-427	-92	-302	36
pH in pH Units	6.2 - 8.5	7.78	7.43	11.66	10.11	9.56	7.53	9.46
Specific Conductance in us/cm		3,178	2,415	14,017	6,502	6,581	33,116	4,523
Temperature in deg C		11.9	18.5	14.0	10.5	19.2	15.8	18.2
Turbidity in NTU		1.78	15	3.06	NM	110	11	NM

mg/L = milligrams per liter
mVolts = millivolts
ORP = oxygen reduction potential
NM = not measured
NTU = Nephelometric Turbidity Units
us/cm = microsiemens
ug/L = micrograms per liter

Notes:

Concentrations in shaded cells indicate value exceeds Groundwater Screening Level for Industrial Land Use.
Concentrations within bold border indicate value exceeds Groundwater Screening Level for Unrestricted Land Use.

Table 5-1 - Proposed Groundwater Cleanup Levels for Chlor-Alkali RAU

Project No. 070188, Chlor-Alkali RAU, GP West Site, Bellingham, Washington

ANALYTE (BY GROUP)	Groundwater Screening Level for Marine Water and Sediment Protection	Vapor Intrusion Groundwater Screening Levels for Unrestricted Land Use	Practical Quantitation Level (PQL)	Proposed Groundwater Cleanup Level for Unrestricted Land Use[1]
Total Petroleum Hydrocarbons (TPH)				
Gasoline-Range Hydrocarbons in µg/L	1000		250	**1000**
Diesel-Range Hydrocarbons in µg/L	500		250	**500**
Oil-Range Hydrocarbons in µg/L	500		500	**500**
Metals				
Arsenic in µg/L	5		0.5	**5**
Cadmium in µg/L	8.8		0.02	**8.8**
Chromium (Total) in µg/L	260		0.2	**260**
Copper in µg/L	3.1		0.1	**3.1**
Lead in µg/L	8.1		0.02	**8.1**
Mercury in µg/L	0.059	0.89	0.001	**0.059**
Nickel in µg/L	8.2		0.2	**8.2**
Zinc in µg/L	81		0.5	**81**
Polycyclic Aromatic Hydrocarbons (PAHs)				
Acenaphthene in µg/L	3.3		0.02	**3.3**
Acenaphthylene in µg/L			0.02	
Anthracene in µg/L	9.6		0.02	**9.6**
Benzo(g,h,i)perylene in µg/L			0.02	
Fluoranthene in µg/L	3.3		0.02	**3.3**
Fluorene in µg/L	3		0.02	**3**
Phenanthrene in µg/L			0.02	
Pyrene in µg/L	15		0.02	**15**
1-Methylnaphthalene in µg/L			0.02	
2-Methylnaphthalene in µg/L			0.02	
Naphthalene in µg/L	83	8.9	0.02	**8.9**
Benz(a)anthracene in µg/L			0.02	
Benzo(a)pyrene in µg/L			0.02	
Benzo(b)fluoranthene in µg/L			0.02	
Benzo(k)fluoranthene in µg/L			0.02	
Chrysene in µg/L			0.02	
Dibenzo(a,h)anthracene in µg/L			0.02	
Indeno(1,2,3-cd)pyrene in µg/L			0.02	
Total cPAHs TEQ in µg/L	0.018		0.02	**0.02**
Conventionals				
pH in pH units	<6.2 or >8.5			**<6.2 or >8.5**

cPAH = carcinogenic polycyclic aromatic

TEQ = toxic equivalent concentration

ug/L = micrograms per liter

Notes:

1) Refer to Section 5 and Table 5-1 of the RI for derivation of groundwater screening levels that are proposed as groundwater cleanup levels. Cleanup levels are the most stringent value protective of all exposure pathways.

Table 5-2 - Proposed Soil Cleanup Levels for Chlor-Alkali RAU

Project No. 070188, Chlor-Alkali RAU, GP West Site, Bellingham, Washington

ANALYTE (BY GROUP)	Groundwater Protection for Unrestricted Land Use		Unrestricted Direct Contact (mg/kg)	Natural Background (mg/kg)	Practical Quantitation Level (PQL) (mg/kg)	Proposed Unrestricted Soil Cleanup Levels(1)	
	Unsaturated Soil (mg/kg)	Saturated Soil (mg/kg)				Unsaturated Soil (mg/kg)	Saturated Soil (mg/kg)
Total Petroleum Hydrocarbons (TPH)							
Diesel-Range Organics			2,000		25	**2,000**	**2,000**
Heavy Oils			2,000		100	**2,000**	**2,000**
Oil-Range TPH in Million Gallon Tanks Subarea	10,000	10,000	4000(2)			**4,000**	**4,000**
Heavy Metals							
Arsenic	2.9	0.15	20	20	0.5	**20(3)**	**20(3)**
Cadmium	1.2	0.061	80	1	0.02	**1.2**	**1**
Chromium (Total)	5,200	260			0.2	**5,200**	**260**
Copper	1.4	0.069	3,200	36	0.1	**36**	**36**
Lead	1,600	81	250	17	0.05	**250**	**81**
Mercury, pH < 10 (4)	100	100	24	0.07	0.001	**24**	**24**
Nickel	11	0.54	1,600	48	0.2	**48**	**48**
Zinc	100	5	24,000	85	0.5	**100**	**85**
Conventionals							
pH			<2.5 or >11.0			**<2.5 or >11.0**	**<2.5 or >11.0**
Polycyclic Aromatic Hydrocarbons (PAHs)							
Acenaphthene	5.2	0.26	4,800		0.0005	**5.2**	**0.26**
Acenaphthylene					0.0005		
Anthracene	71	3.5	24,000		0.0005	**71**	**3.5**
Benzo(g,h,i)perylene					0.0005		
Fluoranthene	52	2.6	3,200		0.0005	**52**	**2.6**
Fluorene	7.4	0.37	3,200		0.0005	**7.4**	**0.37**
Phenanthrene					0.0005		
Pyrene	330	16	2,400		0.0005	**330**	**16**
1-Methylnaphthalene			35		0.001	**35**	**35**
2-Methylnaphthalene			320		0.001	**320**	**320**
Naphthalene	3.5	0.17	1,600		0.001	**3.5**	**0.17**
Benz(a)anthracene					0.0005		
Benzo(a)pyrene					0.0005		
Benzo(b)fluoranthene					0.0005		
Benzo(k)fluoranthene					0.0005		
Chrysene					0.0005		
Dibenzo(a,h)anthracene					0.0005		
Indeno(1,2,3-cd)pyrene					0.0005		
Total cPAHs TEQ	6.2	0.31	0.14		0.00076	**0.14**	**0.14**
Polychlorinated Biphenyls (PCBs)							
Total PCBs	0.99	0.05	0.5		0.05	**1**	**1**
Dioxins/Furans							
Total 2,3,7,8 TCDD (TEQ)	7.8E-02	3.9E-03	1.1E-05		6.3E-06	**1.1E-05**	**1.1E-05**

cPAH = carcinogenic polycyclic aromatic hydrocarbon
mg/kg = milligrams per kilogram
TEQ = toxic equivalent concentration

Notes:

1) Refer to Section 5 and Table 5-2 of the RI for derivation of soil screening levels that are proposed as soil cleanup levels. Except as noted below, proposed cleanup levels are the most stringent value protective of all exposure pathways.
2) Refer to Section 7.5.2.1 of the RI for derivation of the unrestricted direct contact screening level for oil-range TPH in the Million Gallon Tanks subarea.
3) The proposed soil cleanup level for arsenic is based on background concentrations for Washington state (173-340-900 WAC Table 740-1).

4) A mercury soil concentration of 100 mg/kg is determined to be protective of groundwater in near-neutral pH conditions, i.e. outside of the caustic core (pH < 10) (refer to FS Section 5.3.1.1).

Table 6-1 - Summary of Screening of Remedial Technologies

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	Mercury Exceedance and High pH Areas					Petroleum Hydrocarbon Exceedance Areas		Miscellaneous Dissolved Metals Exceedances in Groundwater
	Soil Hg Only		Soil and Groundwater Hg and High pH	Groundwater Hg and High pH	Groundwater Hg Only	Soil TPH and PAHs	Groundwater PAHs	
Remedial Technologies	**Chemfix**	**Other**						
Institutional Controls[1]	▨ X	▨ X	▨ X	▨ X	▨ X	▨ X	▨ X	▨ X
Monitored Natural Attenuation of Groundwater[2]			▨ X	▨ X	▨ X		▨ X	▨ X
***In-Situ* Containment Technologies**								
Soil Capping	(Note 8)	▨ X	▨ X			▨ X		
Physical Containment of Groundwater[3]			▨ X	▨ X	▨ X		▨ X	▨ X
***In-Situ* Treatment Technologies**								
Chemically Enhanced Extraction/Treatment[4]		X	X					
Solidification/Stabilization	(Note 8)	▨ X	▨ X					
Electrochemical Treatment		X	X					
Thermal Desorption		X	X					
Vitrification		X	X					
pH Buffering/Neutralization[5]			▨ X	▨ X				
Mercury Precipitation/Immobilization[5]					▨ X			
Chemical Oxidation						▨ X	▨ X	
Enhanced Aerobic Bioremediation						▨ X	▨ X	
Technologies Involving Source Soil Excavation								
On-site Soil Consolidation		▨ X				X		
Off-site Soil Disposal in Landfill[6]	▨ X	▨ X	▨ X			▨ X		
Physical Particle Size Separation Methods		▨ X	▨ X					
On-site (*Ex-Situ*) Solidification/Stabilization		▨ X	▨ X					
On-site (*Ex-Situ*) Thermal Desorption		X	X					
Acid Extraction		X	X					
Groundwater Extraction[7]			▨ X	▨ X	▨ X		▨ X	▨ X

Notes:

1) Institutional controls are measures undertaken to limit or prohibit activities that may interfere with a cleanup action or result in exposure to hazardous substances.

2) Natural attenuation encompasses a variety of naturally occurring removal mechanisms, including sorption, precipitation, dilution, dispersion, and biological transformation.

3) Physical containment involves installing a structural barrier that limits movement of groundwater, preventing off-site migration of contamination.

4) Chemically enhanced extraction/treatment involves acidification/oxidation of mercury source areas to promote formation of mercuric chloride, which is the leachate from the REMERC process.

5) pH buffering/neutralization and mercury precipitation/immobilization are inter-related technologies. Refer to Section 6.5.6.

6) Excavated soil may require treatment prior to landfill disposal to comply with dangerous waste regulations. Candidate treatment technologies are not included in this table.

7) In addition to effecting removal of dissolved contamination, groundwater extraction can be used for excavation dewatering and hydraulic containment of contaminant plumes.

8) Soil excavated from the wastewater settling basin in 1976 was treated by *ex situ* stabilization prior to onsite disposal and capping in the Chemfix subarea.

▨ = Shaded cells indicate retained technology.

Hg = mercury

PAH = polycyclic aromatic hydrocarbon

TPH = total petroleum hydrocarbon

Table 7-1 - Assembly of Technologies into Remedial Alternatives (1, 2)

Project No. 070188, Chlor-Alkali RAU, GP West Site, Bellingham, Washington

Site Areas	General Response Actions	Remedial Technologies	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8
			Containment and *In-Situ* Treatment of Accessible Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA	**Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Removal of Soils with Visible Hg and Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of "Caustic Core," Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of Groundwater with pH > 8.5, Aggressive Removal of Obstructions and *In Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of Groundwater with pH > 8.5, Removal of Hg-Impacted Soils to Achieve Groundwater Protection, Capping of Residual Impacted Soils , and Groundwater MNA**	**Removal of All Soils Exceeding Cleanup Levels, Neutralization of Groundwater with pH > 8.5, and Groundwater MNA**	**Removal of All Soils Exceeding Cleanup Levels, Neutralization of Groundwater with pH > 8.5, *In-Situ* Treatment of Fill Unit Groundwater Impacted by Hg and PAHs, and MNA for Residual Impacted Groundwater(8)**
Mercury Exceedance & High pH Areas	Institutional Controls	Environmental Covenants	X	X	X	X	X	X	X	X
	Groundwater MNA	-	X	X	X	X	X	X	X	(Note 8)
	Containment	Capping(3)	Soils with [Hg] > 24 mg/kg	Soils with [Hg] > 24 mg/kg	Soils with [Hg] > 24 mg/kg	Soils with [Hg] > 24 mg/kg	Soils with [Hg] > 24 mg/kg	Soils with [Hg] > 24 mg/kg(7)	--	--
		Groundwater Containment	Areas of visible Hg; contingency action elsewhere (Note 3)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)
	In-Situ Treatment	Solidification/Stabilization	Accessible soils with visible Hg	Soils with visible Hg	--	Soils with visible Hg	Soils with visible Hg	--	--	--
		pH Buffering/Neutralization	--	--	--	"Caustic Core" groundwater (pH > 10)	Groundwater with pH > 8.5	Groundwater with pH > 8.5	Groundwater with pH > 8.5	Groundwater with pH > 8.5
		Hg Precipitation/Immobilization	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	Hg-impacted Fill Unit groundwater outside pH > 8.5 area
	Ex-Situ Treatment	Solidification/Stabilization	--	--	Soils with visible Hg	--	--	Soils with visible Hg	Soils with visible Hg	Soils with visible Hg
	Excavation	On-site Consolidation	(Note 5)	(Note 5)	(Note 5)	(Note 5)	(Note 5)	(Note 5)	--	--
		Off-site Soil Disposal in Landfill(6)	Soils near Log Pond with [Hg] > 300 mg/kg	Soils near Log Pond with [Hg] > 300 mg/kg	Soils near Log Pond with [Hg] > 300 mg/kg	Soils near Log Pond with [Hg] > 300 mg/kg	Soils near Log Pond with [Hg] > 300 mg/kg	Soils with [Hg] > 100 mg/kg(7)	Soils with [Hg] > 24 mg/kg	Soils with [Hg] > 24 mg/kg
Other Contaminant Exceedance Areas	Institutional Controls	Environmental Covenants (see box at lower right)	X	X	X	X	X	X	X	X
	Groundwater MNA	-	X	X	X	X	X	X	X	(Note 8)
	Containment	Capping(3)	Residual soils impacted by TPH and/or PAHs	Residual soils impacted by TPH and/or PAHs	Residual soils impacted by TPH and/or PAHs	Residual soils impacted by TPH and/or PAHs	Residual soils impacted by TPH and/or PAHs	Residual soils impacted by TPH and/or PAHs	--	--
		Groundwater Containment	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)	(Note 4)
	In-Situ Treatment	Chemical Oxidation/Enhanced Aerobic Bioremediation								PAH-impacted groundwater
	Excavation/Disposal	Off-site Soil Disposal in Landfill	TPH-impacted soils in southeast corner of Cell Building	TPH-impacted soils in southeast corner of Cell Building	TPH-impacted soils in southeast corner of Cell Building	TPH-impacted soils in southeast corner of Cell Building	TPH-impacted soils in southeast corner of Cell Building	TPH-impacted soils in southeast corner of Cell Building	All soils impacted by TPH and/or PAHs.	All soils impacted by TPH and/or PAHs.

-- Dashes indicate action not included for that alternative.
Hg mercury

mg/kg milligrams per kilogram
MNA monitored natural attenuation
RAU remedial action unit

Notes:

1) Refer to Table 6-1 for a summary screening of remedial technologies.
2) All remedial alternatives include cleanup actions already completed within the RAU. Most significant among these are: a) removal and Chemfix-stabilization of mercury-contaminated sludge from the Wastewater Settling Basin in 1976-1977; and b) removal and landfill disposal of mercury-contaminated soils and building materials from the Caustic Plume Subarea in 2013.
3) All caps will be low-permeability "hard caps."
4) Technology to be evaluated for potential implementation as a contingency action at the shoreline in the event that the remedy is not sufficiently protective of the marine environment.
5) In Alternatives 1 through 5, soils in the BNSF portion of the Stormwater Swale with [Hg] > 24 mg/kg would be excavated and placed on the Port portion of the Stormwater Swale, and then capped to prevent direct contact. Alternative 6 is similar except that the small amount of BNSF soils with [Hg] > 100 mg/kg would be excavated and disposed of off-site.
6) In Alternatives 3 through 8, a portion of the soils excavated in the mercury exceedance and high-pH areas would likely require treatment prior to landfill disposal and/or disposal in a RCRA Subtitle C (hazardous waste) landfill. *Ex situ* soil treatment technologies that may be implemented to facilitate landfill disposal and/or reduce disposal costs (e.g., physical particle size separation methods) are not included in this table.
7) Although material in the Chemfix area has mercury concentrations that exceed the cleanup level for groundwater protection,it has been stabilized and is not a threat to groundwater. Therefore, Alternative 6 includes capping (not excavation/disposal) of Chemfix area material.
8) In Alternative 8, MNA applies to Fill Unit groundwater with miscellaneous dissolved metals exceedances and Lower Sand groundwater with mercury exceedances.

Institutional Controls will likely:
- Prohibit extraction of groundwater for drinking or any other beneficial use
- Provide notification regarding the presence of residual contaminated materials, and regulate the disturbance/management of those materials
- Provide for long-term monitoring and stewardship of the cap and other cleanup action components, including access for groundwater monitoring
- Require that vapor intrusion (VI) potential be evaluated and/or VI controls constructed beneath future buildings in areas where volatile contaminants (including mercury) have not attenuated to below cleanup levels
- Prohibit activities that may impact or interfere with the remedial action, including disturbance of Chemfix area material or creation of preferential pathways for contaminant migration, without prior written approval from Ecology
- In the event that any portion of the RAU is sold, provide for continued implementation of the cleanup action and continued compliance with these institutional controls.

Table 7-2 - Components of Remedial Alternatives

Project No. 070188, Chlor-Alkali RAU, GP West Site, Bellingham, Washington

Remedial Alternative Components	**Remedial Alternative**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Prior cleanup actions	X	X	X	X	X	X	X	X
Institutional controls	X	X	X	X	X	X	X	X
Groundwater MNA	X	X	X	X	X	X	X	X
Consolidation of mercury-impacted soils from BNSF property onto Port property prior to capping	X	X	X	X	X	X		
Capping of soils exceeding cleanup levels	X	X	X	X	X	X		
Removal of TPH-impacted soils in southeast corner of Cell Building	X	X	X	X	X	X	X	X
Removal of Wastewater Settling Basin soils near Log Pond with [Hg] > 300 mg/kg	X	X	X	X	X	X	X	X
Containment of groundwater in contact with soils containing visible mercury	X							
In-situ treatment of readily accessible soils with visible mercury(1)	X							
Aggressive removal of obstructions and *in situ* treatment of soils with visible mercury(2)		X		X	X			
Neutralization of groundwater in the "Caustic Core" (area with pH > 10)				X	X	X	X	X
Neutralization of groundwater in areas with 8.5 < pH < 10					X	X	X	X
Removal of soils with visible mercury			X			X	X	X
Removal of mercury-impacted soils to achieve groundwater protection						X	X	X
Removal of all soils exceeding cleanup levels							X	X
In-situ treatment of PAH-impacted groundwater								X
In-situ treatment of Hg-impacted Fill Unit groundwater outside pH > 8.5 area								X

AOC	area of contamination	MNA	monitored natural attenuation
FS	feasibility study	RAU	remedial action unit
[Hg]	mercury soil concentration	TPH	total petroleum hydrocarbon
mg/kg	milligrams per kilogram		

Notes:

1) In Alternative 1, near-surface debris and foundation components, but not deeper obstructions (e.g., piles), would be removed to access impacted soils.

2) In Alternatives 2, 4, and 5, soil would be moved to the extent needed to cut piles off at base of Fill Unit. All work would be conducted within an AOC.

Table 7-3 - Summary of Estimated Remedial Alternative Construction Quantities, Construction Duration, and Restoration Time Frame

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	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**	**Alternative 7**	**Alternative 8**
	(Figures 7-1 and 7-2)	(Figures 7-1 and 7-3)	(Figures 7-1 and 7-4)	(Figure 7-5)	(Figure 7-6)	(Figure 7-7)	(Figure 7-8)	(Figure 7-9)
Estimated Construction Quantities	**Containment and *In-Situ* Treatment of Accessible Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Removal of Soils with Visible Hg and Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of "Caustic Core," Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of Groundwater with pH > 8.5, Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of Groundwater with pH > 8.5, Removal of Hg-Impacted Soils to Achieve Groundwater Protection, Capping of Residual Impacted Soils, and Groundwater MNA**	**Removal of All Soils Exceeding Cleanup Levels, Neutralization of Groundwater with pH > 8.5, and Groundwater MNA**	**Removal of All Soils Exceeding Cleanup Levels, Neutralization of Groundwater with pH > 8.5, *In-Situ* Treatment of Fill Unit Groundwater Impacted by Hg and PAHs, and MNA for Residual Impacted Groundwater**
Clean Soil Import (BCY)	9,000	10,000	18,000	10,000	11,000	44,000	120,000	120,000
New Asphalt Pavement (acre)	3.7	3.7	3.7	3.7	3.7	3.7	--	--
Slurry Wall (lf)	1,300	--	--	--	--	--	--	--
Soil Treated *In Situ* (ton)	16,000	20,000	--	20,000	20,000	--	--	--
Groundwater Neutralization Trench (lf)	--	--	--	1,000	4,700	4,100	3,900	3,900
Permeable Reactive Barrier (lf)	--	--	--	--	--	--	--	3,100
Soil and Debris Disposed of in Off-site Landfills (ton):								
- Hazardous waste requiring macro-encapsulation	380	1,000	1,000	1,000	1,000	1,000	1,000	1,000
- Hazardous waste requiring stabilization(2)	--	--	27,000	--	--	27,000	27,000	27,000
- Hazardous waste (stabilization not required)	1,600	1,600	1,600	1,600	1,600	6,700	20,000	20,000
- Nonhazardous waste	4,700	4,700	4,700	7,300	16,000	49,000	150,000	160,000
Estimated Construction Duration	1 to 2 years	1 to 2 years	1 to 2 years	2 to 3 years	2 to 3 years	2 to 3 years	3 to 4 years	3 to 4 years
Estimated Restoration Time Frame(3)	>100 years	>100 years	>100 years	74 years	34 years	34 years	34 years	10 years

Notes:

1) Construction quantity estimates are displayed to two significant digits.

2) Estimated weight includes weight of stabilization amendments.

3) Restoration time frame estimates assume a standard point of compliance for groundwater (i.e., throughout the aquifer).

-- dashes indicate not applicable
BCY = bank cubic yards
Hg = mercury
lf = linear feet
MNA = monitored natural attenuation

Table 8-1 - Disproportionate Cost Analysis

Project No. 070188, Chlor-Alkali RAU, GP West Site, Bellingham, Washington

			Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8
Remedial Alternative Components(2):			**Containment and *In-Situ* Treatment of Accessible Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Removal of Soils with Visible Hg and Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of "Caustic Core," Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of Groundwater with pH > 8.5, Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**	**Neutralization of Groundwater with pH > 8.5, Removal of Hg-Impacted Soils to Achieve Groundwater Protection, Capping of Residual Impacted Soils, and Groundwater MNA**	**Removal of All Soils Exceeding Cleanup Levels, Neutralization of Groundwater with pH > 8.5, and Groundwater MNA**	**Removal of All Soils Exceeding Cleanup Levels, Neutralization of Groundwater with pH > 8.5, *In-Situ* Treatment of Fill Unit Groundwater Impacted by Hg and PAHs, and MNA for Residual Impacted Groundwater**
Remedial Design Concept:			Figures 7-1 and 7-2	Figures 7-1 and 7-3	Figures 7-1 and 7-4	Figure 7-5	Figure 7-6	Figure 7-7	Figure 7-8	Figure 7-9
	Weighting Factor(3)									
Criteria to Evaluate Use of Permanent Solutions to the Maximum Extent Practicable	Overall Protectiveness	30%	2 Human and terrestrial ecological soil direct contact and soil erosion exposure pathways addressed primarily by capping with ICs. Combination of containment, removal, and treatment in Chlorine Plant Area limits Hg/TPH migration and VI potential. Soil removal from former Wastewater Settling Basin limits Hg migration. Relies on long-term effectiveness of natural attenuation (with compliance monitoring) and ICs.	4 Increased protectiveness in Chlorine Plant Area relative to Alt. 1 because soils with visible elemental Hg are more completely treated via *in-situ* stabilization with aggressive removal.	6 Increased protectiveness in Chlorine Plant Area relative to Alt. 2 because soils containing visible Hg are removed from the RAU rather than stabilized *in situ*.	5 Benefits of Alt. 2 plus less long-term reliance on ICs to ensure protectiveness in "Caustic Core" (due to groundwater neutralization).	6 Increased protectiveness relative to Alt. 4 resulting from less long-term reliance on ICs to ensure protectiveness in area surrounding "Caustic Core" with groundwater pH > 8.5 (due to broader application of groundwater neutralization).	8 Increased protectiveness relative to Alt. 5 because all soils with leachable Hg (including soils with visible Hg) are removed.	9 Increased protectiveness relative to Alt. 6 because risk of direct contact exposure to contaminated soils is eliminated (removal vs. reliance on capping and ICs). Protectiveness with respect to groundwater also increases because soils with leachable naphthalene are removed.	10 Increased protectiveness relative to Alt. 7 with respect to Fill Unit groundwater because the PAH plume and dissolved Hg in neutral-pH areas are actively treated (vs. reliance on MNA).
	Permanence	20%	1 Containment and partial soil treatment in Chlorine Plant Area reduce Hg mobility in both groundwater and soil vapor. Soil removal from former Wastewater Settling Basin reduces Hg leaching. Natural attenuation reduces elevated pH levels in groundwater, which, in turn, reduces Hg mobility. Capping reduces potential mobility of soil contamination via erosion.	2 Increased permanence in Chlorine Plant Area relative to Alt. 1 because soils with visible elemental Hg are more completely treated via *in-situ* stabilization, thereby further reducing the potential for Hg mobility in groundwater and soil vapor.	4 Same benefits as Alt. 2, but has a higher permanence rating because soils containing visible Hg are removed from the RAU rather than stabilized and left on-site.	5 Benefits of Alt. 2 plus additional benefit of permanent pH reduction, as well as reduced Hg mobility, in "Caustic Core" (due to groundwater neutralization).	6 Benefits of Alt. 4 with expanded area of permanent pH reduction and reduced Hg mobility (area surrounding "Caustic Core" with groundwater pH > 8.5) due to broader application of groundwater neutralization.	8 Higher permanence rating than Alt. 5 because soils containing visible Hg are removed from the RAU rather than stabilized and left on-site, and because soils with leachable Hg are also removed from the RAU.	9 Increased permanence relative to Alt. 6 alternatives because all soils exceeding cleanup levels are removed from the RAU. However, no reduction in contaminant toxicity or volume (beyond potential natural attenuation in off-site landfill).	10 Potential for increased permanence relative to Alt. 7 because active treatment (vs. reliance on MNA) may reduce the mobility of PAHs and/or Hg in Fill Unit groundwater.
	Long-Term Effectiveness	20%	1 Long-term effectiveness is dependent on long-term compliance with ICs, as well as the long-term integrity of *in-situ* Hg stabilization, the containment wall, and the caps.	3 Increased long-term effectiveness in Chlorine Plant Area relative to Alt. 1 because of reduced VI concerns (due to more comprehensive stabilization of visible Hg).	4 Long-term benefits expected to be similar to Alt. 2. However, ranking is higher because long-term effectiveness of soil removal is more certain than leaving stabilized soils on-site.	5 Increased long-term effectiveness relative to Alt. 2 due to the additional treatment of the "Caustic Core."	6 Increased long-term effectiveness relative to Alt. 4 by expanding active groundwater treatment to area with pH > 8.5, thus eliminating the cause of enhanced Hg mobility in groundwater.	7 Increased long-term effectiveness relative to Alt. 4 because soil is removed from the RAU rather than treated and/or managed in place, and groundwater is actively treated in the area with groundwater pH > 8.5.	9 Increased long-term effectiveness relative to Alt. 6 because a much larger volume of soil is removed from the RAU rather than managed in place.	10 Increased long-term effectiveness relative to Alt. 7 because of additional treatment of residual impacted groundwater.
	Short-Term Risk Management	10%	9 Relatively minor short-term risks to workers, due primarily to large rotating equipment and other general construction hazards. Potential for air emissions associated with soil excavation and *in-situ* stabilization.	7 Significantly greater short-term risks relative to Alt. 1 due to labor-intensive process of removing obstructions (e.g., piles) in Chlorine Plant Area prior to *in-situ* soil stabilization.	8 Less short-term risk relative to Alt. 2 because *ex-situ* stabilization process can be more closely controlled to reduce potential for worker exposure to contamination and physical hazards.	6 Greater short-term risks relative to Alt. 2 because excavation of trenches in "Caustic Core" (the area of the highest Hg concentrations in groundwater and highest pH) is required.	5 Marginallly greater short-term risks relative to Alt. 4 due to additional excavation of trenches in area surrounding "Caustic Core" with groundwater pH > 8.5.	4 Greater short-term risks compared to Alt. 5 because a much greater volume of highly impacted soils is excavated.	2 Greater short-term risks compared to Alt. 6 because a much greater volume of impacted soils is excavated. Major earthwork construction project would create significant issues with respect to worker safety, dust and erosion control, etc.	1 Slightly greater short-term risks relative to Alt. 7 due to construction of PRBs in areas where groundwater is marginally impacted by Hg.
	Implementability	10%	6 *In-situ* stabilization of visible Hg soils using large-diameter augers would have significant implementation challenges in this alternative, since piles are left in place.	7 *In-situ* stabilization would be more straightforward than in Alt. 1, since piles are first removed. However, the pile removal process would have major implementation challenges.	8 Implementability of removing and treating Chlorine Plant Area soils with visible Hg has been demonstrated (interim action). However, challenges associated with removing subsurface structures would be significant.	6 Somewhat lower implementability compared to Alt. 2 due to design challenges associated with neutralization of groundwater.	5 Lower implementability relative to Alt. 4 because groundwater neutralization trenches would extend onto DNR property (west of Inner Harbor Line).	5 Implementability similar to Alt. 5 because, although volume of impacted soils to be removed is much larger, removal of soils with visible Hg is more straightforward than *in-situ* stabilization.	2 Significantly lower implementability relative to Alt. 6 due to challenges associated with removing a large volume of impacted soils, including previously stabilized sludge from the Chemfix area.	1 Potentially somewhat lower implementability relative to Alt. 7 because the requirement for trenching on DNR property (west of Inner Harbor Line) would increase in order to treat dissolved Hg in neutral-pH areas.
	Consideration of Public Concerns	10%	2	3	5	5	6	8	9	10
MTCA Benefits Ranking(4)			**2.7**	**3.9**	**5.5**	**5.2**	**5.8**	**7.1**	**7.6**	**8.2**
Estimated Cost(5)			**$12,200,000**	**$16,200,000**	**$22,800,000**	**$18,400,000**	**$24,300,000**	**$39,100,000**	**$63,800,000**	**$69,800,000**
Benefit/Cost Ratio(6)			**0.22**	**0.24**	**0.24**	**0.28**	**0.24**	**0.18**	**0.12**	**0.12**

Notes:

1) A scale of 1 to 10 is used to rate the alternatives with respect to the criteria, where "1" indicates the criterion is satisfied to a very low degree, and "10" to a very high degree. Rating values are shown in **RED**.
2) All alternatives listed in this table also include: a) prior cleanup actions; b) removal of TPH-impacted soils in the southeast corner of the Cell Building; and c) institutional controls. Refer to Tables 7-1 and 7-2.
3) The weighting factors are based on Ecology input provided for feasibility studies conducted on other Port of Bellingham sites.
4) The MTCA benefits ranking is obtained by multiplying the rating for each criterion by its weighting factor and summing the results for the five criteria.
5) Net present value costs are estimated in 2016 dollars and were calculated using a discount factor of 0.7 percent. The costs shown are rounded to three significant figures. Itemized cost estimates are provided in Appendix A.
6) The benefit/cost ratio is obtained by dividing the alternative's MTCA benefits ranking by its estimated cost (in $million).

DCA = disproportionate cost analysis
Hg = mercury
IC = institutional control
MNA = monitored natural attenuation
MTCA = Model Toxics Control Act
PRB = permeable reactive barrier
RAU = Remedial Action Unit
TPH = total petroleum hydrocarbon
VI = vapor intrusion

Table 9-1 Evaluation of Alternative 4 with Respect to Reasonable Restoration Time Frame

Project No. 070188, Chlor-Alkali RAU, GP West Site, Bellingham, Washington

	Remedial Components of Alternative 4 (Refer to Figure 7-5)	**Neutralization of "Caustic Core," Aggressive Removal of Obstructions and *In-Situ* Treatment of Soils with Visible Hg, Removal of Hg-Impacted Soils near Log Pond, Capping of Residual Impacted Soils, and Groundwater MNA**		
	Proposed Point of Compliance for Groundwater	**Standard Point of Compliance (throughout the Aquifer)**	**Conditional Point of Compliance at the Property Boundary(1)**	**Conditional Point of Compliance at the Shoreline(2)**
	Estimated Restoration Time Frame	74 years	55 years	34 years
Factors Used to Determine Whether the Restoration Time Frame is Reasonable (173-340-360(4)(b) WAC)	*i) Potential risks posed by the Site to human health and the environment*	Risk is low because: groundwater is not potable; restricted access and existing cap features address direct contact; and contaminant plumes do not currently, and are not expected to, reach sediment/surface water, which is the point of exposure upon which the groundwater cleanup levels are based.		
	ii) Practicability of achieving shorter restoration time frame	Groundwater modeling predicts that Alternatives 5 through 8 would achieve a shorter restoration time frame than Alternative 4, assuming a standard point of compliance. However, the DCA determined that those alternatives are not practicable.		
	iii) Current use of Site, surrounding areas, and associated resources that are, or may be, affected by releases from the Site	Current use of RAU is limited by presence of contamination. There are no confirmed releases from RAU posing an adverse risk to benthic/aquatic or human receptors.		
	iv) Potential future use of Site, surrounding areas, and associated resources that are, or may be, affected by releases from the Site	Plans currently being developed by the Port are expected to result in a mix of industrial and commercial uses. Redevelopment is not expected to be significantly limited by presence of contamination.		
	v) Availability of alternate water supplies	City of Bellingham municipal water supply is readily available and would not be affected by RAU cleanup.		
	vi) Likely effectiveness and reliability of institutional controls	ICs are expected to be effective and reliable at protecting receptors *in perpetuity* .		
	vii) Ability to control and monitor migration of hazardous substances from the Site	The collective data indicate that there is no migration of hazardous substances from the RAU.		
	viii) Toxicity of the hazardous substances at the Site	Mercury (inorganic) dissolved in groundwater has a relatively high toxicity.		
	ix) Natural processes that reduce concentrations of hazardous substances and have been documented to occur at the Site or under similar Site conditions	Natural processes, which reduce concentrations of hazardous substances, have been documented to occur at the Site.		
	Conclusion Regarding Reasonableness of Restoration Time Frame	Estimated restoration time frame is unreasonably long.	Estimated restoration time frame is unreasonably long.	Estimated restoration time frame is reasonable.

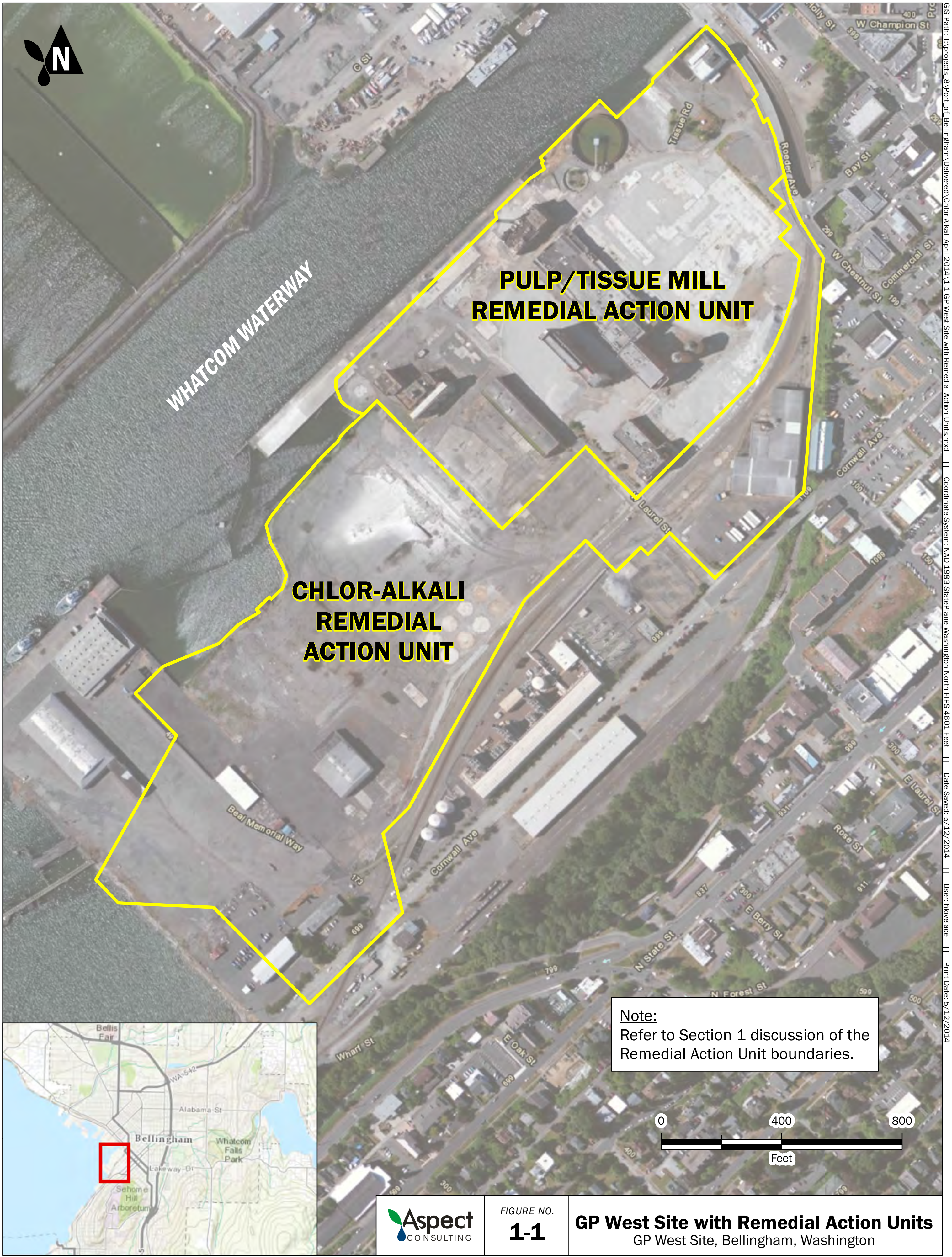
IC = institutional control
MNA = monitored natural attenuation
RAU = remedial action unit
RI = remedial investigation

Notes:

1) The Inner Harbor Line and the Port's parcel boundary within the Log Pond (tidelands) represent the property boundaries to the west and north, respectively.

2) The pertinent surface water bodies are Bellingham Bay to the west and the Log Pond to the north.

FIGURES



Note:
Refer to Section 1 discussion of the Remedial Action Unit boundaries.

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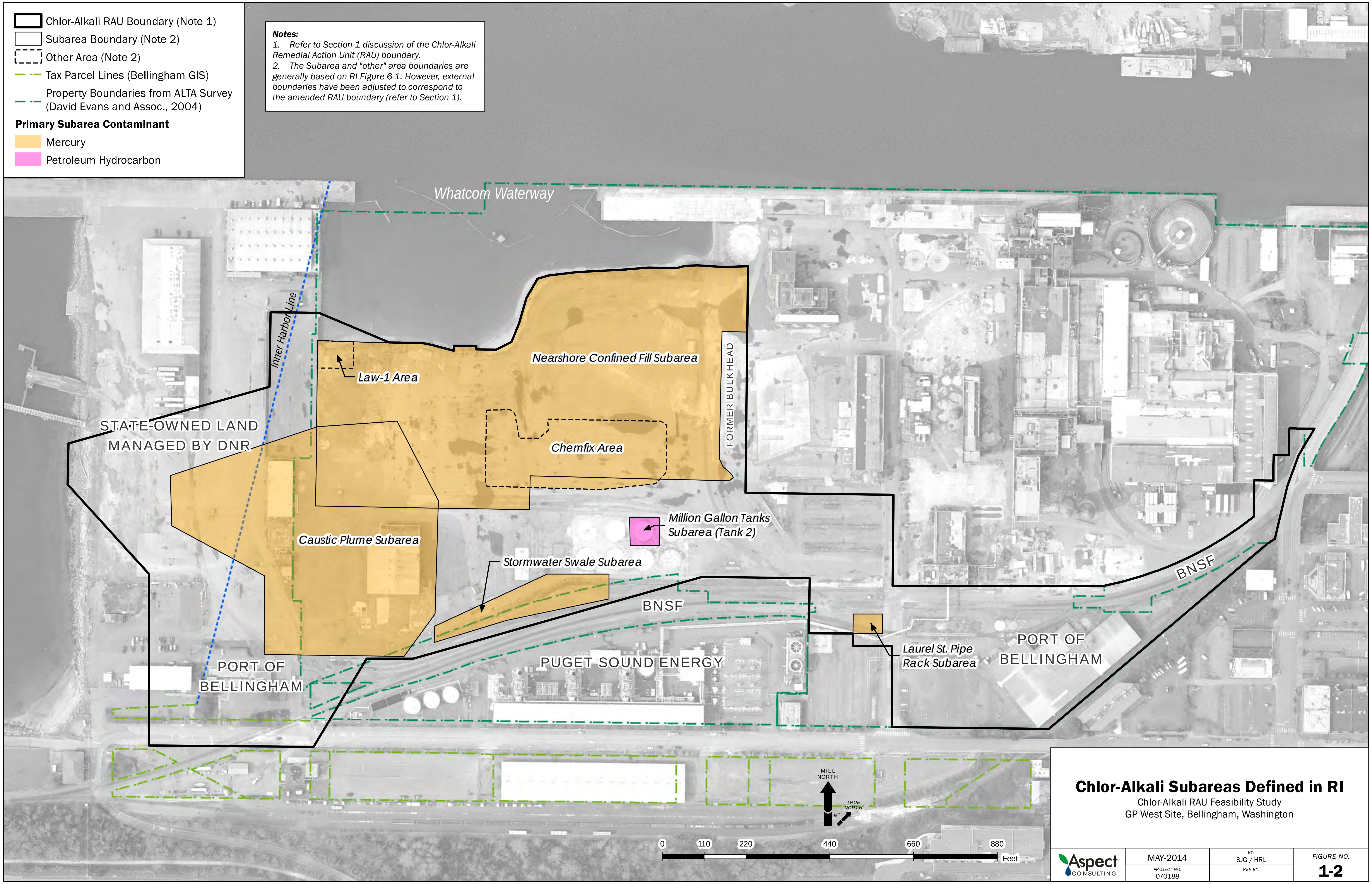
FIGURE NO.
1-1

GP West Site with Remedial Action Units
GP West Site, Bellingham, Washington

GIS Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali April 2014\1-1 GP West Site with Remedial Action Units.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 5/12/2014 || User: hlovelace || Print Date: 5/12/2014

Basemap Layer Credits | | Copyright:© 2013 Esri, DeLorme, NAVTEQ, TomTom
Sources: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User



Notes:
1. *Refer to Section 1 discussion of the Chlor-Alkali Remedial Action Unit (RAU) boundary.*
2. *The Subarea and "other" area boundaries are generally based on RI Figure 6-1. However, external boundaries have been adjusted to correspond to the amended RAU boundary (refer to Section 1).*

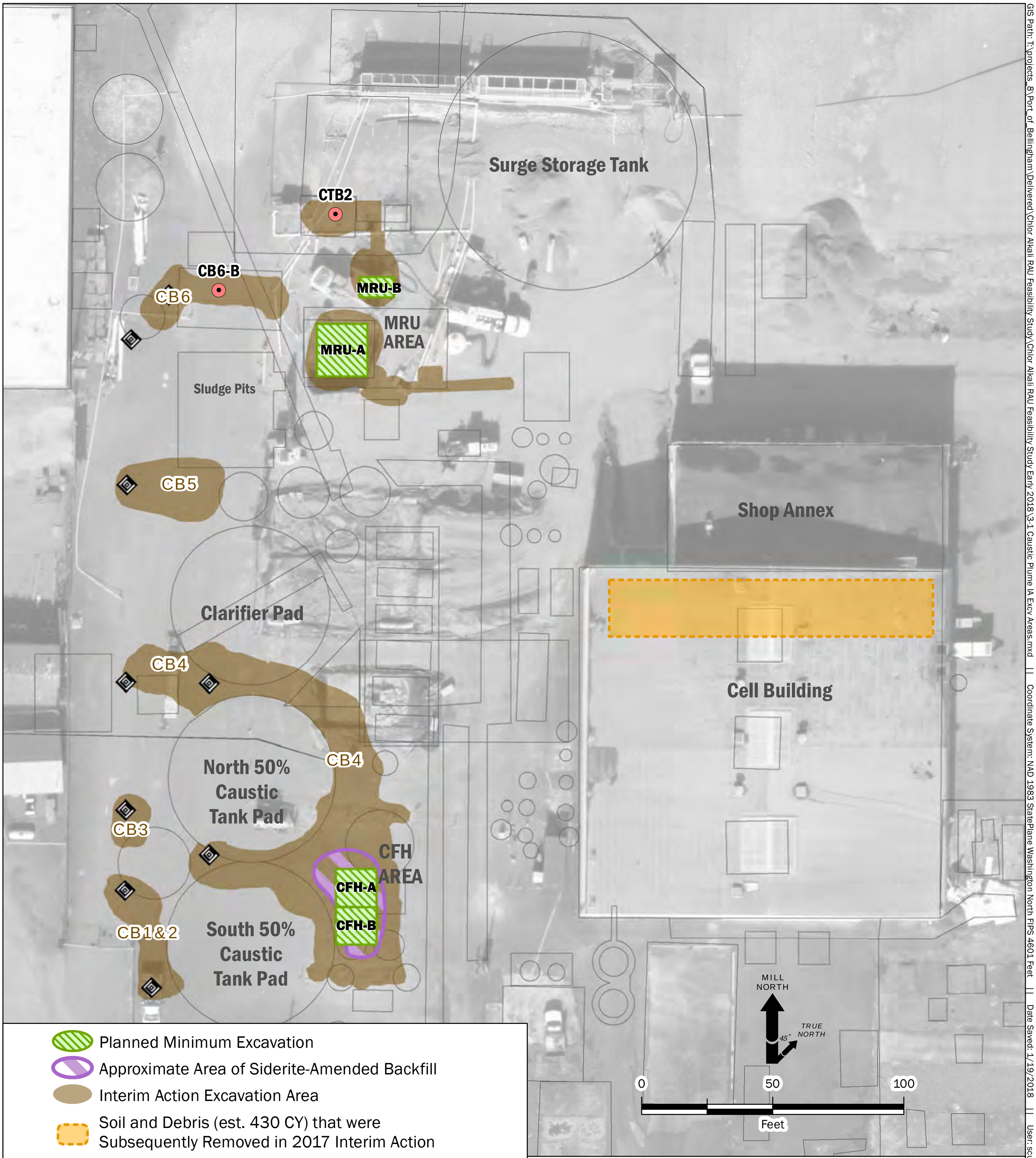
Chlor-Alkali Subareas Defined in RI

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING

MAY-2014	*BY:* SJG / HRL	*FIGURE NO.*
PROJECT NO. 070188	*REV BY:* - - -	**1-2**

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali April 2014\1-2 Chlor-Alkali Subareas Defined in the RI.mxd



🟩 Planned Minimum Excavation

🟪 Approximate Area of Siderite-Amended Backfill

🟫 Interim Action Excavation Area

🟧 Soil and Debris (est. 430 CY) that were Subsequently Removed in 2017 Interim Action

▣ Former Catch Basin

● Verification Soil Sampling Location where Mercury Concentration Exceeded Interim Action Soil Remediation Level

Monitoring Wells

⊕ Fill Unit Well

⊕ Decomissioned Monitoring Well

⊕ Lower Sand Well

Caustic Plume - Cell Building Interim Action Excavation Areas

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING	JAN-2018	BY: SJG / HRL	FIGURE NO.
	PROJECT NO. 070188-001-21	REVISED BY: PPW / RAP / SCC	3-1

GIS Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\3-1 Caustic Plume IA Excv Areas.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 1/19/2018 || User: scudd || Print Date: 1/19/2018

Note: *The floor troughs, floor sump, and a small portion of other Cell Building near-surface foundation components were removed during the Caustic Plume-Cell Building inteirm action.*

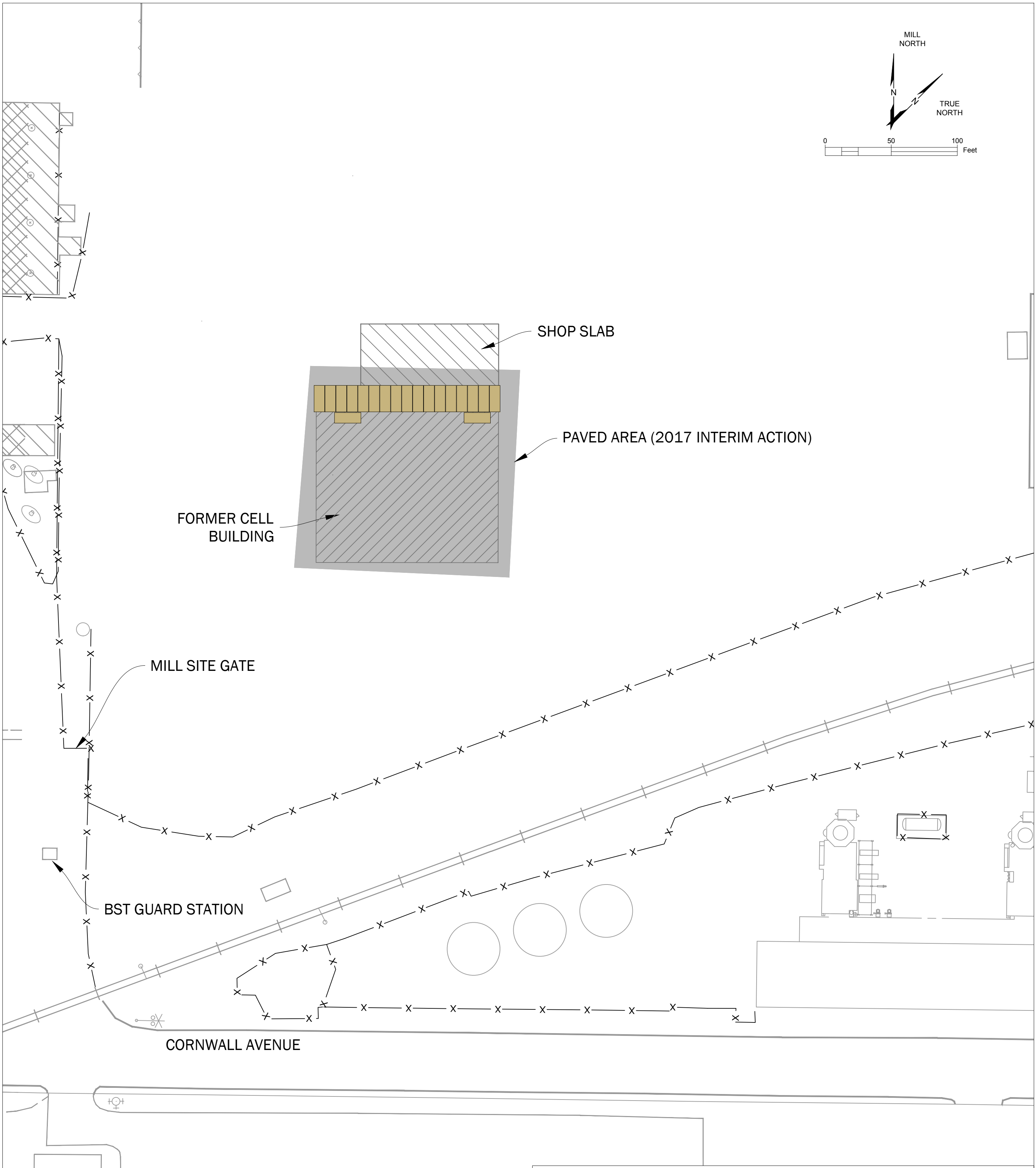
Near-Surface Foundation Components Former Cell Building

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING

APR-2015	BY: MAV / HRL	FIGURE NO. **3-2**
PROJECT NO. 070188-018	REVISED BY: DAH / RAP	

GIS Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\3-2 Near-Surface Foundation Components Beneath Former Cell Building.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 4/30/2015 || User: rpepin || Print Date: 4/30/2015



LEGEND

—x— FENCE

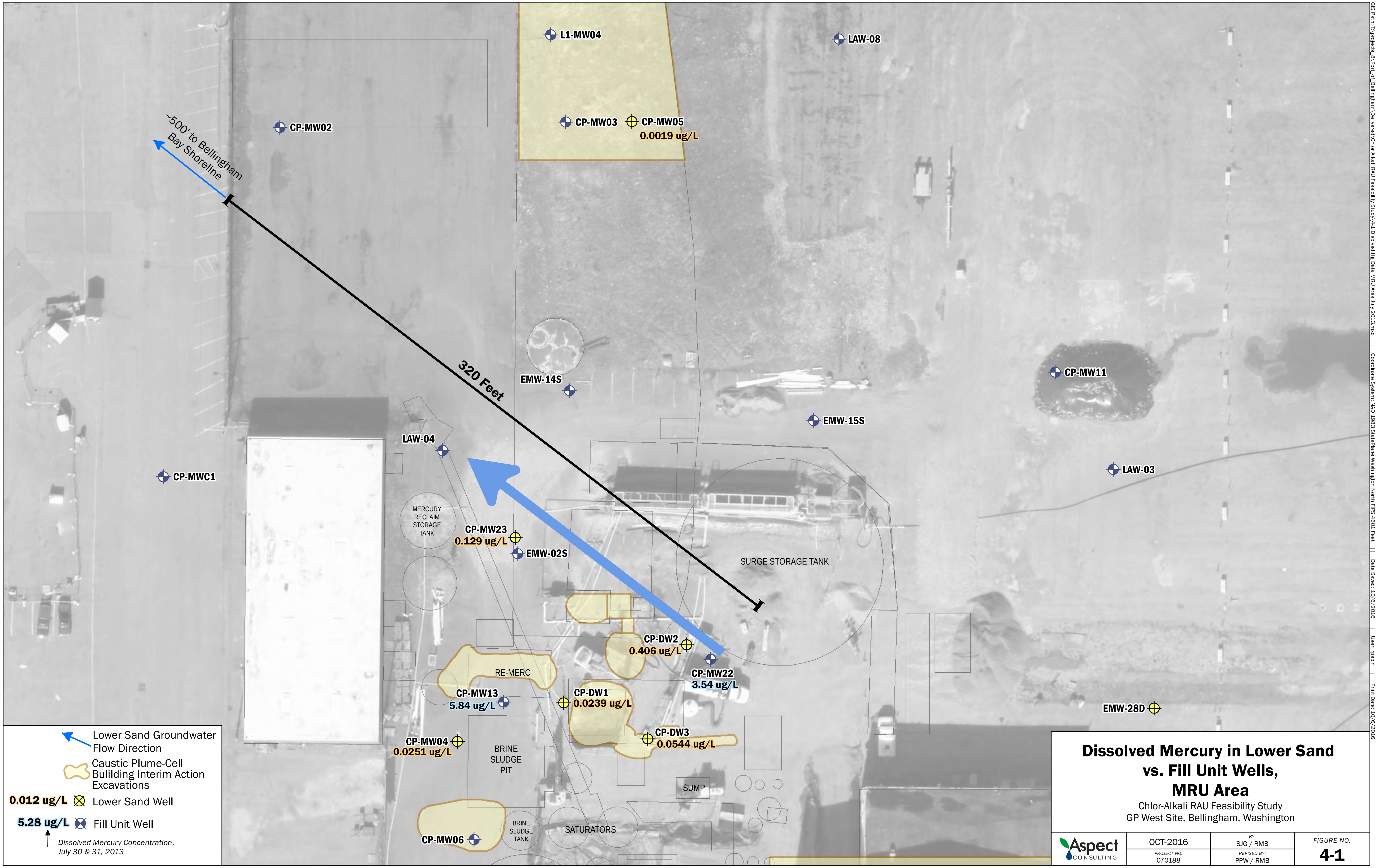
🟨 STEEL ROAD PLATE BENEATH PAVEMENT AND CRUSHED SURFACING BASE COURSE

Pavement Installed Over Cell Building Footprint in December 2017

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING	Feb-2018	BY: DAH/SCC	FIGURE NO.
	PROJECT NO. 070188	REVISED BY: SCC	3-3

CAD Path: Q:\Port of Bellingham\070188 Former GP Mill Property\2018-01 Chlor-Alkali RAU Feasibility Study\070188-02 FS.dwg PAVED AREA AS-BUILT || Date Saved: Feb 13, 2018 2:29pm || User: cvanslyke



Dissolved Mercury in Lower Sand vs. Fill Unit Wells, MRU Area

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

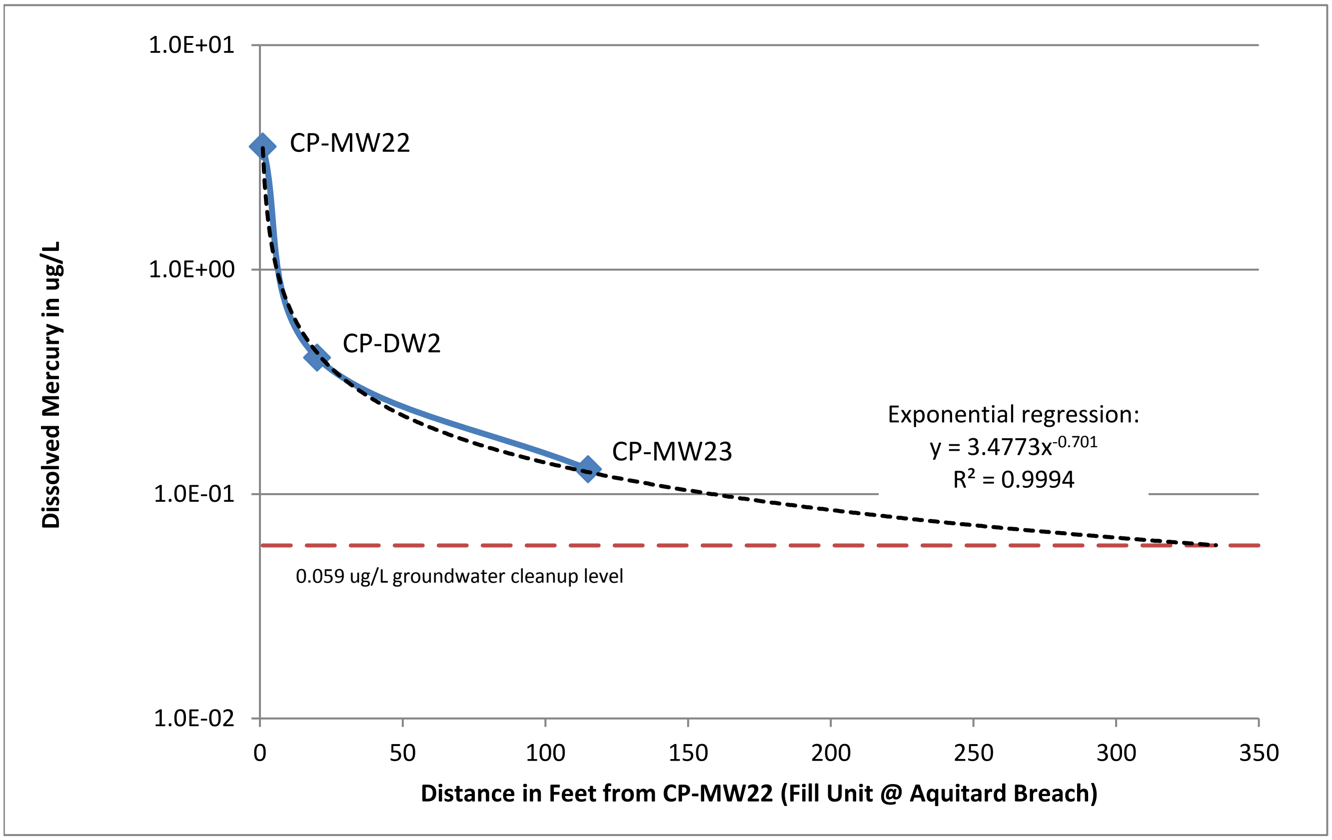
Aspect CONSULTING

OCT-2016	BY: SJG / RMB	FIGURE NO. 4-1
PROJECT NO. 070188	REVISED BY: PPW / RMB	

GIS Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\4-1 Disolved Hg Data MRU Area July 2013.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 10/6/2016 || User: rpepin || Print Date: 10/6/2016

July 2013 Dissolved Mercury Data

Sample ID	Dissolved Mercury in ug/L	
Lower Sand Wells		
CP-DW1-073013	0.0239	
CP-DW2-073013	0.406	
CP-DW3-073013	0.0544	
CP-MW04-073013	0.0251	
CP-MW05-073013	0.00185	
CP-MW23-073113	0.129	
Fill Unit Wells		
CP-MW13-073113	5.84	near downgradient edge of Mercury Recovery Unit (MRU)
CP-MW22-073013	3.54	at aquitard breach
CP-MW24-073113	1.3	downgradient of siderite amended backfill at Caustic Filler House (CFH)

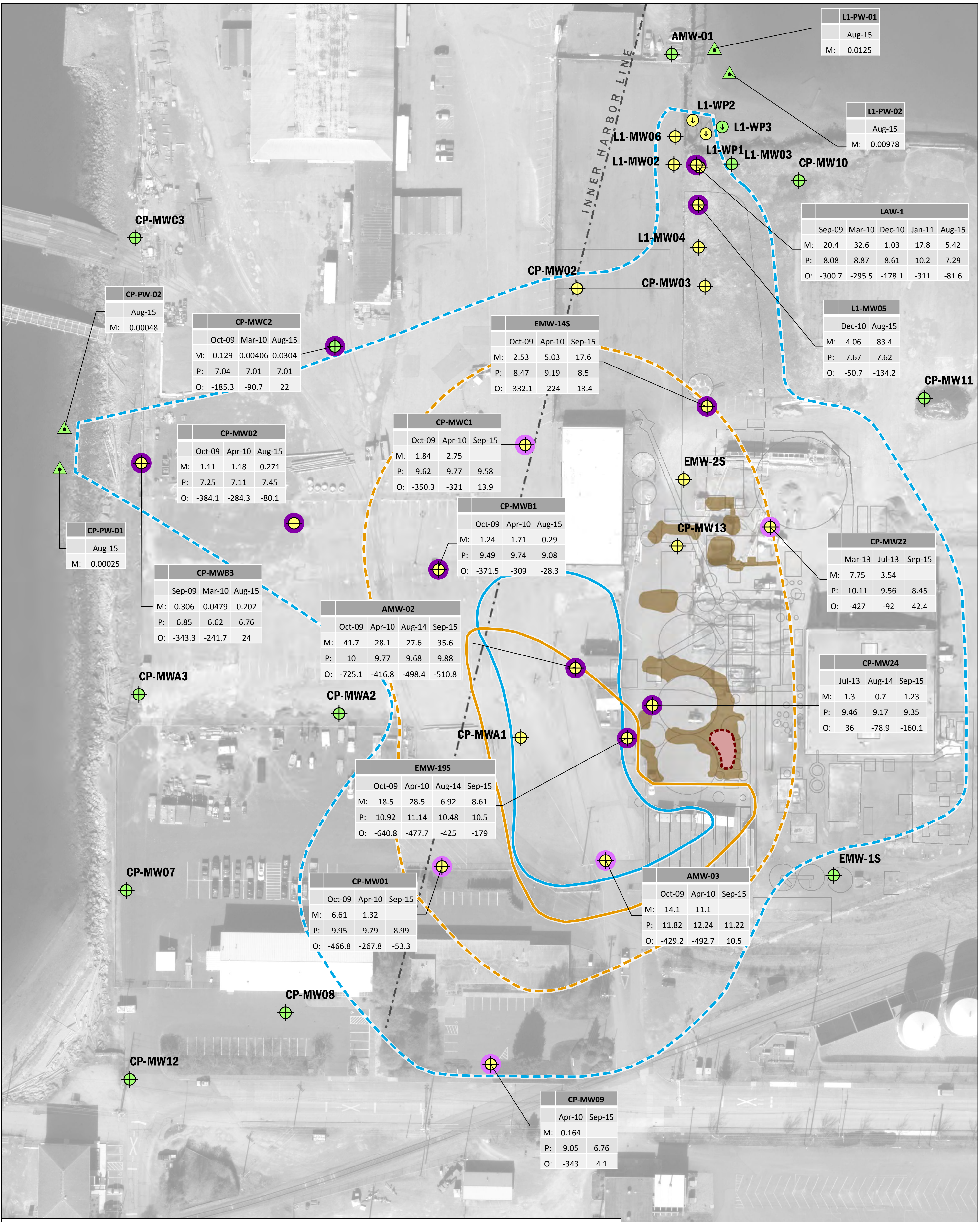


Note: Well CP-MW22 is in Fill Unit; wells CP-DW2 and CP-MW23 are in Lower Sand.

Figure 4-2
Lower Sand Dissolved Mercury vs. Distance from Aquitard Breach
Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, WA

Aspect Consulting
6/5/14
V:\070188 Port Bellingham\Deliverables\Chlor-Alkali RAU Feasibility Study\Internal Draft\FS Figures\Fig 4-2 Lower Sand Hg Data and Extrapolation Plot 6-5-14.xlsx

GIS Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\4-3 GW and Intertidal Porewater Data.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 2/18/2016 || User: rbobich || Print Date: 2/18/2016



	L1-PW-01
	Aug-15
M:	0.0125

	L1-PW-02
	Aug-15
M:	0.00978

	LAW-1				
	Sep-09	Mar-10	Dec-10	Jan-11	Aug-15
M:	20.4	32.6	1.03	17.8	5.42
P:	8.08	8.87	8.61	10.2	7.29
O:	-300.7	-295.5	-178.1	-311	-81.6

	L1-MW05	
	Dec-10	Aug-15
M:	4.06	83.4
P:	7.67	7.62
O:	-50.7	-134.2

	CP-PW-02
	Aug-15
M:	0.00048

	CP-MWC2		
	Oct-09	Mar-10	Aug-15
M:	0.129	0.00406	0.0304
P:	7.04	7.01	7.01
O:	-185.3	-90.7	22

	EMW-14S		
	Oct-09	Apr-10	Sep-15
M:	2.53	5.03	17.6
P:	8.47	9.19	8.5
O:	-332.1	-224	-13.4

	CP-MWB2		
	Oct-09	Apr-10	Aug-15
M:	1.11	1.18	0.271
P:	7.25	7.11	7.45
O:	-384.1	-284.3	-80.1

	CP-MWC1		
	Oct-09	Apr-10	Sep-15
M:	1.84	2.75	
P:	9.62	9.77	9.58
O:	-350.3	-321	13.9

	CP-PW-01
	Aug-15
M:	0.00025

	CP-MWB1		
	Oct-09	Apr-10	Aug-15
M:	1.24	1.71	0.29
P:	9.49	9.74	9.08
O:	-371.5	-309	-28.3

	CP-MW22		
	Mar-13	Jul-13	Sep-15
M:	7.75	3.54	
P:	10.11	9.56	8.45
O:	-427	-92	42.4

	CP-MWB3		
	Sep-09	Mar-10	Aug-15
M:	0.306	0.0479	0.202
P:	6.85	6.62	6.76
O:	-343.3	-241.7	24

	AMW-02			
	Oct-09	Apr-10	Aug-14	Sep-15
M:	41.7	28.1	27.6	35.6
P:	10	9.77	9.68	9.88
O:	-725.1	-416.8	-498.4	-510.8

	CP-MW24		
	Jul-13	Aug-14	Sep-15
M:	1.3	0.7	1.23
P:	9.46	9.17	9.35
O:	36	-78.9	-160.1

	EMW-19S			
	Oct-09	Apr-10	Aug-14	Sep-15
M:	18.5	28.5	6.92	8.61
P:	10.92	11.14	10.48	10.5
O:	-640.8	-477.7	-425	-179

	CP-MW01		
	Oct-09	Apr-10	Sep-15
M:	6.61	1.32	
P:	9.95	9.79	8.99
O:	-466.8	-267.8	-53.3

	AMW-03		
	Oct-09	Apr-10	Sep-15
M:	14.1	11.1	
P:	11.82	12.24	11.22
O:	-429.2	-492.7	10.5

	CP-MW09	
	Apr-10	Sep-15
M:	0.164	
P:	9.05	6.76
O:	-343	4.1

Well ID→

Sample Date→

Dissolved Mercury (in µg/L)→

pH→

ORP (mV)→

	LAW-1				
	Sep-09	Mar-10	Dec-10	Jan-11	Aug-15
M:	20.4	32.6	1.03	17.8	5.42
P:	8.08	8.87	8.61	10.2	7.29
O:	-300.7	-295.5	-178.1	-311	-81.6

Qualifiers:
U = Not Detected,
J = Estimated Concentration.
(Blank = No Sample)

MILL NORTH

TRUE NORTH

45°

0 50 100

Feet

Sample Location Not Sampled Aug 2015 (symbol):

- ⌖ Fill Unit Monitoring Well
- ⓘ Intertidal Well Point

Mercury in Groundwater (post-interim action) (symbol color):

- 🟩 Dissolved Hg <= 0.059 ug/L
- 🟨 Dissolved Hg > 0.059 ug/L

Fill Unit Groundwater pH (post-interim action):

- > 8.5
- > 10

Fill Unit Dissolved Hg in Groundwater (post-interim action):

- > 0.059 µg/L
- > 10 µg/L

Aug 2015 Sample Locations

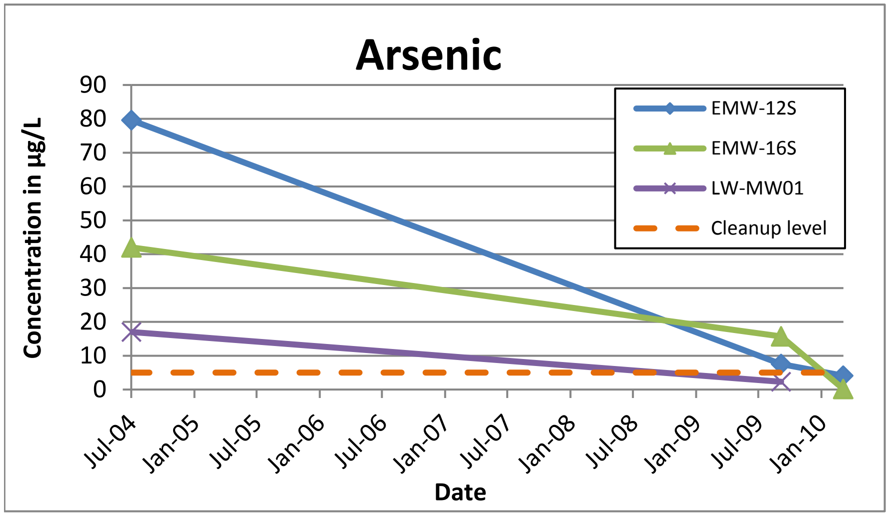
- ▲ Intertidal Porewater Sample (Hg and pH)
- ● Monitoring well (Hg and pH)
- ● Monitoring well (pH)
- Approximate Area of Siderite-Amended Backfill
- Previous Soil Removal Areas, Caustic Plume Interim Action

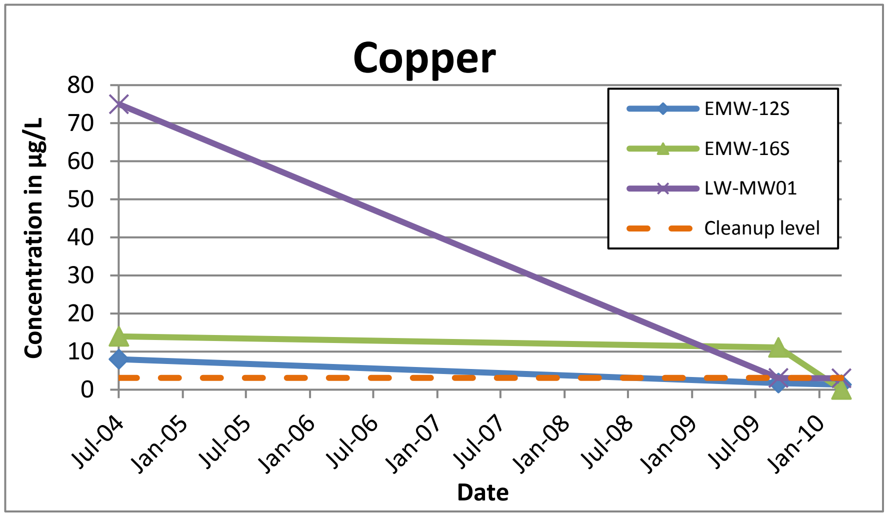
Groundwater and Intertidal Porewater Data (Mercury, pH, and ORP) for Locations Sampled in Summer 2015

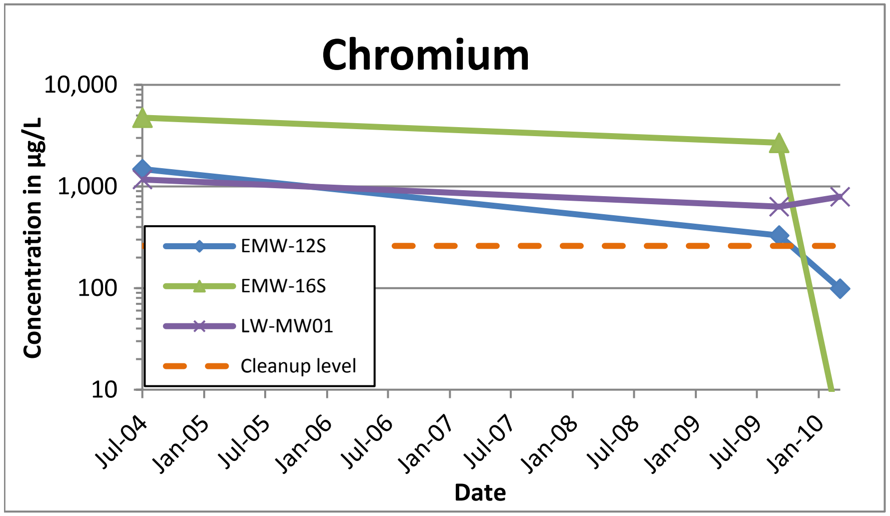
Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING

FEB-2016	BY: PPW	FIGURE NO.	
PROJECT NO. 070188	REVISED BY: EAC	4-3	







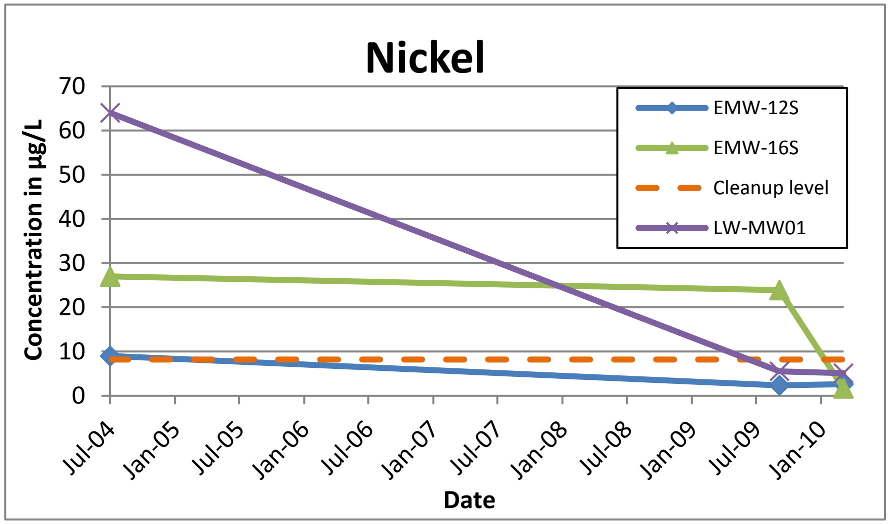


Figure 4-4
Miscellaneous Dissolved Metals Concentrations over Time

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, WA

Aspect Consulting
6/5/14
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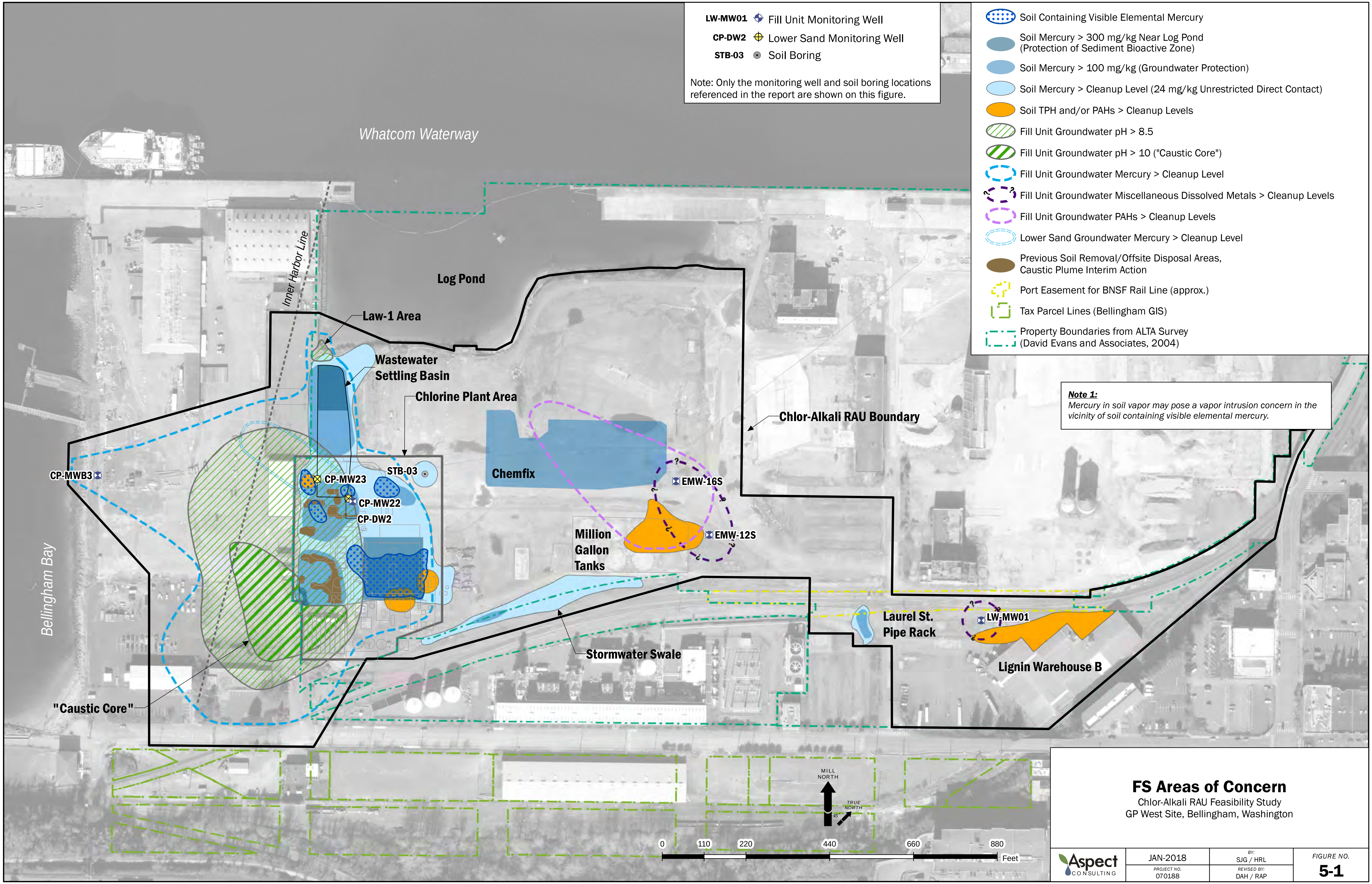


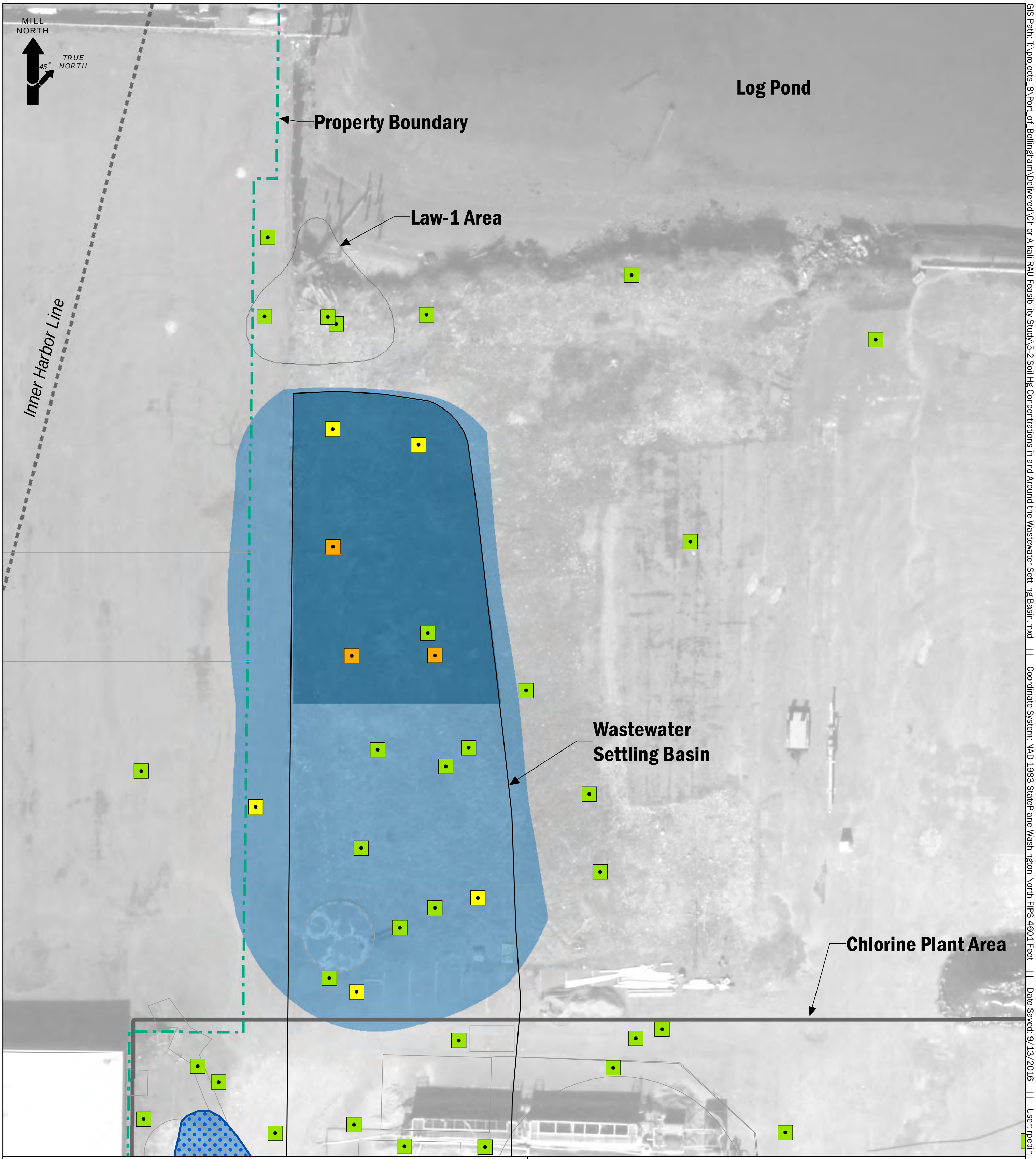
FS Areas of Concern

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING

JAN-2018	BY: SJG / HRL	FIGURE NO. 5-1
PROJECT NO. 070188	REVISED BY: DAH / RAP	

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\5-1 FS Areas of Concern.mxd



Soil Sampling Locations and Mercury Concentration Ranges

- 🟩 [Hg] ≤ 100 mg/kg
- 🟨 100 < [Hg] ≤ 300 mg/kg
- 🟧 [Hg] > 300 mg/kg

- ▨ Soil Containing Visible Elemental Mercury
- ● Soil Mercury > 300 mg/kg
- ● Soil Mercury > 100 mg/kg

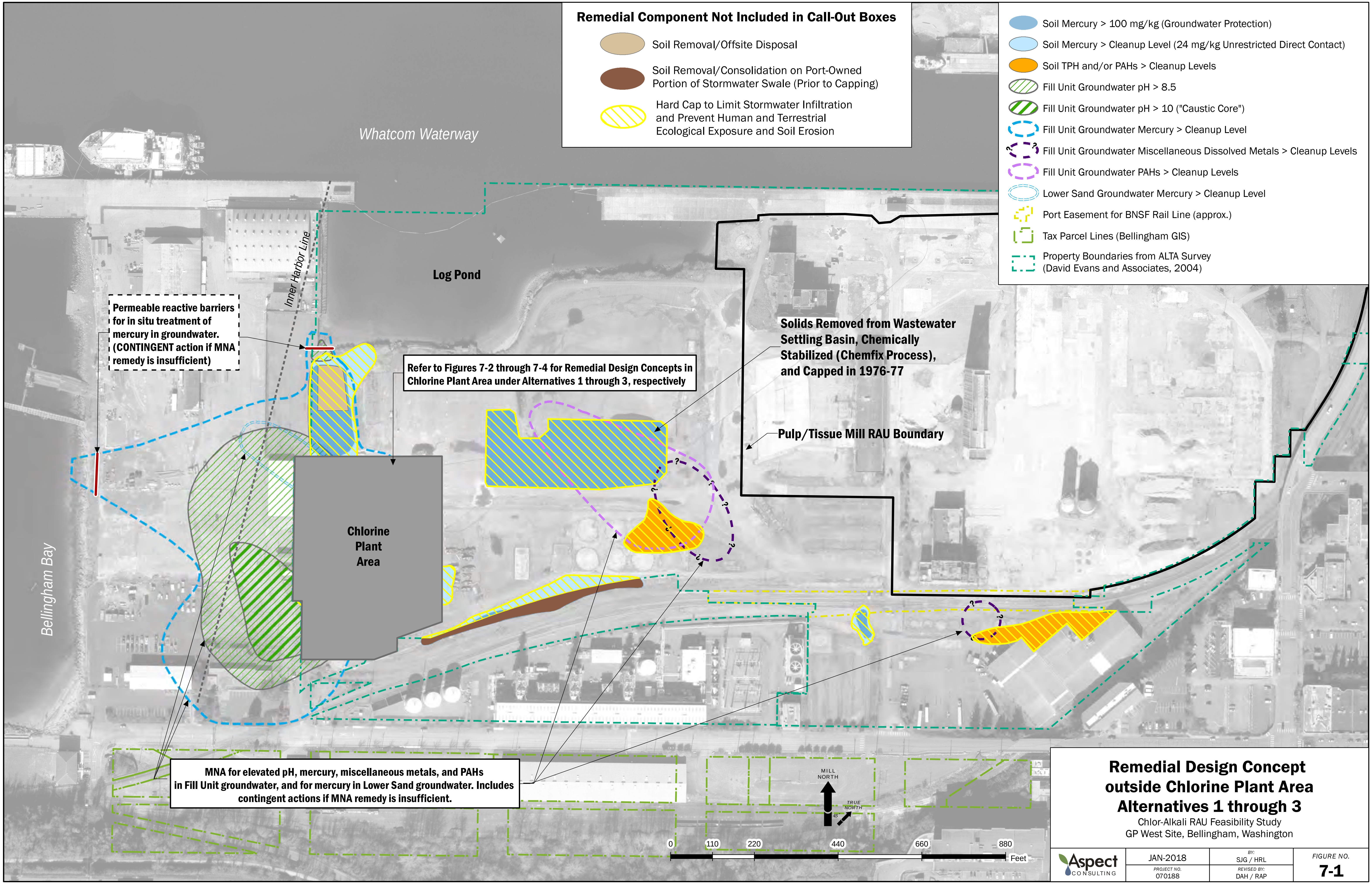
0 25 50 100
Feet

Soil Mercury Concentrations in and Around the Wastewater Settling Basin

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

SEP-2016	BY: DAH / RAP	FIGURE NO. 5-2
PROJECT NO. 070188	REVISED BY: - - -	

GIS Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\5-2 Soil Hg Concentrations in and Around the Wastewater Settling Basin.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/13/2016 || User: rpepin || Print Date: 9/13/2016



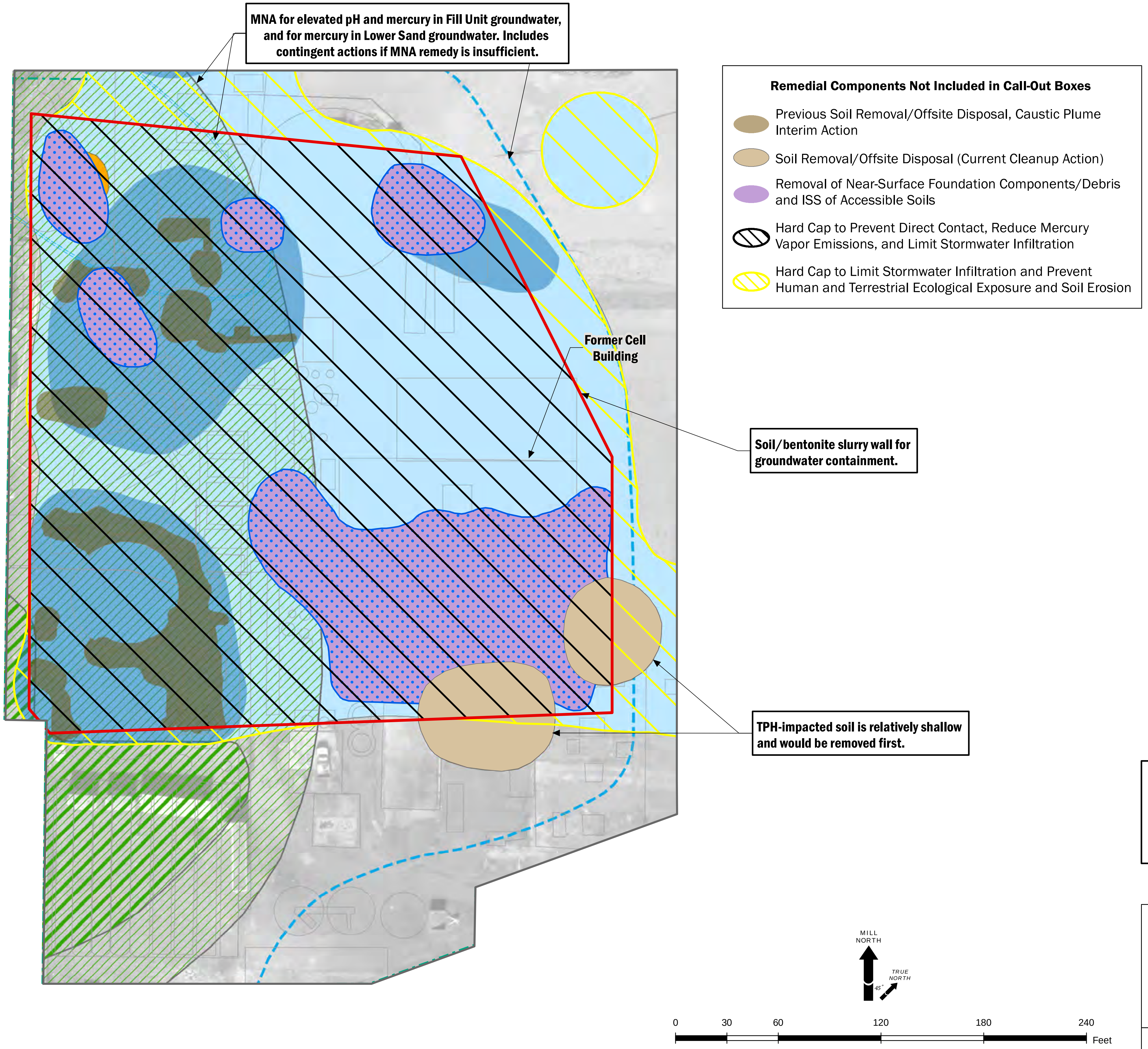
Remedial Design Concept outside Chlorine Plant Area Alternatives 1 through 3

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING

JAN-2018	BY: SJG / HRL	FIGURE NO.	
PROJECT NO. 070188	REVISED BY: DAH / RAP	7-1	

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-1 Remedial Design Concept Alternative 1-3.mxd



- Soil Containing Visible Elemental Mercury
- Soil Mercury > 100 mg/kg (Groundwater Protection)
- Soil Mercury > Cleanup Level (24 mg/kg Unrestricted Direct Contact)
- Soil TPH and/or PAHs > Cleanup Levels
- Fill Unit Groundwater pH > 8.5
- Fill Unit Groundwater pH > 10 ("Caustic Core")
- Fill Unit Groundwater Mercury > Cleanup Level
- Lower Sand Groundwater Mercury > Cleanup Level
- Property Boundaries from ALTA Survey (David Evans and Associates, 2004)

Notes:
1. The areas of previous soil removal are assumed to be capped along with the surrounding soils that exceed cleanup levels, although capping of these areas would not be required.
2. Areas of current soil removal are capped where impacted soils remain at depth.

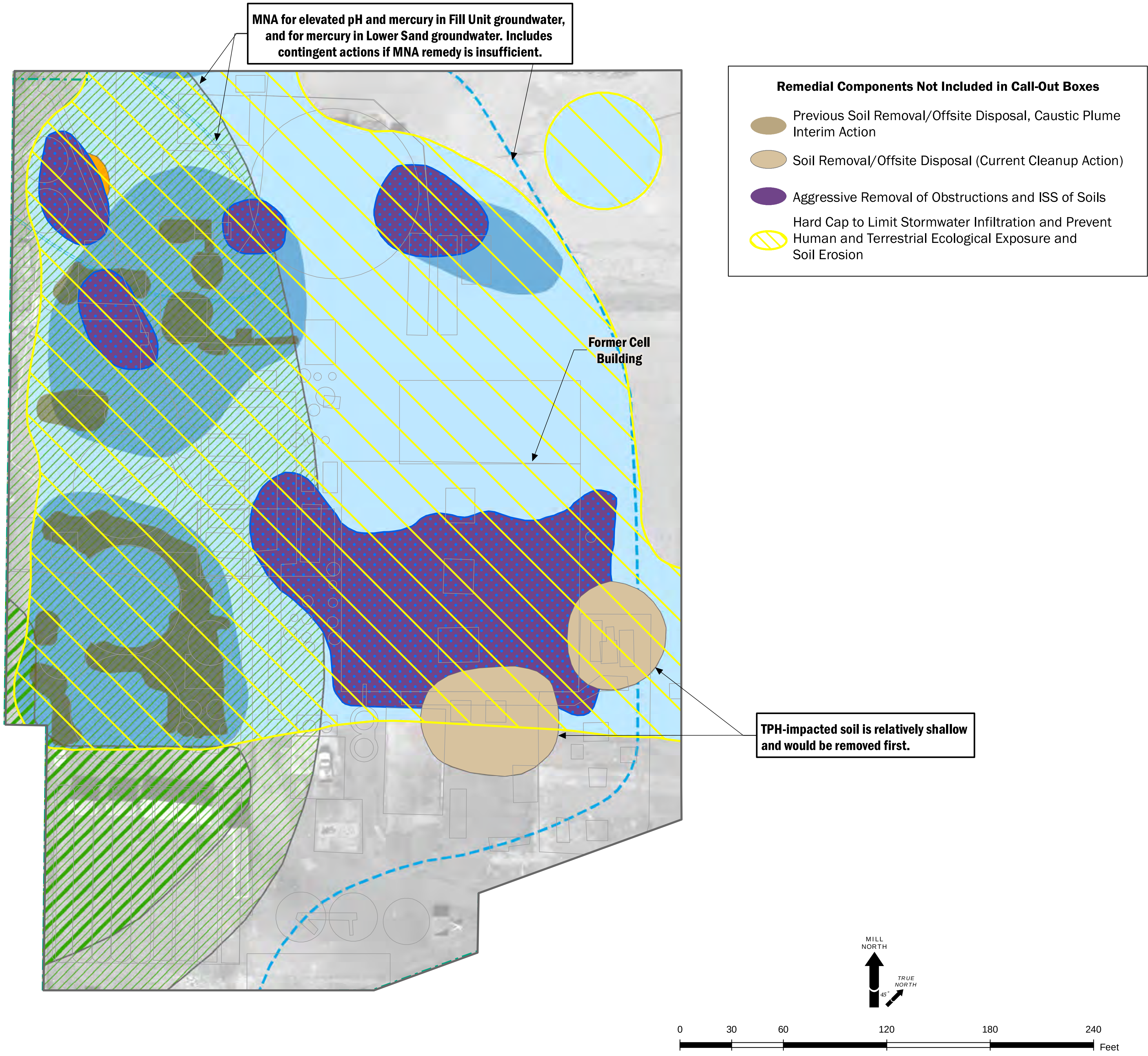
Remedial Design Concept in Chlorine Plant Area Alternative 1

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING

JAN-2018	BY: DAH / RAP	FIGURE NO. 7-2
PROJECT NO. 070188	REVISED BY: - - -	

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-2 Remedial Design Concept in CPA Alternative 1.mxd



MNA for elevated pH and mercury in Fill Unit groundwater, and for mercury in Lower Sand groundwater. Includes contingent actions if MNA remedy is insufficient.

TPH-impacted soil is relatively shallow and would be removed first.

Remedial Components Not Included in Call-Out Boxes

🟫	Previous Soil Removal/Offsite Disposal, Caustic Plume Interim Action
🟫	Soil Removal/Offsite Disposal (Current Cleanup Action)
🟪	Aggressive Removal of Obstructions and ISS of Soils
▨	Hard Cap to Limit Stormwater Infiltration and Prevent Human and Terrestrial Ecological Exposure and Soil Erosion

⬭	Soil Containing Visible Elemental Mercury
🟦	Soil Mercury > 100 mg/kg (Groundwater Protection)
🟦	Soil Mercury > Cleanup Level (24 mg/kg Unrestricted Direct Contact)
🟧	Soil TPH and/or PAHs > Cleanup Levels
▨	Fill Unit Groundwater pH > 8.5
▨	Fill Unit Groundwater pH > 10 ("Caustic Core")
⬭	Fill Unit Groundwater Mercury > Cleanup Level
⬭	Lower Sand Groundwater Mercury > Cleanup Level
⬚	Property Boundaries from ALTA Survey (David Evans and Associates, 2004)

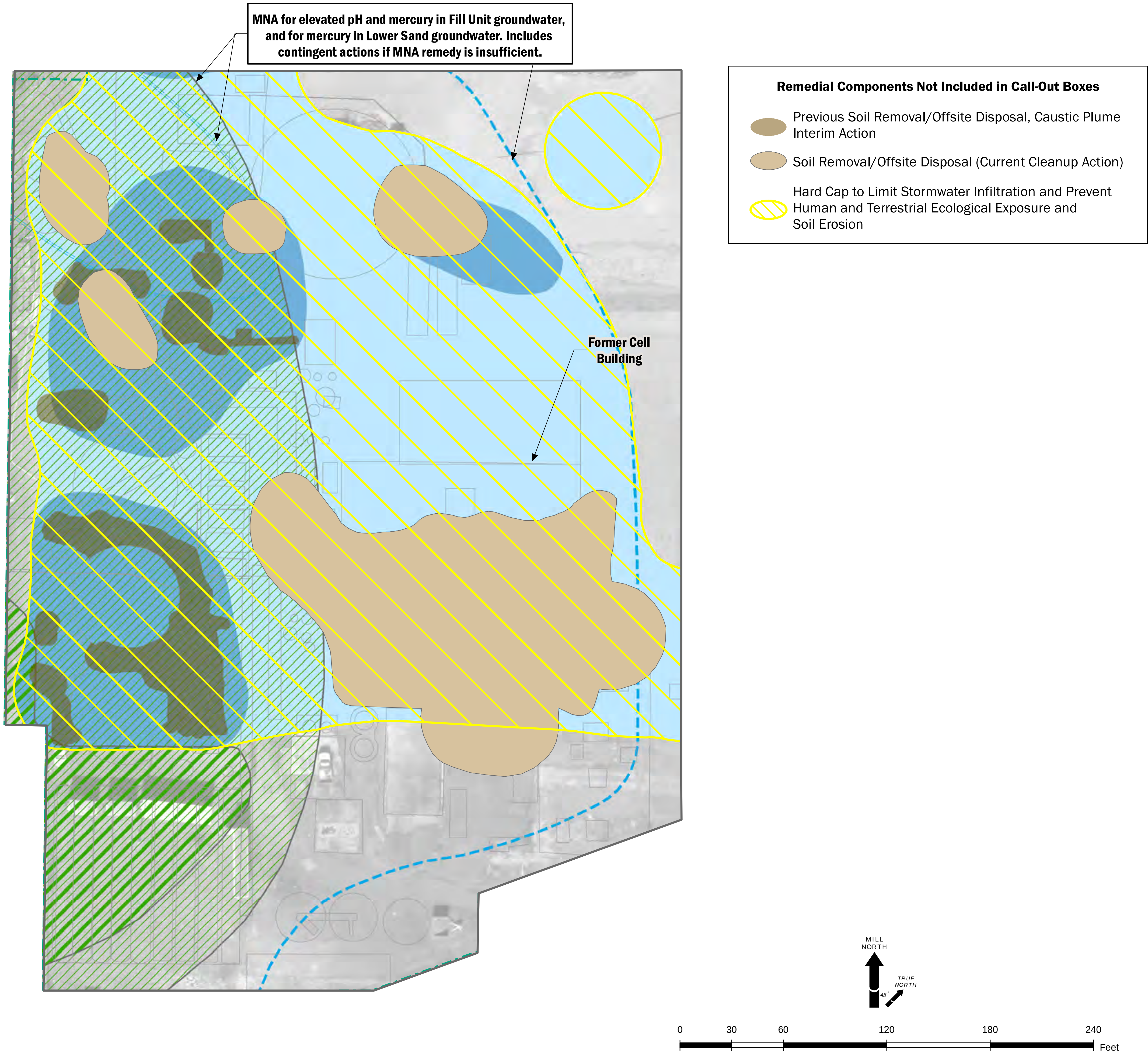
Notes:
1. The areas of previous soil removal are assumed to be capped along with the surrounding soils that exceed cleanup levels, although capping of these areas would not be required.
2. Areas of current soil removal are capped where impacted soils remain at depth.

Remedial Design Concept in Chlorine Plant Area Alternative 2

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING	JAN-2018	BY: DAH / RAP	FIGURE NO.
	PROJECT NO. 070188	REVISED BY: SCC	7-3

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-3 Remedial Design Concept in CPA Alternative 2.mxd



- Soil Mercury > Cleanup Level (24 mg/kg Unrestricted Direct Contact)
- Soil Mercury > 100 mg/kg (Groundwater Protection)
- Fill Unit Groundwater pH > 8.5
- Fill Unit Groundwater pH > 10 ("Caustic Core")
- Fill Unit Groundwater Mercury > Cleanup Level
- Lower Sand Groundwater Mercury > Cleanup Level
- Property Boundaries from ALTA Survey (David Evans and Associates, 2004)

Notes:

1. The areas of previous soil removal are assumed to be capped along with the surrounding soils that exceed cleanup levels, although capping of these areas would not be required.
2. Areas of current soil removal are capped where surrounding and/or underlying soils exceed the mercury cleanup level for unrestricted direct contact.

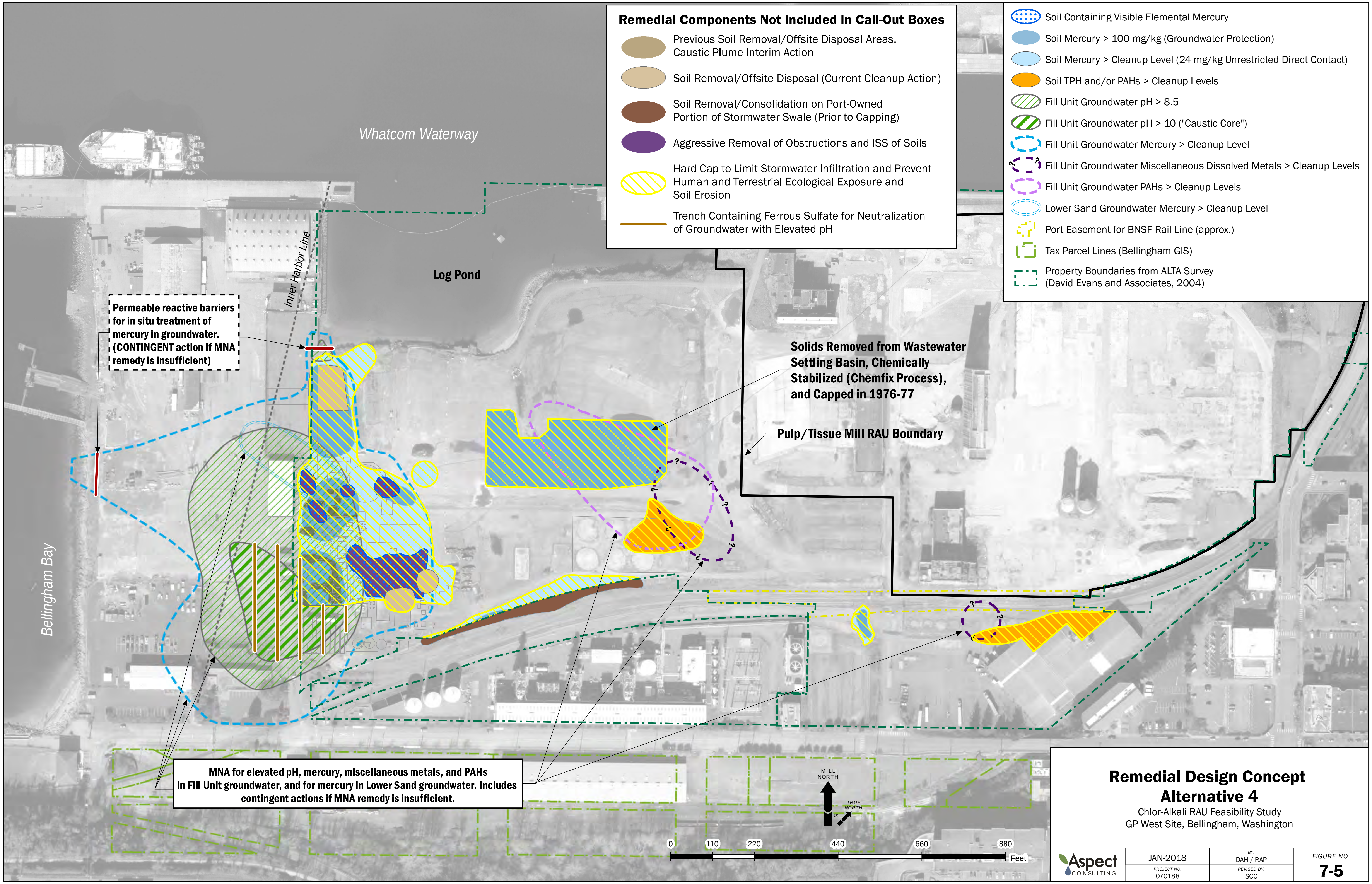
Remedial Design Concept in Chlorine Plant Area Alternative 3

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING

JAN-2018	BY: DAH / RAP	FIGURE NO. 7-4
PROJECT NO. 070188	REVISED BY: SCC	

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-4 Remedial Design Concept in CPA Alternative 3.mxd



Remedial Components Not Included in Call-Out Boxes

- Previous Soil Removal/Offsite Disposal Areas, Caustic Plume Interim Action
- Soil Removal/Offsite Disposal (Current Cleanup Action)
- Soil Removal/Consolidation on Port-Owned Portion of Stormwater Swale (Prior to Capping)
- Aggressive Removal of Obstructions and ISS of Soils
- Hard Cap to Limit Stormwater Infiltration and Prevent Human and Terrestrial Ecological Exposure and Soil Erosion
- Trench Containing Ferrous Sulfate for Neutralization of Groundwater with Elevated pH

- Soil Containing Visible Elemental Mercury
- Soil Mercury > 100 mg/kg (Groundwater Protection)
- Soil Mercury > Cleanup Level (24 mg/kg Unrestricted Direct Contact)
- Soil TPH and/or PAHs > Cleanup Levels
- Fill Unit Groundwater pH > 8.5
- Fill Unit Groundwater pH > 10 ("Caustic Core")
- Fill Unit Groundwater Mercury > Cleanup Level
- Fill Unit Groundwater Miscellaneous Dissolved Metals > Cleanup Levels
- Fill Unit Groundwater PAHs > Cleanup Levels
- Lower Sand Groundwater Mercury > Cleanup Level
- Port Easement for BNSF Rail Line (approx.)
- Tax Parcel Lines (Bellingham GIS)
- Property Boundaries from ALTA Survey (David Evans and Associates, 2004)

Permeable reactive barriers for in situ treatment of mercury in groundwater. (CONTINGENT action if MNA remedy is insufficient)

Solids Removed from Wastewater Settling Basin, Chemically Stabilized (Chemfix Process), and Capped in 1976-77

Pulp/Tissue Mill RAU Boundary

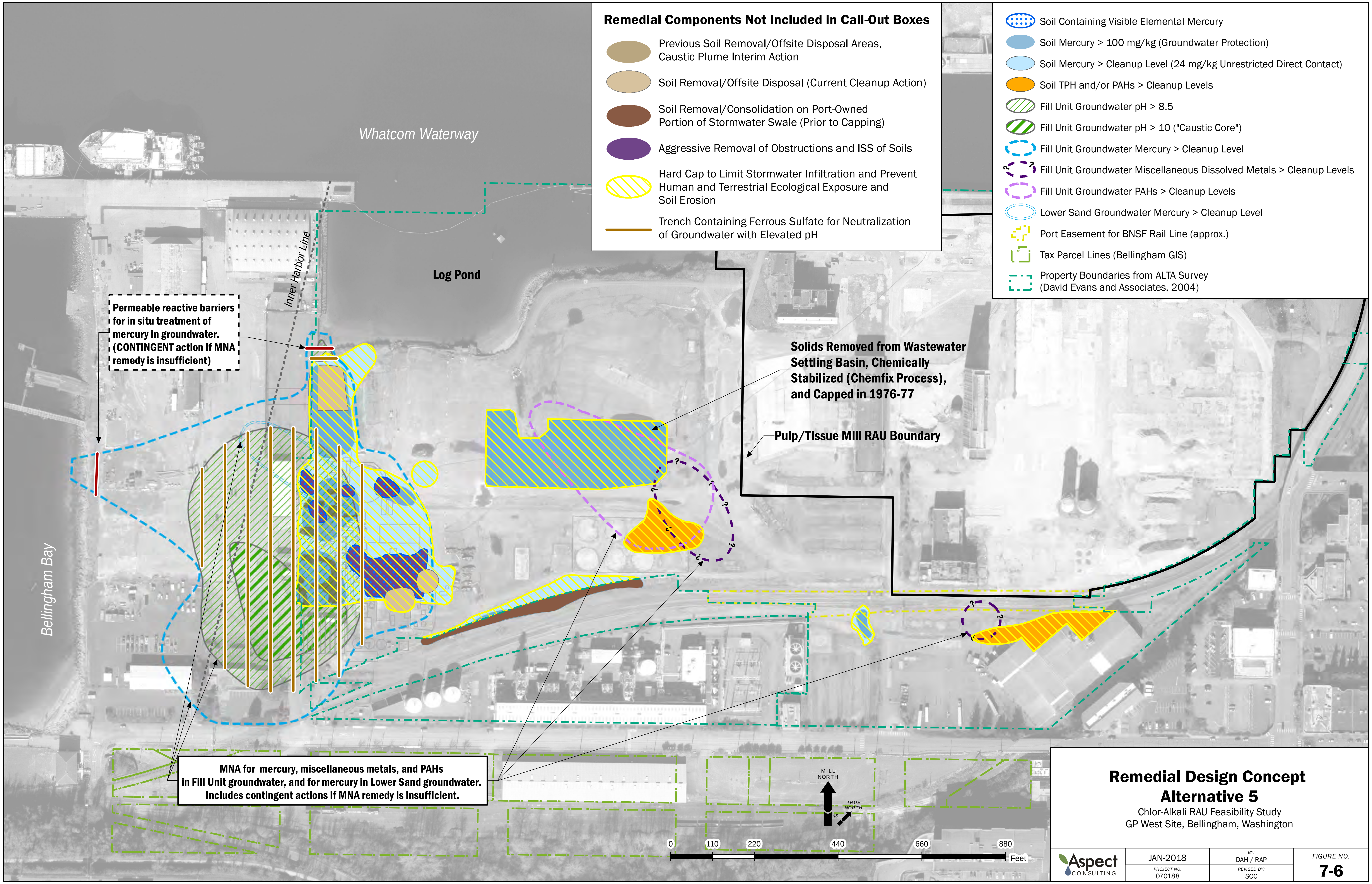
MNA for elevated pH, mercury, miscellaneous metals, and PAHs in Fill Unit groundwater, and for mercury in Lower Sand groundwater. Includes contingent actions if MNA remedy is insufficient.

Remedial Design Concept Alternative 4

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING	JAN-2018	BY: DAH / RAP	FIGURE NO.
	PROJECT NO. 070188	REVISED BY: SCC	**7-5**

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-5 Remedial Design Concept Alternative 4.mxd



Remedial Components Not Included in Call-Out Boxes

- Previous Soil Removal/Offsite Disposal Areas, Caustic Plume Interim Action
- Soil Removal/Offsite Disposal (Current Cleanup Action)
- Soil Removal/Consolidation on Port-Owned Portion of Stormwater Swale (Prior to Capping)
- Aggressive Removal of Obstructions and ISS of Soils
- Hard Cap to Limit Stormwater Infiltration and Prevent Human and Terrestrial Ecological Exposure and Soil Erosion
- Trench Containing Ferrous Sulfate for Neutralization of Groundwater with Elevated pH

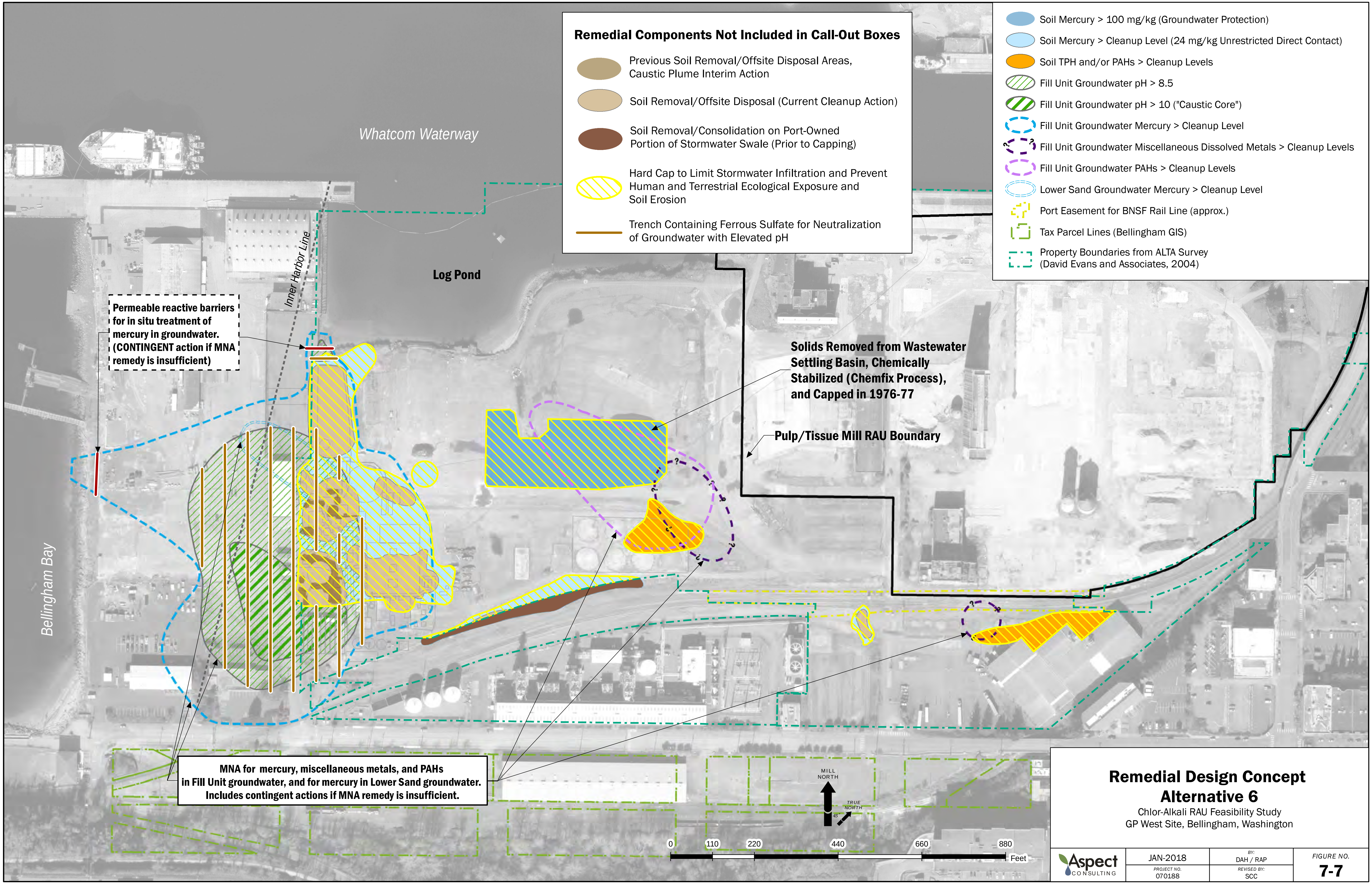
- Soil Containing Visible Elemental Mercury
- Soil Mercury > 100 mg/kg (Groundwater Protection)
- Soil Mercury > Cleanup Level (24 mg/kg Unrestricted Direct Contact)
- Soil TPH and/or PAHs > Cleanup Levels
- Fill Unit Groundwater pH > 8.5
- Fill Unit Groundwater pH > 10 ("Caustic Core")
- Fill Unit Groundwater Mercury > Cleanup Level
- Fill Unit Groundwater Miscellaneous Dissolved Metals > Cleanup Levels
- Fill Unit Groundwater PAHs > Cleanup Levels
- Lower Sand Groundwater Mercury > Cleanup Level
- Port Easement for BNSF Rail Line (approx.)
- Tax Parcel Lines (Bellingham GIS)
- Property Boundaries from ALTA Survey (David Evans and Associates, 2004)

Remedial Design Concept Alternative 5

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING	JAN-2018	BY: DAH / RAP	FIGURE NO. 7-6
	PROJECT NO. 070188	REVISED BY: SCC	

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-6 Remedial Design Concept Alternative 5.mxd



Remedial Components Not Included in Call-Out Boxes

- Previous Soil Removal/Offsite Disposal Areas, Caustic Plume Interim Action
- Soil Removal/Offsite Disposal (Current Cleanup Action)
- Soil Removal/Consolidation on Port-Owned Portion of Stormwater Swale (Prior to Capping)
- Hard Cap to Limit Stormwater Infiltration and Prevent Human and Terrestrial Ecological Exposure and Soil Erosion
- Trench Containing Ferrous Sulfate for Neutralization of Groundwater with Elevated pH

- Soil Mercury > 100 mg/kg (Groundwater Protection)
- Soil Mercury > Cleanup Level (24 mg/kg Unrestricted Direct Contact)
- Soil TPH and/or PAHs > Cleanup Levels
- Fill Unit Groundwater pH > 8.5
- Fill Unit Groundwater pH > 10 ("Caustic Core")
- Fill Unit Groundwater Mercury > Cleanup Level
- Fill Unit Groundwater Miscellaneous Dissolved Metals > Cleanup Levels
- Fill Unit Groundwater PAHs > Cleanup Levels
- Lower Sand Groundwater Mercury > Cleanup Level
- Port Easement for BNSF Rail Line (approx.)
- Tax Parcel Lines (Bellingham GIS)
- Property Boundaries from ALTA Survey (David Evans and Associates, 2004)

Permeable reactive barriers for in situ treatment of mercury in groundwater. (CONTINGENT action if MNA remedy is insufficient)

Solids Removed from Wastewater Settling Basin, Chemically Stabilized (Chemfix Process), and Capped in 1976-77

Pulp/Tissue Mill RAU Boundary

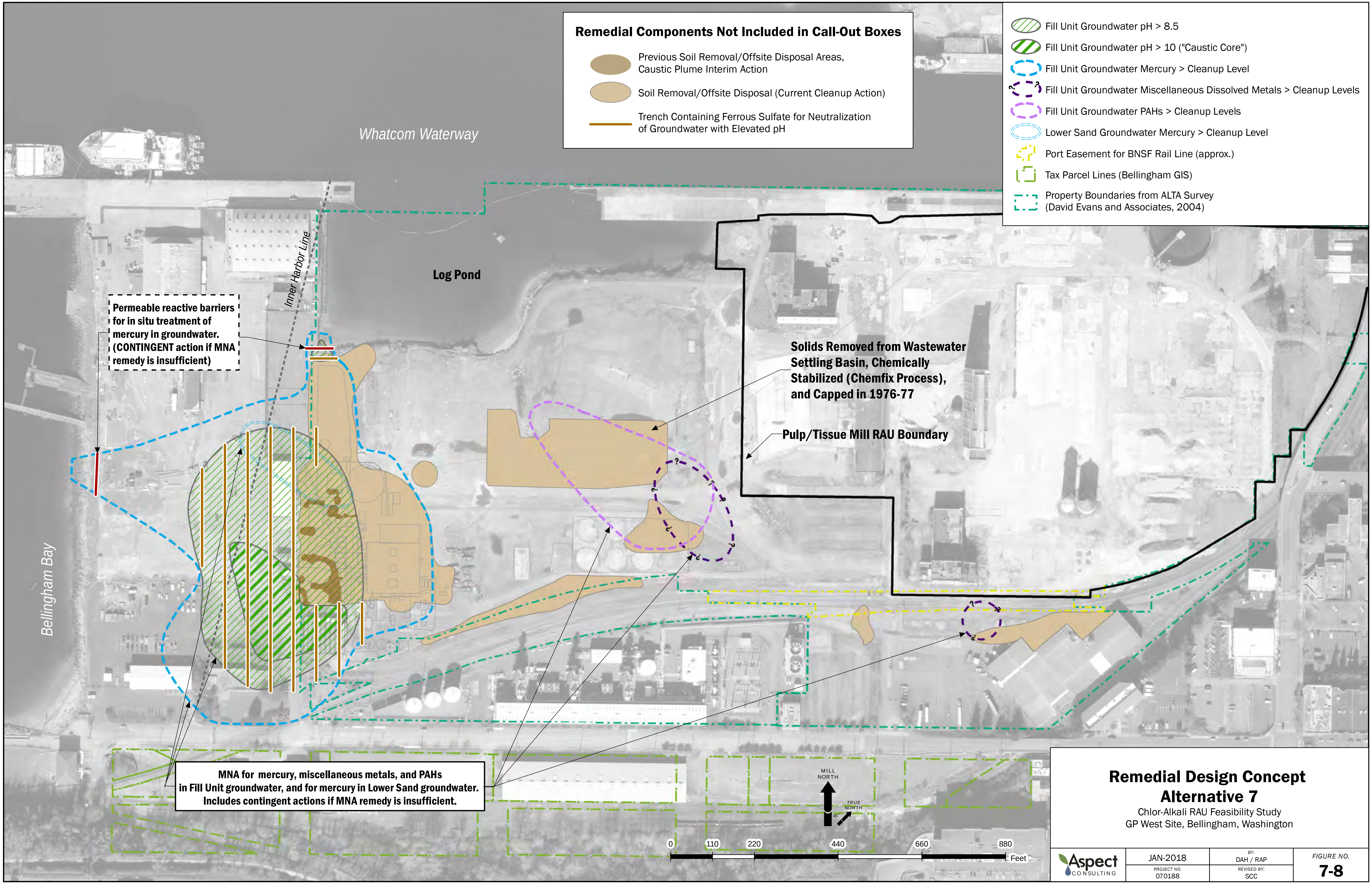
MNA for mercury, miscellaneous metals, and PAHs in Fill Unit groundwater, and for mercury in Lower Sand groundwater. Includes contingent actions if MNA remedy is insufficient.

Remedial Design Concept Alternative 6

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING	JAN-2018	BY: DAH / RAP	FIGURE NO. 7-7
	PROJECT NO. 070188	REVISED BY: SCC	

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-7 Remedial Design Concept Alternative 6.mxd



Remedial Components Not Included in Call-Out Boxes

●	Previous Soil Removal/Offsite Disposal Areas, Caustic Plume Interim Action
●	Soil Removal/Offsite Disposal (Current Cleanup Action)
—	Trench Containing Ferrous Sulfate for Neutralization of Groundwater with Elevated pH

▨	Fill Unit Groundwater pH > 8.5
▨	Fill Unit Groundwater pH > 10 ("Caustic Core")
○	Fill Unit Groundwater Mercury > Cleanup Level
○	Fill Unit Groundwater Miscellaneous Dissolved Metals > Cleanup Levels
○	Fill Unit Groundwater PAHs > Cleanup Levels
○	Lower Sand Groundwater Mercury > Cleanup Level
☐	Port Easement for BNSF Rail Line (approx.)
☐	Tax Parcel Lines (Bellingham GIS)
☐	Property Boundaries from ALTA Survey (David Evans and Associates, 2004)

Permeable reactive barriers for in situ treatment of mercury in groundwater. (CONTINGENT action if MNA remedy is insufficient)

Solids Removed from Wastewater Settling Basin, Chemically Stabilized (Chemfix Process), and Capped in 1976-77

Pulp/Tissue Mill RAU Boundary

MNA for mercury, miscellaneous metals, and PAHs in Fill Unit groundwater, and for mercury in Lower Sand groundwater. Includes contingent actions if MNA remedy is insufficient.

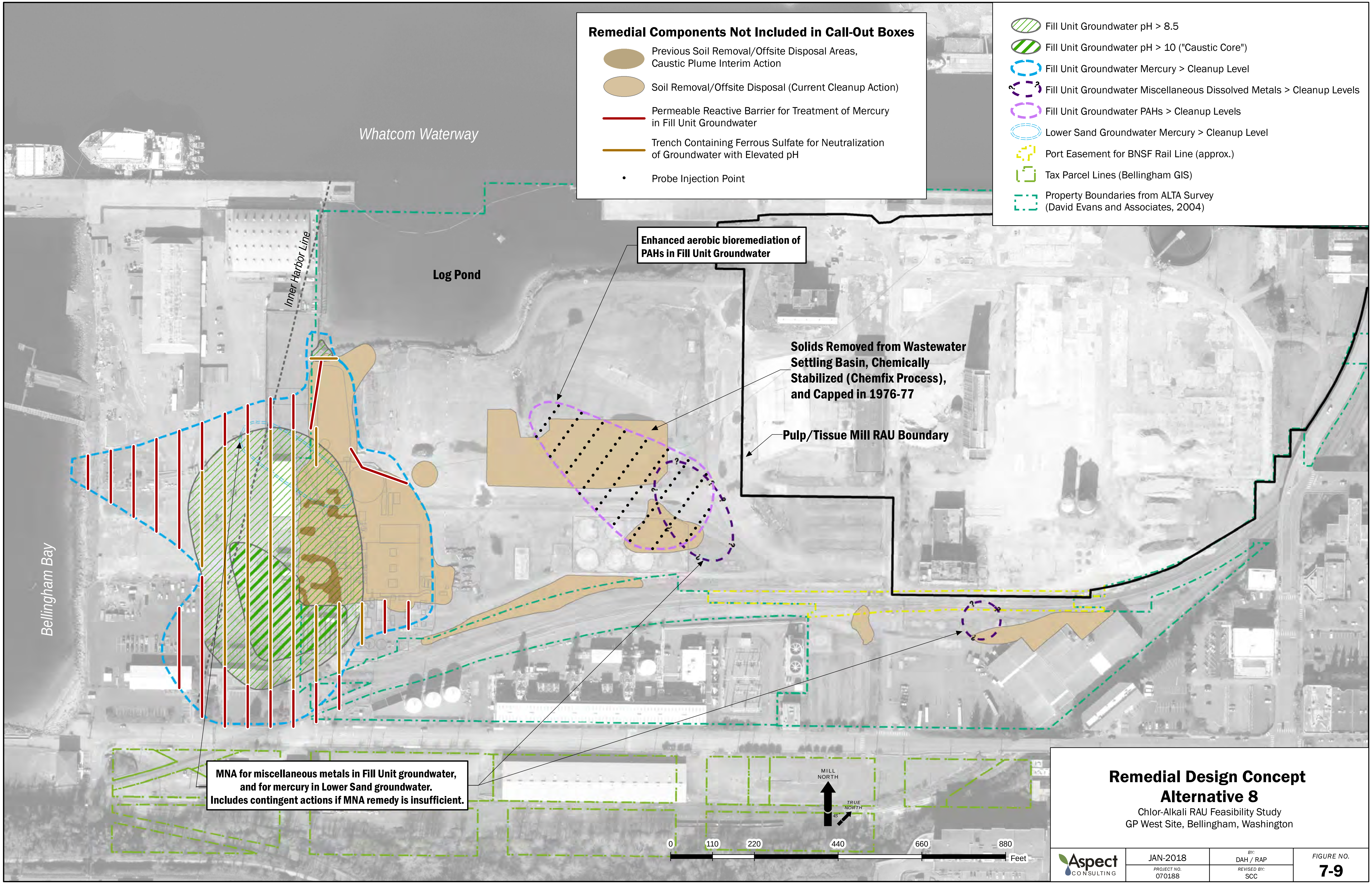
Remedial Design Concept Alternative 7

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING

JAN-2018	BY: DAH / RAP	FIGURE NO. 7-8
PROJECT NO. 070188	REVISED BY: SCC	

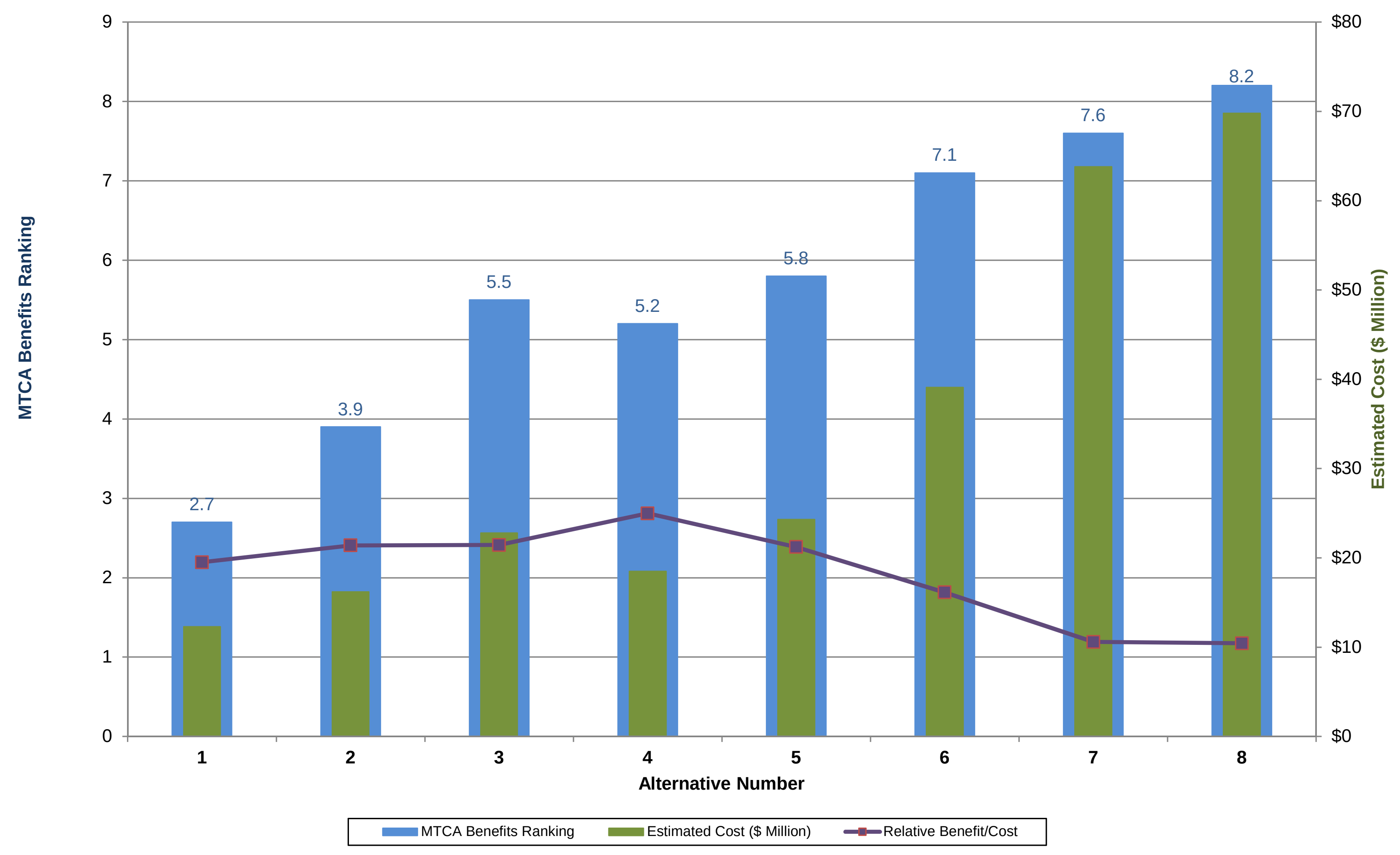
Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-8 Remedial Design Concept Alternative 7.mxd



Remedial Design Concept
Alternative 8
Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, Washington

Aspect CONSULTING
JAN-2018
PROJECT NO. 070188
BY: DAH / RAP
REVISED BY: SCC
FIGURE NO. **7-9**

Path: T:\projects_8\Port_of_Bellingham\Delivered\Chlor Alkali RAU Feasibility Study\Chlor Alkali RAU Feasibility Study Early 2018\7-9 Remedial Design Concept Alternative 8.mxd



Notes:

1) Present worth costs in 2017 dollars, calculated using a discount factor of 0.7%.

2) The benefit/cost ratio values in Table 8-1 have been multiplied by 10 to scale them appropriately to the left axis, for display purposes only.

Aspect Consulting
1/18/2018
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Tbls excl Sec5_Jan 2018.xlsx

Figure 8-1
Disproportionate Cost Analysis Summary

Chlor-Alkali RAU Feasibility Study
GP West Site, Bellingham, WA