Final
Remedial Investigation/Feasibility Study
Volume II: Feasibility Study Report

R.G. Haley Site
Bellingham, Washington

for
City of Bellingham

February 1, 2016

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ABBREVIATIONS AND ACRONYMS

AET	apparent effect threshold
AKART	all known and reasonable technology
AOC	area of contamination
APH	air-phase petroleum hydrocarbons
ARARs	applicable or relevant and appropriate requirements
AST	above-ground storage tank
BBIC	Bellingham Bay Improvement Company
bgs	below ground surface
BEP	bis(2-ethylhexyl)phthalate
BETX	benzene, ethylbenzene, toluene, and xylenes
BNSF	Burlington Northern Santa Fe Railway Company
BSAF	biota-sediment accumulation factors
CAD	confined aquatic disposal
CAO	cleanup action objective
CAP	cleanup action plan
City	City of Bellingham
CLARC	Cleanup Levels and Risk Calculations Volume 3.1
CMP	corrugated metal pipe
COCs	constituents of concern
COPC	constituent of potential concern
cPAH	carcinogenic polycyclic aromatic hydrocarbons
Crossarm	International Crossarm Manufacturing Company
CSL	cleanup screening level
CSM	conceptual site model
CUL	cleanup level
CWA	Clean Water Act
DCA	disproportionate cost analysis
DGPS	differential global positioning system
DMMU	dredged material management unit
DNR	Washington State Department of Natural Resources
Douglas	Douglas Management Company

DQOs	data quality objectives
E & E	Ecology and Environment, Inc.
Ecology	Washington State Department of Ecology
EDD	electronic data deliverables
EF	exceedance factor
EIS	environmental impact statement
ENR	enhanced natural recovery
EPA	U.S. Environmental Protection Agency
EPH	extractable petroleum hydrocarbons
ESA	Endangered Species Act
FML	flexible membrane liner
FPM	free product mobility
FS	feasibility study
GP	Georgia Pacific
GRAs	general response actions
H:V	horizontal to vertical
Haley	R.G. Haley International Corporation
HASP	health and safety plan
HDPE	high density polyethylene
HHWM	higher high water mark
HPA	Hydraulic Project Approval
HRS	hazard ranking system
HVOC	halogenated volatile organic compounds
IC	institutional controls
ICA	interim cleanup action
IDL	instrument detection limit
IHS	indicator hazardous substances
IPA	interim placement area
ISS	*in situ* solidification and stabilization
K_{OC}	soil or sediment organic carbon-water partitioning coefficient
Kd	distribution coefficient (soil or sediment-water partitioning coefficient)
LAET	lowest apparent effect threshold

2LAET	second lowest apparent effect threshold
LCS/LCSD	laboratory control sample/sample duplicate
LDRs	land disposal restrictions
LFG	landfill gas
LNAPL	light non-aqueous phase liquid
MDL	method detection limit
MGP	manufactured gas plant
MHHW	mean higher high water
MLLW	mean lower low water
MNR	monitored natural recovery
MS/MSD	matrix spike/matrix spike duplicate
MTBE	methyl tertiary-butyl ether
MTCA	Model Toxics Control Act
NAD83/98	North American Datum 1983 and 1998
NAPL	non-aqueous phase liquid
NAVD88	North American Vertical Datum 1988
NGVD29	National Geodetic Vertical Datum 1929
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPL	Superfund National Priorities List
NTU	nephelometric turbidity unit
O&M	operation and maintenance
OC	organic carbon normalized
OHWM	ordinary high water mark
Order	Agreed Order No. DE 2186
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-p-dioxins
PCDFs	polychlorinated dibenzofurans
PCL	preliminary cleanup level
PCP	pentachlorophenol
PLP(s)	potentially liable person or persons

PMA	Port Management Agreement
Port	Port of Bellingham
PQL	practical quantitation limit
PRB	permeable reactive barrier
PSDDA	Puget Sound Dredge Disposal Analysis
PSEP	Puget Sound Estuary Program
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
RPD	relative percent difference
SAP	sampling and analysis plan
SCO	sediment cleanup objective
SCUBA	self-contained underwater breathing apparatus
SEPA	State Environmental Policy Act
SHA	site hazard assessment
SL	screening level
SMS	Sediment Management Standards
SOPs	standard operating procedures
State	State of Washington
SVOCs	semivolatile organic compounds
SWAC	surface-area weighted average concentration
TBT	tributyl tin
TEE	terrestrial ecological evaluation
TEF	toxic equivalency factor
TEQ	toxicity equivalent
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers

USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UST	underground storage tank
UTLs	upper tolerance limit
UV	ultraviolet
VOCs	volatile organic compounds
WAC	Washington Administrative Code
WARM	Washington Ranking Method
WDFW	Washington State Department of Fish and Wildlife
WHO	World Health Organization

UNITS OF MEASURE

°C	degrees Celsius
°F	degrees Fahrenheit
µg/L	microgram per liter
cm	centimeter
cm/s	centimeter per second
cm/yr	centimeter per year
cy	cubic yard
ft	feet
ft/day	feet per day
ft^2	square feet
ft^3	cubic feet
ft^3/day	cubic feet per day
g/kg	gram per kilogram
gpm	gallon per minute
km^2	square kilometer
m/sec	meter per second
m^3	cubic meter
mg/kg	milligram per kilogram
mg/L	milligrams per liter

mi^2	square mile
mL	milliliter
ng/kg	nanogram per kilogram
pg/L	picograms per liter
ppt	parts per trillion
µg/kg	microgram per kilogram

9.0 FEASIBILITY STUDY

The overall objectives of the FS are to develop and evaluate a range of cleanup action alternatives for contaminated media at the Site in accordance with MTCA and SMS and to identify the preferred alternative.

This FS report follows MTCA procedures outlined in MTCA (WAC 173-340-350[8]) and SMS (WAC 173-204-550[7]). This FS report identifies applicable or relevant and appropriate requirements (ARARs) for cleanup; proposes cleanup standards protective of human health and the environment; identifies the extent of contaminated media requiring remedial actions; identifies and screens potentially applicable remedial technologies; and assembles technologies into remedial alternatives to address contaminants at the Site. Expectations for cleanup alternatives and requirements for selection of cleanup actions under MTCA are provided in WAC 173-340-370 and WAC 173-340-360, respectively and in SMS WAC 173-204-570. The FS presents a comparison of the remedial alternatives based on protectiveness, effectiveness, permanence, implementability, cost and consideration of public concerns (MTCA evaluation criteria). The MTCA disproportionate cost analysis (DCA) process is used to identify a preferred remedy for Ecology's consideration.

9.1. Areas Requiring Cleanup

The nature and estimated extent of contamination was established in the RI. Soil, groundwater and sediment at the Haley Site contain petroleum hydrocarbons, individual PAHs including cPAHs, PCP and dioxins/furans at concentrations that represent a potential threat to human and ecological health.

In the upland area of the Site, the estimated extent of contamination is defined by the distribution of IHSs (TPH, individual PAHs, cPAHs, PCP and dioxins/furans) in soil and groundwater (Figure 8-1). As noted in Section 1.2 of the RI report, upland areas potentially associated with the Haley Site but not investigated in the RI may be the subject of another RI.

The sediment area potentially requiring remediation is defined based on exceedances of SMS-promulgated chemical and biological criteria for the protection of the benthic invertebrate community (Figure 8-1), and bioaccumulation-based criteria derived for the protection of people and ecological receptors that may consume seafood, as explained below.

Sediment with chemical concentrations exceeding benthic toxicity criteria is located relatively close to the Haley shoreline, in the intertidal and shallow subtidal zones. The lateral extent of the SMS benthic toxicity exceedance area is relatively well-defined, although some additional sediment sampling will be necessary to refine the northern and southern limits in the intertidal zone. Supplement sediment sampling will be conducted prior to remedial design. The entire extent of the benthic toxicity exceedance area will be addressed by remedial action, as described in subsequent sections of this FS.

Bioaccumulative IHSs also exceed sediment screening levels in the nearshore benthic toxicity exceedance area; these (bioaccumulative) screening level exceedances, however, extend further offshore into deeper waters beyond the benthic toxicity exceedance area. The outer boundary of Haley-related bioaccumulative screening level exceedances has not yet been identified. The lateral extent of Haley-related bioaccumulative compounds to the north, south and west will be evaluated based on additional sediment data collected prior to remedial design, as well as other factors (Section 9.5.3).

9.1.1. Site Units

For the purpose of the FS, the Site is divided geographically into the upland unit and marine unit shown in Figure 9-1. The marine unit is also referred to in the FS as the sediment unit. The environmental setting of each unit is different; however, both units were affected by contaminant releases from historical Haley wood treatment operations. Contamination extends from the upland into the adjacent sediment unit; the boundary between the two units is established at the ordinary high water mark (OHWM) near the top of the shoreline bank. This FS presents separate discussions for each unit. Integration of the selected alternatives for each unit, as well as compatibility of those remedial alternatives with the adjacent and overlapping Cornwall Landfill and Whatcom Waterway cleanups, are discussed in the FS (Sections 9.5, 9.6 and 10.0). Design and implementation of the selected remedial alternatives for the Haley Site will also require coordination and construction sequencing with actions on the Cornwall Landfill site (Section 10.0).

9.1.1.1. UPLAND UNIT

The upland unit is approximately 7.5 acres in size; the footprint of the upland unit covered by the RI incorporates the locations where soil and/or groundwater IHSs are present at concentrations greater than screening levels (Figure 8-1) and incorporates the upland AOC. The west boundary of the upland unit is the OHWM and the north and east boundaries of the upland unit are the Haley property line. The southern portion of the upland unit overlaps with the northern portion of the Cornwall Landfill upland unit. The Inner Harbor Line extends across the upland unit due to historical tideland filling. Natural resources that may be present in the upland unit are described in Section 4.3.

9.1.1.2. MARINE UNIT

The marine unit is defined as the area of Bellingham Bay adjacent to the Haley upland unit where site-related contaminants exceed screening levels. The marine unit adjoins the upland unit at the OHWM and encompasses the entire area of SMS benthic toxicity exceedances based on existing data. It will also include intertidal and subtidal lands where Haley-related bioaccumulative compounds (dioxins/furans, cPAHs, and PCP) exceed cleanup levels.

For purposes of evaluating remedial alternatives in this FS, the assumed outer (bayward) boundary of the marine unit is approximately at the -10 to -15 foot (NAVD88) contours (Figure 9-1). This outer boundary established in the FS is appropriate because it includes the entire area where active remedial measures are anticipated. The outer boundary of the Haley marine unit also generally coincides with the position of the outer boundary of the proposed active remedy for the adjoining Cornwall Landfill site. The full extent of the Haley marine unit will be further evaluated based on supplemental sediment sampling collected prior to remedial design, and other factors (Section 9.5.3). A future bayward expansion of the Haley marine unit, if warranted based on supplemental sediment data, would likely be addressed by MNR.

Any changes to the marine unit outer boundaries based on an evaluation of the concentrations and distribution of Haley-related bioaccumulative compounds are not anticipated to affect the selection of a preferred alternative in this FS; rather, the areal extent to which a particular component of the remedy is applied will be refined through the pre-design and design phases of the cleanup.

The marine unit is located on State-owned aquatic lands managed by DNR. A port management unit (PMA 3) overlaps the northern portion of the marine unit. The 2013 Haley interim action was constructed on aquatic lands authorized by an easement granted to the City by DNR. The easement area falls within the marine unit. The Haley marine unit overlaps with portions of the proposed active remedy for the Cornwall site as described above; it also overlaps with a portion of the Whatcom Waterway site that is designated for MNR.

Biological communities and natural resources associated with the marine unit are presented in Section 4.3. Existing substrate conditions are described in Section 4.1.

9.2. Basis for Cleanup Action

Cleanup action objectives (CAOs) form the basis for evaluating and selecting remedial technologies and cleanup actions that will be successful at a given site. CAOs consist of location-, chemical- and medium-specific goals for protecting human health and the environment. CAOs are dependent on the chemicals and pathways that represent a risk to people and natural resources associated with a site. Development of CAOs involves several steps, as described below and in the following sections:

- Identify laws and regulatory standards (ARARs) that set the framework and requirements for the development of cleanup standards and implementation of a cleanup action;
- Develop cleanup levels and points of compliance at which an acceptable risk level is attained; and
- Identify locations and media requiring cleanup based on selected cleanup standards.

9.2.1. Potentially Applicable or Relevant and Appropriate Requirements

Cleanup actions conducted under MTCA and SMS must comply with all state and federal laws (WAC 173-340-710) that have jurisdiction over the cleanup (i.e., are applicable) or that Ecology determines may apply to the cleanup (i.e., are relevant and appropriate). Collectively these laws, implementing regulations, standards, limitations or other requirements are referred to as ARARs.

The ARARs identified for cleanup of the Haley Site are listed in Table 9-1. The procedures, standards and other requirements specified in MTCA and SMS are the primary ARARs governing cleanup actions at the Site. Additional ARARs regulate specific components of the cleanup including disposal of hazardous waste, management of stormwater during construction, and worker safety during implementation.

Most of the requirements associated with the additional ARARs are specified as part of various permit conditions; however, cleanup actions conducted under a Consent Decree are generally exempt from the procedural requirements of many state and local permits. Typically, cleanup actions are exempt from the procedural requirements of the Washington State Clean Air Act, solid waste management, construction projects in state waters (specifically Hydraulic Project Approvals [HPAs]), water pollution control, the SMA, and local regulations. However, permits associated with two national regulations that are administered by the State — the Clean Water Act (CWA) National Pollution Discharge Elimination System (NPDES) permits, and those permits required for treatment, storage or disposal of hazardous waste under the Resource, Conservation and Recovery Act (RCRA) — still apply, as do all federally-required permits. Regardless of the permit exemptions, all cleanup actions must meet the substantive requirements of the subject regulations. Ecology is responsible for consulting and coordinating with the lead agencies for the exempted permits and identifying the substantive requirements.

9.2.1.1. AREA OF CONTAMINATION POLICY

Remediation-derived waste (e.g., soil, sediment and debris) containing wood treatment-related chemicals from historical operations at the R.G. Haley facility will be classified as F032-listed dangerous waste and subject to Land Disposal Restrictions (LDRs) unless managed within the boundaries of an Area of Contamination (AOC) in accordance with Ecology's AOC Policy (Policy) (Ecology 1991). Ecology has designated an AOC at the Haley Site for the purpose of on-site excavation, movement, stabilization and consolidation of contaminated soil and sediment (Ecology 2007a, 2013d, 2014a). The AOC boundary (Appendix N) is based on the footprint of continuous Haley-related soil and groundwater contamination that exceeds applicable MTCA cleanup levels, and sediment contamination that exceeds SMS criteria based on protection of the benthic community. Ecology's AOC Policy states that moving dangerous waste within an AOC is not considered "generation" as defined by the Dangerous Waste Regulations (Chapter 173-303 WAC). The Policy further states that "containment, treatment and disposal of consolidated wastes within an AOC does not automatically trigger the dangerous waste regulations" and that LDRs will not automatically become applicable at sites where dangerous wastes are being excavated, consolidated or moved within the defined AOC.

Most of the cleanup alternatives developed for the Haley Site (Section 9.5) include the consolidation of remediation-derived waste within the boundaries of the designated upland AOC. The estimated costs for these alternatives are based on the expectation that these actions will not trigger LDRs or other aspects of the Federal RCRA or State dangerous waste regulations except those determined to be relevant and appropriate to the Site and action.

9.2.1.2. ANTICIPATED PERMITS

A number of the ARARs governing cleanup of sediment will be addressed through the Joint Aquatic Resource Permit Application (JARPA). The JARPA coordinates information applicable to the US Army Corps of Engineers (USACE)-issued CWA Section 10 and Section 404 permits (Nationwide 38 or individual 404 permit), Ecology-issued CWA Section 401 Water Quality Certifications, Washington Department of Natural Resources Use Authorizations for State-Owned Aquatic Lands, among others. The USACE is also responsible for consultation with natural resource trustees regarding potential project impacts on species and habitats protected under the Endangered Species Act (ESA) and subsequent requirements. An NPDES permit may be required for any on-site water treatment or discharge of stormwater from the cleanup site during implementation of the remedy.

Many of the permits likely to be associated with the upland cleanup action are either exempted from the corresponding procedural requirements per MTCA, although substantive requirements must be met, or would be coordinated as part of a City land use permit requirements.

Ecology will be responsible for issuing the final approval for the cleanup action, following consultation with other federal, state and local regulators. The USACE will separately be responsible for issuing approval of the project under Nationwide Permit 38, following ESA consultation with the federal natural resource trustees, and also incorporating Ecology's 401 Water Quality Certification.

9.2.2. Cleanup Action Objectives

The general objective of the cleanup action is to eliminate, reduce, or otherwise control to the extent feasible and practicable, unacceptable risks to human health and the environment posed by hazardous substances in impacted media in accordance with the MTCA cleanup regulation (Chapter 173-340 WAC), SMS (Chapter 173-204 WAC), and other applicable regulatory requirements. The individual CAOs for the cleanup action at the Haley Site are specific to certain media and contaminants of concern, exposure routes and receptors. The CAOs permit a range of treatment and containment alternatives to be developed in the subsequent sections of the FS. The media and exposure pathways of concern for the Haley Site are identified in Section 8.4, and include potential human and ecological exposures by direct and indirect contact with soil, sediment, groundwater and LNAPL associated with Haley sources.

Other considerations for cleanup actions at the Haley Site include:

- The cleanup action should be compatible with, and not be detrimental to, cleanup actions currently planned at nearby sites (i.e., Cornwall Landfill site, Whatcom Waterway site).
- The cleanup action should be compatible with the plans to develop the Haley Site, as well as the Cornwall Landfill Site, in the future as a public park. Current park plans include vegetated open areas, limited structures, and enhancing access and use of shoreline and intertidal beach areas.

Specific CAOs for the impacted media at the Haley Site are presented below.

9.2.2.1. UPLAND UNIT CAOS

The objective of the upland cleanup is to reduce or control to the extent feasible, risks from hazardous substances in soil, soil vapor and groundwater associated with the following potential exposure routes:

- People coming in contact (i.e., dermal contact, including incidental ingestion) with hazardous substances in soil;
- People being exposed to (i.e., inhaling) hazardous substances in vapor form;
- Contact (i.e., dermal contact, including incidental ingestion) by ecological receptors with hazardous substances in soil;
- Transport of upland contaminated soil to marine sediment or surface water as a result of erosion; and
- Transfer of contaminants from soil to groundwater and subsequent discharge to sediment or surface water.

As described in Section 5.1.2 of the RI report, groundwater beneath the Haley Site is classified as non-potable. Therefore, the CAOs do not include preventing use of groundwater as potable water; however, institutional controls will be included in the remedy that prevent withdrawal of groundwater from the Site for potable and non-potable uses.

9.2.2.2. MARINE UNIT CAOS

The objective of the in-water cleanup is to reduce or control to the extent feasible, risks from hazardous substances in sediment associated with the following potential exposure routes:

- People coming in direct contact (i.e., dermal contact, including incidental ingestion) with hazardous substances in sediment;
- Exposure of aquatic organisms to hazardous substances in sediment within the biologically active zone (the upper 12 cm of sediment);
- Exposure of higher trophic level receptors (fish, aquatic-dependent birds and mammals) to contaminated benthic invertebrate prey via ingestion; and
- People ingesting fish and shellfish contaminated with hazardous substances through bioaccumulation of Site-related contamination.

9.2.3. Cleanup Standards

Selection and use of cleanup standards in the development of remedial alternatives and cleanup decisions provide a mechanism to achieve the CAOs. Cleanup standards consist of: (1) chemical concentrations in environmental media or biological effect thresholds that are protective of human health and the environment, and (2) the locations where the cleanup levels must be met (i.e., point of compliance). The screening levels compiled in the RI report (Section 5.1) provide a basis for developing preliminary cleanup levels for Site media. Additional sediment risk-based criteria to address bioaccumulative effects were considered for cPAHs, dioxins/furans, and PCP (see Section 9.2.3.1).

Proposed points of compliance are identified in this FS and evaluated relative to each cleanup action alternative. However, the points of compliance along with other aspects of the cleanup standards will be finalized by Ecology in the cleanup action plan (CAP). Media-specific preliminary cleanup levels and points of compliance for sediment, groundwater, and soil are presented in the following sections.

9.2.3.1. SEDIMENT

Cleanup levels for sediment are selected from a range of values, from the SMS Sediment Cleanup Objective (SCO) below which no adverse effects or unacceptable risks are anticipated, to the Cleanup Screening Level (CSL) above which adverse effects or unacceptable risks would be expected. Preliminary sediment cleanup levels are based on both protection of benthic organisms from direct toxicity through multiple pathways, and protection of people and ecological receptors that may consume seafood foraged from the Site (bioaccumulation pathway).

People coming into direct contact with sediment during beach play, clamming and net-fishing also were considered when developing preliminary sediment cleanup levels for the Site. Any nearshore remedial action at the Site will require erosion controls (armoring) that will prevent direct contact to underlying sediment through beach play, clamming or net-fishing (Section 5.1.1). This same armoring will also preclude deeper-burrowing, harvestable clam populations from becoming established, eliminating the need to apply bioaccumulation-based cleanup levels for protection of human health in the nearshore environment. Bioaccumulation-based cleanup levels will be applied in subtidal areas that will not require armoring for protection of the constructed remedy.

The SMS specifies cleanup levels that are protective of benthic invertebrate communities but does not provide numeric cleanup levels for constituents that pose a risk to human and ecological receptors as a result of bioaccumulation. Rather, it provides a process whereby cleanup levels can be developed that take into account site-specific risks, as well as background concentrations and practical limitations to quantifying contaminants in environmental media. Bioaccumulation-based cleanup levels representing both the SCO and CSL were developed according to Ecology guidance and input and are documented in Appendix O.

Preliminary sediment cleanup levels are presented in Table 9-2 along with the basis for each value. These preliminary sediment cleanup levels were selected from among the SCOs and CSLs that are presented in Tables 9-3 and 9-4, respectively.

In general, SCOs for a sediment contaminant are set as the highest of the following levels:

- The lowest risk-based level protective of benthic invertebrate communities (multiple pathways), human health (bioaccumulation), or higher trophic level ecological receptors (bioaccumulation);
- Natural background; or
- Practical quantitation limits (PQL).

CSLs are set similarly, except that risk-based levels are higher, and regional background is used in place of natural background.

Tables 9-3 and 9-4 include values selected or derived for each of these criteria and the proposed SCOs and CSLs for each sediment IHS. SCOs and CSLs are expressed as both dry-weight and organic carbon (OC)-normalized concentrations, per the SMS. Generally, OC-normalized concentrations (both the cleanup level and the sample data) are used when the sample-specific sediment organic carbon content is between 0.5 and 3.5 percent (inclusive). The dry-weight cleanup levels and sample concentrations are used when the sediment organic carbon content is less than 0.5 percent or greater than 3.5 percent.

Protection of Benthic Organisms: The SCOs and CSLs for protection of benthic organisms (direct contact and ingestion of sediment) in Tables 9-3 and 9-4 are generally consistent with the benthic sediment screening levels in Table 5-1. The differences between the benthic sediment screening levels and the SCO and CSL values included in Tables 9-3 and 9-4 are due to changes in the AET criteria recommended by Ecology for 2-methylnaphthalene, acenaphthene, naphthalene, and phenanthrene. The currently recommended AET values are from Ecology's SCUM II guidance (Ecology 2015b; Table 8-1). The current SMS criteria are included in Table III of the revised SMS (Chapter 173-204 WAC).

Bioaccumulation: SCOs and CSLs were derived for the protection of people and ecological receptors that may consume seafood foraged from the Site for the Haley sediment bioaccumulative chemicals of concern (cPAHs, PCP, and dioxins/furans), as described in Appendix O.

For carcinogenic compounds, SCOs and CSLs for protection of human health are based on cancer risks of 1×10^{-6} and 1×10^{-5}, respectively. Both the SCOs and CSLs are based on a hazard quotient of 1 for non-carcinogenic compounds.

SCOs and CSLs for bioaccumulative IHSs were also derived for aquatic life (fish and invertebrates), individual aquatic-dependent wildlife (i.e., individual fish, birds or mammals), and populations of aquatic-dependent wildlife. These SCOs and CSLs are based on a hazard quotient of 1.

Appendix O includes additional details on the derivation of the bioaccumulation SCOs and CSLs, including the biota-sediment accumulation factors (BSAF) used, consumption rates, and the methodology for deriving dioxin/furan and cPAH levels using risk-based criteria for individual congeners and cPAHs.

Background: According to the revised SMS, natural background values are considered in the development of SCOs, while regional background values are considered in the development of CSLs.

Ecology calculated the 90th confidence interval of the 90th percentile (90:90 UTL) for natural background sediment values in the SCUM II guidance (Ecology 2015b). Ecology used data from the OSV Bold Study (DMMP 2009) and data from Ecology-approved reference sites and other Puget Sound sites that Ecology determined were "appropriately similar to reference sites in terms of anthropogenic impact." Ecology derived 90:90 UTLs for cPAHs and dioxins/furans of 21 µg/kg and 4 ng/kg, respectively; these concentrations are included in Table 9-3.

Regional background values have been recently published for cPAHs and dioxins/furans as part of Ecology's Bellingham Bay regional background study (Ecology 2015a). Regional background values are 86 µg/kg and 15 ng/kg, respectively (Table 9-4).

PQL: PQLs were obtained for individual PAHs, PCP and TPH from Analytical Resources, Inc. of Tukwila, Washington. However, PQLs were not available for cPAHs and dioxins/furans because concentrations are reported as group sums, rather than individually analyzed constituents. Derived PQLs for these two sediment IHSs are explained below and are included in Tables 9-3 and 9-4.

- Dioxins/furans: Ecology derived a programmatic PQL-based cleanup level of 5 ng/kg TEQ in Table 11-1 of the SCUM II guidance (Ecology 2015b).
- cPAHs: Ecology derived a programmatic PQL-based cleanup level of 9 ng/kg TEQ in Table 11-1 of the SCUM II guidance (Ecology 2015b).

Preliminary Sediment Cleanup Levels: Sediment cleanup levels are initially established at the SCO and may be adjusted up to, but not higher than, the CSL. The preliminary sediment cleanup levels for the non-carcinogenic PAHs (2-methylnaphthalene, acenaphthene, fluoranthene, naphthalene, and phenanthrene) and for benzo(a)anthracene and TPH are presented as the SCO values. The SCO values for these seven sediment IHSs are based on protection of benthic organisms. The preliminary sediment cleanup levels for the remaining three sediment IHSs (dioxins/furans, cPAHs, and PCP) are discussed below. The preliminary sediment cleanup levels are presented in Table 9-2.

- Dioxins/furans and cPAHs: The preliminary sediment cleanup levels are set at the regional background levels for these IHSs (15 ng/kg and 86 µg/kg, respectively). These regional background values represent CSLs for these chemicals, and were selected as preliminary cleanup levels because it is not possible to attain and maintain lower sediment cleanup levels (e.g., SCOs) due to recontamination by dioxins/furans and cPAHs that are present throughout

Bellingham Bay. The selection of regional background as the preliminary sediment cleanup level for dioxins/furans and cPAHs is consistent with the consent decree for the Cornwall Landfill site.

- PCP: The preliminary sediment cleanup level is set at the PQL of 100 µg/kg. The lowest risk-based sediment criteria is less than 100 µg/kg.

Point of Compliance: For marine sediments potentially affected by SMS hazardous substances, the point of compliance is the biologically active zone (BAZ), which is considered the upper 12 cm of sediment (i.e., surface to 0.39 feet below the mudline [Section 7.3.5.2]). This point of compliance addresses protection of benthic organisms on a point-by-point basis, bioaccumulation in the aquatic food chain on an area-weighted average basis, and direct contact by net fishers on an area-weighted average basis. A point of compliance for dermal contact/incidental ingestion of sediment and ingestion of shellfish is not applicable because all remedial alternatives will preclude direct contact with contaminated sediment in the intertidal zone, as well as clamming activities. Specifically, an armor layer required to maintain the physical integrity of any cap would prevent larger organisms (including clams) from burrowing into the cap and would impede people from digging into the cap.

9.2.3.2. GROUNDWATER

Groundwater IHSs were selected for the Site based on criteria presented in Section 5.2; seven IHSs were used in the RI report to evaluate the nature and extent of groundwater contamination at the Site. PCP was not carried forward for development of groundwater cleanup levels in the FS because PCP was not detected in 2012 groundwater samples (Section 6.4.4) at concentrations greater than the screening level except at one isolated location (CL-MW-6) in the extreme southeastern (upgradient) portion of the Site. In addition, PCP was not detected in the two LNAPL samples obtained in 2000 (Table 6-2). The PCP detected in the beach oil seep sample may have been due to the presence of impacted beach sediment in the sample.

Dioxins/furans also were not carried forward for development of cleanup levels in the FS. Multiple lines of evidence (Section 6.4.5) suggest that detectable concentrations of dioxins/furans in Site groundwater are associated with suspended solids in samples, and therefore are an artifact of the sampling process. Dioxin/furan groundwater data at the Site are consistent with the characteristics and expected behavior of this contaminant group; dioxins/furans are extremely hydrophobic and preferentially sorb to soil. As a result, these compounds do not readily partition into groundwater as dissolved-phase contaminants, and their mobility in groundwater is extremely limited. Site groundwater data also suggest that cosolvent processes are not substantially influencing dioxin/furan mobility at the Site (Section 6.4.5). The limited risks associated with this transport mechanism will be addressed by remedial actions that reduce the leaching of Site compounds potentially capable of mobilizing dioxins/furans (e.g., 2-methylnaphthalene). Preliminary cleanup levels are proposed for 2-methylnaphthalene for all media.

Preliminary groundwater cleanup levels are presented in Table 9-5 along with the basis for each value. Preliminary groundwater cleanup levels for the resulting five groundwater IHSs are based on protection of marine surface water and sediment. As discussed in Section 5.1.2, Ecology has determined that groundwater beneath the Haley Site and other waterfront cleanup sites in Bellingham Bay is non-potable; therefore, groundwater ingestion is not a potentially complete exposure pathway and was not considered in development of groundwater cleanup levels. The preliminary groundwater cleanup levels for the groundwater IHSs are the same as the groundwater screening levels for these same compounds presented in Table 5-2.

Point of Compliance: The standard point of compliance for groundwater under MTCA is throughout the site. MTCA allows use of a conditional point of compliance, however, when it can be demonstrated that it is not practicable to meet cleanup levels throughout the site within a reasonable restoration time frame (WAC 173-340-720[8][c]). At sites where groundwater cleanup levels are based on the protection of surface water beneficial uses, MTCA allows Ecology to approve use of a conditional point of compliance located as close as technically possible to the point where groundwater flows into surface water (WAC 173-340-720[8][d][i]). Use of this conditional point of compliance is subject to several conditions. Those conditions and their applicability to the Haley Site are described below.

- *Contaminated groundwater enters the surface water and will continue to enter the surface water even after implementation of the selected cleanup acti*on. This condition is demonstrated in the RI by groundwater quality at shoreline monitoring wells and the continuity of contamination from the upland into sediment, and based on the cleanup alternatives as described in the FS (Section 9.5).
- *It is not practicable to meet the cleanup level at a point within the groundwater before entering the surface water, within a reasonable restoration time frame*. This condition is established through the technology screening and cleanup alternatives evaluations described in the FS (Section 9.6).
- *A mixing zone is not used to demonstrate compliance with surface water cleanup levels*. Methods to document remedy compliance with cleanup levels will not utilize the mixing zone concepts.
- *All known available and reasonable methods of treatment shall be used for groundwater before discharge to surface wa*ter. An evaluation of all known available and reasonable technology (AKART) methods of groundwater treatment is presented in the FS and applicable methods are incorporated into the cleanup alternatives.
- *Groundwater discharges do not result in exceedances of sediment quality values in Chapter 173-204 WAC*. Groundwater cleanup levels are protective of marine sediment (Section 5.1.2).
- *Groundwater and surface water monitoring are performed to evaluate performance of the cleanup action including consideration of the potential for discharges at levels below method detection limits to affect bioaccumulative effec*ts. Compliance monitoring for remedy performance will be conducted following implementation; details will be specified in the CAPs.
- *Notice of proposed conditional points of compliance is made to natural resource trustees, DNR and USACE*. Required notice and request for comment will be made by Ecology after the cleanup alternative has been selected.

9.2.3.3. SOIL

Preliminary soil cleanup levels are based on protection of human health from direct contact and incidental soil ingestion, and protection of groundwater. Potential terrestrial ecological exposures to soil, and erosion of soil to sediment were considered in the development of soil cleanup levels;

however, as discussed in Section 5.1.3, these exposure pathways will be addressed by the upland remedy which will include an engineered cap and institutional controls that will prevent terrestrial ecological exposures and erosion of upland soil.

Preliminary soil cleanup levels for vadose zone and saturated soil are presented in Table 9-6 along with the basis for each value. The preliminary cleanup levels for the soil IHSs are the same as the soil screening levels presented in Table 5-3, except for dioxins/furans. The dioxin/furan soil screening level of 11 ng/kg was the MTCA Method B cleanup level for direct contact (unrestricted land use). In May 2014 Ecology made a number of updates to the CLARC database/website, including the toxicity values used to calculate the Method B soil cleanup level for 2,3,7,8-TCDD. The new toxicity values result in a Method B soil cleanup level for dioxins/furans of 13 ng/kg (TEQ).

Point of Compliance: The standard point of compliance for soil based on the protection of groundwater is throughout the Site. For the protection of human health via direct contact, the standard point of compliance for soil is from ground surface to 15 feet bgs. MTCA recognizes that soil cleanup levels would typically not be met at the standard point of compliance for cleanups involving containment and that the cleanup alternatives involving containment still comply with cleanup standards under certain conditions (WAC 173-340-740[6][f]). The six conditions ([i] through [vi]), specified to demonstrate soil compliance where containment remedies are used are outlined below followed by an explanation of applicability for the Haley Site.

- *The selected remedy is permanent to the maximum extent practicable.* This determination will be demonstrated in the cleanup alternatives evaluation of the FS (Section 9.6).
- *The cleanup action is protective of human health.* This determination will be demonstrated in the cleanup alternatives evaluation of the FS.
- *The cleanup action is protective of terrestrial ecological receptors.* Future paved parking areas, buildings and capped areas will prevent ecological receptor exposures to hazardous substances that would remain in soil under the containment alternatives.
- *Institutional controls are put in place to prohibit or limit activities that could interfere with the long-term integrity of the containment system*. Institutional controls established to maintain an engineered cap will be included as part of the respective cleanup alternatives.
- *Compliance monitoring and periodic reviews are designed to ensure the long-term integrity of the containment system*. Monitoring will be included as part of any remedy implemented at the Site.
- *The draft cleanup action plan specifies the hazardous substances remaining and the measures used to prevent migration and direct contact*. This information will be included in the draft CAP.

9.3. Pilot Studies and Interim Action Technologies

Pilot studies and several phases of interim actions have previously been conducted on the Site. The pilot testing results and performance observations from prior interim actions inform the technology screening (Section 9.4) and alternatives development and evaluation (Sections 9.5 and 9.6) for the FS. Based on previous pilot testing and prior interim actions, site-specific and technology-specific implementability issues that may affect technologies or alternatives being considered in the FS are described below.

9.3.1. Pilot Testing

Field and bench-level tests of enhanced soil agitation were performed in January 2007 to evaluate agitation as a remedial technology to remove LNAPL in the Haley upland soil (Appendix P). However, soil agitation was not retained during technology screening for this FS because soil agitation has relatively high short-term risks (as described in Section 9.4.3.2) in comparison to other available technologies for LNAPL removal. This section briefly describes the field and bench-level tests conducted in 2007 to evaluate this technology. Some of the conclusions resulting from the 2007 field and bench-level pilot tests are applicable to other LNAPL removal technologies retained through the screening process.

The 2007 soil agitation field test utilized an auger or backhoe bucket to “mix” saturated smear zone soil within an open excavation after removal of approximately 8 feet of overlying soil. A rotary-drum skimmer was placed in the lowest portion of the open excavation to remove LNAPL that accumulated on the water surface during the agitation activities. The bench test utilized hand tools and mixing bowls in a laboratory setting to mimic soil agitation. LNAPL removal effectiveness was evaluated based on direct measurement of the recovered LNAPL quantity during the field test, and through comparison of pre-test and post-test diesel-range hydrocarbon concentrations in the bench test soil samples, and comparison of pre-test and post-test free product mobility testing (using ASTM D425M, API RP40, Appendix P) of field test soil samples from the agitation area and of bench test soil samples. An estimated 195 gallons of LNAPL were liberated by soil agitation methods during the field test. Pre- and post-test soil samples indicated that soil agitation reduced diesel-range hydrocarbon concentrations by 70 to 90 percent, and also reduced residual LNAPL mobility.

The enhanced soil agitation field test revealed several constructability considerations that could apply to other *ex situ* or *in situ* technologies being considered for upland cleanup actions. Below is a summary of constructability considerations that remain relevant, given the updated conceptual site model developed in the RI (Section 8.0):

- Subsurface timber piles encountered near the shoreline can create obstructions for excavation and *in situ* technologies requiring soil mixing.
- Trench box shoring or sheet piles can be utilized to more successfully accomplish *in situ* treatment of small excavation areas.
- Wood debris is present in smear zone soil and may float on the groundwater surface in open excavations, thereby inhibiting effective recovery of LNAPL from the water surface by some techniques.
- Agitating silt that is present in the upland fill unit produces an emulsified oily slurry that inhibits the release of LNAPL to the surface of water in an open excavation.
- Sufficient agitation and residence time on the order of hours to days are needed to liberate otherwise immobile residual LNAPL to the point that LNAPL can be recovered using normally-accepted engineering methods.

9.3.2. Interim Action Technologies

Independent actions to recover LNAPL and control intermittent seeps were performed between 1986 and 2012 (RI Section 2.4.8) and an Interim Action was completed in 2013 (GeoEngineers 2014

"Interim Action Completion Report" February 12, 2014). The technology performance and implementation challenges observed during these prior actions as described below are relevant to the technology screening and alternatives evaluation for the FS.

LNAPL recovery: The automated LNAPL pumping and collection system that operated in 2001 and 2002 resulted in low LNAPL recovery rates, averaging less than 8 gallons/month (Section 6.2.4). The system utilized 2- and 4-inch-diameter vertical recovery wells installed east of the sheet pile barrier, 10-inch-diameter vertical recovery wells in a gravel-filled drainage slot on the upgradient (east) side of the sheet pile barrier, horizontal LNAPL recovery trenches and a pneumatic hydrophobic pump. Recovery rates from this system were low, due to several inter-related factors such as the relatively low quantity of mobile LNAPL compare to immobile LNAPL, high LNAPL viscosity and very low LNAPL gradients (Section 7.2). Manual LNAPL recovery from monitoring and recovery wells using hand bailers, peristaltic pumps, and centrifugal pumps had similarly low overall recovery rates, equivalent to an average of 4 gallons/month (Section 6.2.4). Future LNAPL recovery from recovery or monitoring wells at the Site is anticipated to result in relatively low quantities of recoverable LNAPL primarily because a substantial portion of LNAPL at the Site is immobile due to the length of time that has passed since the original release(s) of P-9 carrier oil, discontinuous spatial distribution of LNAPL in soil, and frequent water table fluctuation at the shoreline from tidal effects (Section 7.2). Recovered LNAPL requires off-site treatment and disposal at an approved hazardous waste facility. LNAPL recovery was carried forward for further evaluation in FS technology screening (Section 9.4); although it is expected that the quantity of recoverable LNAPL is anticipated to be relatively low.

Sheet pile barrier at shoreline: The sheet pile barrier addressed the intertidal oil seep that occurred in 2000 and effectively prevented further LNAPL migration. Therefore, low-permeability barrier technologies are carried forward into the FS. The implementation challenges that occurred during construction of the barrier are mentioned here because one alternative evaluated in this FS uses this remedial technology. Specifically, the requirements to collect, contain and manage LNAPL, soil and dewatering fluids generated during construction of the drainage slot on the upland side of the sheet pile barrier and liner were significant due to waste designation and associated regulatory requirements. In addition, buried obstructions (e.g., wood) were encountered during sheet pile installation causing installation difficulties.

The sheet pile barrier also affects groundwater flow which is an important consideration in the development and design of cleanup alternatives. Specifically, based on groundwater monitoring and the groundwater model findings explained in the RI, there is a slight mounding of groundwater on the upgradient side of the barrier wall. In addition, a longer groundwater discharge flow path is created by virtue of groundwater flowing beneath the wall.

The barrier also prevented further erosion of the shoreline bank. However, natural beach processes have resulted in both erosion and deposition of sediment and sand along the length of the wall, depending on location, seasonal tides, currents and wind. Where erosion protection rock and quarry spalls were placed along a portion of the wall, no erosion has occurred.

Sediment removal: Sediment removal in the intertidal zone was conducted in 2001 in connection with actions taken to address oil sheen emerging from the sediment (Section 2.4.8.2). The sediment removal, in combination with the sheet pile barrier, effectively addressed the oil sheen observed in 2000. The 2001 activities confirmed that a track-mounted excavator positioned on the upland can be utilized to minimize the footprint of sediment disturbance during excavation in intertidal areas. Implementation challenges that may apply to future similar actions, included capturing LNAPL released from the sediment matrix as a result of being disturbed, caving within the excavation, and handling/managing the loose saturated, excavated material. Sediment removal was retained as a remedial technology based on the technology screening (Section 9.4).

Amended sand cap: The design and construction of the amended sand cap in a localized area of the intertidal zone (2013 interim action) informs remedial technologies considered in this FS. The cap consists of a 6-inch-thick layer of amended sand covering approximately 5,000 square feet of intertidal zone between the shoreline bluff and approximately elevation 0 feet (NAVD88). The amended cap was constructed to eliminate an oil sheen that was emanating from this portion of the intertidal zone, south of the existing sheet pile barrier (Section 2.4.8.2). The amended sand cap effectively eliminated the petroleum sheen observed at this location. Amended sand cap was retained as a remedial technology based on the technology screening (Section 9.4).

Organoclay was selected as the cap amendment based on the design objectives for the interim action that included preventing release of dissolved-phase contaminants and mobile LNAPL emerging from sediment. A 6-inch-thick layer of amended sand, consisting of a 50:50 ratio of organoclay mixed with imported well-graded clean sand, was used for the cap.

The interim action cap was constructed during a period of low tide events that allowed the work to be completed in the dry. In addition, the cap was placed without removal of any existing sediment. Large rocks and piling were removed to enable effective cap placement and performance. The cap was constructed using a long-reach excavator and conveyor equipment staged in the adjacent upland, thereby minimizing disturbance to the marine environment.

Water quality protection controls were utilized effectively during the interim action construction, as required by permit, including floating debris berms with a silt curtain, as well as an oil boom.

9.4. Identification and Screening of Remedial Technologies

This section identifies and presents a screening evaluation of potentially applicable general response actions (GRAs) and associated remedial technologies for developing cleanup action alternatives in accordance with MTCA requirements, WAC 173-340-350. Sources of information used to develop the list of technology process options include EPA publications and databases, bench-scale and pilot-scale test data, text references, vendor information, and professional experience at similar sites.

The technology screening evaluation was performed for environmental media at the Site (soil, groundwater, sediment) and for LNAPL. Based on the screening evaluation, selected response actions and technologies were carried forward for use in developing cleanup action alternatives for the upland unit and sediment unit (Section 9.5).

GRAs are actions that can be taken to reduce or eliminate the adverse impact of chemicals on human health and the environment. The technology screening tables (Tables 9-7 through 9-10) first identify GRAs that can potentially achieve CAOs. Remedial technology types and associated remedial technology process options that could be used to implement the GRAs are then identified. Specific remedial technologies, known as technology process options, were screened based on EPA's criteria of effectiveness, implementability and cost (EPA 1988b). In the final step of technology screening, the technology process options least suitable to address impacted media and achieve CAOs were eliminated from further evaluation and the most suitable technologies were carried forward in the development of alternatives.

9.4.1. Screening of Technology Process Options

The remedial technology screening is presented in Tables 9-7 through 9-10. The results of the screening are discussed further in Sections 9.4.2 through 9.4.5. Those technology process options considered technically effective, implementable given current knowledge of the Site, and cost-effective relative to competing options were retained for inclusion in cleanup action alternatives, which are described in Section 9.5. The components of each of the three primary screening criteria, effectiveness, implementability and relative cost, are explained below.

9.4.1.1. EFFECTIVENESS

The effectiveness evaluation focused on the ability of each technology process option to address CAOs, site-specific COCs, and protect human health and the environment relative to the other remedial technologies. The effectiveness evaluation was based on the following:

- The ability of a technology process option to achieve the established CAOs.
- The degree to which the technology process option protects human health and the environment during construction and implementation.
- Likely effectiveness considering Site-specific conditions.

9.4.1.2. IMPLEMENTABILITY

The implementability evaluation focused on the technical and administrative feasibility of a technology process option. The implementability evaluation was based on the following:

- The institutional aspects of implementation, including the ability to obtain necessary permits and public acceptance.
- The availability of support services and equipment, and the degree to which the technology process option has been demonstrated to be implementable at other sites.

9.4.1.3. RELATIVE COST

This criterion was used to compare capital and operation and maintenance (O&M) costs of the technology process options. Relative capital and O&M costs between alternatives were used in the technology screening. Each technology was evaluated based on whether relative costs (based on engineering judgment) are expected to be low, moderate, or high compared to other remedial technologies.

9.4.2. Soil Remedial Technologies

A range of potential GRAs and remedial technologies were evaluated for upland soil at the Site to support the development of cleanup action alternatives. The GRAs considered in the screening evaluation included institutional controls, soil containment, soil removal, soil management and *in situ* treatment (Table 9-7). GRAs that were evaluated are discussed further below. *Ex situ* treatment processes were screened out as GRAs for upland soil because *ex situ* treatment would constitute RCRA "placement" under EPA's AOC guidance (EPA 1989) and could not be performed at the Site without triggering LDRs.

9.4.2.1. IN SITU TREATMENT BY SOLIDIFICATION AND STABILIZATION

In situ treatment of soil is defined as the in-place treatment of soil without removing it from its natural/native location (Watts 1998). Several common *in situ* treatment technologies were evaluated for applicability to the contaminants and conditions at the Site including chemical, biological, thermal, and physical treatment methods (Table 9-7). The retained technologies were *in situ* solidification and stabilization techniques that leave contaminants in place, but physically and chemically bind them to reduce contaminant leaching to groundwater.

In situ solidification and stabilization (ISS) are processes that mix treatment materials directly into the contaminated soil to physically or chemically change the contaminant/soil environment such that contaminants are chemically or physically bound to soil and/or treatment reagents, or physically isolated from surrounding groundwater, significantly reducing the potential to partition into groundwater. ISS binds and immobilizes the contaminants in a physically isolated state, thereby preventing contaminant migration to other media and associated exposures. Soil treatment by ISS is most commonly employed by mixing contaminated soil with portland cement or another cementitious material. Where organic contaminants are present, additives such as organophilic clay are used to adsorb the contaminants and allow the portland cement to cure (CETCO 2008) to achieve a stable matrix.

EPA (EPA 2000) defines the two separate ISS processes as follows:

- Solidification — The process of encapsulating contaminated material to form a solid material and restrict contaminant migration by decreasing the surface area exposed to leaching or by coating the contaminated material with low-permeability materials. Solidification traps the contaminated material within a granular or monolithic matrix.
- Stabilization — The process in which chemical reactions occur between the reagents and contaminated material to reduce the leachability of contaminated material and create a stable insoluble form. Stabilization chemically binds free liquids and immobilizes contaminated materials or reduces their solubility through a chemical process, but does not result in a solidified, low-permeability mass.

For the contaminants present at the Site, the *in situ* solidification process retained in this FS relies on the addition of organoclay to portland cement to facilitate the curing process in soil that contains substantial concentrations of LNAPL (Conner 1990). Organoclay is a bentonite material modified by an ion exchange process that converts the material from strongly hydrophilic to a hydrophobic and organophilic state, and is sometimes referred to as "organophilic clay". Once converted, organoclays are capable of adsorbing many times their weight in organic contaminants, and are particularly effective at adsorbing the diesel-range hydrocarbons and PAHs present at the Haley Site. Traditionally, organoclays have been used in the oil and gas production industry, particularly in off-shore drilling, as an effective process water treatment method. Recently, the addition of organoclay to the *in situ* solidification process has allowed this technology to be applied to organic contaminants in soil that would otherwise not be amenable to the solidification process due to their detrimental effect on the cement materials used for solidification (EPA 2009a). Organoclay additives in the solidification process have been demonstrated to adsorb the organic contaminants to the degree necessary to allow the cement to cure and achieve the leachability and permeability requirements.

In situ solidification would be implemented at the Site using standard excavation equipment for shallow applications (approximately less than 15 feet bgs). Solidification of deeper soil would necessitate the use of more specialized *in situ* mixing equipment, such as large-diameter mixing augers.

In situ stabilization using organoclay was retained as a component of cleanup alternatives that include soil treatment in upgradient portions of the Site. Stabilization is a more desirable form of *in situ* treatment in these areas where the soil profile requiring treatment extends down to bedrock. Solidification of the entire saturated soil horizon in this (upgradient) portion of the Site would cause groundwater management challenges as a result of the low-permeability matrix produced by the solidification treatment process. *In situ* stabilization would be achieved by mixing granular organoclay throughout the contaminated soil profile in the shallow aquifer at the Site. The organic contaminants in the treatment zone would adsorb to the organoclay without significantly reducing the permeability of the treated soil matrix. This technology is capable of stabilizing residual LNAPL and dissolved-phase organic contaminants, and is therefore considered an effective remedial technology for both soil and groundwater (Tables 9-7 and 9-9). The resulting treated soil matrix does not significantly affect groundwater flow, but reduces contaminant mobility. *In situ* stabilization using organoclay would be implemented in the same manner as described above for *in situ* solidification, using common soil mixing methods.

In situ solidification and stabilization would require treatability testing to evaluate the most effective reagent mixes and assess the resulting effect on contaminant leachability. The effect of subsurface debris (e.g. wood waste, pilings, landfill waste) on ISS will need to be evaluated during remedial design.

9.4.2.2. SOIL EXCAVATION AND MANAGEMENT

Soil excavation is considered an effective technology to permanently eliminate the risk of exposure to contaminants at the Site. Excavation is generally implementable using common and available processes and equipment. For the purpose of this FS, standard excavation methods are assumed to be feasible in the upland portion of the Site, including dewatering and water handling where excavation occurs below the water table. Shoring may be necessary for safe excavation in certain situations; however, shoring was not included in the FS cost estimates for upland alternatives that involve deep excavation.

Excavated soil can be managed on-site within the boundaries of the designated AOC without triggering LDRs under federal RCRA and state dangerous waste regulations (Section 9.2.1.1 and Appendix N). Excavated soil can be amended to enhance geotechnical suitability as needed to manage the material in the upland AOC. These actions can be conducted within the AOC without being considered a dangerous waste “generation” event under the AOC policy.

Off-site treatment and disposal of excavated soil also were retained for use in the upland remedial action alternatives. Off-site treatment and disposal requirements for excavated soil will depend on waste designations, but for purposes of estimating costs in this FS it is assumed that all soil will be

F-listed (F032) hazardous waste, and a portion of the soil will require treatment by incineration prior to disposal to comply with LDRs. Additional details concerning off-site waste treatment and disposal assumptions are presented in Section 9.5 and in the FS cost estimates (Appendix Q).

9.4.2.3. SOIL CONTAINMENT

Methods for preventing people and ecological receptors from being exposed to contaminated soil include various types of surface and subsurface engineered caps. For the Haley Site, low-permeability cap technologies were retained for use in the cleanup action alternatives. Low-permeability caps will prevent direct exposure to contaminated soil, while also significantly reducing or eliminating stormwater infiltration in the upland portion of the Site. The reduced infiltration is one component of upland source control because it reduces contaminant leaching to groundwater and overall contaminant flux from the upland to marine unit.

The Haley upland cap would include a subsurface low-permeability geomembrane, and in places an at-grade asphalt or concrete pavement cap. The subsurface low-permeability geomembrane would consist of 40-mil synthetic liner (Section 9.5.2.1) that would impede stormwater infiltration. The Haley low-permeability cap would be generally equivalent to the two-layer low-permeability cap system at the Cornwall site.

The low-permeability function of any upland cap would necessitate the collection and management of Site stormwater. Subsurface landfill gas (LFG) and other volatile organic compounds may be present in the area of overlap between the Haley and Cornwall Sites, or in broader portions of the Haley upland. The Cornwall remedy will include a collection and ventilation system to mitigate the buildup of gas beneath the landfill cap (Landau 2013). Gas collection and management needs beneath the Haley cap will be evaluated during remedial design, similar to Cornwall. Capping and gas collection components of both remedies will be integrated across both Sites. In addition, physical vapor barriers could be utilized, if needed, to prevent the intrusion of soil vapors into indoor air space of future park structures. Vapor barriers were retained in the technology screening but their necessity and potential use will depend on future park plans.

9.4.2.4. INSTITUTIONAL CONTROLS

Institutional controls (ICs) include regulatory or legal restrictions and access controls to reduce risk to people or ecological receptors by preventing contact with contaminants. Environmental covenants that limit land use are typical legal mechanisms for preventing exposure, while fencing and warning signage are typical access control methods. Any ICs implemented at the Site would require long-term monitoring to ensure compliance with the CAOs.

An environmental covenant would not be an acceptable cleanup action on its own because it would not achieve the CAOs for the upland soil areas. However, land use restrictions accomplished using an environmental covenant were retained as a component of cleanup action alternatives, as they can be effective and implementable in combination with engineered containment controls and other GRAs. As an example, a covenant can require maintenance of a protective barrier that keeps people and ecological receptors from being exposed to impacted soil. ICs may be needed to protect the integrity of the selected remedy; however, any restrictions imposed by ICs would not preclude the planned use of the Site as a park.

Access controls such as permanent fencing were not considered implementable because fencing would not be compatible with the proposed future use of the Site as a park (Section 9.1.2).

9.4.3. LNAPL Remedial Technologies

A range of potential containment, removal and treatment remedial technologies were evaluated for LNAPL (Table 9-8) and are discussed further below.

9.4.3.1. IN SITU TREATMENT BY SOLIDIFICATION AND STABILIZATION

In situ treatment methods were also retained for addressing LNAPL at the Site. The *in situ* solidification and stabilization processes described above for soil (Section 9.4.2.1) are applicable to LNAPL at the Site. Similar to the processes described for soil, *in situ* solidification and *in situ* stabilization were retained for use where applicable. Solidification and stabilization have been proven effective at reducing the leachability of organic contaminants and the mobility of NAPL (ITRC 2011a). Implementation techniques for the *in situ* solidification and stabilization of LNAPL would be performed as described in Section 9.4.2.1.

9.4.3.2. LNAPL REMOVAL

Several LNAPL removal technologies were evaluated for potential use in remedial alternatives at the Site (Table 9-8). Based on Site conditions, including the immobile nature of most LNAPL at the Site, only excavation and passive LNAPL skimming were retained for inclusion in the development of cleanup action alternatives.

The soil agitation process that was previously tested at the Site (Section 9.3) was considered, but not retained for further evaluation primarily because of the high cost, duration of implementation, and because the soil agitation process has a higher potential for short-term impacts. These potential impacts include a risk of increased LNAPL mobilization and contaminant dissolution to groundwater on a short-term basis.

Excavation methods retained for LNAPL removal were the same as those retained for soil (Section 9.4.2.2). Due to the high contaminant concentrations in LNAPL-impacted soil, excavation methods will require controls to prevent the release of LNAPL during construction. It will also be necessary to separate free liquids (including LNAPL) from the excavated soil, or stabilize these liquids in the soil prior to off-site transport or on-site management within the AOC. Excavated soil in the area of potentially mobile LNAPL, if removed from the Site, is expected to require treatment by incineration prior to disposal (Section 9.5).

Passive LNAPL removal was also retained for inclusion in cleanup action alternatives for this FS. The large area of immobile LNAPL (Section 6.2) and limited degree of LNAPL recoverability (Section 7.2) prohibit cost-effective removal by more aggressive techniques such as dual- or multi-phase extraction. Passive LNAPL skimming utilizes in-well skimmers to selectively remove LNAPL from the well casings. The passive skimming process does not affect the hydraulic gradient or generate the large volumes of water that would be generated using more active extraction (pumping) technologies. Skimming is capable of effectively removing large volumes of LNAPL under suitable conditions (Leppert et al. 2012). LNAPL skimming in combination with other containment technologies that prevent exposure to the LNAPL are retained for inclusion in the cleanup alternatives.

9.4.3.3. LNAPL CONTAINMENT

Engineered containment methods for LNAPL considered in this FS included physical LNAPL barriers, such as low-permeability sheet pile walls and slurry walls. The success of the existing sheet pile wall (Section 9.3.2) at containing LNAPL indicates that this technology can be effective at reducing further impacts to the marine unit. As an alternative to a sheet pile barrier, a slurry wall may also be an implementable low-permeability barrier technology. The effectiveness of a slurry wall is expected to be equivalent to that of a sheet pile wall. While both sheet pile and slurry walls were retained through the screening process, cost estimates in this FS assume use of a sheet pile wall for those alternatives that include use of a vertical LNAPL containment wall. Final selection of the wall type would be made during remedial design.

LNAPL containment using a sheet pile wall would be implemented in a manner similar to the existing sheet pile wall, with the vertical barrier installed as close to the shoreline as possible and to depths corresponding to near the top of the upland soil unit comprising native marine sediment. The sheet pile wall would be designed as a permanent, low-permeability barrier by enhancing standard sheet piling with materials such as grouted joints, epoxy coatings and cathodic protection.

9.4.4. Groundwater Remedial Technologies

A range of groundwater remedial technologies were also evaluated for potential use in cleanup alternatives at the Site. The GRAs considered in the screening evaluation included institutional controls, containment, *in situ* groundwater treatment, and groundwater collection (Table 9-9). Specific technology process options that were retained are discussed further below.

9.4.4.1. IN SITU PASSIVE GROUNDWATER TREATMENT

Passive groundwater treatment using a permeable reactive barrier (PRB) was retained for evaluation as a component of cleanup action alternatives. In a typical application, a PRB is designed to intercept and remediate a contaminant plume (ITRC 2011b). While considered *in situ* treatment, a PRB is also a barrier technology as it is intended to prevent downgradient migration of contaminants as a result of focusing the treatment within the PRB. PRBs are typically installed at a point downgradient of the contaminant source to intercept contaminants migrating with groundwater to a known receptor or to a location off-property. At the Haley Site, the PRB would be located as close to the shoreline as possible to prevent migration of contaminants from the upland area to the marine unit, which would require the PRB to be located within or very near an area where potentially mobile LNAPL is present. This is not a typical application for a PRB and is expected to result in implementability issues associated with construction of the PRB without temporarily mobilizing contaminants from within the area of potentially mobile LNAPL.

Many commonly used *in situ* treatment technologies can be used in a PRB application. For the mobile groundwater contaminants at the Site (primarily PAHs and diesel-range hydrocarbons) granular organoclay is expected to be an effective reactive medium for use in a PRB. The organoclay would provide treatment of the contaminants by adsorption, attenuating contaminant concentrations as groundwater passes through the PRB.

PRBs can be constructed several ways depending on the treatment technology being used. PRBs that rely on placing a reactive media within the groundwater flow path need to be constructed in a way that injects the material into the subsurface or physically mixes the material with soil or replaces the soil with the reactive material. The granular nature of organoclay as a PRB material is not suitable to inject into the subsurface and would require placement in an excavated trench or mixed *in situ* using specialized construction equipment. The width of the PRB is determined by both the construction method and the treatment requirements. The width of trenched PRBs installed with excavators can be no narrower than the width of the excavator bucket, while innovative *in situ* mixing methods allow reactive media to be placed as a narrow PRB.

9.4.4.2. GROUNDWATER CONTAINMENT

Groundwater containment methods were retained for use in upland remedial alternatives. The existing sheet pile containment wall directs groundwater flow into deeper, less contaminated soil (Section 4.2.2.4). This lengthened flow path through cleaner soil enhances attenuation processes, resulting in substantially lower dissolved-phase contaminant concentrations in groundwater flowing beneath the sheet pile barrier (Section 6.8). As noted above in Section 9.4.3.3, both low-permeability sheet pile and slurry walls were considered potentially implementable and effective groundwater containment. In this FS, however, it is assumed that a sheet pile wall would be used in remedial alternatives that include a vertical containment wall near the shoreline.

Full containment of groundwater, preventing any groundwater from flowing from the upland to the marine unit, was not retained for further consideration in this FS. Full containment of groundwater at the shoreline would require extraction, treatment and disposal of groundwater in perpetuity. It would be difficult to achieve upland groundwater containment via extraction without inducing marine surface water flow beneath the upland, thereby producing large volumes of extracted groundwater. Treatment and disposal of this large volume of extracted water would prove to be disproportionately costly.

9.4.4.3. INSTITUTIONAL CONTROLS

ICs include land use restrictions to reduce risk to receptors by preventing contact with contaminants. Land use restrictions in the form of environmental covenants are required at sites that use engineering controls (e.g. containment technologies) as a component of remedial actions. The environmental covenants prevent actions that might threaten the integrity of the remedy. They also dictate the maintenance and monitoring requirements of engineering controls.

9.4.5. Sediment Remedial Technologies

A range of remedial technologies was evaluated for Site marine sediment. The SMS (WAC 173-204-570 [4][b]) provides a list of likely technologies that may be used to clean up contaminated sediment. Incorporating that list, the GRAs considered in the screening evaluation included institutional controls, capping, *in situ* sediment treatment, sediment removal, management of excavated sediment, enhanced natural recovery, and monitored natural recovery (Table 9-10). Specific GRAs, technology types, and process options that were retained for use in alternatives development are discussed further below.

9.4.5.1. CAPPING

Sediment capping is a common containment technology that relies on physical, chemical and biological isolation of contaminants left in place to reduce risks to people and aquatic receptors. Caps may be a sole response action or combined with removal technologies that leave some contaminated sediment in place. Caps can be designed to accommodate site-specific conditions such as land use, navigation requirements, slope, bottom depth, sediment geotechnical properties, contaminant type and concentration, and exposure to waves or other erosive forces.

Conventional caps typically consist of a layer of sand or other granular material with a thickness that varies based on site-specific conditions, and is placed over contaminated sediment. More complex caps may be layered to include impermeable geomembranes, permeable geotextile fabrics or other materials (e.g., clay layer) to enhance chemical or physical isolation and stability of the cap. The top (surface) layer of a cap can be designed to provide habitat. Specialized materials can be part of a cap design to enhance chemical isolation and may include various types of amendments (e.g., activated carbon, organoclay) or engineered layers (e.g., reactive core mat) that attenuate the flux of contaminants from the underlying contaminated sediment to the overlying water column. Sediment capping methods are described in Table 9-10.

Cap placement technologies vary based on the location and type of material used. Cap materials can be placed using conventional construction equipment (loaders, backhoes etc.), if conducted in the dry. In-water placement methods include barge dumping, hydraulic spreading, or diver placement.

Short-term risks associated with cap placement include contaminated sediment disturbance/resuspension, release of potentially contaminated porewater as a result of sediment consolidation, and smothering of benthic communities and aquatic vegetation. Long-term risks associated with capping include potential release of contamination left in place, should the integrity of the cap be compromised.

Capping methods that chemically and physically isolate contaminated sediment as well as those that provide enhanced chemical isolation were retained for consideration in this FS. Specifically, conventional sand caps and sand caps that would incorporate an amendment to sequester organic contaminants were retained. The cap specifications, such as thickness and amendment quantity would be determined during design. Armoring would be a component of caps where the physical environment requires additional protection from wave or current-induced resuspension and erosion or bioturbation.

9.4.5.2. SEDIMENT REMOVAL

Removal is a common remedial technology that is applied to contaminated sediment. Removal methods include land-based excavation, mechanical or hydraulic dredging. Land-based removal utilizes excavators staged from the shoreline or intertidal areas during low-tide periods to remove a specified depth of contaminated sediment. Sediment removal areas can be covered with geotextile or a thin sand layer to reduce contaminant releases during periods of tidal inundation. Alternatively, engineered systems such as berms, sheet piling and pumping can be used to isolate the excavation area from surface water.

Dredging is a removal technology conducted from a barge or other in-water platform. Dredging is typically conducted by lowering a bucket to scoop sediment from the bottom, lifting the filled bucket through the water column onto a barge where the sediment is dewatered. The dredged material is then transported to an on-site disposal facility, confined or open water aquatic disposal facility or transloading facility for off-site disposal. Different buckets are used for different purposes—clamshell buckets can remove consolidated sediment and debris better than many other buckets and provide high productivity due to bucket size and volume. Environmental buckets reduce loss of material during dredging and are effective in soft sediment; they can also be sized to provide greater productivity. Almost all dredging equipment is effective in shallow (less than 100 feet) water but becomes more difficult to implement with increasing depths. Mechanical dredging and land-based excavation techniques incorporate less water with the sediment, thereby reducing the amount of water that must be managed (i.e., treated and/or disposed).

Hydraulic dredging typically uses various types of cutters or devices to disturb the sediment, drawing it into a suction pipe for transport to a dewatering facility prior to disposal. Very soft sediment can be hydraulically removed without the use of cutters. Diver-assisted hydraulic dredging can be used for very specific, small-scale applications (e.g., removal around a pier structure). Use of a hydraulic dredge may not avoid the need for mechanical dredging; a clamshell bucket is still often required to remove debris prior to hydraulic dredging. Hydraulic dredging entrains a substantial volume of water along with the dredged material and requires dewatering and water treatment prior to disposal. Dewatering requires an upland facility proximal to the dredge area for efficient transfer and treatment of the sediment/water mixture. Sediment removal methods, as well as handling and disposal methods, are described in Table 9-10.

Short-term risks associated with dredging include resuspension of sediment and possible exposure of aquatic organisms to particulate or water-borne contaminants within the remediation footprint. Long-term risks are associated with the production of dredging residuals, which is contamination that remains within or adjacent to the dredge area after dredging, or off-site transport of resuspended material.

Land-based excavation and mechanical dredging were retained for use in the FS. Intertidal sediment would be excavated using land-based equipment. Contaminated sediment in lower intertidal and subtidal areas would be removed using barge-mounted dredging equipment. Dredged sediment would be placed on an additional barge near the dredging equipment and would need to be off-loaded to the upland at an off-site transloading facility.

9.4.5.3. EXCAVATED/DREDGED MATERIALS MANAGEMENT

Implementation of removal technologies would require a final fate for excavated material. Contaminated sediment can be beneficially reused (e.g., incorporated into construction materials) or disposed. Disposal may be in-water in a confined aquatic disposal facility (CAD) or at an unconfined (open water) disposal site, or in an upland facility. Beneficial reuse requires a current project that is willing to incorporate any material generated and may require sediment treatment prior to reuse; no available projects have been identified to date. In-water disposal has extensive siting and permitting requirements. Currently, there is no regional CAD facility for contaminated sediment and Site sediment is unlikely to meet open water disposal requirements. Upland disposal facilities are available regionally, but have additional requirements for characterization and material properties that must be met.

Two techniques were retained for managing excavated/dredged sediment at the Site. They include off-site treatment and disposal, and managing the material on-site within the upland AOC. Excavated sediment would be consolidated within the AOC in areas within the footprint of the low-permeability upland cap system. Sediment will likely require addition of amendments to strengthen the material for geotechnical suitability during consolidation within the upland AOC. Soil strengthening methods would need to be consistent with EPA's and Ecology's AOC policies and guidance.

Off-site treatment and disposal of contaminated sediment and debris would be in accordance with state dangerous waste and RCRA regulations. Based on existing sediment data, most excavated sediment could be placed directly in a Subtitle C or D landfill. Some sediment would designate as a land-banned hazardous waste and require incineration prior to disposal in a Subtitle C landfill.

9.4.5.4. NATURAL RECOVERY PROCESSES

The natural recovery of sediment refers to natural processes such as chemical and biological degradation, sedimentation (i.e., burial beneath clean sediment) and bioturbation (e.g,, mixing, oxidation) that result in reduced contaminant concentrations in surface sediment over time. When conditions causing natural recovery of sediment are expected to reach cleanup goals within a reasonable time frame (defined as 10 years in SMS), or other technologies are determined to not be practicable, MNR can be applied. This cleanup approach requires long-term monitoring to demonstrate the rate of recovery to ensure that CAOs are met. The monitoring program associated with an MNR remedy typically includes a combination of physical, chemical and biological testing.

The natural load of clean sediment from the Nooksack River is sufficient for sediment to naturally recover through mixing and burial processes alone in many areas of Bellingham Bay, including the vicinity of the Haley Site (see Section 7.3.5.1). MNR is a component of the Whatcom Waterway cleanup areas that are adjacent to or overlap with the Haley Site; MNR is also a component of the cleanup for portions of the adjacent Cornwall site. MNR was retained for consideration as a component of remedial alternatives in subtidal areas where sediment concentrations are low enough that natural recovery will achieve cleanup levels within a reasonable time frame.

In scenarios where sedimentation is the primary recovery process, but recovery rates or existing sediment concentrations prevent achieving cleanup levels within a reasonable time, natural recovery can be enhanced by placing a thin layer of clean sediment (commonly about 6 inches) to reduce surface sediment concentrations and accelerate natural recovery processes. This process, enhanced natural recovery (ENR), may achieve cleanup levels in a reasonable restoration time frame under conditions in which MNR would not. ENR was retained as a component of sediment remedial alternatives for areas where natural recovery would be expected to occur, but sediment concentrations are too high relative to the natural sedimentation rates for MNR to achieve CAOs in an acceptable restoration time frame.

9.4.5.5. INSTITUTIONAL CONTROLS

ICs considered for addressing contaminated sediment at the Site include various restrictions or legal agreements that would prevent people or ecological receptors from being exposed to contamination left in place and that would protect the physical integrity of the remedy over time. ICs can only be proposed as the sole response action in cases where an active remedy is not feasible. Accordingly, ICs are typically combined with various engineered responses. ICs can be applied during implementation, post-remediation, and may even continue after CAOs have been achieved to ensure the long-term efficacy of the remedy. Environmental covenants that restrict the use of the marine unit in order to meet one or more of the CAOs (e.g., protection of human health) would likely be part of most remedies. Activities such as dredging, boat anchoring, large vessel maneuvering or in-water construction that could potentially damage a sediment cleanup action would be prohibited using environmental covenants. Such covenants are legally binding agreements regardless of property ownership or future land use; however, most covenants take into account likely future use scenarios. In addition, covenants are enforceable by Ecology and parties to the covenant.

Public notice, education and/or advisories may also be applicable to the sediment remedy. Appropriate ICs will be identified as part of the selection of the final remedy for the Site.

9.5. Description of Cleanup Action Alternatives

Cleanup alternatives were developed based on current approaches for upland and sediment remediation projects in the United States, with special attention to Washington State, following regulations and guidance developed by Ecology, EPA and USACE. Each alternative was designed to meet MTCA and/or SMS threshold requirements. The remedial alternatives are generally presented in order of increasing levels of removal and/or treatment of contaminated media, with the last alternative for each Site unit involving complete removal of contaminated media to the extent practicable. The alternatives were sufficiently developed on a conceptual basis to meet the objectives of the FS: to perform a comparative evaluation of remedial alternatives and identify a preferred alternative. The final design for the selected alternative may differ somewhat from the alternative descriptions presented in this FS depending on agency decisions, input from the public and other stakeholders, permit requirements, and supplemental data that may be collected to support design.

The remedial alternatives include a range of treatment, removal, and containment technologies to achieve cleanup standards for impacted media. The upland alternatives include actions that satisfy the expectations of MTCA (WAC 173-340-350 through -370). For example, the alternatives include various technologies that remove, destroy, immobilize, and/or contain NAPL and associated contaminants in soil, groundwater and sediment. These technologies combined with upland capping and stormwater controls will achieve a key goal of MTCA and SMS: upland source control. Collectively, these actions will eliminate or control to the extent practicable contaminant migration from the upland to marine units.

Sections 9.5.2 and 9.5.3 describe the primary components of each upland and sediment alternative, along with the key assumptions, basis and rationale for including the alternative in the FS.

Each of the upland remedial alternatives includes the following common elements, which are not repeated in the subsequent alternative descriptions. Costs for these comment elements, however, are included in the FS cost estimates.

- Removal of the existing sheet pile barrier, UST, surge tank and associated underground product piping.
- Removal of remnants of the former facility stormwater system to the extent needed to yield a protective remedy.
- Improved upgradient drainage controls to reduce stormwater infiltration along the BNSF right-of-way.
- Passive engineering control (e.g., vapor barriers) of soil vapors, if needed, during construction of future structures.
- Recontouring and capping of the shoreline bank to integrate the upland and sediment remedies, and accommodate planned redevelopment of the Site as a park (e.g., beach access).

Common elements of the sediment alternatives include the following:

- Removal of the Interim Action cap that was installed in 2013 in the intertidal zone at the south end of the Site.
- Removal and disposal of debris and piling that could otherwise adversely affect the performance of the remedy if left in place.
- Armoring of the shoreline bank to address erosion processes known to have occurred at the Site.

9.5.1. Future Site Redevelopment

The City's Master Plan for Cornwall Beach Park envisions a 17-acre park that will include portions of the Haley Site and Cornwall Landfill site, approximately 14 acres of upland (City- and State-owned) and 3 acres of intertidal (State-owned). Consistent with the proposed Waterfront District Sub-Area Plan, the Cornwall Beach Master Plan includes such features as enhanced shoreline access, shoreline and beach restoration, paved and lighted parking with associated underground utilities and other park amenities such as restrooms, picnic shelters, a playground, a pavilion and concessions. The park design has not been finalized. Some or all of these park features may be located within the boundaries of the Haley Site.

All components of the remedial alternatives developed for the Haley Site are driven solely by the CAOs, exclusive of any park considerations. As a result, the estimated cleanup costs have not been influenced by any aspects of the conceptual park design. The remedial alternatives, however, would be compatible with future use of the Site as a park. The design and implementation of the Haley Site cleanup and proposed park will be coordinated during future design, planning and permitting phases of both projects. Additional discussion regarding compatibility of the preferred alternative with future use of the site as a park is presented in Section 10.0.

9.5.2. Cleanup Action Alternatives – Upland

Six different remedial alternatives were developed for the upland unit, with three of the alternatives (U3a, U3b and U3c) using similar technologies in different areas of the Site. Each alternative includes a combination of technologies retained through the screening process (Section 9.4). The matrices below indicate the key concepts and remedial technologies of each upland alternative. The upland alternatives are summarized in Table 9-11 and discussed in Sections 9.5.2.1 through 9.5.2.6.

UPLAND REMEDIAL ALTERNATIVES

Key Concepts of Alternative	U1	U2	U3a	U3b	U3c	U4
Prevent direct contact	●	●	●	●	●	●
Reduce groundwater recharge	●	●	●	●	●	
Physical groundwater barrier	●		●	●		
Groundwater treatment		●				
Soil treatment			●	●	●	
Soil removal					●	●
Removal all soil > CULs						●

Key Remedial Technologies	U1	U2	U3a	U3b	U3c	U4
Low-permeability cap	●	●	●	●	●	
Vertical barrier (sheet pile) at shoreline	●					
Permeable reactive barrier (PRB)		●				
LNAPL removal/off-site incineration	●	●				●
In situ LNAPL/soil solidification			●	●	●	
In situ soil stabilization				●	●	
Soil/LNAPL removal					●	●
On-site management of excavated soil					●	
Off-site management of excavated soil						●
Institutional controls	●	●	●	●	●	

9.5.2.1. ALTERNATIVE U1: PASSIVE LNAPL REMOVAL, VERTICAL SHORELINE BARRIER, UPLAND CAP

Upland Alternative U1 primarily utilizes containment technologies in conjunction with LNAPL recovery to reduce risks to human health and the environment. The containment features would include a low-permeability vertical barrier near the shoreline to prevent LNAPL migration to the marine unit, and an engineered low-permeability cap over the entire footprint of soil that exceeds cleanup levels (Figures 9-2 and 9-3).

The vertical barrier included in Alternative U1 would function similar to the existing sheet pile wall. This wall would contain potentially mobile LNAPL in the upland, while causing groundwater to flow deeper beneath the wall through cleaner soil. The deeper groundwater flow path through cleaner soil would enhance attenuation process, thereby reducing the concentration of dissolved-phase contaminants in groundwater that flows beneath the wall to the marine unit. This process is occurring today based on groundwater monitoring data (Section 6.8). Groundwater quality would be further improved by LNAPL removal and other components of the alternative that are described below.

The vertical barrier would be located at the shoreline bank along the entire extent where LNAPL is potentially mobile (Figure 9-2). The barrier would prevent migration of the potentially mobile LNAPL in this area (Section 7.2). For the purpose of this FS, it is assumed the vertical barrier would consist of a sheet pile wall with sealed joints, epoxy coating, cathodic protection, and other features that enhance its low-permeability characteristics and provide longevity.

LNAPL would be removed on the upgradient side of the vertical barrier using passive oil skimming equipment. Dedicated LNAPL skimmers (pneumatic or belt-type skimmers) would be placed in each of approximately 25 recovery wells located where LNAPL is potentially recoverable. Passive skimmers slowly remove recoverable LNAPL without generating significant volumes of water that would require costly treatment and disposal. The skimmers would be operated on a continuous basis and controlled by a central operation system. The recovered LNAPL would be transported off-site for incineration at a permitted facility.

The oil recovery system described above would satisfy the MTCA requirement to remove LNAPL to the extent practicable using normally accepted engineering practices. Oil removal and off-site incineration also would satisfy the MTCA preference for removal and destruction of highly concentrated and potentially mobile contamination at cleanup sites.

Alternative U1 also includes an engineered low-permeability cap to prevent direct contact with contaminated soil, and reduce the infiltration of stormwater. Reducing stormwater infiltration would decrease contaminant leaching from vadose zone soil and reduce groundwater (and contaminant) flux from the upland to marine unit. The primary source of groundwater flowing through the Haley upland is stormwater that directly falls on the Site. It is estimated that construction of a low-permeability cap in the upland would reduce stormwater infiltration by approximately 95 percent within the footprint of the cap. Results of groundwater flow modeling indicated that groundwater flux at the mudline is reduced by approximately 70 percent as a result of the upland cap construction. Appendix R provides additional details regarding the effects of the upland cap on groundwater flux.

The low-permeability cap (described further below) would primarily utilize a synthetic low-permeability liner (assumed 40 mil thickness) to prevent stormwater infiltration covered by at least a 2-foot thick layer of clean soil (Figure 9-3). This Haley low-permeability cap would be generally equivalent to the two-layer low-permeability cap system (i.e., 20-mil polyethylene liner and low-permeability soil) at the Cornwall site. The cap would encompass all portions of the Site where contaminant concentrations in soil exceed cleanup levels, including areas where Haley Site contaminants overlap onto the Cornwall site. In the event additional data are needed to refine the northern boundary of the low-permeability cap system and drainage controls, additional sampling would be conducted during the design phase.

Any soil and/or sediment excavated to implement cleanup actions in other portions of the Site would be relocated beneath the footprint of the cap. All these activities would occur within the boundaries of the Haley AOC (Section 9.2.1.1). Any excavated soil (or sediment) consolidated within the upland AOC within the low-permeability cap footprint would be graded as needed to achieve the desired subgrade elevations for the overlying cap.

For purposes of the FS, the conceptual design of the upland cap would include the following components from bottom to top:

- A flexible geotextile separation layer to prevent finer-grained underlying soils from mixing with overlying cap materials and to demarcate underlying contaminated soil from overlying clean media.
- A gas-collection layer, if needed, based on additional evaluations to be conducted during remedial design. It is assumed this horizon would be 6-inches thick and would provide passive migration of vapors and venting to ambient air.
- A low-permeability synthetic liner such as a 40-mil PVC geomembrane on top of the gas-collection layer.
- A high-permeability drainage horizon, assumed to be approximately 1-foot thick, to collect and convey infiltrated stormwater to a discharge point. Drainage details would be developed during remedial design.

- A flexible geotextile separation layer on top of the drainage layer to separate the drainage layer from the final fill layer(s).
- A cap surface horizon consisting of a growing medium and vegetated (hydroseeded) surface or a paved surface with appropriate subgrade. For FS cost estimating purposes, it is assumed that approximately 70 percent of the cap area would be vegetated and 30 percent would be paved.

Upland alternatives utilizing a low-permeability cap include cap costs for the area overlapping with the Cornwall upland cap. Actual construction costs for capping in this overlap area, however, would be shared between the two projects.

Collectively, the various components of Alternative U1 would provide source control measures to eliminate or reduce to the extent practicable contaminant migration from the upland to marine units. The actions described above would not only reduce contaminant leaching and migration via the groundwater pathway, but prevent the erosion and transport of contaminated soil by stormwater runoff.

Alternative U1 would require operation and maintenance (O&M) of some remedial components, including the LNAPL recovery system. For cost estimating purposes, it is assumed that LNAPL recovery system will be operated for a period of ten years. In addition, costs associated with periodic maintenance and repairs for the cap and the shoreline barrier are included in the O&M costs for this alternative. For comparison purposes, the duration of maintenance is assumed to be 30 years. Monitoring costs to evaluate performance of the cleanup action were also included in the FS cost estimates. Annual monitoring of the condition of the cap components and the barrier wall is included to ensure that the components are functioning properly. Groundwater monitoring is expected to be required to evaluate the performance of the cleanup action. For purposes of the FS, long-term monitoring of cleanup action components and groundwater conditions in the upland will be required for a period of 30 years. Institutional controls would be used to prevent activities that might jeopardize the integrity of the remedy, and provide for long term O&M and monitoring requirements.

The estimated cost of Alternative U1 is $10,090,000 (Appendix Q Table Q-4). For all alternatives, cost estimates are in 2014 dollars, include contingencies, and represent order-of-magnitude with a range of -30 percent to +50 percent based on EPA guidance (EPA 2000a).

9.5.2.2. ALTERNATIVE U2: PERMEABLE REACTIVE BARRIER (PRB), PASSIVE LNAPL REMOVAL, UPLAND CAP

Alternative U2 would utilize passive groundwater treatment in conjunction with LNAPL recovery and soil containment to reduce risks to human health and the environment (Figures 9-4 and 9-5).

Alternative U2 would utilize the same engineered low-permeability cap and passive LNAPL skimming technique as Alternative U1. The upland cap would prevent direct contact with contaminated soil and reduce stormwater infiltration. As with Alternative U1, reducing stormwater infiltration would reduce the flux of groundwater and contaminant mass from the upland to the marine units. This also would have the effect of reducing flow through the PRB. LNAPL recovered by the skimming system would be destroyed by incineration at an off-site facility, the same as in Alternative U1.

The PRB in Alternative U2 would treat groundwater as it flows from the upland to marine unit (Figure 9-4). The treatment media in the PRB would be organoclay, which is capable of sequestering LNAPL and dissolved-phase organic contaminants in Site groundwater. The PRB would be comprised of a mixture of granular organoclay and clean sand to provide a permeable vertical treatment wall adjacent to the shoreline. The thickness (width) of the PRB and the fraction of organoclay needed to achieve proper treatment over an assumed 30-year lifespan would be established during remedial design. For cost estimating purposes, it is assumed that the PRB would be 2-feet-thick and contain 20 percent organoclay by volume.

PRBs can be installed using several construction methods, including one-pass trenching techniques and *in situ* placement of the reactive media using soil mixing technologies. For Alternative U2, it is assumed that soil would be removed from a trench at the desired location of the PRB, after which the trench would be backfilled with a mixture of clean imported soil and organoclay.

Alternative U2 would require O&M of the LNAPL recovery system. For cost estimating purposes, it is assumed that the LNAPL recovery system will be operated for a period of ten years. It is possible that the reactive media in the PRB could reach its sorbtive capacity in the future at which time the spent organoclay/sand media would need to be replaced. For cost estimating purposes, it is assumed that the PRB is replenished after 30 years. Monitoring and maintenance of the components of the upland cap would be required, as described for Alternative U1. Long-term groundwater monitoring will be required to evaluate the effectiveness of the remedy. For purposes of the FS, it is assumed that groundwater monitoring will be required for a period of 30 years. Institutional controls would be used to prevent activities that might jeopardize the integrity of the remedy, and provide for long term O&M and monitoring requirements.

The estimated cost of Alternative U2 is $10,710,000 (Appendix Q Table Q-5).

9.5.2.3. ALTERNATIVE U3A: NEARSHORE IN SITU SOIL SOLIDIFICATION, UPLAND CAP

Alternative U3a is one of three upland alternatives that utilize an *in situ* soil treatment method. In this alternative, *in situ* solidification would be used to treat soil in the area of potentially mobile LNAPL near the shoreline (Figures 9-6 and 9-7). Alternative U3a would also include the same upland low-permeability cap described in previous alternatives to prevent direct exposure to contaminated soil and reduce infiltration of stormwater.

In situ solidification would treat soil near the shoreline to immobilize LNAPL and reduce contaminant leaching to groundwater. Solidification would be accomplished by mixing a cement and organoclay blend directly into soil in the area where LNAPL is potentially mobile. This material permanently micro-encapsulates the soil particles and associated contamination, and has been proven to be a successful treatment technology for soil contaminated with organic compounds (Section 9.4.2.4). The solidification process would require treatability testing to determine the appropriate mixture of cement and organoclay and other reagents required to achieve treatability goals including low-permeability of the treated matrix, reduced leachability of treated contaminants, and strength and stability of the solidified mass to ensure long-term effectiveness.

The solidification process would produce a monolithic matrix near the shoreline that would impede groundwater flow. Similar to the vertical shoreline barrier in Alternative U1, groundwater from upgradient locations would flow beneath the solidified monolith through cleaner soil. The solidification process of Alternative U3a, however, would have the added benefit of sequestering LNAPL and associated soil contamination in the solidified mass, thereby reducing contaminant leaching into groundwater.

In situ solidification would be implemented by removing and stockpiling unsaturated soil above the top of the smear zone. In the area of overlap with the Cornwall Landfill, it is assumed that some debris would need to be removed from the refuse horizon for solidification to be successfully implemented. For cost estimating purposes, it is assumed that 25 percent of the material in this area will require off-site transport and treatment/disposal as hazardous waste. Standard excavation equipment would be used to mix the cement/organoclay blend directly into the soil. Soil would be treated to a depth below the deepest extent of residual LNAPL to provide a factor of safety to account for unknown subsurface conditions. For cost estimating purposes, it is assumed the soil treatment zone would range in thickness from approximately 8- to 13-feet, with an average thickness of approximately 11 feet. The stockpiled overburden would be backfilled on top of the treated soil after completing the treatment process.

Alternative U3a would require long-term groundwater monitoring to evaluate the effectiveness of the remedy. For purposes of the FS, it is assumed that groundwater monitoring will be required for a period of 30 years. Costs were included for annual monitoring of the cap condition to ensure that damage to the cap has not occurred. The upland cap could require monitoring and maintenance as described for Alternative U1. Institutional controls would be used to prevent activities that might jeopardize the integrity of the remedy, and provide for long term O&M and monitoring requirements.

The estimated cost of Alternative U3a is $10,250,000 (Appendix Q Table Q-6).

9.5.2.4. ALTERNATIVE U3B: EXPANDED IN SITU SOIL SOLIDIFICATION AND STABILIZATION, UPLAND CAP

Upland Alternative U3b would incorporate an expanded soil solidification footprint that extends farther inland than Alternative U3a (Figures 9-8 and 9-9). In addition, soil upgradient of the solidification area would be treated *in situ* using a stabilization process. Alternative U3b would utilize the same low-permeability upland cap described for other alternatives to prevent direct exposure to contaminated soil and reduce infiltration of stormwater.

Alternative U3b utilizes *in situ* soil treatment technologies throughout the majority of the smear zone. Solidification would be used within approximately 150 feet of the shoreline, which includes areas where LNAPL is potentially mobile. *In situ* stabilization using organoclay would be used between the area of solidification and the upgradient boundary of the Site. As described above for Alternative U3a, it is assumed that 25 percent of the treatment zone in the landfill overlap area will be removed and transported off-site for treatment/disposal as hazardous waste. Collectively, the solidification and stabilization treatment actions would sequester LNAPL and dissolved-phase organic contaminants in soil and groundwater. Stabilization, as opposed to solidification, would be used in the upgradient portion of the Site to enable treatment of the full vertical extent of the smear zone without precluding groundwater flow through the shallow aquifer in this portion of the Site (see Section 9.4.2.1 and Figure 9-9). Closer to the shoreline, groundwater would flow beneath the solidified soil mass through cleaner soil, as described above for Alternative U3a.

Implementation of the *in situ* solidification process would be the same as described for Alternative U3a. *In situ* stabilization would be completed using similar construction techniques. Both processes would require treatability testing to determine the appropriate treatment materials and quantities, prior to implementation. The selected reagents would be directly mixed into soil using standard excavation equipment. Treatment would be performed to a depth below the vertical extent of residual LNAPL (Figure 9-9) to add a factor of safety to account for unknown subsurface conditions. For cost estimating purposes, it is assumed the soil solidification zone would range in thickness from approximately 6- to 13-feet, with an average thickness of 9 feet. Thickness of the soil stabilization zone is assumed to range from approximately 3-feet to 8-feet, with an average thickness of 6.5 feet.

Long-term monitoring and potential maintenance requirements for Alternative U3b would be the same as those described for Alternative U3a. Institutional controls would be used to prevent activities that might jeopardize the integrity of the remedy, and provide for long term O&M and monitoring requirements.

The estimated cost of Alternative U3b is $21,050,000 (Appendix Q Table Q-7). The substantially increased cost of U3b over U3a is driven by the differences in the volume of soil treated.

9.5.2.5. ALTERNATIVE U3C: SOIL REMOVAL, IN SITU SOIL SOLIDIFICATION AND STABILIZATION, UPLAND CAP

Upland Alternative U3c is a variation of Alternative U3b that utilizes the same *in situ* treatment processes to address contaminated soil; however, in Alternative U3c soil in the area where LNAPL is potentially mobile would be removed by excavation rather than treated *in situ* (Figures 9-10 and 9-11). The excavated soil would be consolidated within the footprint of the broader *in situ* solidification area farther upland within the AOC under the low-permeability cap. Outside of the excavation area, the footprint of *in situ* soil treatment would be the same as described for Alternative U3b. Alternative U3c also incorporates a low-permeability upland cap to prevent direct exposure to contaminated soil and reduce infiltration of stormwater, as described in previous alternatives.

The added component of soil removal for Alternative U3c would involve removal of smear zone soil within the areal limits of potentially mobile LNAPL (Figure 9-10). Soil would be excavated to the lower limit of the smear zone using common excavation methods. The total volume of contaminated soil, landfill waste and debris excavated under this alternative is assumed to be approximately 25,000 cy, of which 22,200 cy is assumed to be managed on-Site by consolidation within the upland AOC. The assumed quantity of landfill waste or debris from the excavation area that would be transported off-site for disposal as hazardous waste because it cannot be effectively consolidated within the AOC is nearly 2,800 cy. Soil removed from the excavation area would be temporarily stockpiled prior to consolidating it beneath the upland cap within the AOC. If necessary to strengthen the excavated soil for use as fill within the AOC, the soil would be prepared using the same solidification process used for *in situ* solidification. For cost estimating purposes, the 15,300 cubic yards of excavated soil within the smear zone is assumed to require solidification treatment while the remaining 6,700 cubic yards of overburden soil is assumed to not require solidification.

Soil removal under this alternative would likely require temporary shoring and dewatering to safely excavate soil from the deepest part of the smear zone; costs for temporary shoring and water management were included in the FS cost estimate for this alternative. The excavation would be backfilled using clean imported fill.

All aspects of *in situ* soil treatment would be the same for this alternative as for Alternative U3b, except under Alternative U3c *in situ* soil treatment would not be performed in the soil removal area. The upland low-permeability cap would extend over the excavated and backfilled area to limit stormwater infiltration as in other alternatives. During remedial design, it could be determined that the upland cap would not need to extend over the entire soil removal area depending on sediment remedy considerations.

Long-term monitoring and potential maintenance requirements for Alternative U3c would be the same as those described for Alternative U3a. Institutional controls would be used to prevent activities that might jeopardize the integrity of the remedy, and provide for long term O&M and monitoring requirements.

The estimated cost of Alternative U3c is $24,990,000 (Appendix Q Table Q-8).

9.5.2.6. ALTERNATIVE U4: COMPLETE REMOVAL

Alternative U4 would consist of excavating all upland soil with contaminant concentrations exceeding cleanup levels, to the maximum extent practicable. This action would also remove residual and potentially mobile LNAPL from the upland. Excavated soil would be transported off-site for treatment/disposal in accordance with state and federal dangerous/hazardous waste regulations. Dewatering necessary to accomplish excavation, and corresponding water handling, treatment and disposal, were included in the FS cost estimate for this alternative.

The lateral extent of soil removal assumed for Alternative U4 includes the footprint of contaminant concentrations exceeding soil cleanup levels (Figure 9-12). Based on this framework, the assumed depth of excavation ranges from 8 to 30 feet bgs (Figure 9-13). The total volume of contaminated material removed from the Site in this alternative is assumed to be approximately 187,000 cy. The Site would be reconstructed to original grade using clean imported fill. Unlike the previous upland remedial alternatives, no upland cap would be required to prevent direct contact with contaminated soil or reduce stormwater infiltration. In addition, no institutional controls would likely be required. Groundwater monitoring would be required for a relatively short period of time to demonstrate the effectiveness of the remedy; it is assumed these monitoring activities would be terminated after 5 years.

Estimated costs for off-site treatment and disposal of remediation-derived waste were based on characterization data from the RI. Excavated soil containing Haley-related contaminants would be classified as F032-listed dangerous waste. The primary cost driver for this alternative is the quantity of soil that is expected to require incineration prior to disposal due to concentrations of dioxins/furans and/or individual PAHs that exceed respective RCRA alternative LDR treatment standards for remediation-derived contaminated soil (10-times the universal treatment standards specified in 40 CFR 268.48). Based on the existing soil data, it is assumed that approximately 40 percent of the total quantity of excavated soil under this alternative would be transported and incinerated at a RCRA Subtitle C facility in Aragonite, Utah at a cost of approximately $878 per ton. Corresponding volumes and costs for the disposal assumptions based on waste characterization data are presented in the detailed FS cost estimates, Appendix Q.

The estimated cost of Alternative U4 is $167,600,000 (Appendix Q Table Q-9).

9.5.3. Cleanup Action Alternatives – Sediment

Five alternatives were developed to achieve CAOs for the sediment unit; the alternatives incorporate various combinations of sediment removal, capping and natural recovery technologies. The matrices below summarize the key concepts and technologies that comprise each alternative. The alternatives are summarized in Table 9-12 and described in detail in Sections 9.5.3.1 through 9.5.3.5.

SEDIMENT REMEDIAL ALTERNATIVES

Key Concepts of Alternative	S1	S2	S3	S4	S5a	S5b
Containment only (no removal)	●					
Remove some smear zone sediment		●		●		
Remove all smear zone sediment			●		●	●
Remove all sediment > CULs					●	●
Maintains bathymetry				●	●	●
Maintains existing eelgrass habitat				●		
Key Remedial Technologies	**S1**	**S2**	**S3**	**S4**	**S5a**	**S5b**
Sediment removal		●	●	●	●	●
Conventional sand cap	●	●	●	●		
Amended sand cap	●	●		●		
Enhanced natural recovery (ENR)	●	●	●	●	●	●
Monitored natural recovery (MNR)	●	●	●	●	●	●
On-site management of majority of excavated sediment	●	●	●	●	●	
Off-site management of majority of excavated sediment					●	●
Institutional Controls	●	●	●	●	●	●

Some or all of the most highly contaminated smear zone sediment would be removed under each alternative except for one; the corresponding quantities of sediment removed under each alternative are outlined below.

ALTERNATIVE SEDIMENT QUANTITIES

Alternative	Approximate volume of contaminated material excavated or dredged (cubic yards)
S1	0
S2	3,700
S3	7,700
S4	8,200
S5a	20,000
S5b	20,000

Capping is incorporated in each alternative where sediment contamination remains at concentrations greater than cleanup levels after the sediment removal action (S1 through S4). Nearshore sediment removal and capping actions are carefully paired in Alternatives S2, S3 and S4 to provide for chemical containment in this heavily impacted area. A conventional sand cap is proposed for one alternative that removes more of the underlying contaminated sediment near the shoreline (S3); amended sand caps are proposed for other alternatives (S1, S2 and S4) that remove less (or no) contaminated sediment in this area. Farther from the shoreline, only conventional caps are proposed. No cap is required in Alternative S5 because all contamination is removed in the intertidal and shallow subtidal areas, although clean material will be used to backfill the excavated/dredged areas.

All alternatives include ENR and MNR in deeper waters surrounding the removal and capping areas. For all sediment remedies, the footprint of the ENR and MNR areas will be refined as part of remedial design data collection. In this FS, ENR is conservatively proposed for an area outside of the sediment cap boundary where Haley-related dioxin/furan concentrations are estimated to be greater than two times the regional background-based cleanup level and natural sedimentation is occurring (Section 9.2.3.1). MNR would be proposed throughout the remainder of the Site where Haley-related dioxin/furan concentrations are less than two times the cleanup level. The actual footprint of ENR and MNR will be revised after completion of this FS based on the following factors:

- Additional sediment analytical data that will likely be obtained to further evaluate concentrations of bioaccumulative compounds in the ENR/MNR areas;
- Further evaluation of the anticipated effect of natural recovery in the ENR/MNR areas; and
- Interpretation of the Site data on a surface-area weighted average concentration (SWAC) basis.

The estimated sediment remedy costs presented in this FS include costs for ENR in the area described above (dioxin/furan concentrations greater than two times the cleanup level). This is a conservative assumption and the ENR area will be refined during remedial design based on the factors described above. Although the MNR boundary has not been fully determined, monitoring costs were included in the FS to account for a reasonable scope of MNR for the alternatives. Each of the sediment alternatives in this FS utilizes MNR in the same manner and scale. The inclusion of the MNR costs is not intended to compare different technologies applied for a particular area of the Haley Site, but is intended to better reflect the overall cost of each of the alternatives. This allows a more complete evaluation of the alternatives in the DCA.

Existing bathymetry would be preserved in several alternatives through a balanced removal and capping approach; other alternatives would result in decreased water depths in some areas. All alternatives provide improved benthic habitat features; existing eelgrass habitat is preserved in one alternative. Institutional controls would be required for all alternatives. Long-term monitoring to assure the effectiveness of the remedy would be included in each alternative; chemical, physical and biological sampling elements were assumed for the purpose of costing in the FS.

9.5.3.1. ALTERNATIVE S1: CONTAINMENT

This alternative would rely on capping to prevent people and aquatic organisms from coming into contact with contaminated sediment in intertidal and shallow subtidal areas (Figures 9-14 and 9-15). Organoclay would be added to capping material in the smear zone area to enhance chemical isolation in this approximately 0.6-acre upper intertidal area. A conventional sand cap would be placed over the remaining 1.1-acre area exceeding benthic toxicity-based cleanup levels. Debris and remnant piling that could affect the performance of the capping system would be removed prior to cap placement and disposed off-site. An area within the upland AOC would be used to store debris prior to transport to a permitted disposal facility.

The entire cap area would be armored to maintain the physical integrity of the cap because the nearshore area is subject to wave action and currents. The cap would also be designed to prevent disturbance by recreational vessels that may operate or anchor in the area. Fish mix, constituting a habitat material with a range of grain sizes used by various species, would be used to fill in spaces among armor rock.

ENR would be proposed in shallow subtidal areas seaward of the cap. A sand layer (assumed to be approximately 6 inches thick) would be placed over the area with moderate exceedances of bioaccumulation-based cleanup levels. For the purpose of estimating the remedy cost, ENR is assumed to extend a distance from the shoreline similar to the thin cap component of the adjacent Cornwall remedy. This results in an ENR area for the Haley Site of approximately 2 acres. The ENR layer is not intended to confine contamination; rather, it would mix with the underlying sediment over time to reduce risks to ecological receptors (e.g., fish and crab) that may consume benthic invertebrate prey and ultimately, people that may eat seafood from the bay. Risk reduction in deeper subtidal areas with lower concentrations of bioaccumulative chemicals would be achieved through MNR; these areas receive significant deposition of clean sediment from the Nooksack River.

Institutional controls would be used to prevent activities in the marine unit that could potentially damage the sediment remedy (examples could include dredging, large vessel maneuvering or in-water construction). Other types of institutional controls may also be applicable.

Implementation of Alternative S1 would not be dependent on the timing of construction for the upland remedy; additional discussion regarding remedy compatibility is included in 9.5.3.6.

The estimated cost of Alternative S1 is $3,820,000 (Appendix Q Table Q-10). For all alternatives, cost estimates are in 2014 dollars, include contingencies, and represent order-of-magnitude with a range of -30 percent to +50 percent based on EPA guidance (EPA 2000a).

9.5.3.2. ALTERNATIVE S2: UPPER INTERTIDAL SEDIMENT REMOVAL AND AMENDED CAP

Alternative S2 would include removal of approximately 3,700 cy of contaminated sediment primarily from the smear zone over approximately 1.0 acre in the upper intertidal zone (Figures 9-16 and 9-17). Remaining contaminated sediment in the removal area would be contained beneath a 2-foot-thick amended cap closest to the shoreline, transitioning to a conventional sand cap to the north and south of the smear zone and farther from the shoreline to the west. Outside of the sediment removal area, the conventional sand cap would be placed directly on the existing sediment surface throughout the remaining footprint of benthic toxicity exceedances. As a result, the conventional sand cap would extend into the shallow subtidal zone (Figure 9-17).

The areal extent of the amended sand cap and conventional sand cap in this alterative would be 0.6 acres and 1.1 acres, respectively. The sediment removal and capping approach in this alternative would preserve existing bathymetry in the upper intertidal zone. The conventional sand cap in the lower intertidal and shallow subtidal areas would effectively decrease water depths, resulting in habitat conversion in an approximately 0.7-acre area. The existing eelgrass bed also would be covered by the sand cap. Conventional land-based excavation equipment would be used to remove contaminated sediment prior to capping, and construct portions of the cap closest to the shoreline (for the purpose of the FS cost estimate, land-based equipment would also be used to construct the sand cap in the shallow subtidal zone).

Excavated sediment would be consolidated beneath the upland cap within the upland AOC, after screening, removing debris and appropriately strengthening the material for geotechnical suitability. Recovered debris, assumed to represent approximately 20 percent of the excavated sediment, would be transported off-site for disposal. Methods for handling and strengthening excavated sediment so that it can be consolidated within the upland AOC would be in accordance with EPA and Ecology AOC policies and guidance. Implementation of this alternative would be dependent on the timing of construction of the upland remedy (Section 9.5.3.6).

ENR and MNR technologies would be implemented in the same areas as described in Alternative S1. Institutional controls would be used to prevent activities in the marine unit that could potentially damage the sediment remedy. Other types of institutional controls may also be applicable.

The estimated cost of Alternative S2 is $5,140,000 (Appendix Q Table Q-11).

9.5.3.3. ALTERNATIVE S3: UPPER INTERTIDAL SEDIMENT REMOVAL AND SAND CAP

Alternative S3 would include removal of approximately 7,700 cy of contaminated sediment over about 1 acre in the upper intertidal zone (Figures 9-18 and 9-19). Remaining contaminated sediment in the removal area would be contained beneath an approximately 4-foot thick conventional sand cap. Outside of the sediment removal area, a 2-foot thick conventional sand cap would be placed directly on the existing sediment surface throughout the remaining footprint of benthic toxicity exceedances. The conventional sand cap would extend into the shallow subtidal zone (Figure 9-19).

The areal extent of the conventional sand cap in this alterative would be 1.7 acres. The sediment removal and capping approach in this alternative would preserve existing bathymetry in the upper intertidal zone. As with Alternative S2, the conventional sand cap in the lower intertidal and shallow subtidal areas would effectively decrease water depths, resulting in habitat conversion in an approximately 0.7-acre area and the existing eelgrass bed would be covered by the sand cap.

Excavated sediment would be screened to remove debris and consolidated within the upland AOC similar to the description for Alternative S2 (Section 9.5.3.2); debris would be disposed off-site. Implementation of this alternative would be dependent on timing of construction of the upland remedy (Section 9.5.3.6).

ENR and MNR technologies would be implemented in the same areas as described in Alternative S1. Institutional controls preventing portions of the marine unit to be used for activities that could potentially damage the sediment cleanup action would be included as appropriate. Other types of institutional controls may also be applicable.

The estimated cost of Alternative S3 is $5,470,000 (Appendix Q Table Q-12).

9.5.3.4. ALTERNATIVE S4: INTERTIDAL AND SHALLOW SUBTIDAL REMOVAL AND AMENDED CAP

Sediment removal associated with Alternative S4 in the upper intertidal zone is similar to Alternative S2; the use of a 2-foot thick organoclay amended cap to contain remaining contaminated sediment in the upper intertidal smear zone is also similar to Alternative S2 (Figures 9-20 and 9-21). Alternative S4 proposes continued seaward removal of contaminated sediment in the lower intertidal/shallow subtidal area where surface sediment exceeds benthic toxicity-based criteria, except in areas with existing eelgrass beds (Figures 9-20 and 9-21). Remaining contaminated sediment in the extended sediment removal area would be contained beneath a conventional sand cap. The approximate total volume of contaminated sediment that would be removed under this alternative is 8,200 cy.

The areal extents of the amended sand cap and conventional sand cap in this alterative are approximately 0.6 acres each and the sediment removal and capping approach in this alternative preserves existing bathymetry throughout this entire capping area.

Excavated sediment would be screened to remove debris and consolidated beneath the upland cap within the upland AOC similar to the description for Alternative S2 (Section 9.5.3.2). Implementation of this alternative would be dependent on timing of construction of the upland remedy (Section 9.5.3.6).

ENR and MNR technologies would be implemented in the same areas as described in Alternative S1, with the exception that the ENR area would also be applied in the eelgrass bed that was identified in the southern portion of the Site to preserve this existing sensitive habitat. Institutional controls would be used to prevent activities in the marine unit that could potentially damage the sediment remedy. Other types of institutional controls may also be applicable.

The estimated cost of Alternative S4 is $6,640,000 (Appendix Q Table Q-13).

9.5.3.5. ALTERNATIVES S5A AND S5B: COMPLETE REMOVAL

Alternative S5 removes all sediment in the intertidal and shallow subtidal zone (1.7 acres) that exceeds cleanup levels (about 20,000 cy), using land-based excavation as well as dredging methods, and backfilling with clean material (Figures 9-22 and 9-23). Surface sediment contamination in subtidal areas that is likely to naturally recover (including enhanced natural recovery) would be left in place; ENR and MNR technologies would be implemented in the same areas as described in Alternative S1 and institutional controls would be included as appropriate. No conversion of bathymetry occurs under this alternative; however, existing eelgrass habitat is removed.

The difference between Alternative S5a and S5b relates to the handling of excavated sediment. Alternative S5a assumes that as much of the excavated contaminated sediment as possible is consolidated within the upland AOC (assumed quantity represents 50 percent of the excavated sediment). Therefore, implementation of Alternative S5a would be dependent on the timing of construction of the upland remedy (Section 9.5.3.6). Excavated sediment that cannot be accommodated within the upland AOC would be transported off-site for disposal at a permitted landfill. Assumptions made for the purposes of FS costing were that contaminant concentrations in the excavated sediment transported off-site for disposal meet conditions for a contained-in determination allowing disposal of contaminated sediment at a Subtitle D landfill. Debris that may adversely affect implementation of the remedy or its long-term performance would also be disposed of off-site as in Alternative S1.

Alternative S5b assumes that all excavated sediment and debris would be transported off-site for treatment and disposal. Alternative S5b therefore is essentially not dependent on the timing of construction of the upland remedy, except to the extent of transition and integration of the remedies at the shoreline.

For the purposes of developing cost estimates for Alternatives S5a and S5b, remediation waste characterization, designation and treatment/disposal assumptions were made based on interpretation of Site characterization data and on regulatory and landfill requirements. Treatment/disposal costs for excavated sediment transported off-site were based on comparison of sediment sample chemical analytical data to treatment standards and waste designation criteria. It was assumed that federal and state LDRs would apply to excavated sediment, which would classify remediation-derived sediment waste as an F032-listed hazardous waste, and a fraction of the most highly contaminated material would likely exceed applicable treatment standards requiring incineration prior to disposal. Corresponding volumes and costs for the disposal assumptions based on waste characterization data are presented in the detailed FS cost estimates, Appendix Q.

The estimated cost of Alternative S5a is $7,460,000 (Appendix Q Table Q-14). The estimated cost of Alternative S5b is $12,180,000 (Appendix Q Table Q-15).

9.5.3.6. COMPATIBILITY WITH OTHER REMEDIES

Remedies for two adjacent cleanup sites overlap with the Haley Site. The Whatcom Waterway MNR area overlaps with the Haley Site MNR area, but creates no conflicts with implementation of either project. The proposed Cornwall Landfill sediment cap also overlaps with the Haley sediment remedy. The Haley capping alternative (S1) or various removal and capping alternatives (S2 through S5) can be designed and constructed to be compatible with the adjacent Cornwall Landfill remedy; however, coordination during design and construction would be required to ensure that the constructed cleanup action meets the cleanup action objectives of both Sites in the overlap area. If the southern intertidal boundary of SMS exceedances associated with the Haley Site extends further south than depicted in Figures 9-14 through 9-23, the Haley sediment remedy would need to take precedence in the Haley-Cornwall area of overlap due to the differences in required cap function.

All Haley sediment alternatives would be compatible with Haley upland alternatives, with the possible exception of upland Alternative U4 (total removal and backfill). This upland remedy does not have a component to reduce stormwater infiltration and subsequent groundwater flow from the upland to marine units. As a result, some sediment alternatives would potentially need to be modified to enhance the chemical containment function of nearshore caps. In addition, it may not be possible to manage excavated sediment within the upland AOC under upland Alternative U4 and therefore off-site disposal of excavated sediment would increase the cost of the sediment remedy. Timing of construction for the upland alternative and any sediment alternative would need to be coordinated for those sediment alternatives that rely on use of the upland AOC.

9.5.3.7. HABITAT MITIGATION

Habitat mitigation may be required for some of the alternatives considered in the FS. Current regulations define the conditions under which loss of habitat must be compensated for; permits implementing those regulations specify the type and amount of mitigation required.

Placement of a cap without prior sediment removal would result in alteration of the bottom depth and slope. The maximum area affected would be 1.7-acres if the intertidal and shallow subtidal areas of the sediment unit were to be capped with no prior sediment removal as in Alternative S1. In addition, an eelgrass bed in the southern portion of the Site between elevation 0 and -10 feet NAVD88 would be buried by a cap placed at these elevations (Alternatives S1, S2, and S3) or removed (Alternative S5). The CWA requires that impacts to aquatic resources and ecological functions be avoided, minimized or mitigated (Section 9.2). If the USACE determines through review of NWP Section 38 (or 404) permit application that there are unavoidable impacts, then some form of compensatory mitigation would be required, which can involve habitat enhancement, restoration, creation, preservation or *in lieu* fees. The need for mitigation would be determined once the design of a remedy for the Haley Site is approved by Ecology; both impacts and benefits associated with the remedy would be weighed in the development of any mitigation elements, should they be necessary.

Potential impacts associated with implementation of a sediment remedy may be offset by the benefits associated with various elements of the sediment remedies. All alternatives evaluated in the FS would provide clean substrate that would improve habitat for benthic and demersal species that live in or migrate through Bellingham Bay. Remedies implemented in the intertidal zone would provide features that enhance the transition between riparian and nearshore habitats that are currently absent or degraded. Remnant pilings in the intertidal area would be removed or cut off below surface grades. Final surface substrates and slopes of the constructed remedy could be designed to provide specific habitat functions that support the overall restoration goals for Bellingham Bay.

Assumptions for habitat mitigation were included in the FS cost estimates, based on the area of potentially converted habitat, without consideration of habitat improvements that may reduce mitigation requirements.

9.6. Evaluation of Cleanup Action Alternatives

This section presents the evaluation of each of the cleanup alternatives with respect to threshold and other requirements for cleanup actions set forth in MTCA and in SMS. This section is organized as follows:

Section 9.6.1 Upland Cleanup Alternatives Evaluation Criteria: The MTCA evaluation criteria by which the upland alternatives are evaluated are described in Sections 9.6.1.1 (threshold requirements) and 9.6.1.2 (other requirements). Section 9.6.1.3 explains the specific evaluation criteria used in the DCA and the general DCA process for cleanup alternatives.

Section 9.6.2 Upland Alternatives Evaluation: Each upland cleanup action alternative is evaluated with respect to the MTCA criteria. The comparative evaluation, whereby the upland alternatives are compared relative to one another for each evaluation criteria, is summarized in Table 9-13.

Section 9.6.3 Upland Alternatives DCA: This section presents results of the DCA for the upland cleanup alternatives. Table 9-15 summarizes the DCA scoring and ranking for the upland alternatives and Figure 9-24 illustrates the Upland DCA in graphical format.

Section 9.6.4 Upland Preferred Alternative: The preferred alternative for the upland unit, based on the results of the DCA, is identified.

Section 9.6.5 Sediment Cleanup Alternatives Evaluation Criteria. This section describes the SMS evaluation criteria by which the sediment alternatives are evaluated.

Section 9.6.6 Sediment Alternatives Evaluation: Each sediment cleanup action alternative is evaluated with respect to the SMS criteria. The comparative evaluation of the sediment alternatives is summarized in Table 9-14.

Section 9.6.7 Sediment Alternatives DCA: This section presents results of the DCA for the sediment cleanup alternatives. Table 9-16 summarizes the DCA scoring and ranking for the sediment alternatives and Figure 9-25 illustrates the Sediment DCA in graphical format.

Section 9.6.8 Sediment Preferred Alternative: The preferred alternative for the sediment unit, based on the results of the DCA is identified.

9.6.1. Upland Cleanup Alternatives Evaluation Criteria

This section describes the threshold requirements for cleanup actions under MTCA and additional criteria used to evaluate the cleanup action alternatives; evaluation of the alternatives relative to these criteria is presented in Sections 9.6.2 and 9.6.3 for the upland cleanup alternatives and Sections 9.6.6 and 9.6.7 for the sediment cleanup alternatives.

9.6.1.1. MTCA THRESHOLD REQUIREMENTS

Cleanup actions performed under MTCA must comply with several basic requirements, termed "threshold requirements." Cleanup action alternatives that do not comply with these criteria are not considered suitable cleanup actions under MTCA. As provided in WAC 173-340-360(2)(a), the four threshold requirements that cleanup actions must meet are:

- *Protect human health and the environment.* The completed cleanup action MTCA must ensure that both human health and the environment are protected.
- *Comply with cleanup standards.* Compliance with cleanup standards requires, in part, that cleanup levels are met at the applicable points of compliance. Where a cleanup action involves containment of soil with hazardous substance concentrations exceeding cleanup levels at the point of compliance, the cleanup action may be determined to comply with cleanup standards, provided the requirements specified in WAC 173-340-740(6)(f) are met.
- *Comply with applicable state and federal laws.* The term "applicable state and federal laws" includes legally applicable requirements and those requirements that Ecology determines to be relevant and appropriate as described in WAC 173-340-710.
- *Provide compliance monitoring*. Compliance monitoring for a cleanup action includes the following elements:
    - Protection monitoring confirms that human health and the environment are adequately protected during the cleanup action.
    - Performance monitoring confirms that the cleanup levels have been achieved.

- Confirmation monitoring confirms the long-term effectiveness of the cleanup action once cleanup levels and other performance standards have been reached.

9.6.1.2. OTHER MTCA REQUIREMENTS

Under MTCA, when selecting from the alternatives that meet the minimum requirements described in Section 9.6.1.1, the alternatives shall be further evaluated against the following additional criteria (WAC 173-340-360[2][b]):

- *Use permanent solutions to the maximum extent practicable*. MTCA specifies that the permanence of qualifying alternatives be evaluated by balancing the costs and benefits of each of the alternatives using a "disproportionate cost analysis" in accordance with WAC 173-340-360(3)(e). The criteria for conducting this analysis are described in Section 9.6.1.3.
- *Provide a reasonable restoration time frame*. MTCA requires that several factors be considered when evaluating whether a remedial alternative provides a reasonable restoration time frame (WAC 173-340-360[4]). Collectively, these factors characterize how an alternative is anticipated to perform over the long term, particularly for alternatives that leave hazardous substances in-place at concentrations greater than cleanup levels. The practicability of achieving a shorter restoration time frame is also considered.
- *Consideration of public concerns*. Ecology will seek public comments during the RI/FS process prior to making a preliminary selection of a preferred remedial alternative. This preliminary selection is subject to further public review and comment when the proposed remedy is published in the draft CAP.

9.6.1.3. DISPROPORTIONATE COST ANALYSIS EVALUATION CRITERIA

The DCA process uses a qualitative evaluation of benefits and a quantitative evaluation of costs. Environmental benefits for upland cleanup alternatives are evaluated based on the six criteria in WAC 173-340-360(3)(f): protectiveness, permanence, long-term effectiveness, technical and administrative implementability and consideration of public concerns. Descriptions for each criterion are provided in Table 9-13 (Upland Alternatives) and Table 9-14 (Sediment Alternatives). To evaluate long-term effectiveness, MTCA identifies a hierarchy of cleanup technologies used as a guide. For upland remedies, the following types of cleanup action components, in descending order, are used as a guide in assessing the relative degree of long-term effectiveness:

- Reuse or recycling;
- Destruction or detoxification;
- Immobilization or solidification;
- On-site or off-site disposal in an engineered, lined and monitored facility;
- On-site isolation or containment with attendant engineering controls; and
- Institutional controls and monitoring.

The DCA process is also applicable for in-water cleanup actions. The evaluation criteria under SMS WAC 173-204-570(4) are identical to the MTCA evaluation criteria for protectiveness, permanence, management of short-term risks, technical and administrative implementability and consideration of public concerns (Table 9-14). The evaluation criterion for long-term effectiveness of sediment remedies under SMS uses a different hierarchy of cleanup technologies. For sediment remedies, the following remedial technologies, in descending order, are used as a guide for assessing the relative degree of long-term effectiveness for sediment cleanup alternatives:

- Source control (e.g., cleanup of upland facilities, regulation of wastewater discharges, implementation of stormwater pretreatment requirements, removal of creosoted pilings) in combination with other cleanup technologies;
- Beneficial reuse of sediment;
- Treatment to immobilize, destroy or detoxify contaminants;
- Dredging and disposal in an upland engineered facility;
- Dredging and disposal in a nearshore, in-water confined aquatic disposal facility;
- Containment in-place with an engineered cap;
- Dredging and disposal in an approved unconfined open-water disposal site;
- Enhanced natural recovery;
- Monitored natural recovery in areas of relatively low levels of contamination with sufficient rate of clean sedimentation; and
- Institutional controls (e.g., site use restrictions, no-anchor zones, environmental covenants, etc.) and monitoring.

The DCA is used to compare the relative benefit and cost of the cleanup alternatives and select a remedy based on the most permanent, practicable remedy following the procedures identified in WAC 173-340-360:

Benefits: The benefits of an alternative were evaluated based on the six MTCA DCA criteria. For each criterion, an alternative was scored on a scale 1 to 10 scale based on the degree to which the alternative satisfies the full description for an individual criterion: a score of 1 indicates the alternative is considered to satisfy the elements of the criterion to a very low degree and a score of 10 indicates the alternative is considered to satisfy the elements of the criterion to a very high degree. For each alternative, the individual criterion scores were then weighted according the corresponding weighting factors that Ecology has identified for use in numerous feasibility studies, as follows:

DCA CRITERIA WEIGHTING FACTORS

DCA Criteria	Weighting Factor (%)
Protectiveness	30
Permanence	20
Long-term effectiveness	20
Management of short-term risks	10
Technical and administrative implementability	10
Consideration of public concerns	10

The weighted benefit scores for each alternative were summed to a total weighted benefit score for each alternative.

Costs: Detailed FS-level cost estimates were prepared for each alternative (Appendix Q). For all alternatives, cost estimates are in 2014 dollars, include contingencies, and represent order-of-magnitude with a range of -30 percent to +50 percent based on EPA guidance (EPA 2000a). The estimated total costs for the upland alternatives are included in Table 9-15 and for the sediment alternatives in Table 9-16. The alternative costs address remediation of the entire Haley Site, without consideration of cleanup actions planned for the Cornwall Landfill Site in overlapping areas. This approach for FS cost estimating results in a more accurate estimate of the full cleanup action cost for the alternatives evaluated for the Haley Site. The overall cost of the remedy will be reduced for both sites, once designs are coordinated. The outcome of the upland DCA does not change if costs are shared.

The MTCA DCA analysis uses a relative benefit/cost ratio to compare the alternatives and determine whether costs are disproportionate to benefits. The relative benefit/cost ratio was calculated by dividing the total weighted benefit score by the total cost for that alternative. To facilitate graphical presentation of the relative benefit/cost (Figures 9-24 and 9-25), the total cost of each alternative was divided by $5,000,000. The resulting relative benefit/cost ratio was plotted. Under MTCA, "*costs are disproportionate to benefits if the incremental costs of the alternative over that of a lower cost alternative exceed the incremental degree of benefits achieved by the alternative over that of lower cost alternative*" (WAC 173-340-360[3][e][i]). Graphically, this concept is illustrated by the alternative which has the maximum relative benefit-cost ratio.

Under MTCA, preference is given to cleanup actions that use permanent solutions to the maximum extent practicable. The DCA is used to determine whether a cleanup action uses permanent solutions to the maximum extent practicable. By definition (WAC 173-340-200), permanent remedies are those that would require no additional action to meet cleanup standards following implementation. A practicable cleanup action is one that can be designed, constructed and implemented in a reliable, cost-effective manner. A cleanup action is not considered practicable if the incremental costs are disproportionate to the benefits when compared to lower cost alternatives; this determination is illustrated by the relative benefit/cost ratio. Alternatives are compared from least cost to highest cost; alternatives having additional incremental benefits that are disproportionate to the incremental additional cost, produce lower relative benefit/cost ratios.

9.6.2. Upland Alternatives Evaluation

This section presents the upland alternatives evaluation relative to the MTCA criteria identified in Section 9.6.1. The alternatives were compared relative to one another for each evaluation criteria as summarized in Table 9-13.

9.6.2.1. THRESHOLD REQUIREMENTS

All of the upland alternatives meet the threshold requirements of MTCA, which include protection of human health and the environment, compliance with cleanup standards and ARARs, and compliance monitoring provisions. The alternatives use a combination of treatment, removal and containment technologies to prevent human and ecological exposures to Site contaminants. Each alternative also includes compliance monitoring to evaluate the effectiveness of the remedy. Institutional controls are used to protect the integrity of the remedy for those alternatives that include a containment component. Collectively, these actions will prevent exposures in the upland and address contaminant migration from the upland to marine units.

Alternative U1 would rely on LNAPL removal and incineration, and an upland low-permeability cap and vertical shoreline barrier to prevent direct contact with upland contaminants and significantly reduce contaminant leaching and transport in groundwater. Institutional controls would be used to assure the long-term integrity of the containment features, and provide for O&M of the LNAPL removal system.

Upland Alternatives U2, U3a, U3b and U3c would be protective of human health and the environment to a progressively increasing degree. Each of these alternatives would prevent direct contact exposures using the same low-permeability cap as in Alternative U1. The addition of groundwater treatment and/or soil treatment technologies, however, would provide a greater degree of source control by reducing contaminant leaching and migration in groundwater. These treatment technologies include use of a PRB in Alternative U2, and *in situ* solidification and/or stabilization in Alternatives U3a through U3c. Alternative U3c includes the additional benefit of removing soil and potentially mobile LNAPL from near the shoreline, followed by backfilling with clean soil. Alternative U4 would provide the greatest level of protection of human health and the environment by removing all contaminated soil and LNAPL at the Site and transporting the material off-site for treatment and/or disposal.

Alternative U4 is the only alternative that would leave no contaminated media in the upland at concentrations exceeding cleanup levels at the standard point of compliance. The other alternatives result in contamination remaining on Site. Potential risks associated with the residual contaminated media would be managed by engineering controls that are components of these remedies (e.g., upland cap), and institutional controls that would ensure the integrity of these controls and provide for long-term monitoring. City ownership and use of the Site as a public park will provide further assurances that these controls will remain in place and effective over the long term.

All upland alternatives include source control components to significantly reduce contaminant migration in groundwater, thereby allowing design of a successful sediment remedy. Excluding Alternative U4, upland alternatives are not likely to attain groundwater cleanup levels at the standard point of compliance. The cumulative effect of the upland and sediment remedies ultimately selected for the Site, however, will comply with cleanup levels at the conditional point of compliance, as defined in WAC 173-340-720(8)(d)(i). The Haley Site satisfies the conditions for use of a conditional point of compliance as described in Section 9.2.3.2.

9.6.2.2. REQUIREMENT FOR REASONABLE RESTORATION TIME FRAME

All of the upland cleanup action alternatives are expected to achieve CAOs within a reasonable time frame. The time frame required to achieve CAOs was evaluated in accordance with the factors outlined in MTCA (WAC 173-340-360[4]). As described in Section 9.6.2.1, most of the upland alternatives include containment of contaminated media. The contaminated media can be effectively contained using engineering controls that have been proven reliable at a multitude of cleanup sites. These alternatives would be particularly compatible for the planned end use of the Site as a City park. Long-term ownership, use and maintenance of the Site as a park provides a favorable land use scenario that would prevent Site activities that otherwise could potentially jeopardize the integrity of the alternatives being considered. Park maintenance activities also could be effectively integrated with future cap monitoring and maintenance obligations.

The restoration time frame for each upland alternative includes the estimated duration to design, permit and construct the cleanup action components. For Alternatives U1 and U2, the restoration time frame is estimated to be 2 to 3 years to construct the cleanup action and achieve protection; contaminant reduction through operation of the LNAPL recovery system would continue for up to 10 years. For the remaining upland alternatives that do not rely on treatment system operations, the restoration time frame includes the time to complete the initial construction of the cleanup action, varying from 2 to 3 years for Alternatives U3a and U4, to 3 to 4 years for Alternatives U3b and U3c. For all of the upland alternatives, cleanup standards would be achieved immediately following construction of the cleanup action as a result of construction of the upland cap and/or removal of the contaminated media from the Site. The upland alternatives are considered to have similar and reasonable restoration time frames.

9.6.2.3. REQUIREMENT FOR PERMANENT SOLUTIONS TO THE MAXIMUM EXTENT PRACTICABLE

MTCA requires that cleanup actions be permanent to the maximum extent practicable. To determine which alternatives are permanent to the maximum extent practicable, MTCA specifies that a DCA be used that compares costs and relative benefits of the alternatives (Section 9.6.3).

9.6.3. Upland Alternatives DCA

The DCA criterion and scoring for each upland alternative are presented in Table 9-15; the following sections discuss the rationale for the benefit scores determined for the upland alternatives.

9.6.3.1. PROTECTIVENESS

All of the upland alternatives would protect human health and the environment through a combination of *in situ* treatment, off-site treatment, containment and/or off-site disposal technologies. Reduction of risk associated with upland contaminants would be achieved within a relatively short time frame, with manageable short-term risks associated with construction of the alternatives.

Alternative U4 is considered the most protective upland alternative (score 9 out of 10) as a result of complete removal of upland contaminated soil and LNAPL from the Site. A significant amount of contaminant mass would be destroyed by incineration under Alternative U4, but the high reliance on landfill disposal and risks associated with off-site transport of contaminated soil slightly reduces the overall protectiveness of this alternative. Alternatives U3c, U3b, U3a, U2 and U1 have progressively lower levels of overall protectiveness relative to Alternative U4 because of corresponding decreases in the amount of removal and off-site treatment and disposal, and decreasing levels of on-site treatment. Alternative U1 was given the lowest score (4 out of 10) for protectiveness because it relies the most on containment technologies.

9.6.3.2. PERMANENCE

The upland alternatives were evaluated with respect to the degree to which the toxicity, mobility, or volume of hazardous substances would be reduced. The permanence score for each alternative was primarily based on the alternative's reliance on technologies that reduce toxicity, mobility or volume and result in the greatest level of irreversibility. All of the upland alternatives would result in an overall reduction of toxicity, mobility or volume.

Alternative U4 would achieve the highest degree of permanence of all upland alternatives as a result of removing all contaminated soil and LNAPL from the Site, and destroying substantial contaminant mass by incineration. These actions significantly reduce the toxicity, mobility and volume of hazardous substances at the Site. A permanence score of 9 out of 10 was assigned to Alternative U4; a less than a perfect 10 score was because under state and federal hazardous waste regulations, not all contaminated soil is required to be treated before landfill disposal.

Alternatives U3a, U3b, and U3c were given moderate to moderately high scores for permanence as a result of the use of *in situ* treatment methods that would significantly reduce the mobility of contaminants, preventing upland contaminants from being transported to the marine unit. The application of *in situ* solidification in the upland area with the highest concentrations of contaminants and the highest potential for migration earned Alternative U3a a score of 6 out of 10 for permanence. The larger footprint of *in situ* solidification and stabilization included in Alternative U3b warranted a slightly higher score (7 out of 10) relative to U3a. However, because the area of expanded stabilization in Alternative U3b has lower contaminant concentrations and limited LNAPL mobility, U3b offers less net benefit per unit area of treatment resulting in a nominal (1 point) benefit of U3b over U3a. Alternative U3c achieved a higher score (8 out of 10) relative to U3b due to the removal of soil and LNAPL near the shoreline.

Alternative U1 was given the lowest score for permanence (3 out of 10) because of its heavy reliance on physical containment technologies (capping and vertical shoreline barrier). These technologies do, however, reduce contaminant mobility; furthermore, toxic contaminants are destroyed through off-site incineration of recovered LNAPL. Alternative U2 scores slightly higher (4 out of 10) than U1 for permanence because the PRB would be expected to further reduce contaminant mobility and prevent releases to the marine environment to a greater degree than the vertical shoreline barrier.

9.6.3.3. LONG-TERM EFFECTIVENESS

The upland alternatives were evaluated for long-term effectiveness primarily based on the certainty that the technologies will achieve the CAOs, the reliability of the alternatives during the period when contamination will remain at concentrations exceeding cleanup levels, and the degree to which the alternatives use technologies that MTCA ranks higher for long-term effectiveness (Section 9.6.1.3).

Alternative U4 achieved the highest score for long-term effectiveness because of the certainty of achieving the CAOs, and the high ranking that MTCA provides for alternatives that include contaminant destruction technologies (e.g., incineration for a significant quantity of soil removed under Alternative U4). Alternatives U3a, U3b, and U3c earned scores ranging from moderately high (7 out of 10 for U3a) to high (9 out of 10 for U3c) because of the increasing use of *in situ* solidification and stabilization technologies, and soil removal in the case of U3c, and the corresponding relative preferences for these technologies. The *in situ* soil treatment technologies used in these alternatives rank high under MTCA, directly behind contaminant destruction. Alternatives U3a and U3b would immobilize progressively more contaminant mass, including the area near the shoreline where LNAPL is potentially mobile. Alternative U3c provides a greater certainty of success by removing the contaminated soil and LNAPL nearest to the marine unit, and backfilling the removal area with imported clean fill.

Alternatives U1 and U2 would primarily utilize containment (capping) and less aggressive treatment methods to achieve CAOs, although both provide for destruction of contaminants through incineration of recovered LNAPL. Alternative U2 scored higher than Alternative U1 because of the use of groundwater treatment through the PRB. The long-term effectiveness score for U2 (4 out of 10) was moderated based on the possible need to replenish the absorptive media. Alternatives U1 and U2 scored lower (3 out of 10 for Alternative U1 and 4 out of 10 for Alternative U2) relative to the other alternatives that utilize more preferable treatment technologies that immobilize or destroy contaminants.

9.6.3.4. MANAGEMENT OF SHORT-TERM RISKS

The upland alternatives were evaluated with respect to potential risks to human health and the environment associated with materials and methods used during construction of the alternatives. Generally, alternatives that would involve limited exposure to, and management of, contaminated materials by workers or the public during the cleanup scored high for management of short-term risk, and alternatives that would generate the potential for workers to be exposed to contaminants, utilize construction methods that would increase risk, or result in mobilization of contaminants to other media scored lower for management of short-term risk.

Alternative U1, involving primarily containment technologies with less relative potential exposure risk during construction, scored high (9 out of 10) relative to other upland alternatives. Alternatives U2, U3a, and U3b achieved moderate to moderately high scores (7 out of 10 for U2 and U3a, and 6 out of 10 for U3b) due to the use of construction methods that could generate the potential for exposure to contaminated soil (i.e., PRB installation and *in situ* treatment). However, it is expected that standard environmental remediation construction methods and safety practices would mitigate these potential risks. Alternative U3c had a lower score (5 out of 10) for management of short-term risks based on risks posed by removal of upland soil containing the highest contaminant concentrations and LNAPL, and the need to handle the material on site to consolidate it within the upland AOC. This added component of U3c, relative to U3b, could potentially generate additional on-site risks to remediation construction workers.

Alternative U4 had the lowest score for the management of short-term risks (3 out of 10) due to the extensive soil removal that would be required for this alternative, and the degree to which the alternative would rely on off-site transport of contaminated soil, including LNAPL-impacted soil, to an off-site facility by trucking. This magnitude of transport increases the risk for potential off-site releases of contaminated media relative to other alternatives.

9.6.3.5. TECHNICAL AND ADMINISTRATIVE IMPLEMENTABILITY

All of the upland alternatives are expected to be technically implementable using common and readily available construction materials and methods. Administrative implementability considerations include permitting, and compliance with EPA's and Ecology's AOC policies and guidance for managing excavated soil within the AOC (Alternative U3c).

Alternatives U1 and U3a scored moderately high (8 out of 10) for implementability due to the expected ease of installation of the upland cap and the limited footprints of the vertical shoreline barrier for Alternative U1 and *in situ* solidification for Alternative U3a. These alternatives did not warrant the highest score of 10 because of the potential for difficulties associated with installation of the vertical shoreline barrier in Alternative U1 and the need for treatability testing to design the solidification process of Alternative U3a. Alternatives U3b and U3c had progressively lower scores (7 for U3b, and 6 for U3c) for implementability as a result of the significantly increased treatment footprint (Alternatives U3b and U3c) and inclusion of soil removal near the shoreline and AOC considerations (Alternative U3c).

Alternative U2 achieved only a moderate (6 out of 10) score for implementability, primarily due to the anticipated testing and construction issues associated with installation of the PRB and the potential need to replace or amend organoclay in the PRB.

Alternative U4 scored the lowest for implementability of the upland alternatives, although it still achieved a moderate score of 5 out of 10. This alternative, relative to the other upland alternatives, would rely primarily on removal of contaminated soil, including LNAPL-impacted soil adjacent to the shoreline that would require implementing significant site controls to effectively complete cleanup construction.

9.6.3.6. CONSIDERATION OF PUBLIC CONCERNS

Public concerns are typically widely divergent on environmental cleanup projects; stakeholders including agencies, environmental groups, businesses, citizens, tribal members and the City have different mandates, responsibilities and opinions. Best professional judgment and past experience on similar projects formed the basis of the evaluation of the alternatives relative to public acceptance. In general, it was assumed that there would be greater acceptance of alternatives that treat or remove contaminants, rather than contain them. However, alternatives with extraordinarily high costs would also be expected to have some public disapproval since the cleanup action requires public funds.

Alternative U1 has the lowest score (3 out of 10) for consideration of public concerns due to its heavy reliance on containment without *in situ* treatment or soil removal. Alternative U2 scores higher (4 out of 10) than Alternative U1 as a result the inclusion of groundwater treatment to protect marine sediment and surface water. Alternatives U3a, U3b, and U3c scored moderate to moderately high as a result of the use of *in situ* treatment of contaminated soil, progressively increasing with respect to the scale of solidification and stabilization and inclusion of soil removal in Alternative U3c. Alternative U4 scored high (9 out of 10) for consideration of public concerns due to the complete removal of contaminated media from the Site, and achieving a cleanup without the need for institutional controls; the score was moderated because of the high cost.

9.6.4. Upland Preferred Alternative

The individual DCA criterion benefit scores (Section 9.6.3 and Table 9-13), weighting factors, weighted scores and total weighted benefit score for each of the upland alternatives are summarized in Table 9-15. The total weighted benefit scores range from 4.4 (Alternative U1) to 8.2 (Alternative U4). The estimated costs of the alternatives range from $10,090,000 (Alternative U1) to $167,600,000 (Alternative U4). The total weighted benefit scores and estimated costs for each of the upland alternatives are illustrated graphically in Figure 9-24.

The relative benefit/cost ratio was calculated for each alternative as explained in Section 9.6.1.3. The quantified ratio of relative benefit/cost increases progressively from Alternative U1 (ratio of 2.18), to U2 (ratio of 2.24), to U3a (ratio of 3.12) (Figure 9-24). The relative benefit/cost ratios decrease for the remaining alternatives U3b (ratio of 1.66), U3c (ratio of 1.52) and U4 (ratio of 0.24) driven by the high relative cost of *in situ* solidification and stabilization technologies in the expanded footprints of U3b and U3c (relative to U3a), and the very high cost of a large quantity of soil requiring off-site incineration at a hazardous waste facility (U4) (Figure 9-24).

The highest degree of benefit/cost is provided by Alternative U3a. Upland Alternatives U3b, U3c and U4 would provide greater benefits than U3a; however, the relative benefit to cost ratio for these alternatives is lower than that of U3a indicating that their associated incremental additional costs are disproportionately high relative to the incremental added benefit. Therefore, Alternatives U3b, U3c and U4 are considered disproportionately costly and not practicable. The costs of upland Alternatives U1 and U2 are both lower than the cost of Alternative U3a; however, Alternative U3a has a higher total weighted benefit and higher relative benefit/cost ratio compared to Alternatives U1 and U2 and therefore the additional incremental cost of U3a relative to U1 and U2 is not considered disproportionate relative to the added benefits provided by U3a. Therefore, based on the DCA, Alternative U3a is the most permanent, practicable alternative and is identified as the preferred upland alternative for the Haley Site.

9.6.5. Sediment Cleanup Alternatives Evaluation Criteria

This section presents a description of the threshold requirements for cleanup actions under SMS and additional criteria used to evaluate the sediment cleanup action alternatives. Evaluation criteria under MTCA and SMS are similar in intent; however, the structure and terminology differ slightly as explained below.

9.6.5.1. SMS EVALUATION CRITERIA

The cleanup action alternatives for sediment are evaluated based on requirements in SMS (WAC 173-204-570[3]). The SMS evaluation criteria, although structured somewhat differently than MTCA, are similar to and intended to be compatible with MTCA.

SMS requires evaluation of sediment cleanup alternatives relative to improvement in overall environmental quality, known as net environmental benefit, and for adverse environmental impacts. Net environmental benefit includes restoration of water quality, sediment quality, habitat and fisheries and public access and recreation aesthetics. Environmental impacts to be considered include construction-related water and sediment quality degradation, habitat value or acreage lost, and land use or access restrictions. The evaluation of alternatives for net environmental benefit and for adverse environmental impacts is addressed through the SMS evaluation criteria described below.

Each alternative must meet the following minimum criteria:

- Protect human health and the environment.
- Comply with ARARs.
- Comply with sediment cleanup standards.
- Implement effective source controls, where needed.
- Meet the requirements for implementation of a sediment recovery zone, if cleanup standards cannot be achieved within 10 years.
- Use institutional controls that limit exposure and ensure the integrity of the cleanup action.

- Provide opportunity for public review.
- Include long-term monitoring to ensure remedy effectiveness.
- Provide periodic review of remedy effectiveness where containment, enhanced or natural recovery, institutional controls, sediment cleanup levels based on practical quantitation limits or sediment recovery zones are elements of a cleanup action.

The alternatives are also evaluated relative to the following:

- *Use of permanent solutions, to the maximum extent practicable*. The permanence of the cleanup action is established based on the DCA.
- *Provision of a reasonable restoration time frame*. The reasonable restoration time frame is evaluated considering the following:
    - Length of time it will take to achieve site-specific cleanup standards;
    - Potential risks posed by the site or cleanup units to people and ecological resources;
    - Practicability of achieving the cleanup standards in less than 10 years;
    - Current and potential future use of the site (or cleanup units), surrounding areas and associated resources that may be adversely affected by residual contamination;
    - State aquatic land-use classification of the site (or units);
    - Likely effectiveness of source control measures to reduce the time to achieve site-specific cleanup standards;
    - Likely effectiveness and reliability of institutional controls;
    - Degree of, and ability to control and monitor migration of residual contamination; and
    - Degree that natural recovery is expected to reduce contamination.

The DCA evaluation criteria and evaluation process for the sediment alternatives are explained in Section 9.6.1.3.

9.6.6. Sediment Alternatives Evaluation

This section presents the sediment alternatives evaluation relative to the SMS criteria identified in Section 9.6.5. Table 9-14 summarizes and compares the alternatives evaluation.

9.6.6.1. MINIMUM REQUIREMENTS

Sediment alternatives developed for the Site meet the minimum requirements for protection of human health and the environment, compliance with applicable regulations and cleanup standards, use of effective source control measures and institutional controls, provision of public review opportunities and monitoring and periodic assessment of long-term remedy effectiveness (Table 9-14).

Each alternative proposes a combination of technologies (capping, removal with on-site consolidation or off-site treatment/disposal) that would prevent people and ecological receptors from being exposed to contamination in the sediment and prevent further uncontrolled releases (e.g., erosion, resuspension and subsequent transport) to the environment. For those areas of the

Site with moderate to low level exceedances of cleanup levels, ENR and MNR are used in each of the cleanup alternatives to achieve risk reduction in a reasonable time frame (Section 9.5).

To be protective of human health and the environment, Alternative S1 would use capping technologies to provide for the physical and chemical isolation of contaminated sediment in intertidal and shallow subtidal areas (including enhanced chemical isolation in the upper intertidal area through use of cap amendments) to prevent exposure to underlying contaminated sediment.

Alternatives S2 and S4 would provide greater certainty in reducing risks because sediment with the highest contaminant concentrations (smear zone) would be removed from the upper intertidal areas and remaining underlying contaminated sediment would be confined with an amended cap that would enhance chemical isolation. A conventional cap would be used in the remaining portions of the SMS exceedance area, thereby preventing benthic exposures.

Alternative S3 would provide a higher level of certainty by removing all highly contaminated sediment in the smear zone and placing a conventional sand cap over this zone and the remainder of the SMS exceedance area to reduce risks.

Alternatives S5a and S5b provide the most extensive removal of contaminated sediment and greatest certainty in long-term risk reduction. Any possibility of future contact with, or transport of, contaminants in the marine environment from underlying contaminated sediment is significantly limited under Alternatives S5a and S5b.

Sediment removed from the marine unit would either be consolidated in the upland AOC beneath the upland cap or transported off-site to a permitted facility for treatment/disposal; some sediment transported off-site requires treatment by incineration prior to disposal. In all cases, management of sediment would permanently reduce risks associated with potential exposure of people and ecological receptors and any threat of release.

Implementation of the retained technologies (Section 9.5) would achieve the CAOs identified for the Haley Site and meet cleanup standards. Conducting the cleanup under MTCA and SMS regulations and associated permits would ensure that all applicable and relevant state and federal regulations, as identified in Section 9.2, would also be met.

Each alternative would include source control measures and institutional controls that have been shown to be effective at other sediment cleanup sites in Puget Sound. City ownership and future development as a public park would help ensure that the measures and controls are complied with, and maintained, over time.

It is assumed that all alternatives would include long-term monitoring to document the protectiveness of the remedy over time. Monitoring would likely include physical (e.g., cap thickness, bathymetry), chemical (e.g., surface sediment chemistry) and biological (e.g., toxicity testing) elements; the actual monitoring program would be defined in the CAP.

MTCA and SMS both require public review of the RI/FS and CAP; these reviews will be conducted for the Haley cleanup project. In addition, the CAP would include requirements for periodic reviews of the remedy performance over time and the process to maintain, modify or repair the remedy, as needed.

9.6.6.2. REQUIREMENT FOR REASONABLE RESTORATION TIME FRAME

All sediment remedies would achieve the CAOs within a reasonable time frame (Table 9-14). Cleanup standards would be achieved immediately following construction in the actively remediated area. Design and construction is likely to take two years excluding permitting time; the duration of the permitting process depends on many factors and cannot be estimated at this point in time. Once constructed, biological communities, specifically benthic invertebrates, will likely re-establish within three years in areas where removal or capping are performed. Restoration of eelgrass beds, where disturbed, may require a longer time frame.

Subtidal areas of Bellingham Bay receive an influx of clean sediment from the Nooksack River. Sedimentation rates are sufficient to support reaching the cleanup standards within 10 years in subtidal areas of the Site with low levels of contamination where MNR will be proposed. Where ENR is applied in subtidal areas with moderate levels of contamination, standards will likely initially be met because the amount of clean sand placed will be greater than 12 cm, which is the point of compliance for sediment. The ENR layer may function as a cap or may mix with underlying contaminated sediment but still result in recovery within 10 years due to ongoing natural deposition of cleaner sediment in ENR areas over time. The boundaries of the ENR and MNR areas will be established based on consideration of additional data, further evaluation of sedimentation rates on natural recovery, and interpretation of the effect of active remediation on the SWAC in sediment. Actual rates of recovery in ENR and MNR areas would be documented as part of long-term monitoring.

9.6.6.3. REQUIREMENT FOR PERMANENT SOLUTIONS TO THE MAXIMUM EXTENT PRACTICABLE

SMS requires that cleanup actions be permanent to the maximum extent practicable as identified through the DCA (Section 9.6.7). This criterion is met through the following analysis.

9.6.7. Sediment Alternatives DCA

The DCA criterion and scoring for each sediment alternative are presented in Table 9-16; the following sections discuss the rationale for the benefit scores determined for the sediment alternatives. As explained in Section 9.6.1.3, the DCA is used to compare the relative cost and benefits of cleanup alternatives and select a remedy based on the most permanent, practicable remedy. The DCA evaluation follows the procedures identified in WAC 173-340-360.

9.6.7.1. PROTECTIVENESS

All alternatives would protect human health and the environment through a combination of capping technologies, sediment removal, ENR, MNR, institutional controls and long-term monitoring (see Table 9-14). In addition, habitat quality and functions would be restored by reducing the risk of contaminant exposures and replacing the present-day debris-filled substrate with a more suitable habitat material.

Alternatives S5a and S5b were considered the most protective (9 out of 10 and 8 out of 10, respectively) because all contaminated sediment would be removed from the marine environment to the extent practicable. These alternatives would effectively eliminate long-term risks for people and ecological receptors in the intertidal and shallow subtidal zones, and substantially reduce risk in subtidal areas that have relatively low contaminant concentrations (ENR and MNR areas). Alternative S5b scores slightly lower than S5a because of the greater short-term risk associated with more sediment being transported off-site for disposal in Alternative S5b.

Alternative S3 is ranked the next most protective (7 out of 10) because all of the smear zone sediment would be removed; all other sediment exceeding SMS criteria would be confined with a conventional cap, effectively controlling this potential exposure pathway.

Alternative S4 would also provide a high degree of risk reduction, and therefore protectiveness (6 out of 10), through removal of the upper 2 feet of smear zone and other contaminated sediment, including the biologically active zone, throughout the SMS benthic toxicity exceedance area. Use of an amended cap in nearshore areas would enhance chemical isolation where remaining contaminant concentrations are greatest.

Alternative S2 (5 out of 10) scored lower than Alternatives S3, S4 and S5 because less contaminated sediment would be removed from the marine unit, although enhanced chemical isolation in the nearshore area would be similar to Alternative S4.

Alternative S1 scored the lowest for protectiveness (2 out of 10) because no contaminated sediment would be removed; rather, it would be confined in place using capping technologies, including use of cap amendments to enhance chemical isolation in the upper intertidal area.

9.6.7.2. PERMANENCE

All alternatives would reduce the mobility of contaminants through sediment removal and disposal, and/or capping. All alternatives except S1 would reduce the volume of contamination in the marine environment, albeit by different amounts. Only Alternative S5b would provide permanent reduction in contaminant toxicity for the portion of remediation waste incinerated at a permitted facility. Accordingly, Alternative S5b scored the highest (9 out of 10) with respect to reduced toxicity, mobility and volume because all contamination, to the extent practicable, would be removed from the sediment unit and transported to a permitted treatment/disposal facility. Alternative S5a had a slightly lower score (8 out of 10) because the most highly contaminated waste would be consolidated within the upland portion of the AOC, rather than incinerated off-site or disposed.

Alternative S3 scored moderately high (7 out of 10) because all smear zone sediment would be consolidated within the upland portion of the AOC.

Alternatives S2 and S4 were assigned moderate scores (5 out of 10 and 6 out of 10, respectively) in that they would remove a similar volume of the most contaminated sediment from the smear zone, and isolate remaining contamination beneath an amended cap that would enhance adsorption of any releases from underlying contamination. Alternative S4 scored slightly higher than Alternative S2 because more contaminated sediment would be removed from the marine unit, consolidated in the upland portion of the AOC.

Alternative S1 scored the lowest (2 out of 10) because it would not reduce the volume of contamination in the marine environment. Contamination would be entirely contained beneath conventional and amended sand caps, the latter of which would enhance adsorption of any releases from underlying contamination.

9.6.7.3. LONG-TERM EFFECTIVENESS

All alternatives would be effective over time, although some alternatives have greater certainty because greater volumes of contamination would be removed from the marine environment. Alternatives S5a and S5b have the greatest long-term effectiveness (8 out of 10 and 9 out of 10, respectively) because all smear zone and other contaminated sediment in the SMS benthic toxicity exceedance area would be removed from the marine environment to the extent practicable. Alternative S5b scored slightly higher than S5a because a portion of the contaminated material would be incinerated and disposed at an off-site facility.

Alternative S3 (6 out of 10) scored slightly higher than S4 (5 out of 10) because Alternative S3 would remove all smear zone sediment. Alternative S4 would remove a larger overall volume of contaminated sediment but would require use of cap amendments to enhance adsorption of any potential releases associated with the remainder of the smear zone sediment. Further, Alternative S4 avoids impacts to existing eelgrass beds, but would potentially require more intensive long-term monitoring to evaluate the performance of ENR.

Alternatives S1 and S2 received moderately low scores (3 out of 10 and 4 out of 10, respectively) because all or almost all contamination would be confined in-place using amended and conventional sand caps.

9.6.7.4. MANAGEMENT OF SHORT-TERM RISKS

Short-term risks associated with all alternatives can be minimized with various engineering controls, sequencing of activities, timing or best management practices that have been established for in-water remediation technologies. In addition, management of excavated/dredged sediment within the footprint of the AOC also helps mitigate short-term risks. Alternative S1 has the least short-term risks (9 out of 10) because no contaminated sediment would be removed or transported; therefore, possible short-term releases and off-site migration of contamination would be minimized. Disturbance from debris removal and capping is also expected to be minimal.

Alternative S2 scored moderately high (8 out of 10) because the least volume of contaminated sediment would be removed; removal would occur during low tides, reducing the potential for release and off-site impacts.

The remaining alternatives scored incrementally lower according to the corresponding quantities of sediment removed from the marine unit. Alternative S4 (6 out of 10) scored lower than Alternative S3 (7 out of 10) because Alternative S3 has a lower relative quantity of sediment removed. Alternative S3 scored higher than Alternatives S5a and S5b (5 out of 10 and 4 out of 10, respectively) because Alternatives S5a and S5b have the highest quantities of sediment removed. Alternative S5b scored lower than Alternative S5a based on the additional short-term risk associated with transporting a larger volume of contaminated sediment to a permitted landfill.

9.6.7.5. TECHNICAL AND ADMINISTRATIVE IMPLEMENTABILITY

All alternatives would be implementable; however, some alternatives are anticipated to be more complex to implement than others. Technically, all alternatives rely on proven technologies and process options and would be implementable. Scores tended to be driven by administrative complexity primarily related to permitting, project approvals and the relationship to other cleanup actions.

All alternatives except Alternative S1 and S5b are dependent on the timing of the upland cleanup action because contaminated sediment removed from the marine unit would be consolidated with the upland AOC. If the upland and sediment cleanups are out of sequence, an upland transloading facility would need to be identified, permitted and developed, which would greatly increase the costs and schedule for implementation of Alternatives S2, S3, S4 and S5a. In addition, meeting the requirements of EPA's and Ecology's AOC policies, would likely add complexity to all alternatives except S1 and S5b. Use of amendments and demonstration of their effectiveness in sequestering contaminants may add complexity to the project approval process for Alternatives S1, S2, and S4. Habitat mitigation may be a component of most remedies; Alternative S4 is the only alternative that would not likely require habitat mitigation to address the conversions of bottom and water column habitats and/or the loss of eelgrass beds due to capping.

Alternatives S5a and S5b scored the highest (9 out of 10 and 10 out of 10, respectively) because the overall preference for contaminant removal, treatment and disposal would facilitate project approvals and permitting; Alternative S5a scored slightly lower than S5b because about half of the dredged sediment volume would be consolidated within the upland portion of the AOC. Both of these alternatives would likely have the least mitigation requirements, because only the loss of eelgrass beds would need to be addressed (i.e., no habitat conversion occurs elsewhere).

Alternative S3 was given a moderately high score (8 out of 10) because no amendments in capping material are proposed; in addition, the area requiring mitigation would be less than one acre. Alternatives S2 and S4 would both use amendments in the upper intertidal cap placed over the smear zone; however, Alternative S2 would likely have higher mitigation requirements (and thus scored lower, 6 out of 10) than Alternative S4 (7 out of 10) because Alternative S4 preserves both bathymetry and eelgrass habitat.

Alternative S1 uses amendments in the upper intertidal cap and the greatest (1.7 acres of habitat conversion and loss of eelgrass beds) potential mitigation requirements; however, it would be the easiest remedy to implement technically and thus scored similarly to Alternative 2 (6 out of 10).

9.6.7.6. CONSIDERATION OF PUBLIC CONCERNS

As with the evaluation of upland alternatives, this criterion was weighed primarily using best professional judgment and experience with similar projects. It is likely that stakeholders' views and mandates will vary widely and some may conflict. We have assumed for the purpose of the FS that alternatives that are the most protective and the most permanent would largely address public concerns.

Alternative S5b scored the highest (9 out of 10) with respect to consideration of public concerns because all contamination, to the extent practicable, would be removed from the marine environment. Subsequent treatment and disposal in a permitted landfill facility would provide the greatest certainty regarding reductions in risk to the Bellingham community and would offset the short-term risk of contaminated material transport.

Alternative S5a was given a slightly lower score (8 out of 10) because the most highly contaminated sediment would be consolidated in the upland portion of the AOC (off-site disposal is still a component of S5a; approximately half of the material would go to a permitted landfill). Although contamination would be immobilized and risk reduction would be highly certain, public concerns may remain regarding transport of material and the high cost of the project.

The remaining alternatives that would utilize removal scored incrementally lower based on the volume that would be removed from the marine environment (i.e., Alternative S4 [7 out of 10] scored higher than S3 [6 out of 10], which scored higher than S2 [5 out of 10]). Alternative S1 had the lowest score (3 out of 10); this alternative would likely elicit the greatest public concern because all contamination would be confined in place and isolated/contained in the marine environment.

9.6.8. Sediment Preferred Alternative

The individual DCA criterion benefit scores (Section 9.6.7 and Table 9-14), weighting factors, weighted scores and total weighted benefit score for each of the sediment alternatives are summarized in Table 9-16. The total weighted benefit scores range from 3.4 (Alternative S1) to 8.3 (Alternative S5b). The estimated cost of the alternatives ranged from $3,820,000 (Alternative S1) to $12,180,000 (Alternative S5b). The total weighted benefit scores and estimated costs for each of the upland alternatives are illustrated graphically in Figure 9-25.

The relative benefit/cost ratio was calculated for each alternative as explained in Section 9.6.1.3. The quantified ratio of relative benefit/cost increases progressively from Alternative S1 (ratio of 4.5), to S2 (ratio of 5.1), to S3 (ratio of 6.2) (Figure 9-25). The relative benefit/cost ratios for the remaining Alternatives S4 (ratio of 4.5), S5a (ratio of 5.3) and S5b (ratio of 3.4) are lower than S3, driven by the more extensive excavation and off-site treatment/disposal costs for S4, S5a and S5b.

The highest degree of benefit per unit cost is provided by Alternative S3. Sediment Alternatives S4, S5a and S5b would provide greater benefits than S3; however, the relative benefit to cost ratio for these alternatives is lower than that of S3 indicating that the associated incremental additional costs of S4, S5a and S5b are disproportionately high relative to the incremental added benefits. Therefore, alternatives S4, S5a and S5b are considered disproportionately costly and not practicable. The costs of sediment Alternatives S1 and S2 are both lower than the cost of Alternative S3; however, Alternative S3 has a higher total weighted benefit and higher relative benefit per unit cost compared to lower cost Alternatives S1 and S2 and therefore the additional incremental cost of Alternative S3 relative to S1 and S2 is not considered disproportionate relative to the added benefits provided by Alternative S3. Therefore, based on the DCA, Alternative S3 as the most permanent, practicable alternative and is identified as the preferred sediment alternative for the Haley Site.

Table 9-1: Potential Applicable Laws and Relevant and Appropriate Requirements (ARARs) Governing Cleanup

Subject Regulated	State/Local Statutes and Implementing Regulations	Federal Statutes and Implementing Regulations	Notes
Hazardous waste cleanup	Model Toxics Control Act (MTCA) Cleanup Regulation (RCW 70.105D; Chapter 173-340 WAC)	Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 USC Chapter 103; 40 CFR Chapter I, Subchapter J)	State law has precedence; primary regulations governing upland cleanup actions at the Site. Most state and local permits are waived because the work is being conducted under an Agreed Order, but MTCA requires that permit substantive requirements must be met. All federal permits governing the remedial action are still required.
Sediment quality, investigation and cleanup	Sediment Management Standards (RCW 90.48 and 70.105D; Chapter 173-204 WAC)	No Federal equivalent	Primary regulations governing sediment cleanup actions at the Site. MTCA is one of the authorities defining the SMS; thus, waivers of state and local permits also apply to sediment cleanups.
Environmental impact review	State Environmental Policy Act (SEPA) (RCW 43.21C, Chapters 197-11 and 173-802 WAC)	National Environmental Policy Act (NEPA) (42 USC Chapter 55 § 4321 et seq.; 40 CFR Chapter V, Parts 1500-1508)	The City would likely be the lead agency and make the determination of compliance with SEPA.
Water quality			
General	Water Pollution Control Act (RCW 90.48); Water Quality Standards for Surface Waters of Washington (Chapter 173-201A WAC)	Federal Water Pollution Control Act (aka Clean Water Act (CWA)) (33 USC Chapter 26 §1251 et seq.; 40 CFR Chapter 1, Subchapter D)	State implements most components of the CWA. Water quality is considered in the development of cleanup objectives, short-term performance during construction, and long-term performance of the remedy.
Discharge of dredge, excavated or fill materials	No State equivalent	CWA Section 404	Applies to waters of the US; affects sediment remedies that have a removal or capping component. Requires a US Army Corps of Engineers (USACE) Nationwide 38 or Section 404 individual permit, which will be part of the Joint Aquatic Resources Application (JARPA) Permit.
Discharge of return water from dredged material	Water Pollution Control Act (RCW 90.48); Water Quality Standards for Surface Waters of Washington (Chapter 173-201A WAC)	CWA Section 401	State certifies consistency with Clean Water Act. Applies to sediment remedies; any requirements are typically specified in a Consent Decree or Cleanup Action Plan.
Discharge of stormwater	Water Pollution Control Act (RCW 90.48); National Pollution Discharge Elimination System Program (Chapter 173-220 WAC)	CWA Section 402	Applies to both sediment and upland remedies. Dewatering of sediment may, and upland construction will, require an NPDES permit which is administered by the State. Local NPDES requirements for stormwater may also apply.
Disposal of contaminated material			
Management, transport and disposal of hazardous wastes	Solid and Hazardous Waste Management Act (RCW 70.105); Dangerous Waste Regulations (Chapter 173-303 WAC)	Resource Conservation and Recovery Act (RCRA) (40 CFR 260 and 261)); 49 USC Chapter 51 Transportation of Hazardous Material; 40 CFR 171-180	Federal regulations are implemented by the State. Pertains to soil, sediment, water, and debris waste handling and landfill disposal. Management and disposal process is administered by the State and all substantive requirements must be met. Transportation is regulated by the US Department of Transportation.
Management, transport and disposal of solid wastes	Solid and Hazardous Waste Management Act (RCW 70.95; Chapters 173-305, 173-350 WAC and others)	Resource Conservation and Recovery Act (40 CFR 257 Subpart A)	Affects land disposal and transportation of dredged or excavated material and debris from the Site; process is administered by the State and all substantive requirements must be met.
Impacts to navigation	Hydraulic Code Rules (Chapter 77.55.100; Chapter 220-110 WAC)	Rivers and Harbors Act (Section 10)	Rules designed to protect navigation; applies to sediment remedy. Addressed as part of the JARPA permit process.
Shoreline construction or development	Shoreline Management Act (RCW 90.48; Chapter 173-16 WAC); City of Bellingham Shoreline Master Program	Coastal Zone Management Act (Public Law 92-583; 16 USC Chapter 33)	Regulation is implemented by state and local agencies; substantive requirements apply to both upland and sediment remedies that extend out to the jurisdictional boundaries of the implementing government.
Air quality	Clean Air Act (RCW 70.94); Ambient Air Quality Standards (Chapter 173-746 WAC)	Clean Air Act (42 USC, Chapter 85 Air Pollution, Prevention and Control)	Administered by the State and local authorities; substantive requirements apply to construction activities during implementation of the remedy.
Protection of species and habitats			
Protection/restoration of endangered or threatened species and critical habitats	Fish and Wildlife or Natural Resource Conservation Areas (Various RCW Titles 77 and 79; Chapter 232-12 WAC)	Endangered Species Act (16 USC §1361 et seq. 50 CFR 216)	State rules primarily address salmon and their recovery along with general conservation strategies for state lands/state resources. Bellingham Bay is used by species protected under ESA. Consultation with natural resource trustees will take place as part of the USACE Section 404 permit.
Protection of essential fish habitat	No State equivalent	Magnuson-Stevens Fishery Conservation and Management Act (50 CFR Part 600.920)	Essential fish habitat has a specific definition under the Magnuson-Stevens Act. In practice, the State's HPA addresses similar issues. Requirements for protection of essential fish habitat will be part of the USACE Section 404 permit.
Protection of marine mammals	No State equivalent	Marine Mammal Protection Act (16 USC §1531 et seq. 50 CFR 17)	Not likely to be applicable; however, if necessary, would be addressed as part of USACE Section 404 permit.

Table 9-1: Potential Applicable Laws and Relevant and Appropriate Requirements (ARARs) Governing Cleanup

Subject Regulated	State/Local Statutes and Implementing Regulations	Federal Statutes and Implementing Regulations	Notes
Protection of migratory birds	No State equivalent	Migratory Bird Treaty Act (16 USC §703 50 CFR §10.12)	Species protected by this Act use Bellingham Bay on a seasonal basis; potential impacts will be addressed as part of USACE Section 404 permit.
Protection of fish and fish habitat	Hydraulic Code Rules (Chapter 77.55.100; Chapter 220-110 WAC)	No Federal equivalent	Rules designed to protect fish; substantive requirements apply to sediment remedy.
Critical areas	Bellingham Municipal Code Chapter 16.55 Critical Areas; Growth Management Act (GMA) (RCW 36.70A)	No Federal equivalent	City ordinance implementing State's GMA requirements for identifying and restoring sensitive habitats and other natural resources that provide critical services (water quality, habitat, erosion protection, etc.). May affect habitat goals in relation to portions of final remedy.
Health and safety	Washington Industrial Safety and Health Act (WISHA) (RCW 49.17; Chapters 296-62, 296-843 WAC and others)	Occupational Safety and Health Act (OSHA) (29 USC Chapter 15; 29 CFR 1910, 1926)	Applicable to investigation and construction phases of a cleanup.
Objects, landscapes or structures of historical or archaeological significance	Regulations regarding these resources are part of SEPA, the Governor's Executive Order 05-05, and SMA (i.e., no one single regulation or authority). RCW 27.53; WAC 365-196-450 and others also apply.	National Historic Preservation Act (16 USC 470 et seq. Section 106)	State laws govern local projects; federal law governs those requiring federal permits or funds. Protection of significant historic, archaeological and traditional cultural sites from damage or loss during development is coordinated by the State's Department of Archaeological and Historic Preservation (State Historic Preservation Office), and includes evaluating compliance with Section 106 of the federal law.

Table 9-2

Preliminary Sediment Cleanup Levels

R.G. Haley Site

Bellingham, Washington

Indicator Hazardous Substance	Preliminary Sediment Cleanup Level Organic Carbon (0.5% to 3.5%)	Organic Carbon (<0.5% or >3.5%)	Basis for Preliminary Sediment Cleanup Level
Dioxins/Furans			
Dioxin TEQ	15 ng/kg dw	15 ng/kg dw	Regional background (CSL)
PAHs			
2-Methylnaphthalene	38 mg/kg oc	670 µg/kg dw	Benthic organism toxicity - direct contact (SCO)
Acenaphthene	16 mg/kg oc	500 µg/kg dw	Benthic organism toxicity - direct contact (SCO)
Benzo(a)anthracene	110 mg/kg oc	1,300 µg/kg dw	Benthic organism toxicity - direct contact (SCO). Potential bioaccumulation risks associated with benzo(a)anthracene are addressed by the cPAH TEQ preliminary sediment cleanup level.
cPAH TEQ	86 µg/kg dw	86 µg/kg dw	Regional background (CSL)
Fluoranthene	160 mg/kg oc	1,700 µg/kg dw	Benthic organism toxicity - direct contact (SCO)
Naphthalene	99 mg/kg oc	2,100 µg/kg dw	Benthic organism toxicity - direct contact (SCO)
Phenanthrene	100 mg/kg oc	1,500 µg/kg dw	Benthic organism toxicity - direct contact (SCO)
SVOCs			
Pentachlorophenol	100 µg/kg dw	100 µg/kg dw	Practical quantitation limit (SCO/CSL)
Petroleum Hydrocarbons			
TPH Sum (diesel-range + lube oil-range)	260 mg/kg dw	260 mg/kg dw	Benthic organism toxicity - direct contact (SCO/CSL)

Notes:

CSL = cleanup screening level, see Table 9-4

OC = Organic Carbon

PAH = polycyclic aromatic hydrocarbons

PQL = practical quantitation limit

SCO = sediment cleanup objective, see Table 9-3

TEQ = toxic equivalency concentration

ng/kg = nanogram per kilogram

µg/kg = microgram per kilogram

mg/kg = milligram per kilogram

Table 9-3

Preliminary Sediment Cleanup Objectives (SCOs)

R.G. Haley Site

Bellingham, Washington

Indicator Hazardous Substance	Direct Contact - Benthic Organisms		Bioaccumulation - Protective of People [c]		Bioaccumulation - Protective of Ecological Receptors			Modifying Factors		Proposed SCOs	
	SMS Criteria [a]	AET Criteria [b]	Subsistence Fishers - Low Exposure	Subsistence Fishers - High Exposure	Aquatic Life (Fish and Invertebrates)	Aquatic Dependent Wildlife (Individual Birds and Mammals)	Aquatic Dependent Wildlife (Bird and Mammal Populations)	Natural Background [d]	PQL [e]	Organic Carbon (0.5% to 3.5%)	Organic Carbon (<0.5% or >3.5%)
Dioxins/Furans (ng/kg)											
Dioxin TEQ	n/a	n/a	1.7	0.087	55	2.8	48	4	5	5	5
PAHs (µg/kg unless otherwise noted)											
2-Methylnaphthalene	38 mg/kg oc	670	3,400,000	8,500	n/a	n/a	n/a	<RBCs	5	38 mg/kg oc	670
Acenaphthene	16 mg/kg oc	500	530,000,000	1,300,000	n/a	n/a	n/a	<RBCs	5	16 mg/kg oc	500
Benzo(a)anthracene	110 mg/kg oc	1,300	790	40	n/a	n/a	n/a	n/a	5	110 mg/kg oc [g]	1,300 [g]
cPAH TEQ	n/a	n/a	130	6.6	n/a	n/a	n/a	21	9	21	21
Fluoranthene	160 mg/kg oc	1,700	95,000,000	240,000	180,000	37,000	180,000	<RBCs	5	160 mg/kg oc	1,700
Naphthalene	99 mg/kg oc	2,100	22,000,000	55,000	n/a	n/a	n/a	<RBCs	5	99 mg/kg oc	2,100
Phenanthrene	100 mg/kg oc	1,500	>max	3,200,000	n/a	n/a	n/a	<RBCs	5	100 mg/kg oc	1,500
SVOCs (µg/kg)											
Pentachlorophenol	360	360	160	8.1	3.5	29,000	140,000	ND	100	100	100
Petroleum Hydrocarbons (mg/kg)											
TPH Sum (diesel-range + lube oil-range)	260 [f]	n/a	Not bioaccumulative		Not bioaccumulative			n/a	50	260	260

Notes:

[a] Sediment Management Standards (Table III; Chapter 173-204 WAC). These values used if sediment organic carbon is between 0.5% and 3.5%.

[b] Apparent Effects Threshold criteria from Ecology's SCUM II guidance (Table 8-1; Ecology 2015b). These values used if sediment organic carbon is less than 0.5% or greater than 3.5%.

[c] Based on a cancer risk of 1 x 10^{-6} or a hazard quotient of 1. Values calculated using equations and assumptions from Ecology's December 2013 draft SCUM II guidance (see Appendix O for details; Ecology 2013f). These values were not updated to incorporate minor changes to exposure assumptions in Ecology's SCUM II guidance (Ecology 2015b) because these changes would not affect the values selected as Proposed SCOs.

[d] Natural background values calculated as the 90/90 UTL from Ecology's SCUM II guidance (Table 10-1; Ecology 2015b).

[e] Practical quantitation limits (PQLs) for Dioxin TEQ and cPAH TEQ are the Programmatic PQL values from Ecology's SCUM II guidance (Table 11-1; Ecology 2015b). PQL values for individual cPAHs, pentachlorophenol and TPH Sum are from Analytical Resources, Inc. of Tukwila, Washington.

[f] Value based on Haley site-specific bioassay results.

[g] Potential bioaccumulation risks associated with benzo(a)anthracene are addressed by the SCO value for cPAH TEQ.

n/a = no criterion is currently available for this analyte

ND = not detected (68 of 70 samples were ND)

OC = Organic Carbon

PAH = polycyclic aromatic hydrocarbons

TEQ = toxic equivalency concentration

ng/kg = nanogram per kilogram

µg/kg = microgram per kilogram

mg/kg = milligram per kilogram

<RBC = natural background value not calculated, but assumed to be less than direct contact (benthic) or bioaccumulation (human health and ecological) risk-based concentrations.

>max = risk-based value is greater than 1,000,000,000 µg/kg

Shading indicates basis for proposed SCO

Table 9-4

Preliminary Sediment Cleanup Screening Levels (CSLs)

R.G. Haley Site

Bellingham, Washington

Indicator Hazardous Substance	Direct Contact - Benthic Organisms		Bioaccumulation - Protective of People [c]		Bioaccumulation - Protective of Ecological Receptors			Modifying Factors		Proposed CSLs	
	SMS Criteria [a]	AET Criteria [b]	Subsistence Fishers - Low Exposure	Subsistence Fishers - High Exposure	Aquatic Life (Fish and Invertebrates)	Aquatic Dependent Wildlife (Individual Birds and Mammals)	Aquatic Dependent Wildlife (Bird and Mammal Populations)	Regional Background [d]	PQL [e]	Organic Carbon (0.5% to 3.5%)	Organic Carbon (<0.5% or >3.5%)
Dioxins/Furans (ng/kg)											
Dioxin TEQ	n/a	n/a	17	0.87	55	2.8	48	15	5	15	15
PAHs (µg/kg unless otherwise noted)											
2-Methylnaphthalene	64 mg/kg oc	670	3,400,000	8,500	n/a	n/a	n/a	22	5	64 mg/kg oc	670
Acenaphthene	57 mg/kg oc	500	530,000,000	1,300,000	n/a	n/a	n/a	25	5	57 mg/kg oc	500
Benzo(a)anthracene	270 mg/kg oc	1,600	7,900	400	n/a	n/a	n/a	33	5	270 mg/kg oc [g]	1,600 [g]
cPAH TEQ	n/a	n/a	1,300	66	n/a	n/a	n/a	86	9	86	86
Fluoranthene	1,200 mg/kg oc	2,500	95,000,000	240,000	180,000	37,000	180,000	132	5	1,200 mg/kg oc	2,500
Naphthalene	170 mg/kg oc	2,100	22,000,000	55,000	n/a	n/a	n/a	26	5	170 mg/kg oc	2,100
Phenanthrene	480 mg/kg oc	1,500	>max	3,200,000	n/a	n/a	n/a	113	5	480 mg/kg oc	1,500
SVOCs (µg/kg)											
Pentachlorophenol	690	690	1,600	81	3.5	29,000	140,000	79	100	100	100
Petroleum Hydrocarbons (mg/kg)											
TPH Sum (diesel-range + lube oil-range)	260 [f]	n/a	Not bioaccumulative		Not bioaccumulative			n/a	10	260	260

Notes:

[a] Sediment Management Standards (Table III; Chapter 173-204 WAC). These values used if sediment organic carbon is between 0.5% and 3.5% (inclusive).

[b] Apparent Effects Threshold criteria from Ecology's SCUM II guidance (Table 8-1; Ecology 2015b). These values used if sediment organic carbon is less than 0.5% or greater than 3.5%.

[c] Based on a cancer risk of 1×10^{-5} or a hazard quotient of 1. Values calculated using equations and assumptions from Ecology's December 2013 draft SCUM II guidance (see Appendix O for details; Ecology 2013f). These values were not updated to incorporate minor changes to exposure assumptions in Ecology's SCUM II guidance (Ecology 2015b) because these changes would not affect the values selected as Proposed CSLs.

[d] Regional background values for bioaccumulative compounds in Bellingham Bay sediment have been established by Ecology (Ecology 2015a).

[e] Practical quantitation limits (PQLs) for Dioxin TEQ and cPAH TEQ are the Programmatic PQL values from Ecology's SCUM II guidance (Table 11-1; Ecology 2015b). PQL values for individual cPAHs, pentachlorophenol and TPH Sum are from Analytical Resources, Inc. of Tukwila, Washington.

[f] Value based on Haley site-specific bioassay results.

[g] Potential bioaccumulation risks associated with benzo(a)anthracene are addressed by the CSL value for cPAH TEQ.

n/a = no criterion is currently available for this analyte

OC = Organic Carbon

PAH = polycyclic aromatic hydrocarbons

TEQ = toxic equivalency concentration

ng/kg = nanogram per kilogram

µg/kg = microgram per kilogram

mg/kg = milligram per kilogram

>max = risk-based value is greater than 1,000,000,000 µg/kg

Shading indicates basis for proposed CSL

Table 9-5

Preliminary Groundwater Cleanup Levels

R.G. Haley Site
Bellingham, Washington

Indicator Hazardous Substance	Preliminary Groundwater Cleanup Level	Basis for Preliminary Groundwater Cleanup Level
PAHs (µg/l)		
1-Methylnaphthalene	15	2-methylnaphthalene is the surrogate compound for 1-methylnaphthalene.
2-Methylnaphthalene	15	Protection of sediment (benthic organisms - direct contact)
Acenaphthene	3.3	Protection of sediment (benthic organisms - direct contact)
Benzo(a)anthracene	0.018	Protection of surface water (human health - consumption of organisms)
cPAH TEQ	0.018	Protection of surface water (human health - consumption of organisms)

Notes:

PAH = polycyclic aromatic hydrocarbons

PQL = practical quantitation limit

TEQ = toxic equivalency concentration

µg/L = microgram per liter

Table 9-6

Preliminary Soil Cleanup Levels

R.G. Haley Site

Bellingham, Washington

Analyte	Preliminary Soil Cleanup Level		Basis for Preliminary Soil Cleanup Level
	Vadose	Saturated	
Dioxins/Furans (ng/kg)			
Dioxin TEQ	13	13	Human health - direct contact (updated by Ecology May 2014)
PAHs (µg/kg)			
1-Methylnaphthalene	820	42	Protection of groundwater - based on protection of sediment (benthic organisms - direct contact)
2-Methylnaphthalene	800	41	Protection of groundwater - based on protection of sediment (benthic organisms - direct contact)
Benzo(a)anthracene	130	6.5	Protection of groundwater - based on protection of surface water (human health - consumption of organisms)
cPAH TEQ	137	137	Human health - direct contact
SVOC (µg/kg)			
Pentachlorophenol	47	6.3	Based on protection of groundwater (to protect surface water for human health consumption of organisms) for the vadose zone. Based on the PQL for the saturated zone, because analytical laboratory cannot detect PCP to meet the lowest soil risk-based criteria, which is protection of groundwater (to protect surface water for human health consumption of organisms).
TPH (mg/kg)			
TPH Sum (diesel-range + lube oil-range)	1,534	1,534	Human health - direct contact

Notes:

PAH = polycyclic aromatic hydrocarbons

TEQ = Toxic equivalency concentration

ng/kg = nanogram per kilogram

µg/kg = microgram per kilogram

mg/kg = milligram per kilogram

TABLE 9-7. REMEDIAL TECHNOLOGY SCREENING - SOIL

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
Soil Containment	Capping	Permeable Vegetated Soil Cap	Placement of a layer of clean, permeable soil over contaminated soil to prevent exposure and isolate contaminants, while allowing stormwater infiltration.	Effective for preventing direct contact exposure (i.e., dermal contact or ingestion) and erosion of source material. Not effective at reducing infiltration.	Technically implementable. The proposed development of a park at the Site is generally compatible with a vegetated soil cap.	Low capital cost relative to other cap methods. Low O&M cost.	Conditions requiring a cap to prevent exposure from remaining contamination are expected to also require reduced infiltration. Not retained.
		Low-Permeability Cap with Drainage Controls, Vegetated Surface	A low-permeability cap material (clay soil, HDPE liner material, etc.) would be placed over contaminated soil, overlain by a vegetated soil surface. Surface water collection and discharge would be designed to reduce infiltration of stormwater at the Site.	Effective for preventing direct contact exposure, erosion of source material, reducing stormwater infiltration, and enhancing immobility.	Technically implementable. The proposed development of a park at the Site is generally compatible with a low-permeability/vegetated soil cap. Additional considerations for stormwater collection, treatment, and discharge will be needed.	Moderate capital cost. Low O&M cost. Treatment requirements for Site stormwater may affect capital and O&M cost.	Applicable and effective where vegetated surfaces are planned. Retained.
		Low-permeability Cap with Drainage Controls, Hard Surface (pavement, structure foundations, etc.)	Installation of asphalt or concrete cap over contaminated soil. Primary function of the cap is to prevent direct contact with contaminated soil and stormwater infiltration. May also include foundations for structures planned for the Site, provided consideration is made for collection of stormwater.	Effective for preventing direct contact exposure, erosion of source material, reducing infiltration of stormwater, and reducing contaminant mobility.	Technically implementable. The proposed development of a park at the Site is expected to include hard surfaces that can be designed as effective low-permeability cap features.	Moderate capital cost considering paved surfaces would be planned as part of the park design. Low O&M cost. Treatment requirements for Site stormwater may affect capital and O&M costs.	Applicable and effective where hard surfaces and structures are planned. Retained.
	Physical Vapor Barrier	Synthetic Membrane Beneath Buildings	Installation of membrane vapor barrier below building foundations to prevent soil vapor intrusion into indoor air.	Effective for preventing migration of VOCs into indoor air spaces.	Technically implementable using standard building methods during construction of future structures.	Low additional capital cost. Negligible O&M cost.	Applicable for buildings proposed at the Site. Retained.
Soil Removal	Removal	Excavation	Excavation of contaminated soil using common excavation methods for upland soil removal. Excavation at the Site may require shoring and/or dewatering for excavation sidewall stability.	Effective for complete range of contaminant groups. Shoring and dewatering considerations may be required for effective removal under some conditions.	Technically implementable in most areas of contaminated soil. Shoring and dewatering considerations will be required to safely excavate under some conditions.	Moderate to high capital cost. Negligible O&M cost.	Applicable and common method for soil removal. Retained.
Soil Management	On-site Management	Consolidation within AOC	Excavated soil can be managed on-site within the boundaries of the designated AOC without triggering LDRs under federal RCRA and state dangerous waste regulations (Section 9.2.1.1 and Appendix N).	Effective utilizing standard construction methods provided on-site management (e.g. capping) is protective of upland exposure scenarios.	Technically and administratively implementable within a designated AOC.	Low capital cost. Negligible O&M.	Retained.

TABLE 9-7. REMEDIAL TECHNOLOGY SCREENING - SOIL

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
Soil Management Continued	Off-Site Disposal	Landfill	Disposal of contaminated soil at a permitted, off-site landfill. Treatment may be required prior to landfill disposal.	Common and effective method of disposal for contaminated soil. Based on contaminant concentrations, and dangerous/hazardous waste regulations, some contaminated soil may require pre-treatment due to potential land disposal restrictions.	Technically implementable. Impacted soil must be profiled and meet land disposal requirements. Pre-treatment may be required if material does not meet requirements.	Moderate to high capital cost depending on types of waste present and type and location of landfill. Negligible O&M cost.	Common disposal option for excavated soils, where appropriate. Retained.
		Incineration	High temperatures are used to combust (in the presence of oxygen) organic contaminants in excavated soil at an off-site, permitted facility.	Required treatment/disposal method for some Site contaminants. Effective for removing/destroying organic contaminants.	Technically implementable. Incineration would be accomplished at a permitted off-site facility.	Very high capital cost. Incineration of highly organic debris (wood waste) lowers cost due to heat value. Negligible O&M.	High cost relative to other *ex situ* technologies, but required under some circumstances. Retained.
In Situ Soil Treatment	Monitored Natural Attenuation	Natural Attenuation	Natural biotransformation processes such as volatilization, biodegradation, adsorption, and chemical reactions with soil materials are used to reduce contaminant concentrations.	Generally not effective for reducing risk to human health and ongoing threats to groundwater in a reasonable time frame. Effectiveness is highest in combination with other technologies as a final step to achieve cleanup levels when risks to human health and the environment are low.	Technically implementable. Monitoring may be required to ensure adequate reduction rate. May require institutional controls during treatment period.	Negligible capital cost. Moderate O&M cost. Costs for O&M are the result of monitoring associated with the long duration required for treatment.	Remediation time frame would not be reasonable. Not retained.
	Biological Treatment	Bioventing	Oxygen is supplied through direct low-flow air injection into contaminated soil.	Effective in more permeable soil for petroleum hydrocarbons and other organics amenable to aerobic degradation. Degradation is relatively slow. Ineffective for organic constituents not degradable by aerobic mechanisms.	Technically implementable. Monitoring of off-gasses at ground surface may be required. Venting requires infrastructure of air injection piping, blower, controls, etc.	Moderate capital and O&M cost. Moderate cost relative to other *in situ* options.	Slow technology. Not effective for recalcitrant contaminants. Not expected to achieve cleanup levels. Not retained.
		Enhanced Bioremediation	Controlled biological process by which amendments are injected into contaminated soils to enhance microorganism conversion of organic contaminants to innocuous, stabilized by-products.	Reductive dechlorination processes may be partly effective on dioxins/furans, but would not treat most hydrocarbons at the Site. Enhanced aerobic bioremediation would be effective for most lower molecular weight hydrocarbons, but not higher molecular weight PAHs and dioxins/furans.	Difficult to implement due to slow degradation and potential need for multiple processes. Contaminants present would require different processes, and multiple implementations.	High capital cost. Moderate to high O&M cost. Cost increases due to uncertainty of process and expected need to repeat treatment.	Difficult to implement. Not expected to achieve cleanup levels. Not retained.

TABLE 9-7. REMEDIAL TECHNOLOGY SCREENING - SOIL

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
In Situ Soil Treatment Continued	Physical Treatment	Soil Flushing	The extraction of contaminants from soil with aqueous solution accomplished by passing fluid through in-place soils using an injection or infiltration process. Extraction fluids must be recovered from underlying groundwater.	Effective for more soluble chemicals. Presence of fine-grained soils and wood debris limits effectiveness.	Technically implementable, but would require significant safety components to prevent exacerbating groundwater and/or sediment contamination. Regulatory concerns over potential to wash contaminants beyond fluid capture zones and introduction of surfactants in to the subsurface would make permitting difficult.	Moderate capital and O&M costs. Significant cost associated with ensuring capture of contaminants liberated during implementation.	High cost and uncertainty relative to other *in situ* soil treatment technologies. Not retained.
		Soil Vapor Extraction	Vacuum is applied through extraction pipes screened within vadose zone soil to create a pressure/concentration gradient, which induces gas-phase volatile organics to diffuse through soil to extraction wells. The process includes a system for treating off-gas. Air flow also induces aerobic bioremediation of petroleum hydrocarbons.	Commonly used for volatile contaminants, but Site conditions and less volatile organic contaminants would not be amenable to vapor-phase mass transfer processes.	Technically implementable. Typical application involves numerous extraction wells, conveyance piping, and large-scale vacuum blowers.	Moderate capital cost and high O&M cost.	Not applicable for most Site contaminants. Not retained.
		Solidification and Stabilization	Contaminants are physically or chemically bound through use of solidification or stabilization media. Solidification encapsulates the contaminated material and forms a monolithic matrix. Stabilization immobilizes contaminated soil and reduces its leachability.	Solidification and stabilization of organic contaminants in soil have been demonstrated effective at reducing the leachability of contaminants in soil. Wood debris may inhibit effectiveness of technology if applied *in situ*. Treatability testing will be required to design the process and prove effectiveness.	Technically implementable. Solidification and stabilization processes can result in an increase in volume. Treatability testing is required.	Moderate capital cost and no O&M cost. Moderate cost relative to other *in situ* physical/chemical options. Increased volume associated with solidification and stabilization processes may increase costs.	Applicable for Site conditions and contaminants, but requires treatability testing. Retained.
	Chemical Treatment	Self-sustaining Treatment for Active Remediation (STAR)	Utilizes an *in situ* smoldering combustion process to destroy high concentration organics and nonaqueous phase liquid (NAPL).	STAR is an innovative technology that has yet to be proven on full-scale level. Treatability testing on soil with similar contaminant distribution was successful at destroying majority of PAH, pentachlorophenol, and dioxin/furan mass.	Implementability at full-scale is unknown, but is currently planned for full-scale implementation at another site. Treatment elements are similar to other *in situ* thermal and physical processes. Laboratory and field-scale treatability testing would be required.	High capital costs and low O&M costs. High treatability testing cost.	Potentially applicable technology but unproven at full-scale application. Uncertainties associated with wood debris and potential landfill debris. Not retained.
		Chemical Oxidation	Injection of a dilute oxidant solution (i.e., hydrogen peroxide, ozone, potassium permanganate, sodium persulfate, ferric chloride, etc.) into the contaminated zone to convert hazardous compounds to nonhazardous or less toxic compounds that are more stable, less mobile, or inert.	Chemical oxidation has been proven effective at treating many of the Site contaminants. Treatability testing would be required to determine effectiveness. *In situ* application would be inhibited by heterogeneity and high organics (i.e., wood debris) in subsurface.	Implementable using standard injection processes, but difficulties would be expected due to heterogeneity and large debris in subsurface.	High capital and low O&M costs. Moderate treatability testing cost.	*In situ* application of chemical oxidation is not expected to be as effective as other treatment methods. Not retained.

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
In Situ Soil Treatment Continued	Thermal Treatment	Electrically Induced Heating	Electrical current is generated between electrodes installed in subsurface, which gradually raises the ground temperature. The increased temperature volatilizes lighter hydrocarbons, allowing removal by vapor extraction methods. The heat also enhances mobility of NAPLs containing heavier hydrocarbons, allowing more effective NAPL recovery. Removal technologies extract the volatilized or mobilized contaminants.	Resistive heating has been demonstrated effective for enhancing contaminant removal in areas of high concentration contaminants and may be effective when applied to smear zone soil. However, wood debris and landfill waste within treatment area are expected to inhibit contaminant removal by interfering with the resistive heating process and extraction methods, reducing the overall effectiveness of the technology.	Potentially implementable, but heavily reliant on installed components and above-ground equipment which may be incompatible with future site use as a park.	Very high capital cost and low O&M cost. Not a cost-effective application for a broad area, particularly where treatment effectiveness uncertainties exist. Low O&M cost due to aggressive, short-term nature of treatment.	Potentially applicable but high degree of treatment uncertainty, implementation challenges and extremely high capital costs. Not retained.
		Steam Heating	Installation of a series of steam injection wells in the contaminated soil areas. Steam is generated in an on-site boiler and injected through the wells, which raises the temperature of the soil. Similar to the application of electrical resistance heating, the contaminants are extracted by vapor extraction and NAPL recovery methods. The injected steam condenses, resulting in additional water that must be extracted.	Steam heating has been proven effective at sites under certain conditions, but the heterogeneous conditions at the Site would affect steam transport through subsurface. This would result in uncertain and incomplete heat and mass transfer, and impact the effective recovery of volatile or mobilized contaminants	Steam heating has similar implementation issues as electrical heating, with the addition of steam injection issues, the need to collect additional water (condensed steam), and ensure collection of contaminants liberated during implementation.	Very high capital cost and medium O&M cost. Higher O&M relative to electric heating, but is still a relatively short-term treatment duration.	Implementation would be difficult and effectiveness is uncertain given subsurface heterogeneities. Not retained.
Institutional Controls	Land Use Restrictions	Environmental Covenants	Covenants attached to deeds identify long-term commitments for maintenance of caps, treatment systems, etc. along with any site use restrictions.	Effectiveness for protection of human health would depend on enforcement of and compliance with environmental covenants.	Technically implementable. Specific legal requirements and authority would need to be met.	Low capital cost. Low O&M cost.	Potentially applicable in combination with other technologies. Retained.
	Access Control	Fencing and Warning Signage	Construct new or maintain existing Site fencing and signage to control Site access by the general public thereby reducing potential exposure to contaminants.	Signage and fencing has not been effective at controlling Site access. Future Site use intends to provide public access; therefore access controls would not be compatible with the proposed park.	Technically implementable but not consistent with future land use.	Low capital cost. Low O&M cost.	Not compatible with current and proposed land use. Not retained.

Notes:

BETX = benzene, ethylbenzene, toluene, and xylene
HDPE = high-density polyethylene
O&M = operation and maintenance
PAHs = polycyclic aromatic hydrocarbons
SVE = soil vapor extraction
SVOC = semivolatile organic compound
UV = ultraviolet
VOCs = volatile organic compounds
AOC = Area of Contamination

TABLE 9-8. REMEDIAL TECHNOLOGY SCREENING - LNAPL

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
LNAPL Containment	Physical LNAPL Barrier	Low-Permeability Wall	Placement of a low-permeability vertical barrier to restrict LNAPL migration in the downgradient direction. Barrier could be constructed of steel sheet pile. The shallow depth needed to contain LNAPL allows potential use of driven sheet piles or other vertical barrier material (i.e., chemical-resistant impermeable geomembrane) placed to the base of the smear zone.	Effective for containing LNAPL or providing a barrier for LNAPL treatment systems. LNAPL removal may be required to prevent LNAPL from flowing around ends of the wall.	Technically implementable, as demonstrated by installation of the existing sheet pile wall at the Site.	Moderate capital cost. Low O&M cost.	Potentially applicable in combination with other technologies. Retained.
		Low-Permeability Slurry Wall	Below-grade wall consisting of soil-bentonite or cement-bentonite that can function as a permanent structure to restrict LNAPL migration and contaminant mobility.	Effective for containing LNAPL or providing a barrier for LNAPL treatment systems. LNAPL removal may be required to prevent LNAPL from flowing around ends of the wall.	Technically implementable using readily available grout injection or slurry wall technologies. Some slurry wall construction methods involve *in situ* mixing, which may spread LNAPL vertically.	Moderate capital cost. Low O&M cost.	Potentially applicable in combination with other technologies. Retained.
	Hydraulic LNAPL Barrier	LNAPL Interceptor Trench	Subsurface barrier typically constructed with pea gravel, perforated piping, and filter fabric that acts to intercept and prevent LNAPL migration. Generally combined with an LNAPL removal method implemented within the interceptor trench.	Effective for containing and removing LNAPL or providing a barrier for LNAPL treatment systems. Most effective in scenarios with significant quantities of recoverable LNAPL. LNAPL collection would be required within the trench.	Implementable using standard collection trench and LNAPL removal technologies. Removal of soil and replacement with gravel backfill would generate significant remediation-derive listed dangerous waste.	Moderate capital cost. Moderate O&M cost.	Potentially applicable, but not expected to be more effective than standard physical barriers. Not retained.
LNAPL Removal	LNAPL Mass Removal	Hot Spot Excavation	Excavation of contaminated soil where LNAPL is present, including LNAPL extraction from within excavation as required to achieve greatest removal. Removal would be followed by on-site and/or off-site management of excavated soil and LNAPL.	Effective for removing localized hot spots of immobile LNAPL that can't be removed by other extraction methods.	Technically implementable in most areas of LNAPL. Shoring and dewatering considerations will be required to safely excavate under some conditions. Expected treatment requirements for dioxins/furans in recovered groundwater could be difficult to implement.	Moderate capital cost, not considering disposal requirements. Negligible O&M cost.	Applicable and common method for LNAPL-contaminated soil. Retained.
		Enhanced Free Product Removal (Soil Agitation and LNAPL Collection)	Enhanced free product removal refers to the technology previously pilot-tested at the RG Haley Site involving removing fill to the top of the smear zone, agitating the exposed smear zone soil to release immobile LNAPL, and collecting the separate-phase LNAPL using skimming or pumping methods.	Soil agitation was shown to effectively liberate LNAPL within agitation cells and increase removal efficiency. Method would be expected to result in a short-term release of dissolved contaminants into the groundwater.	Demonstrated to be implementable on a small scale during treatability testing on Site. Implementation would be slow due to cell by cell process, but significant implementability issues were not observed during treatability testing.	High capital cost. Low O&M cost. High capital cost due to slow equipment-intensive process.	Soil agitation would impact dissolved contaminant concentrations and contaminant migration to sediment and surface water for duration of agitation activities. Not retained.

TABLE 9-8. REMEDIAL TECHNOLOGY SCREENING - LNAPL

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
LNAPL Removal Continued	Hydraulic LNAPL Recovery	In-Well LNAPL Skimming	Automated skimming mechanisms are placed inside wells screened across the LNAPL/groundwater interface. Separate-phase LNAPL is removed slowly without affecting the gradient and without removing significant volumes of water.	Can effectively reduce the mass of LNAPL in the subsurface where mobile LNAPL remains. Limited effectiveness for residual (immobile) LNAPL.	Technically implementable using readily available skimming processes.	Low capital cost. Moderate O&M cost.	Limited anticipated effectiveness if implemented alone as a mass removal method, but may be applicable in conjunction with a barrier to support LNAPL containment. Retained.
		Multiphase Extraction	LNAPL is recovered by applying a vacuum to simultaneously remove LNAPL, vapors and groundwater. Different forms of multi-phase extraction are possible depending on Site conditions.	Effective for extracting dissolved, vapor and free-phase fuels and VOCs. Limited mobility of remaining LNAPL will reduce effectiveness as a mass removal method.	Difficult to implement properly. Extraction rates needed to lower the water table may exceed the capacity of the local sanitary sewer system. Expected treatment requirements for dioxins/furans in extracted groundwater could be difficult to implement.	Moderate to high capital cost. High O&M cost.	Multiphase extraction is expected to generate a significant volume of water requiring treatment for a minimal additional LNAPL removal. Not retained.
In Situ LNAPL Treatment	Natural Source Zone Depletion (NSZD)	Monitored Natural Attenuation	LNAPL constituents are naturally depleted from the LNAPL body over time through volatilization, dissolution, absorption, and degradation.	Effective for tracking plume migration, concentrations, and remaining LNAPL mass over time. Applicable after LNAPL removal has reached asymptotic levels and remaining immobile LNAPL has been demonstrated to be naturally degrading.	Technically implementable. Monitoring well network already established at and surrounding the Site. No wastes are generated with this option.	Negligible capital cost. Moderate O&M cost.	Timeframe for remediation can be very long compared to other removal/treatment options. Limited application due to proximity of LNAPL to receptors. Not retained.
	Chemical Treatment	Chemical Oxidation	LNAPL is depleted by accelerating LNAPL solubilization by the addition of a chemical oxidant into the LNAPL zone. Oxidation reactions occur in the dissolved phase and destroy organic compounds.	Chemical oxidation breaks down hydrocarbon bonds producing carbon dioxide and water as by-products. Dissolved phase mass destruction drives mass transfer from the LNAPL phase. This process requires significant reagent mass and multiple applications when implemented in the presence of LNAPL.	Generally implemented for dissolved plumes, but can also be applied to smear-zone residual LNAPL. Significant LNAPL mass requires significant oxidant mass, reducing efficiency and implementability.	Moderate to high capital cost. Low O&M cost.	Typically not efficiently applied to LNAPL. Not retained as an LNAPL technology.

TABLE 9-8. REMEDIAL TECHNOLOGY SCREENING - LNAPL

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
In Situ LNAPL Treatment Continued	Chemical Treatment Continued	Surfactant-Enhanced Subsurface Remediation (SESR)	A surfactant is injected that increases LNAPL solubilization and LNAPL mobility. The dissolved phase and LNAPL are then recovered via hydraulic recovery.	Can be effective for more efficient removal of residual LNAPL, but relies on containment and capture elements to prevent increased mobility from exacerbating contaminant distribution. High natural organic content (wood waste) will reduce effectiveness of surfactant flushing.	High degree of heterogenity reduces surfactant delivery efficiency. Mobility enhancement for LNAPL with higher oil-water interfacial tension is less efficient. Recovered surfactant, groundwater, and LNAPL would need to be treated and disposed off-site. Expected treatment requirements for dioxins/furans in extracted groundwater could be difficult to implement.	Moderate to high capital cost. Moderate O&M cost.	Uncertainties associated with enhancing LNAPL mobility with surfactants near a marine environment limit its application. Not retained.
		Granular Organoclay Adsorption	Granular organoclay capable of adsorbing LNAPL mass is placed *in situ*. Can be implemented as a reactive wall that captures LNAPL as it migrates or can be mixed directly with LNAPL-impacted soil.	Organoclay has been proven effective at adsorbing hydrocarbons dissolved in groundwater as well as in LNAPL form. Organoclay can be effectively applied in a PRB across the smear zone to capture migrating LNAPL or can be mixed *in situ*.	Implementability is similar to application for groundwater. Organoclay can also be applied *in situ* as a soil stabilization technology.	Moderate capital cost. Moderate O&M cost.	Potential application for LNAPL treatment as a PRB and/or *in situ* stabilization treatment. Retained.
	Physical Treatment	Air Sparging/Soil Vapor Extraction (AS/SVE)	Sparging injects air into LNAPL body to volatilize LNAPL constituents; VOCs are then removed by SVE.	More effective for mass recovery of LNAPL with higher proportion of volatiles. The aged diesel carrier oil at the Site is less volatile than the ideal AS/SVE treatment application.	More efficient in higher permeability soils that are mostly homogenous. Vapors generated from SVE may require treatment.	Moderate capital and O&M cost.	Not likely to be significantly effective for Site contaminants. Not retained.
		Solidification/ Stabilization	LNAPL body is physically/chemically bound within a stabilized mass to reduce mobility.	Effective at immobilizing and preventing migration of potentially mobile LNAPL. Amendments such as organoclay adsorb LNAPL *in situ*. The resulting mixture reduces groundwater flow, preventing contaminant migration.	Treatability testing required to evaluate applicability, given the high proportion of wood debris in the smear zone. Mixing process may significantly increase *in situ* volume. *In situ* mixing process has been demonstrated at similar sites.	Moderate to high capital cost depending on the footprint of the area to be stabilized. Negligible O&M cost.	Applicable to Site conditions, subject to confirmation by treatability testing. Retained.
		Bioslurping	Enhancement technology that involves application of high vacuum to wells screened across saturated and unsaturated zone soils. The process is capable of removing LNAPL, vapor-phase, and dissolved-phase contamination, while stimulating natural aerobic biodegradation.	Effective for removing LNAPL from the saturated and unsaturated zones under conditions where contaminants are volatile and degradable. Site contaminants would generally be resistant to the bioslurping enhancements.	Equipment-intensive process with longer operation expected. Most efficient in higher permeable soils (sands and gravels).	Moderate capital cost and high O&M cost depending on the life span of the project.	Generally not applicable to the constituents present in LNAPL at the Site. Not retained.

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
In Situ LNAPL Treatment Continued	Thermal Treatment	Electrical Resistance Heating	Electrical current is generated between electrodes installed in subsurface, which gradually raises the temperature of groundwater. The increased temperature volatilizes lighter hydrocarbons, allowing removal by vapor extraction methods. The heat also enhances mobility of NAPLs containing heavier hydrocarbons, allowing more effective NAPL recovery. Removal technologies extract the volatilized or mobilized contaminants.	Shown to be effective at enhancing removal of higher molecular weight organics. Volatilized contaminants are extracted using SVE. Wood debris and landfill waste within treatment area are expected to inhibit contaminant removal by interfering with the resistive heating process and extraction methods, reducing the overall effectiveness of the technology.	Potentially implementable, but heavily reliant on installed components and above-ground equipment which may be incompatible with future site use as a park.	Very high capital cost and low O&M cost. Not a cost-effective application for a broad area, particularly where treatment effectiveness uncertainties exist. Low O&M cost due to aggressive, short-term nature of treatment.	High cost relative to other in situ treatment options and uncertainty, implementation challenges, and high capital costs. Not retained.
	Thermal Treatment Continued	Steam Injection	Installation of a series of steam injection wells within the treatment area. Steam is generated in an on-site boiler and injected through the wells, which gradually raises the temperature of the groundwater and soil. Similar to the application of electrical resistance heating, the contaminants are extracted by vapor extraction and NAPL recovery methods. The injected steam condenses, resulting in additional water that must be extracted.	Steam heating has been proven effective at sites under certain conditions, but the heterogeneous conditions at the Site would affect steam transport through subsurface. This would result in uncertain and incomplete heat and mass transfer, and impact the effective recovery of volatile or mobilized contaminants	Steam heating has similar implementation issues as electrical heating, with the addition of steam injection issues, the need to collect additional water (condensed steam), and ensure collection of contaminants liberated during implementation.	Very high capital cost and medium O&M cost. Higher O&M relative to electric heating, but is still a relatively short-term treatment duration.	Implementation would be difficult and effectiveness is uncertain given subsurface heterogeneities. Not retained.

Notes:

BETX = benzene, ethylbenzene, toluene, and xylene
HDPE = high-density polyethylene
O&M = operation and maintenance
PAHs = polycyclic aromatic hydrocarbons
SVE = soil vapor extraction
SVOC = semivolatile organic compound
UV = ultraviolet
VOCs = volatile organic compounds
AOC = Area of Contamination

TABLE 9-9. REMEDIAL TECHNOLOGY SCREENING – GROUNDWATER

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
Containment	Physical Groundwater Barrier	Low-Permeability Sheet Pile Wall	Construction of a low-permeability vertical barrier such as driven steel sheet piles to restrict groundwater flow and contaminant migration in the downgradient direction. Barrier can be installed down to the nearest aquitard to provide full containment, or installed at a partial depth to direct groundwater deeper. Groundwater extraction may be required to achieve containment under some scenarios. Long-term monitoring of containment structure required.	Effective for containing impacted groundwater or directing groundwater away from a source or receptor, or providing a barrier for groundwater treatment systems. May need to be combined with groundwater pumping in some containment scenarios.	Technically implementable, as demonstrated by installation of the existing sheet pile wall at the Site.	High capital and low O&M cost.	Potentially applicable in combination with other technologies. Retained.
		Low-Permeability Slurry Wall	Below-grade barrier consisting of soil-bentonite or cement-bentonite that can function as a permanent structure to restrict groundwater flow and contaminant migration. Barrier can be installed down to the nearest aquitard to provide full containment, or installed at a partial depth to direct groundwater deeper. Groundwater extraction may be required to achieve containment under some scenarios. Long-term monitoring of containment structure required.	Effective for containing impacted groundwater or directing groundwater away from a source or receptor, or providing a barrier for groundwater treatment systems. May need to be combined with groundwater pumping in some containment scenarios.	Technically implementable using readily available grout injection or slurry wall technologies.	High capital cost and low O&M cost.	Potentially applicable in combination with other technologies. Retained.
	Hydraulic Groundwater Barrier	Groundwater Pumping	Groundwater pumping to establish a hydraulic capture zone and restrict groundwater flow and contaminant migration in the downgradient direction. May be used in conjunction with a physical barrier to achieve full containment.	Potentially effective for hydraulic control of impacted groundwater. May be implemented to increase effectiveness of physical barrier technologies. Requires continuous long-term operation to achieve effective containment and maintenance of treatment components to prevent discharge of contaminated groundwater.	Technically implementable using standard groundwater extraction methods. The need to treat extracted groundwater to acceptable levels to allow discharge will reduce the implementability.	Moderate capital cost and high O&M cost. High O&M costs associated with long-term pumping.	Potentially applicable in combination with other technologies, but at high cost. Not expected to be cost effective if applied as sole containment method. Not retained.
In Situ Groundwater Treatment	Passive Groundwater Treatment	Permeable Reactive Barrier Wall	Permeable reactive barrier (PRB) walls utilize in situ treatment methods in a passive configuration, treating groundwater as it passes through the reactive material. PRBs are effective applications to prevent groundwater contaminants from migrating to on-Site or off-site receptors.	Effective treatment configuration under proper hydrogeologic conditions that direct Site groundwater through PRB. Effectiveness relies on selecting an effective reactive treatment component.	Technically implementable using a variety of PRB installation methods. Reactive component can be placed between impermeable barriers to form a funnel and gate configuration.	Moderate to high capital costs. Moderate O&M cost. O&M costs increase for treatment methods that require frequent replenishment.	May be cost-effective method of treating groundwater leaving upland area. Retained.

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
In Situ Groundwater Treatment Continued	Monitored Natural Attenuation	Intrinsic Bioremediation	Reduction of dissolved concentrations through naturally occurring biodegradation processes, as well as other attenuation processes such as dispersion, volatilization, or adsorption. Involves groundwater sampling and monitoring for indicators of natural attenuation.	Commonly effective for degradation of some organic compounds, particularly fuel hydrocarbons. High level of organics in saturated soil at the Site appears to deplete oxygen quickly, reducing potential for natural aerobic degradation.	Technically implementable. Monitoring well network already established at the Site, but natural attenuation is more suited to implementation following the completion of more active remediation.	Negligible capital cost. Moderate to high O&M cost. Low overall cost relative to active remediation options.	Not considered suitable as a stand-alone remedial technology for groundwater. Not retained.
	Chemical Treatment	Chemical Oxidation	Injection of a dilute oxidant solution (i.e., hydrogen peroxide, ozone, potassium permanganate, sodium persulfate, ferric chloride, etc.) into contaminated groundwater to convert hazardous compounds to nonhazardous or less toxic compounds that are more stable, less mobile, or inert.	Proven effective at converting fuel hydrocarbons and some PAHs to non-hazardous or less toxic compounds. Presence of highly concentrated contaminants, particularly LNAPL, and high concentrations of other organics inhibits degradation and requires repeated applications of oxidant.	Difficult to implement as an *in situ* technology due to heterogeneous saturated zone. Pilot studies would need to be conducted to determine the effectiveness of chemical oxidation given the Site COCs.	High capital cost. Negligible O&M cost.	High cost and high level of difficulty. Not retained.
		Zero-Valent Iron Reduction	Injection of granular slurry of zero-valent iron into contaminated groundwater to destroy contaminants through reductive processes.	More commonly applied for chlorinated compounds. Not widely effective for PAHs or hydrocarbons. Potentially ineffective over the long-term due to decrease in reactive capacity over time.	Difficult to implement. Pilot studies would be needed to determine the effectiveness of zero-valent iron reduction given the Site COCs.	High capital cost. Negligible O&M cost.	High relative cost and low expected effectiveness for most Site contaminants. Not retained.
		Granular Organoclay Adsorption	Place granular organoclay capable of adsorbing dissolved organics and LNAPL. Commonly applied as a permeable reactive wall. Grain size of organoclay prevents directly injecting into saturated zone as done with liquid reagents.	Organoclay has been proven to adsorb heavier fuel hydrocarbons and PAHs and can be applied in different configurations, including as a PRB.	Implementable as a PRB by mixing organoclay with native saturated zone soil. Some applications use proprietary construction methods. Monitoring is needed to evaluate if and/or when material requires replacement or replenishment.	Moderate capital and O&M costs.	Applicable for Site contaminants and implementable under Site conditions. Retained as a component of a PRB.
	Physical Treatment	Air Sparging	Air is injected into the saturated zone to induce mechanical stripping and volatilization of contaminants. Introduction of oxygen also enhances biodegradation. SVE is required to capture vapor phase contaminants.	Not generally effective for less volatile organic contaminants present at the Site.	Technically implementable. Most case studies indicate application requires a dense grid of injection wells which may be compatible with Site conditions before it is redeveloped as a park.	Moderate capital and O&M costs.	Low effectiveness for most Site contaminants. Not retained.

TABLE 9-9. REMEDIAL TECHNOLOGY SCREENING – GROUNDWATER

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
In Situ Groundwater Treatment Continued	Biological Treatment	Enhanced Anaerobic Bioremediation	Injection of a hydrogen-releasing material into the contaminated zone to enhance degradation of organic contaminants through metabolic reactions.	Generally used to induce reductive dechlorination, but is not expected to be successful at treating most Site contaminants	Generally implementable, but slow acting. Treatability testing would be required to determine application details.	Moderate capital cost. Moderate O&M cost.	Low effectiveness for most Site contaminants. Not retained.
		Enhanced Aerobic Bioremediation	Injection of oxygen or oxygen-releasing material into or upgradient of the contaminated zone to enhance degradation of organic compounds through respiration.	Can be effective for hydrocarbons and PAHs in groundwater. Generally applied to lower concentration plumes. Slow acting relative to other technologies.	Technically implementable using available injection technologies. Slow acting due to need to acclimate and generate a substantial microbial population.	Moderate capital cost. Moderate O&M cost.	Limited application for low-concentrations of some Site contaminants but not expected to be able to achieve cleanup levels. Not retained.
	Thermal Treatment	Electrically Induced Heating	Electrical current is generated between electrodes installed in subsurface, which gradually raises the temperature of groundwater. The increased temperature volatilizes lighter hydrocarbons, allowing removal by vapor extraction methods. The heat also enhances mobility of NAPLs containing heavier hydrocarbons, allowing more effective NAPL recovery. Removal technologies extract the volatilized or mobilized contaminants.	Shown to be effective at enhancing removal of heavier organics. Volatilized contaminants are extracted using SVE. Wood debris and landfill waste within treatment area are expected to inhibit contaminant removal by interfering with the resistive heating process and extraction methods, reducing the overall effectiveness of the technology.	Potentially implementable, but heavily reliant on installed components and above-ground equipment which may be incompatible with future site use as a park.	Very high capital cost and low O&M cost. Not a cost-effective application for a broad area, particularly where treatment effectiveness uncertainties exist. Low O&M cost due to aggressive, short-term nature of treatment.	High cost relative to other *in situ* treatment options, uncertainty, implementation challenges, and high capital costs. Not retained.
		Steam Heating	Installation of a series of steam injection wells within the treatment area. Steam is generated in an on-site boiler and injected through the wells, which gradually raises the temperature of the groundwater and soil. Similar to the application of electrical resistance heating, the contaminants are extracted by vapor extraction and NAPL recovery methods. The injected steam condenses, resulting in additional water that must be extracted.	Steam heating has been proven effective at sites under certain conditions, but the heterogeneous conditions at the Site would affect steam transport through subsurface. This would result in uncertain and incomplete heat and mass transfer, and impact the effective recovery of volatile or mobilized contaminants	Steam heating has similar implementation issues as electrical heating, with the addition of steam injection issues, the need to collect additional water (condensed steam), and ensure collection of contaminants liberated during implementation.	Very high capital cost and medium O&M cost. Higher O&M relative to electric heating, but is still a relatively short-term treatment duration.	Implementation would be difficult and effectiveness is uncertain given subsurface heterogeneities. Not retained.

TABLE 9-9. REMEDIAL TECHNOLOGY SCREENING – GROUNDWATER

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
Groundwater Collection	Groundwater Extraction	Vertical Extraction Wells	Groundwater extraction using vertical extraction wells. Objectives of groundwater extraction include removal of dissolved contaminants from the subsurface and containment of contaminated groundwater to prevent migration.	May be effective for plume containment and source area migration control. Effectiveness relies on continuous, long-term (in perpetuity) operation.	Groundwater extraction is technically implementable using standard methods. However, expected treatment requirements for dioxins/furans in extracted groundwater could be difficult to implement. Requires continuous long-term operation to achieve effective containment and redundancies in treatment components to avoid a treatment train bypass that could discharge contaminated groundwater.	Moderate capital cost. High O&M cost assuming long-term operation and water treatment.	Long term operation, high cost and uncertain implementability. Not retained.
Groundwater Collection Continued	Groundwater Extraction Continued	Groundwater Interceptor Trench	Groundwater extraction using horizontal interceptor/extraction trenches. Trenches can be used to extract groundwater from a specific interval and can be combined with LNAPL collection interceptor trenches.	Effective at capturing a specific vertical interval of groundwater to prevent migration off-site or to a specific receptor. Can be implemented in conjunction with an LNAPL removal trench to extract highest concentration groundwater.	Implementable using common trenching and groundwater extraction methods. Can be combined with LNAPL removal if needed. However, expected treatment requirements for dioxins/furans in extracted groundwater could be difficult to implement.	Low to medium capital cost. High O&M cost. Limiting groundwater extraction to a smaller zone reduces O&M cost.	Long term operation, high cost and uncertain implementability. Not retained.
Institutional Controls	Land Use Restrictions	Environmental Covenants	Covenant attached to deed would restrict installation of water supply wells and water usage.	Effectiveness at preventing exposure to impacted groundwater would depend on enforcement of and compliance with environmental covenants and conditions of well permits.	Technically implementable. Specific legal requirements and authority would need to be met.	Low capital cost. Negligible O&M cost.	Potentially applicable in combination with other technologies. Retained.
	Long-term Monitoring	Groundwater Monitoring	Long-term gauging and sampling of monitoring well network to assess plume stability and contaminant concentration trends over time.	Effective for tracking plume migration over time. Not effective for remediating contaminants.	Technically implementable. Monitoring well network already established at and surrounding the Site.	Negligible capital cost and moderate O&M cost. Adding or replacing wells will add capital costs.	Potentially applicable in combination with other technologies. Retained.

Notes:

BETX = benzene, ethylbenzene, toluene, and xylene
HDPE = high-density polyethylene
O&M = operation and maintenance
PAHs = polycyclic aromatic hydrocarbons
SVE = soil vapor extraction
SVOC = semivolatile organic compound
UV = ultraviolet
VOCs = volatile organic compounds
AOC = Area of Contamination

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
Capping	Low-permeability Cap	Clay Cap	Installation of a low-permeability cap over contaminated sediment areas to prevent exposure, isolate contaminants, and prevent localized groundwater transport through impacted sediment. Re-directed groundwater would need to be addressed. Clay cap installation would involve placement of low-permeability clay soil or bentonite aggregate, forming a low-permeability layer in conjunction with other cap components.	Effective for physically stabilizing source material and providing chemical isolation. Effective at directing groundwater away from impacted areas, but the diverted flow paths can be difficult to predict.	Technically implementable using standard cap placement methods. Addressing altered flow paths resulting from low-permeability surface may be difficult.	Moderate capital cost. Potentially moderate O&M cost depending on the design of the cap to resist wave erosion, or the installation of other features to minimize wave energy on the cap.	Low-permeability cap directing groundwater away from the capped area would likely not be desirable considering Site and adjacent site conditions. Not retained.
		Composite (Layered) Cap	Installation of a low-permeability cap over contaminated sediment to prevent exposure, isolate contaminants, and prevent localized groundwater transport through impacted sediment. Re-directed groundwater would need to be addressed. Composite cap may include a combination of permeable or low-permeability synthetic membranes, sand layers, and armoring.	Effective for physically stabilizing source material and providing chemical isolation. Effective at directing groundwater away from impacted areas, but the diverted flow paths can be difficult to predict.	Technically implementable using standard cap placement methods. Addressing altered flow paths resulting from low-permeability surface may be difficult.	Moderate capital cost. Potentially moderate O&M cost depending on the design of the cap to resist wave erosion, or the installation of other features to minimize wave energy on the cap.	Low-permeability cap directing groundwater away from the capped area would likely not be desirable considering Site and adjacent site conditions. Not retained.
	Conventional Cap	Sand Cap	Installation of clean sand cap over contaminated sediment to prevent exposure and isolate contaminants. Attenuation of impacted groundwater is limited to mixing that occurs within cap pore space and the adsorptive capacity of the sand cap. Armoring is used to prevent erosion and ensure cap longevity.	Effective for physically stabilizing source material and providing chemical isolation. Aquatic caps are designed using methods developed by the US Army Corps of Engineers.	Technically implementable using standard cap placement methods. Aquatic caps have been successfully constructed in multiple Puget Sound locations, and at aquatic sites across the country.	Moderate capital cost. Potentially moderate O&M cost depending on the design of the cap to resist wave erosion, or the installation of other features to minimize wave energy on the cap.	Common method to contain contaminated sediment. Retained.
	Amended/Reactive Cap	Amended Sand Cap	Installation of a cap consisting clean sand mixed with an amendment that is capable of adsorbing Site contaminants. Cap amendment materials could include granular organoclay to adsorb LNAPL and dissolved PAHs, or granular activated carbon to adsorb lighter hydrocarbon contaminants like BTEX compounds.	Effective for increasing adsorption of organic contaminants in groundwater and porewater in sediment, and for physically stabilizing source material.	Technically implementable using standard cap placement methods. Successfully implemented as the Interim Action at the Site in 2013. Amendment may reduce thickness of sand cap, which may be more acceptable to permitting agencies and could result in lower construction cost.	Moderate to high capital cost. Potentially moderate O&M cost depending on the design of the cap to resist wave erosion, or the installation of other features to minimize wave energy on the cap.	Effective, implementable and has been successfully used at Puget Sound locations. Contains contaminated sediment and provides enhanced adsorption of contaminants. Retained.
Sediment Removal	Dredging and Excavation	Mechanical Dredging	Conventional dredging techniques using a barge-mounted crane and bucket to remove contaminated sediment.	Commonly used and effective at removing impacted sediments. Pollution-prevention controls are necessary to reduce mobilization of contaminants during dredging as well as during re-handling and transport of contaminated sediment off-site. Residual contamination may be produced as part of dredging.	Technically implementable. Dredging is commonly used in the aquatic environment to remove impacted sediments. Permit requirements will need to be met, which can increase costs and duration. Residual production may require an additional remedy component (e.g., thin-layer placement or capping).	Moderate to high capital cost. Negligible O&M cost.	Potentially applicable in combination with other technologies such as capping in area where the impacted sediment cannot be completely removed. Retained.

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
Sediment Removal Continued	Dredging and Excavation Continued	Hydraulic Dredging	Sediment is agitated; pumps are used to remove the resulting mixture of water and sediment.	Most effective at removing soft sediment, although cutter head can be added to hydraulic train. Effectiveness reduced if debris is present; often requires initial mechanical dredging to address debris. Pollution-prevention controls are necessary to reduce mobilization of contaminants/produced residuals during dredging.	Technically implementable. Hydraulic dredging produces a large volume of water that must be treated and discharged to the sanitary sewer and/or Bellingham Bay. Sediment requires dewatering and possibly consolidation prior to disposal. Residual production may require an additional remedy component (e.g., thin-layer placement or capping).	Moderate to high capital cost. Negligible O&M cost.	Debris content in sediment would cause difficulties. Dewatering and water treatment requires large land-based facility. Not retained.
		Land-Based Excavation	Removal of sediment performed from the land at low tide using land-based earthwork equipment such as a backhoe. This technology may be used in conjunction with shoring/sheet pile walls and dewatering techniques in order to use land-based methods below ordinary high water or to extend work periods.	Commonly used and effective for removing sediments from intertidal areas. Pollution-prevention controls are necessary to reduce mobilization of contaminants during excavation as well as during re-handling and transport of contaminated sediment off-site. Less likely to produce residual contamination; exposed contaminated surfaces can be addressed through use of geotextile or thin-layer placement between work periods.	Technically implementable for sediment areas exposed during low tide or located in shallow areas where an excavator mounted on a barge could reach the sediments.	Moderate to high capital cost. Negligible O&M cost.	Expected to be effective removal method for intertidal sediments. Retained.
On-Site Dredged/ Excavated Material Management	On-Site Disposal	Nearshore Confined Aquatic Disposal (CAD)	Construction of disposal cells within the intertidal/shallow subtidal zone to contain dredged contaminated sediment. Disposal cells would be confined using standard capping methods.	Nearshore CADs have been shown to be environmentally protective in the Puget Sound.	Technically implementable, but likely administratively difficult due to siting and permitting restrictions. Long-term monitoring and mitigation requirements would likely be significant.	Moderate to high capital cost. Moderate O&M cost.	Siting and permitting a nearshore CAD in Bellingham would be extremely difficult. Not retained.
	Managed On-site in Upland	Consolidation within Upland AOC	Sediment would be consolidated within the AOC and capped with a low-permeability cap.	Effective method if managed to be protective of upland exposure scenarios. Sediment may require strengthening to be geotechnically suitable for use as fill.	Technically implementable. Administrative approvals required to manage sediment for consolidation within the upland AOC. This could be compatible with grading anticipated for future development of the Site into a park, which may require a significant additional quantity of fill.	Moderate capital cost. Low O&M cost. Cost to move, consolidate, and regrade sediment would offset future park redevelopment cost to import fill for grading.	Marine sediment is expected to be acceptable for consolidation within upland areas of the AOC, providing a cost effective method for management of excavated sediment. Retained.

TABLE 9-10 REMEDIAL TECHNOLOGY SCREENING - SEDIMENT

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
Off-site Dredged/ Excavated Material Management Continued	Off-Site Disposal	Landfill Disposal	Disposal of contaminated sediment at a RCRA-permitted, off-site upland landfill. Sediment may require dewatering or consolidation before transport and disposal.	Effective for contaminant groups that are identified as acceptable by the individual disposal facility.	Technically implementable. Impacted sediment must be profiled to verify that the materials meet land disposal restrictions.	Moderate to high capital cost. Negligible O&M cost.	Common disposal option for excavated and/or dredged sediments, where appropriate. Retained.
	Off-Site Reuse	Beneficial Reuse	Dredged/excavated materials are recycled and re-used as capping material or for other applications. Sediments targeted for reuse would be required to meet applicable standards identified for the proposed reuse.	On-site treatment would be required before transporting off-site for reuse. Effective if treated concentrations are protective of exposure at reuse location.	Treatment requirements, presence of debris (wood, brick, other fill) in sediment and other administrative restrictions would likely limit potential reuse. Currently, no known reuse opportunities exist.	Moderate capital cost. Negligible O&M cost. Capital cost depends on pre-treatment requirements and proximity of reuse location.	Treatment requirements, presence of debris (wood, brick, other fill) in sediment and other administrative restrictions would likely limit potential reuse. Not retained.
In Situ Sediment Treatment	Chemical Treatment	Electro-Chemical Reduction Technology (ECRT)	Treatment is accomplished by the mineralization of organic contaminants through the Electro-Chemical Geo-Oxidation (ECGO) process.	Reaction rates are inversely proportional to grain size, such that ECRTs remediate finer-grained materials typically found at contaminated sediment sites faster compared to coarse-grained sediment. Not proven effective for PAHs.	Technically implementable. The pilot study at the Georgia Pacific Log Yard indicated multiple operational issues associated with installing anodic and cathodic electrodes in the sediment.	High capital and O&M costs.	High uncertainties associated with this innovative process and unproven effectiveness for most Site contaminants. Not retained.
		Amendment Mixing	Materials commonly used for amended sediment caps such as organoclay or granular activated carbon, are mixed *in situ* with contaminated sediment rather than being placed as a cap.	Can be effective if mixing does not exacerbate contaminant mobility. Site sediment conditions suggest mixing an amendment into surface sediment will potentially cause contaminant mobilization.	Difficult to implement due to tide cycles and uncertainties about contaminant mobility. Not expected to be acceptable to regulators, reducing administrative implementability.	Moderate capital cost. Low O&M cost.	Site conditions would make this process difficult to perform without potentially mobilizing contaminants. Not retained.
Natural Recovery Processes	Sedimentation/ Deposition	Monitored Natural Recovery (MNR)	Reduction of toxicity and bioavailability of contaminants through natural deposition of clean sediment, physical and biological mixing and biodegradation. Monitoring in the form of periodic sediment sampling is performed to verify natural recovery occurs within a reasonable time frame.	Effectiveness limited to areas of low contaminant concentrations/low risk and high sedimentation rates of relatively clean sediment. Long-term risk reduction occurs incrementally over a 10-year period.	Technically implementable. Monitoring would be required to confirm recovery rate.	Negligible capital cost. Moderate O&M cost.	Common method for low-level sediment contaminants. Currently planned with regulatory approval at adjacent sites. Retained.

General Response Action	Type of Remedial Technology	Process Option (Specific Remedial Technology)	Description of Remedial Technology	Effectiveness of Remedial Technology	Implementability of Remedial Technology	Relative Cost of Remedial Technology	Screening Results
Natural Recovery Processes Continued	Sedimentation/ Deposition Continued	Enhanced Natural Recovery (ENR)	Natural sedimentation is enhanced by placement of a thin layer of clean sand. Technology relies on natural mixing processes (e.g., bioturbation) to reduce contaminant levels over time. Similar to MNR, monitoring is performed to confirm performance and rate of recovery.	Initial placement of sediment typically equivalent to thickness of biologically active zone, effectively reducing risks in the short-term. Some movement/mixing is expected over time that achieves long-term reduction in surface sediment concentrations. Not effective in areas where sediment may be eroded or mobilized via currents, vessel activity or other physical means.	Feasibility depends on the specific physical environment and constituent concentrations. Allows sensitive habitats such as those with significant vegetation or shellfish beds to be preserved; however, may require several thin-layer placements to minimize impacts. Has been used throughout Puget Sound.	Moderate capital and O&M costs.	Common method for low-level sediment contaminants. Currently approved for use at adjacent sites. Retained.
Institutional Controls	Land Use Restrictions	Environmental covenants	Legal restrictions associated with future land use and activities (e.g., development, construction, etc.); may also be used to specify long-term maintenance requirements of remediation systems.	Not effective for remediating contaminants. Can be effective at reducing risks and maintaining integrity of a remedy.	Requires implementing agency, responsible parties. Based on property law, which can be complicated.	Low capital cost. O&M cost may vary depending on requirements of the environmental covenant.	May be required to maintain integrity of the sediment remedy. Retained.
		Waterway Use Restrictions	Restrictions on activities such as dredging, boat anchoring, navigation or other activities to prevent physical damage to *in situ* remedies (e.g., caps).	Not effective for remediating contaminants. Enforcement would be required for restrictions to be effective.	Technically implementable but administratively more difficult if channel reauthorization/ deauthorization is necessary. Requires an implementing agency. Some nearshore restrictions may not be compatible with park development plans.	Low capital cost. Negligible O&M cost.	Some restrictions (i.e., dredging, anchoring) are potentially applicable in combination with other technologies. Retained.
	Access Restrictions	Fencing and Warning Signage	Placement of fencing and warning signs to prevent beach access and inform the public regarding health risks.	Not effective for remediating contaminants. Enforcement would be required for restrictions to be effective.	Fencing and restricting access is incompatible with proposed plans to develop the Site as a park.	Low capital cost. Negligible O&M cost.	Not consistent with proposed future land use. Not retained.
	Education/ Information	Consumption Advisories	Advisories to indicate that consumption of fish and shellfish in the impacted area may pose a health risk.	Not effective for remediating contaminants. Expected to have highly variable effectiveness in preventing consumption and reducing risk.	Administratively implementable but not enforceable. Conflicts with Tribal treaty rights. Not expected to be acceptable as an alternative to active remediation.	Low capital cost. Negligible O&M cost.	May be required to address regional issues, but is not expected to be acceptable to address Site contaminants. Not retained.

Notes:

BTEX = benzene, toluene, ethylbenzene and xylene
HDPE = high-density polyethylene
O&M = operation and maintenance
PAHs = polycyclic aromatic hydrocarbons
SVE = soil vapor extraction
SVOC = semivolatile organic compound
UV = ultraviolet
VOCs = volatile organic compounds
AOC = Area of Contamination

Alternative	Objective	Soil Components	LNAPL Components	Groundwater Components
U1 Passive LNAPL Removal, Vertical Shoreline Barrier, Upland Cap	Provide environmental protection with minimal disturbance utilizing LNAPL removal and off-site incineration, attenuation of groundwater flow path, and containment.	Containment of upland contaminated soil to prevent direct contact and reduce stormwater infiltration: • Low-permeability cap. Passive soil vapor collection and venting as needed as part of cap system. • Stormwater collection, treatment, and discharge to reduce infiltration. Improved upgradient drainage controls to reduce stormwater infiltration along the BNSF right-of-way. • Any soil excavated to implement remedy would be consolidated within the upland AOC under the low-permeability cap. • Re-contour and cap shoreline bank to transition between upland remedy and sediment remedy. • Institutional controls to protect the integrity of the remedy.	Passive removal of LNAPL by normally accepted engineering practices, LNAPL incineration off-site and LNAPL containment: • Install low-permeability vertical barrier (driven sheet pile, trenched geomembrane, or other methods) to approximately 5 feet below the bottom of smear zone. • Recover mobile LNAPL to the maximum extent practicable using oil-only skimming pumps in recovery wells located immediately upgradient of low-permeability wall.	Reduction of upland contaminant source and groundwater flux: • Upland low-permeability cap will reduce infiltration and stormwater recharge to groundwater. • LNAPL removal will reduce groundwater contaminant source. • Low-permeability vertical barrier will increase attenuation by lengthening groundwater flow path and rerouting flow through deeper, cleaner soil. • Institutional controls to protect the integrity of the remedy and provide for long-term O&M and monitoring requirements.
U2 PRB, Passive LNAPL Removal, Upland Cap	Provide environmental protection beyond that offered in U1 by including groundwater treatment.	Same as U1.	*In situ* groundwater treatment at shoreline using PRB with passive LNAPL removal at shoreline directly upgradient of PRB: • PRB installed at depths necessary to intercept contaminated groundwater using granular organoclay as the reactive media to adsorb LNAPL and dissolved organic contaminants. Refined design could potentially include funnel and gate configuration whereby side (funnel) sections would consist of low-permeability wall sections (sheet pile or a trenched slurry wall) designed to direct groundwater/LNAPL toward a central permeable reactive section (gate). • Recover LNAPL to the maximum extent practicable using oil-only skimming pumps in recovery wells situated in the areas of potentially mobile LNAPL near the shoreline. • Institutional controls to protect the integrity of the remedy and provide for long-term O&M and monitoring requirements.	
U3a Nearshore *In Situ* Soil Solidification, Upland Cap	Provide environmental protection beyond that offered in U1 or U2 by immobilizing contaminants in soil and where LNAPL is potentially mobile at locations of greatest risk (near the shoreline).	*In situ* solidification of contaminated soil in area of potentially mobile LNAPL to isolate contaminants and reduce permeability of saturated soil at locations where contaminated soil poses the greatest risk: • Excavate and stockpile vadose zone soil in areas where underlying smear zone soil will be solidified. Any soil excavated to implement remedy would be consolidated within the upland AOC. Any landfill waste or debris in the area to be treated would be transported for off-site disposal as hazardous waste. • Perform *in situ* solidification of soil at locations and depths where potentially mobile LNAPL and contaminated soil pose the greatest risk. This generally includes, at a minimum, the area adjacent to the shoreline where LNAPL is potentially mobile. • Solidification of soil will utilize appropriate reagents identified by treatability testing to inhibit contaminant leaching. Reagents likely to consist of organoclay, portland cement and other additives. • Low-permeability cap with passive soil vapor collection and venting as needed and stormwater collection, treatment, and discharge, similar to U1 and U2 except that the upland cap over the solidified areas may be less robust compared to the cap in areas that have not been treated. • Institutional controls to protect the integrity of the remedy.		*In situ* solidification with long-term monitoring: • Soil solidification will reduce contaminant leaching from soil to groundwater and from LNAPL into groundwater, and enhance attenuation by lengthening groundwater flow path and rerouting flow through deeper, less contaminated soil. • Upland low-permeability cap will reduce infiltration and stormwater recharge to groundwater. • Institutional controls to protect the integrity of the remedy and provide for long-term monitoring requirements. .
U3b Expanded *In Situ* Soil Solidification and Stabilization, Upland Cap	Provide environmental protection beyond that offered in U3a by immobilizing contaminants across a broader footprint.	Same as Alternative U3a except that the footprint of *in situ* treatment is expanded to include areas inland of potentially mobile LNAPL, where soil has been heavily impacted by past LNAPL migration. Soil treatment includes *in situ* solidification closest to the shoreline and *in situ* stabilization further inland. *In situ* stabilization by organoclay adsorption is proposed further inland because the organoclay will sorb dissolved-phase contaminants in areas of residual LNAPL without precluding groundwater flow. The footprints of soil solidification and stabilization encompass the areas where IHS concentrations in soil exceed screening levels protective of groundwater _and_ where IHS concentrations in groundwater exceed 10 times their respective screening levels. The footprint of these remedial action components would be refined, if needed, during design.		Same as Alternative U3a except that the expanded footprint of *in situ* soil treatment inhibits contaminants into groundwater (solidification) across a broader footprint and treats groundwater at locations further upgradient (stabilization).

TABLE 9-11. SUMMARY OF CLEANUP ACTION ALTERNATIVES - UPLAND

Alternative	Objective	Soil Components	LNAPL Components	Groundwater Components
U3c Soil Removal, *In Situ* Soil Solidification and Stabilization, Upland Cap	Provide environmental protection similar to U3b but with excavation of soil with potentially mobile LNAPL near the shoreline.	Same as Alternative U3b except that upland smear zone soil and LNAPL in the area of potentially mobile LNAPL will be removed using conventional means: • Removed material would primarily be consolidated within the upland AOC within the footprint of the broader *in situ* solidification area, inland from where it is excavated. Oversize soil, landfill waste or debris that cannot be consolidated within the AOC would be transported off-site to a permitted treatment/disposal facility. Excavated areas would be backfilled to pre-construction (present day) grade with imported fill. • Remaining upland components are the same as Alternative U3b.		Same as Alternative U3b.
U4 Complete Removal	Remove all contaminated soil.	Removal and off-site treatment/disposal of LNAPL and contaminated soil exceeding cleanup levels to the maximum extent practical: • Contaminated upland soil will be excavated using conventional means. • Landfill waste within limits of contaminated soil would also be excavated. • LNAPL would also be removed in conjunction with soil excavation. • Excavated material would be disposed off-site at a permitted treatment/disposal facility. • Excavated areas would be backfilled to pre-construction (present day) grade using imported fill.		Long-term monitoring utilizing a network of upland monitoring wells to evaluate natural degradation of contaminants following soil and LNAPL removal. MNA would be included if groundwater contaminants exceed cleanup levels but for the purpose of FS, MNA is not assumed to be necessary given the extensive degree of excavation assumed for Alternative U4.

Notes:

The following common elements are part of each of the alternatives: remove existing sheet pile barrier, UST, concrete surge tank, associated underground product piping and remove remnants of the former Haley facility stormwater system to the extent needed to yield a protective remedy.

PRB= permeable reactive barrier
MNA = monitored natural attenuation

TABLE 9-12. SUMMARY OF CLEANUP ACTION ALTERNATIVES—SEDIMENT

Alternative	Key Concept	Cleanup Action Components
S1 Containment	Confine sediment exceeding SMS benthic toxicity criteria with amended cap to achieve least short-term risk associated with excavation/dredging; rely on enhanced natural recovery (ENR) in remaining shallow subtidal zone where bioaccumulative chemical exceedances are moderate; monitor for natural recovery in deeper subtidal zone where sedimentation rate is sufficient to achieve bioaccumulative cleanup goals.	• Remove debris (e.g., pilings) in upper intertidal zone (0.6 acre) and cap with 2 feet of amended sand to confine LNAPL-impacted sediment and attenuate contaminant flux. • Cap with 2 feet of unamended sand in remaining intertidal/shallow subtidal area exhibiting benthic invertebrate toxicity (1.1 acre). • Place 6 inches of sand in deeper subtidal area where chemical concentrations exceeding bioaccumulative CULs will not likely recover in a reasonable time frame (i.e., ENR). • Rely on monitored natural recovery (MNR) in other subtidal areas with lower (<2.5x CULs) chemical concentrations[1]. • Protect all capped areas with armor material plus habitat material. • Institutional controls to assure protection of remedy, as appropriate. • Long-term monitoring to gauge remedy performance.
S2 Upper Intertidal Sediment Removal and Amended Cap	Sediment/source (smear zone) removal in the upper intertidal areas sufficient to utilize an amended cap, with the least volume removal compared to other alternatives. Sediment exceeding SMS benthic toxicity criteria bayward of excavation is capped in-place. Remainder of alternative same as S1.	• Remove 3 feet of sediment and debris and cap with 2 feet of amended sand (0.6 acre) transitioning to the north and south to conventional sand cap in upper intertidal area (total capping of 1.0 acre), primarily to confine LNAPL-impacted sediment and to attenuate contaminant flux. • Consolidate excavated sediment in upland portion of AOC under low-permeability cap. • Cap remaining lower intertidal/shallow subtidal area (0.7 acre) exhibiting benthic invertebrate toxicity with 2 feet of unamended sand. • Place 6 inches of sand in deeper subtidal area where chemical concentrations exceeding bioaccumulative CULs will not likely recover in a reasonable time frame (i.e., ENR). • Rely on MNR in other subtidal areas with lower (<2.5x CULs) chemical concentrations[1]. • Protect all capped areas with armor material plus habitat material. • Institutional controls to assure protection of remedy, as appropriate. • Long-term monitoring to gauge remedy performance.
S3 Upper Intertidal Sediment Removal and Sand Cap	Sediment/source (smear zone) removal in the upper intertidal areas sufficient to utilize an unamended cap; quantity of excavated sediment in this alternative is larger than quantity excavated for Alternative S2. Sediment exceeding SMS benthic toxicity criteria bayward of excavation is capped in-place. Remainder of alternative same as S1.	• Remove upper intertidal contaminated sediment, including smear zone to the extent practicable. • Place 4 feet of unamended sand to confine remaining contaminated sediment and attenuate contaminant flux (removal and capping area of 1.0 acre). • Consolidate excavated sediment in upland portion of AOC under cap. • Cap remaining intertidal/shallow subtidal area (0.7 acre) exhibiting benthic invertebrate toxicity with 2 feet of unamended sand. • Place 6 inches of sand in deeper subtidal area where chemical concentrations exceeding bioaccumulative CULs will not likely recover in a reasonable time frame (i.e., ENR). • Rely on MNR in other subtidal areas with lower (<2.5x CULs) chemical concentrations[1]. • Protect all capped areas with armor material plus habitat material. • Institutional controls to assure protection of remedy, as appropriate. • Long-term monitoring to gauge remedy performance.
S4 Intertidal and Shallow Subtidal Removal and Amended Cap	Remove contaminated sediment exceeding SMS benthic toxicity criteria and cap to maintain current bathymetry. Expand ENR into shallower water (lower intertidal) at locations where eelgrass beds exist. Remainder of alternative same as S1.	• Remove 3 feet of intertidal and shallow subtidal sediment and debris except in areas with existing eelgrass beds. • Consolidate excavated sediment within upland portion of AOC under cap. • Cap upper intertidal excavation area with 2 feet of amended sand to confine remaining LNAPL-impacted sediment and attenuate contaminant flux similar to Alternative S2. • Cap lower intertidal/shallow subtidal excavated area with 2 feet of unamended sand (0.6 acre) to physically isolate remaining area of benthic invertebrate toxicity. • Place 6 inches of sand in eelgrass areas and deeper subtidal area where chemical concentrations exceeding bioaccumulative CULs will not likely recover in a reasonable time frame (i.e., ENR). • Rely on MNR in other subtidal areas with lower (<2.5x CULs) chemical concentrations[1]. • Protect all capped areas with armor material plus habitat material with no resulting change in bathymetry/elevation or grade. • Institutional controls to assure protection of remedy, as appropriate. • Long-term monitoring to gauge remedy performance.

TABLE 9-12. SUMMARY OF CLEANUP ACTION ALTERNATIVES—SEDIMENT

Alternative	Key Concept	Cleanup Action Components
S5a and S5b Complete Removal	Remove all sediment exceeding CULs protective of SMS benthic toxicity and bioaccumulative effects, excluding subtidal area where ENR or MNR is expected to achieve CULs in surface sediment.	• Remove all sediment exceeding CULs (and debris) in intertidal and shallow subtidal areas and backfill with sand, armor material, and habitat material with no subsequent change in bathymetry/elevation or grade (i.e., preserve habitat). • Alternative S5a: Consolidate as much excavated sediment as possible within the upland AOC • Alternative S5b: Transport all excavated sediment off site for treatment/disposal as solid or hazardous waste in accordance with State regulations. • Place 6 inches of sand in remaining subtidal area where chemical concentrations will not likely recover in a reasonable time frame (i.e., ENR). • Rely on MNR in other subtidal areas with lower (<2.5x CULs) chemical concentrations[1]. • Institutional controls to assure protection of remedy, as appropriate. • Long-term monitoring to gauge remedy performance.

Notes:

[1] Full extent of ENR and MNR will be refined after completion of the FS based on additional sediment analytical data that will likely be obtained to further evaluate concentrations of bioaccumulative compounds in the ENR/MNR areas, further evaluation of the anticipated effect of natural recovery in the ENR/MNR areas, and interpretation of the Site data on a surface-area weighted average concentration (SWAC) basis.

AOC = Area of Contamination
CULs = cleanup levels
LNAPL = light non-aqueous phase liquid

TABLE 9-13. SUMMARY OF MTCA REMEDIAL ALTERNATIVES EVALUATION – UPLAND

Alternative, Description and Evaluation Criteria	Alternative U1 Passive LNAPL Removal, Vertical Shoreline Barrier, Upland Cap	Alternative U2 PRB, Passive LNAPL Removal, Upland Cap	Alternative U3a Nearshore *In situ* Soil Solidification, Upland Cap	Alternative U3b Expanded *In situ* Soil Solidification and Stabilization, Upland Cap	Alternative U3c Soil Removal, *In situ* Soil Solidification and Stabilization, Upland Cap	Alternative U4 Complete Removal
1. Meets Remedial Action Objectives	Yes	Yes	Yes	Yes	Yes	Yes
2. Compliance with MTCA Threshold Criteria						
Protection of Human Health and the Environment	Yes - Alternative would protect human health and the environment through a combination of removal, containment and institutional controls.	Yes - Alternative would protect human health and the environment through a combination of removal, treatment, containment, and institutional controls.	Yes - Alternative would protect human health and the environment through a combination of treatment, containment, and institutional controls.	Yes - Alternative would protect human health and the environment through a combination of treatment, containment, and institutional controls.	Yes - Alternative would protect human health and the environment through a combination of removal, treatment, containment and institutional controls.	Yes - Alternative would protect human health and the environment through removal.
Compliance With Cleanup Standards	Yes - Alternative is expected to comply with cleanup standards. This alternative utilizes LNAPL removal, modification of the groundwater flow path to reduce migration of contaminants to marine environment. Containment (cap) and institutional controls prevent direct exposure to contaminants exceeding cleanup levels. Compliance would rely on long-term operation and maintenance of removal and containment systems and institutional controls.	Yes - Alternative is expected to comply with cleanup standards. This alternative utilizes *in situ* treatment and LNAPL removal to reduce migration of contaminants to marine environment. Containment (cap) and institutional controls are also used to prevent direct exposure to upland contaminants exceeding cleanup levels. Compliance would rely on long-term monitoring and maintenance of institutional controls.	Yes - Alternative is expected to comply with cleanup standards. This alternative utilizes *in situ* treatment to solidify the most highly concentrated and mobile contaminants closest to the Site sediment unit. Containment (cap) and institutional controls are used to prevent direct exposure to remaining contaminants exceeding cleanup levels. Compliance would rely on long-term monitoring and maintenance of institutional controls.	Yes - Alternative is expected to comply with cleanup standards. This alternative utilizes *in situ* treatment to solidify/stabilize the majority of contaminated upland soil. Containment (cap) and institutional controls are used to prevent direct exposure to remaining contaminants exceeding cleanup levels. Compliance would rely on long-term monitoring and maintenance of institutional controls.	Yes - Alternative is expected to comply with cleanup standards. This alternative utilizes removal and *in situ* treatment to solidify/stabilize the majority of contaminated upland soil. Containment (cap) and institutional controls are used to prevent direct exposure to remaining contaminants exceeding cleanup levels. Compliance would rely on long-term monitoring and maintenance of institutional controls.	Yes - Alternative is expected to comply with cleanup standards through removal and off-site treatment/disposal of all soil with contaminant concentrations greater than cleanup levels.
Compliance With Applicable State and Federal Regulations	Yes	Yes	Yes	Yes	Yes	Yes
Provision for Compliance Monitoring	Yes - Alternative includes provisions for compliance monitoring.	Yes - Alternative includes provisions for compliance monitoring.	Yes - Alternative includes provisions for compliance monitoring.	Yes - Alternative includes provisions for compliance monitoring.	Yes - Alternative includes provisions for compliance monitoring.	Yes - Alternative includes provisions for compliance monitoring.
3. Restoration Time Frame (WAC 173-340-360[4])	Exposure pathways will be eliminated when construction of the remedy is completed. Contaminant removal and reduction will continue as part of ongoing LNAPL removal operations and natural degradation processes. Groundwater monitoring will confirm remedy effectiveness. Future use of upland as a City park will ensure that institutional controls are maintained and reliable. Estimated restoration time frame for this alternative including design, permitting and construction of the remedy is 2 to 3 years and is considered reasonable.	Same as Alternative U1. Restoration time frame is considered reasonable.	Exposure pathways will be eliminated when construction of the remedy is completed. Groundwater monitoring will confirm remedy effectiveness. Future use of upland as a City park will ensure that institutional controls are maintained and reliable. Estimated restoration time frame for this alternative including treatability testing, design, permitting and construction of the remedy is 2 to 3 years and is considered reasonable.	Exposure pathways will be eliminated when construction of the remedy is completed. Construction duration for this Alternative U3b is 1 year longer than Alternative U3a. Groundwater monitoring will confirm remedy effectiveness. Future use of upland as a City park will ensure that institutional controls are maintained and reliable. Estimated restoration time frame for this alternative including treatability testing, design, permitting and construction of the remedy is 3 to 4 years and is considered reasonable.	Same as Alternative U3b. Restoration time frame is considered reasonable.	Exposure pathways will be eliminated when construction of the remedy is completed. Groundwater monitoring will confirm remedy effectiveness. Estimated restoration time frame for this alternative including design, permitting and construction of the remedy is 2 to 3 years and is considered reasonable.

Alternative, Description and Evaluation Criteria	Alternative U1 Passive LNAPL Removal, Vertical Shoreline Barrier, Upland Cap	Alternative U2 PRB, Passive LNAPL Removal, Upland Cap	Alternative U3a Nearshore *In situ* Soil Solidification, Upland Cap	Alternative U3b Expanded *In situ* Soil Solidification and Stabilization, Upland Cap	Alternative U3c Soil Removal, *In situ* Soil Solidification and Stabilization, Upland Cap	Alternative U4 Complete Removal
4. Disproportionate Cost Analysis Relative Benefits Score for MTCA Criteria 173-340-360(3)(f) (Scored from 1 =Low to 10 = High)						
Protectiveness: *"Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternatives and improvement of the overall environmental quality."*	Score = 4 Achieves a moderately low level of overall protectiveness relative to other alternatives due to the reliance on containment technologies. Overall protectiveness for this alternative derives from reducing existing risks primarily through containment in the form of the upland cap and vertical LNAPL containment wall, as well as through LNAPL removal and modification of the groundwater flow path. The time needed to reduce risk to acceptable levels is relatively short once the containment systems are constructed. Implementation would not adversely affect on-site or off-site risks if it is managed in accordance with appropriate design and permitting requirements and construction best management practices (BMPs).	Score = 5 Achieves a moderate level of overall protectiveness relative to other alternatives; slightly higher overall protectiveness than Alternative U1 because dissolved-phase contaminant treatment is achieved in groundwater through the vertical reactive barrier wall adsorption. Protectiveness for this alternative derives from risk reduction provided by the LNAPL removal, groundwater treatment by the PRB, and containment system (cap). Monitoring would be used to evaluate the long-term effectiveness of reactive material in the PRB. Implementation would not adversely affect on-site or off-site risks if it is managed in accordance with appropriate design and permitting requirements.	Score = 6 Achieves a higher level of overall protectiveness than Alternatives U1 and U2 by immobilizing contaminants with greatest concentrations and potential mobility; upland cap reduces groundwater flux and prevents direct contact. The time needed to eliminate risk is contingent on the duration for solidification to take effect, which is relatively short-term. Implementation would not adversely affect on-site or off-site risks if it is managed in accordance with appropriate design and permitting requirements.	Score = 7 Achieves a slightly higher level of protectiveness than Alternative 3a due to the expanded footprint of solidification and stabilization. Implementation would not adversely affect on-site or off-site risks if it is managed in accordance with appropriate design and permitting requirements.	Score = 8 Slightly more protective than Alternative 3b as a result of removing potentially mobile LNAPL and soil near the shoreline, and backfilling the area with clean fill. Score is moderated because of the higher degree of on-site risks posed by the added handling steps of excavating soil with LNAPL and consolidating it within the upland AOC.	Score = 9 Achieves a high level of overall protectiveness through removal of LNAPL and contaminants in soil and transporting the soil off-site for treatment/disposal. However, score is moderated because implementation requires significant management controls to address potential on-site and off-site risks during soil excavation and transport of contaminated soil off-site for treatment/disposal.
Permanence: *"The degree to which the alternative permanently reduces the toxicity, mobility or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree or irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated."*	Score = 3 Achieves a moderately low level of permanence relative to other alternatives. Reduction of contaminant mobility is addressed through containment system, reduction of volume is addressed through LNAPL removal reduction of toxicity is through off-site treatment by incineration of recovered LNAPL.	Score = 4 Achieves a moderate level of permanence; slightly higher degree of permanence than Alternative U1 because of the added reduction of contamination mobility through adsorption (treatment) within the reactive wall material. Alternative reduces toxicity of hazardous substances through off-site treatment by incineration of recovered LNAPL.	Score = 6 Achieves a moderate level of permanence through solidifying the potentially mobile LNAPL and reducing hazardous substance releases to groundwater in the treatment area. The solidification treatment is permanent and results in a greater reduction in contaminant mobility than Alternatives U1 and U2 because the area of potentially mobile LNAPL is treated whereas Alternatives U1 and U2 rely on either a vertical barrier or vertical treatment wall at the shoreline.	Score = 7 Achieves a moderately high level of permanence, slightly higher than Alternative U3a due to the larger *in situ* treatment footprint.	Score = 8 Achieves a moderately high level of permanence, slightly higher than Alternative U3b as a result of removing soil in the area of potential LNAPL mobility near the shoreline, and backfilling the area with clean fill.	Score = 9 Achieves a high level of permanent reduction of mass, toxicity, and mobility of hazardous substances at the Site through removal and off-site treatment and/or disposal; score is higher than Alternative U3b where the excavated soil is consolidated on-site beneath the upland cap.

TABLE 9-13. SUMMARY OF MTCA REMEDIAL ALTERNATIVES EVALUATION – UPLAND

Alternative, Description and Evaluation Criteria	**Alternative U1** **Passive LNAPL Removal, Vertical Shoreline Barrier, Upland Cap**	**Alternative U2** **PRB, Passive LNAPL Removal, Upland Cap**	**Alternative U3a** **Nearshore *In situ* Soil Solidification, Upland Cap**	**Alternative U3b** **Expanded *In situ* Soil Solidification and Stabilization, Upland Cap**	**Alternative U3c** **Soil Removal, *In situ* Soil Solidification and Stabilization, Upland Cap**	**Alternative U4** **Complete Removal**
Long-Term Effectiveness: *"Includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The following types of cleanup action components may be used as a guide, in descending order, when assessing the relative degree of long-term effectiveness: reuse or recycling; destruction or detoxification; immobilization or solidification; on-site or off-site disposal in an engineered, lined and monitored facility; on-site isolation or containment with attendant engineering controls; and institutional controls and monitoring."*	Score = 3 Achieves a moderately low degree of long-term effectiveness because hazardous substances remain on-site and because LNAPL removal system and upland cap require routine monitoring and maintenance for effective long-term performance. Shoreline LNAPL containment barrier would be designed for long-term effectiveness.	Score = 4 Achieves a slightly higher degree of long-term effectiveness than Alternative U1 due to the addition of groundwater treatment through the PRB technology. The score for this criteria is also moderated by the consideration for potentially needing replenishment of PRB adsorptive material.	Score = 7 Achieves a considerably higher degree of long-term effectiveness compared to Alternatives U1 and U2 based on the use of irreversible solidification (immobilization) in the area of potentially mobile LNAPL. Score also reflects the use of immobilization, which has a higher relative MTCA preference than on-site isolation or containment.	Score = 8 Achieves a slightly higher degree of long-term effectiveness than Alternative U3a because a larger area is treated through solidification and stabilization. Score also reflects the higher preference for immobilization over on-site isolation or containment.	Score = 9 Achieves a higher degree of long-term effectiveness than Alternatives U3a and U3b because in addition to *in situ* treatment, soil with potentially mobile LNAPL is removed from the shoreline.	Score = 10 Achieves the highest degree of certainty and long-term effectiveness through removal of hazardous substances from the Site to the greatest degree feasible and the consideration of the high level of contaminant destruction resulting from the required treatment by incineration.
Management of Short-Term Risks: *"The risk to human health and the environment associated with the alternative during construction and implementation, and the effectiveness of measures that will be taken to manage such risks."*	Score = 9 Least short-term risk; risks are primarily related to construction of vertical shoreline barrier. Risks can be effectively managed through conventional construction means and methods.	Score = 7 Short-term risks are primarily related to PRB installation. Most short-term construction risks can be effectively managed through conventional construction means and methods. Some of the construction methods for PRB installation may result in a short-term (temporary) risk of contaminant mobilization.	Score = 7 Similar score as Alternative U2 for this criteria. The potential construction risks for this alternative are associated with use and handling of solidification chemicals. Construction risks can be mitigated through safety protocols established in design and permitting.	Score = 6 Score is lower than Alternative U3a because more extensive solidification and stabilization is performed during construction of the remedy. Construction risks can be mitigated through safety protocols established in design and permitting.	Score = 5 Score is lower than Alternatives U3a and U3b due to higher relative short term risk since construction is more extensive (removal and consolidation). Construction risks are mitigated through safety protocols established in design and permitting.	Score = 3 Highest short-term risk of all the alternatives as a result of construction including excavating a large quantity of contaminated soil, shoring and dewatering. Short-term risks also posed by the large number of truck or rail trips required to transport contaminated soil to off-site facilities. However, these construction and transportation methods are commonly used on similar projects and the risks are mitigated through safety protocols established in design and permitting.

TABLE 9-13. SUMMARY OF MTCA REMEDIAL ALTERNATIVES EVALUATION – UPLAND

Alternative, Description and Evaluation Criteria	Alternative U1 Passive LNAPL Removal, Vertical Shoreline Barrier, Upland Cap	Alternative U2 PRB, Passive LNAPL Removal, Upland Cap	Alternative U3a Nearshore *In situ* Soil Solidification, Upland Cap	Alternative U3b Expanded *In situ* Soil Solidification and Stabilization, Upland Cap	Alternative U3c Soil Removal, *In situ* Soil Solidification and Stabilization, Upland Cap	Alternative U4 Complete Removal
Technical and Administrative Implementability: *"Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions."*	Score = 8 Alternative offers a high level of technical and administrative implementability because technologies utilized are relatively easily implemented and have already been utilized at the Site. Score is moderated because LNAPL skimming requires regular maintenance during operational period.	Score = 6 Degree of technical and administrative implementability is lower than most other alternatives. Although PRB technologies are proven and are expected to be implementable at the Site, this technology requires testing to demonstrate treatability and establish design parameters. The design, future monitoring and maintenance of the PRB would need to consider future use of the Site as a park and poses greater relative implementability challenges than Alternatives U3a, U3b and U3c in this regard.	Score = 8 Degree of technical and administrative implementability for this alternatives is higher than Alternative U2 because *in situ* solidification at similar sites has been demonstrated to a greater degree. Implementation requires testing to ensure treatability and to develop design parameters.	Score = 7 Achieves a slightly lower degree of technical and administrative implementability compared to Alternative U3a based on the significantly larger footprint of solidification and stabilization and use of a second treatment method (stabilization).	Score = 6 Slightly lower implementability score than Alternative U3b due to the addition of soil removal and consolidation within the upland cap.	Score = 5 Lower relative score because soil removal is extensive and requires appropriate controls to perform excavation without releasing contaminants to other areas of the Site.
Consideration of Public Concerns: *"Whether the community has concerns regarding the alternative and, if so, the extent to which the alternative addresses those concerns. This process includes concerns from individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge of the site."*	Score = 3 The extent to which this alternative addresses public concerns is presumed to be moderately low, based on public input for nearby projects including the Cornwall Site, because the alternative relies on containment systems rather than removal or treatment. Long-term City ownership of the Site provides assurance that containment will be maintained in the future.	Score = 4 Public concerns are presumed to be addressed to a slightly higher degree because this alternative incorporates groundwater treatment. .	Score = 5 Public concerns are presumed to be addressed to a greater degree for this alternative due to the incorporation of *in situ* treatment of the most highly contaminated soil in addition to the containment technologies.	Score = 6 Higher than Alternative U3a because a larger area of the upland is treated *in situ*.	Score = 7 Public concerns are presumed to be addressed to an even greater degree for this alternative compared to Alternatives U3a and U3b because areas of potentially mobile LNAPL at the shoreline are removed from the shoreline location. However, the score is moderated somewhat due to possible public concerns about the consolidation of excavated material within the upland AOC.	Score = 9 Addresses presumed public preferences for contaminant removal with no contaminated soil remaining on-site and no reliance on institutional controls. Score is moderated based on potential public concerns regarding high cost, the large amount of truck or rail traffic to transport waste to off-site disposal facilities and the resulting local disturbances.

Notes:

AOC = area of contamination

LNAPL = light non-aqueous phase liquid

MTCA = Model Toxics Control Act

PRB = permeable reactive barrier

TABLE 9-14. SUMMARY OF MTCA REMEDIAL ALTERNATIVES EVALUATION – SEDIMENT

Alternative and Description/ Evaluation Criteria	Alternative S1 (Containment)	Alternative S2 (Upper Intertidal Sediment Removal and Amended Cap)	Alternative S3 (Upper Intertidal Sediment Removal and Sand Cap)	Alternative S4 (Intertidal and Shallow Subtidal Removal and Amended Cap)	Alternative S5a (Complete Removal; Consolidate Sediment Beneath Upland Cap)	Alternative S5b (Complete Removal; Off-site Treatment/Disposal of Sediment)
1. Meets Cleanup Action Objectives	Yes	Yes	Yes	Yes	Yes	Yes
2. Minimum Requirements (WAC 173-204-570[3])						
Protection of Human Health and the Environment	Engineered cap, ENR and MNR technologies would be designed to prevent human and ecological receptors from being exposed to contaminants in underlying sediment. Cap amendments in upper intertidal would enhanced chemical isolation. Institutional controls and long-term monitoring would help ensure protectiveness of the remedy.	Sediment removal (including some of the smear zone) and engineered cap technologies would be designed to prevent human and ecological receptors from being exposed to contaminants in underlying sediment. Cap in upper intertidal area includes amendments to provide enhanced chemical isolation closest to smear zone sediment remaining after excavation. ENR and MNR technologies applied where contaminant concentrations are lower (deeper subtidal zone) would reduce risks and ultimately achieve remediation goals. Institutional controls and long-term monitoring would help ensure protectiveness of the remedy.	Sediment removal (including all of the smear zone) and engineered cap technologies would be designed to prevent human and ecological receptors from being exposed to contaminants in underlying sediment. ENR and MNR technologies applied where contaminant concentrations are lower (deeper subtidal zone) would reduce risks and ultimately achieve remediation goals. Institutional controls and long-term monitoring would help ensure protectiveness of the remedy.	Sediment removal (including some of the smear zone) and engineered cap technologies would be designed to prevent human and ecological receptors from being exposed to contaminants in underlying sediment. Cap in upper intertidal area includes amendments to provide enhanced chemical isolation closest to smear zone sediment remaining after excavation. ENR and MNR technologies applied where contaminant concentrations are lower (deeper subtidal zone) would reduce risks and ultimately achieve remediation goals. Sensitive eelgrass habitat would be preserved. Institutional controls and long-term monitoring would help ensure protectiveness of the remedy.	Removal of all contamination above CULs in intertidal and shallow subtidal areas would prevent human and ecological receptor exposure to contamination. ENR and MNR technologies applied where contaminant concentrations are lower (deeper subtidal zone) would reduce risks and ultimately achieve remediation goals. Institutional controls and long-term monitoring associated with the ENR and MNR areas would help ensure protectiveness of the remedy.	
Compliance with ARARs	Yes	Yes	Yes	Yes	Yes	Yes
Compliance with Cleanup Standards	Yes	Yes	Yes	Yes	Yes	Yes
Use of Permanent Solutions	Yes	Yes	Yes	Yes	Yes	Yes
Reasonable Restoration Time Frame	Yes, cleanup standards achieved immediately following construction in the actively remediated area. Design and construction estimated to take 2 years plus additional time (indeterminate) needed for permitting. Cleanup standards achieved within 10 years in the ENR and MNR areas, which is considered reasonable.	Yes, cleanup standards achieved immediately following construction in the actively remediated area. Design and construction estimated to take 2 years plus additional time (indeterminate) needed for permitting. Cleanup standards achieved within 10 years in the ENR and MNR areas, which is considered reasonable.	Yes, cleanup standards achieved immediately following construction in the actively remediated. Design and construction estimated to take 2 years plus additional time (indeterminate) needed for permitting. Cleanup standards achieved within 10 years in the ENR and MNR areas, which is considered reasonable.	Yes, cleanup standards achieved immediately following construction in the actively remediated. Design and construction estimated to take 2 years plus additional time (indeterminate) needed for permitting. Cleanup standards achieved within 10 years in the MNR area, which is considered reasonable. Recovery time frame within eelgrass beds is anticipated to be achieved within 10 years and will be evaluated through long-term monitoring.	Yes, cleanup standards achieved immediately following construction in the actively remediated area. Design and construction estimated to take 2 years plus additional time (indeterminate) needed for permitting. Cleanup standards achieved within 10 years in the ENR and MNR areas, which is considered reasonable.	Yes, cleanup standards achieved immediately following construction in the actively remediated area. Design and construction estimated to take 2 years plus additional time (indeterminate) needed for permitting. Cleanup standards achieved within 10 years in the ENR and MNR areas, which is considered reasonable.

TABLE 9-14. SUMMARY OF MTCA REMEDIAL ALTERNATIVES EVALUATION – SEDIMENT

Alternative and Description/ Evaluation Criteria	Alternative S1 (Containment)	Alternative S2 (Upper Intertidal Sediment Removal and Amended Cap)	Alternative S3 (Upper Intertidal Sediment Removal and Sand Cap)	Alternative S4 (Intertidal and Shallow Subtidal Removal and Amended Cap)	Alternative S5a (Complete Removal; Consolidate Sediment Beneath Upland Cap)	Alternative S5b (Complete Removal; Off-site Treatment/Disposal of Sediment)
Source Control: Preference is given to alternatives that include source control measures that are more effective at reducing the accumulation of contamination	This alternative would prevent the resuspension and deposition of contaminated sediment using an engineered cap that provides containment. Contaminated sediment in the subtidal (ENR and MNR) areas is in a net depositional area with lower contaminant concentrations that is less subject to disturbance and resuspension. Additional source control measures will be provided as part of the upland remedy.	Removal of a portion of the smear zone sediment in the upper intertidal provides greater certainty, over Alternative S1, of this sediment alternative as a source control action. Contaminated sediment in the subtidal (ENR and MNR) zone is in a net depositional area with lower contaminant concentrations that is less subject to disturbance and resuspension. Additional source control measures will be provided as part of the upland remedy.	Removal of all of the smear zone sediment in the upper intertidal provides greater certainty of this source control action over Alternatives S1 and S2.	Equivalent to Alternative S2.	Removal of all contamination to the degree practicable provides the greatest certainty to the sediment remedy as a source control action.	Equivalent to Alternative S5a.
Use of Sediment Recovery Zone	No sediment recovery zone will be required for this alternative.	No sediment recovery zone will be required for this alternative.	No sediment recovery zone will be required for this alternative.	ENR is selected for the eelgrass area to provide an option for preserving this sensitive habitat. Recovery is likely within 10 years; therefore, no sediment recovery zone is proposed. Long-term monitoring will be conducted to document recovery.	No sediment recovery zone will be required for this alternative.	Equivalent to Alternative S5a.
Compliance with Institutional Controls: Preference given to alternatives relying on controls with a demonstrated ability to limit or prevent exposure and ensure integrity of remedy	Institutional controls, such as no-anchor zones, are anticipated components of all remedies and are implementable and effective. Monitoring requirements and contingency plans will be included as administrative controls in the cleanup action plan to ensure the protectiveness of the capped, ENR and MNR areas.	Equivalent to Alternative S1	Equivalent to Alternative S1	Equivalent to Alternative S1	The degree of institutional controls required to maintain the integrity of this remedy will be minimal because all contamination is removed, except in areas expected to naturally recover.	Equivalent to Alternative S5a.
Public Review	Public review opportunities will be provided as part of the RI/FS, Consent Decree/CAP and permit processes.	Equivalent to Alternative S1	Equivalent to Alternative S1	Equivalent to Alternative S1	Equivalent to Alternative S1	Equivalent to Alternative S1
Compliance Monitoring to Ensure Remedy Effectiveness: Preference given to alternatives with greater ability to monitor effectiveness	Yes, alternative includes provisions for compliance monitoring.	Equivalent to Alternative S1	Equivalent to Alternative S1	Equivalent to Alternative S1	Monitoring only needed for ENR and MNR areas.	Equivalent to Alternative S5a
Provision for Periodic Review	Yes, the CAP will include a periodic review requirement.	Equivalent to Alternative S1	Equivalent to Alternative S1	Equivalent to Alternative S1	Equivalent to Alternative S1	Equivalent to Alternative S1

Alternative and Description/ Evaluation Criteria	Alternative S1 (Containment)	Alternative S2 (Upper Intertidal Sediment Removal and Amended Cap)	Alternative S3 (Upper Intertidal Sediment Removal and Sand Cap)	Alternative S4 (Intertidal and Shallow Subtidal Removal and Amended Cap)	Alternative S5a (Complete Removal; Consolidate Sediment Beneath Upland Cap)	Alternative S5b (Complete Removal; Off-site Treatment/Disposal of Sediment)
3. Disproportionate Cost Analysis—Criteria in MTCA 173-340-360(3)(f) and SMS 173-204-570(4)						
Protectiveness: *"Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternatives and improvement of the overall environmental quality."*	Score = 2 Achieves a low level of overall protectiveness relative to other alternatives because of reliance on containment with no smear zone sediment removal. On- and off-site risks associated with implementation are negligible. Time needed to reduce on-site risks is short in the actively capped area and reasonable (≤ 10 years) in subtidal areas where chemical concentrations are lower. May require the greatest amount of mitigation compared to other alternatives to achieve improvement of overall environmental quality due to conversion of bottom and water column habitats through filling.	Score = 5 Overall protectiveness is higher than Alternative S1 due to increased certainty and improved risk reduction offered through partial smear zone sediment removal in addition to enhanced chemical isolation through use of amended cap. However, risks associated with implementation are greater than Alternative S1 due to handling needed during excavation and consolidation. Off-site risks are relatively low, due to construction methods for sediment removal in the dry that would limit residual production and contaminant migration during construction. With respect to improvement of the overall environmental quality, this alternative results in less near-shore filling than Alternative S1 and a more desirable slope in the intertidal zone, which may reduce the need for habitat mitigation due to filling.	Score = 7 Achieves a higher level of overall protectiveness because all of the smear zone sediment is removed from the aquatic environment, resulting in no need for amendments to achieve chemical isolation. However, on-site risks associated with implementation are slightly greater than Alternative S2 because more contaminated sediment must be managed in the upland. Post-remedy habitat conversion is similar to Alternative S2; thus mitigation requirements to improve the overall environmental quality are likely to be similar.	Score = 6 Scores slightly lower than Alternative S3 for overall protectiveness because while there is more sediment removal for this alternative than Alternative S3, there is less sediment removal in the smear zone compared to Alternative S3. Although similar to Alternative S2 in terms of removal of smear zone sediment, there is a larger footprint of ENR to preserve sensitive eelgrass beds which results in a slightly higher score than Alternative S2 due to improvement of overall environmental quality.	Score = 9 Alternatives S5a and S5b have the highest levels of overall protectiveness of all the alternatives due to the removal of the largest quantity of contaminated sediment. The protectiveness score for Alternative S5a is higher than Alternative S5b because excavated sediment is consolidated into the upland cap, resulting in less risk associated with transport of material for off-site disposal. Score is moderated because of the production of residual contamination and potential migration during dredging that may adversely affect adjacent areas.	Score = 8 Similar to Alternative 5a except that score is lower because more soil is transported off-site for treatment/disposal, resulting in more off-site risks from implementation.
Permanence: *"The degree to which the alternative permanently reduces the toxicity, mobility or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree or irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated."*	Score = 2 Achieves a low level of permanence relative to other alternatives because this alternative does not modify the toxicity or volume of contaminants in sediment. Contaminant mobility is reduced by the use of cap amendments, which sequester dissolved contaminants, reducing the potential for releases from underlying contamination.	Score = 5 Achieves a significantly higher level of permanence that Alternative S1 by removing some of the smear zone sediment from marine areas and consolidating the contaminants beneath the engineered upland cap. However, the volume of contaminated sediment removed from the marine environment is less than other removal-based alternatives.	Score = 7 Achieves a higher level of permanence than Alternative S2 by removing all of the smear zone sediment and additional underlying contaminated sediment in the upper intertidal zone.	Score = 6 Achieves slightly lower degree of permanence compared to Alternative S3 because less smear zone sediment is removed; however, this alternative offers a higher degree of permanence than Alternative S2 because shallow contamination is removed over a much broader footprint.	Score = 8 Achieves a high level of permanent reduction of mass and mobility of hazardous substances at the Site by removing a significant quantity of contaminated sediment from intertidal and shallow subtidal areas and consolidating the majority of it beneath the upland cap, with the remainder taken off-site for disposal.	Score = 9 Achieves a high level of permanent reduction of mass, toxicity, and mobility of hazardous substances at the Site through removal and off-site treatment/disposal at a permitted facility. This alternative scores slightly higher than Alternative S5b because the entire volume of excavated sediment is removed from the Site; a portion of the material may be treated or incinerated.

TABLE 9-14. SUMMARY OF MTCA REMEDIAL ALTERNATIVES EVALUATION – SEDIMENT

Alternative and Description/ Evaluation Criteria	Alternative S1 (Containment)	Alternative S2 (Upper Intertidal Sediment Removal and Amended Cap)	Alternative S3 (Upper Intertidal Sediment Removal and Sand Cap)	Alternative S4 (Intertidal and Shallow Subtidal Removal and Amended Cap)	Alternative S5a (Complete Removal; Consolidate Sediment Beneath Upland Cap)	Alternative S5b (Complete Removal; Off-site Treatment/Disposal of Sediment)
Long-Term Effectiveness: *When assessing the relative degree of long-term effectiveness of cleanup action components, the following types of components are used as a guide WAC 173-204-570(4)(b), in descending order, : (1) source controls in combination with other cleanup technologies; (2) beneficial reuse of sediment; (3) treatment to immobilize, destroy or detoxify contaminants; (4) dredging and disposal in an upland engineered facility; (5) dredging and disposal in a near-shore confined aquatic disposal facility; (6) containment in-place with an engineered cap; (7) dredging and disposal at an approved open-water disposal site; (8) enhanced natural recovery; (9) monitored natural recovery; (10) institutional controls and monitoring.*	Score = 3 Achieves a moderately low degree of long-term effectiveness relative to other alternatives because this alternative relies solely on the less preferred methods of containment in-place, ENR, MNR and institutional controls (i.e., no contaminant removal).	Score = 4 Slightly higher degree of long-term effectiveness compared to Alternative S1 due to higher preferences for source (i.e., smear zone sediment) removal and treatment (achieved by use of cap amendments), which are components of this alternative. However, overall score for this criterion is moderated because there is still substantial reliance on containment in-place, ENR, MNR and institutional controls.	Score = 6 Achieves a higher degree of long-term effectiveness than Alternative S2 through removal of all smear zone sediment from the marine environment. Overall score remains moderate because there is still substantial reliance on containment in-place, ENR, MNR and institutional controls.	Score = 5 Degree of long-term effectiveness achieved is similar to Alternative S2 based on amount of smear zone sediment removal but a greater volume of contaminated sediment is removed outside of the smear zone. Score moderated because of the reliance on containment in-place, ENR, MNR and institutional controls.	Score = 8 Score is higher than Alternatives S2, S3 and S4 because this alternative incorporates removal of the largest quantity of contaminated sediment compared to Alternatives S2, S3 or S4. Consolidation beneath the upland cap within the AOC, as well as off-site disposal at upland engineered facility (landfill) provide containment in place. Reliance on ENR, MNR and institutional controls moderate the score as with other alternatives.	Score = 9 Higher score than Alternative S5a because this alternative does not rely on any on-site consolidation beneath the upland cap.
Management of Short-Term Risks: *"The risk to human health and the environment associated with the alternative during construction and implementation, and the effectiveness of measures that will be taken to manage such risks."*	Score = 9 Least short-term risk of all the alternatives and therefore scores the highest of all the sediment alternatives for this criterion. With the exception of piling and other debris at the current mudline, all contaminated material is confined in place; minimal sediment disturbance is anticipated during capping.	Score = 8 Lower score than Alternative S1 because sediment removal poses some short-term risks during construction; however, the short-term risks are not as significant as other alternatives since the volume of material being excavated is less than other alternatives and because potential short-term risks can be managed through standard construction methods such as excavating during periods of low tide (i.e., in the dry) and through BMPs and other requirements established as part of the USACE permit.	Score = 7 Lower score than Alternative S2 due to the higher volume of material being excavated and thus slightly more short-term risks.	Score = 6 Lower score than Alternative S3 due to the removal of additional sediment at lower elevations, which poses additional short-term risks compared to Alternative S3. Construction risks are minimized by excavating during periods of low tide and through BMPs and other requirements established as part of the USACE permit.	Score = 5 Lower score than Alternative S4 because short-term risk is higher due to a larger volume of contaminated sediment excavated and consolidated or transported off-site, and by the production of dredging residuals. Construction and transportation methods have been used on many similar projects and risks can be addressed through safety protocols established in design and permitting.	Score = 4 Lower score than Alternative S5a because the higher quantity of excavated sediment transported off-site for treatment/disposal for this alternative poses a somewhat increased level of short-term risks relative to Alternative S5a.

TABLE 9-14. SUMMARY OF MTCA REMEDIAL ALTERNATIVES EVALUATION – SEDIMENT

Alternative and Description/ Evaluation Criteria	Alternative S1 (Containment)	Alternative S2 (Upper Intertidal Sediment Removal and Amended Cap)	Alternative S3 (Upper Intertidal Sediment Removal and Sand Cap)	Alternative S4 (Intertidal and Shallow Subtidal Removal and Amended Cap)	Alternative S5a (Complete Removal; Consolidate Sediment Beneath Upland Cap)	Alternative S5b (Complete Removal; Off-site Treatment/Disposal of Sediment)
Technical and Administrative Implementability: *"Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions."*	Score = 6 The degree of technical and administrative implementability for this alternative is moderate. Capping is a common technology, regional expertise in construction methods is readily available, and requirements for supporting services and materials are minimal. Permitting may be more complex because of the likely habitat mitigation requirements and need to demonstrate performance of amendments. The full containment cap for this alternative could be constructed without reliance on the timing of construction for the Site upland remedy. This alternative is highly compatible with the sediment remedy proposed for the adjacent Cornwall Landfill site.	Score = 6 Lower degree of technical and administrative implementability compared to Alternative S1 based on the anticipated degree of complexity related to administrative requirements for Ecology review and approval of methods for managing and consolidating sediment beneath the upland cap per Ecology's AOC policy and relevant EPA guidance. Permitting may be more complex because of potential need to demonstrate the performance of amendments.	Score = 8 Higher degree of technical and administrative implementability relative to Alternative S2 because this alternative does not use amendments in the sediment cap. Score is moderated due to administrative complexities related to AOC requirements.	Score = 7 Alternative is similar to Alternative S2 with respect to technical and administrative implementability because the alternatives use similar technologies. Score is moderated due to administrative complexities related to AOC requirements.	Score = 9 High score for technical and administrative implementability because no amendments are used in the sediment cap and because sediment excavation and dredging are very well-established sediment cleanup actions. Score is moderated due to administrative complexities related to AOC requirements.	Score = 10 Higher score than Alternative S5a because this alternative does not utilize on-site consolidation of excavated sediment.
Consideration of Public Concerns: *"Whether the community has concerns regarding the alternative and, if so, the extent to which the alternative addresses those concerns. This process includes concerns from individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge of the site."*	Score = 3 Low score based on expected degree of public concern associated with leaving all contamination in-place, long-term effectiveness of the engineered cap and restrictions related to future use of the intertidal areas.	Score = 5 Higher score than Alternative S1 based on expected greater degree of public approval for source removal. Score is moderated based on expected degree of public concern associated with on-site consolidation, in-place containment of underlying contamination, long-term effectiveness of engineered cap, and restrictions related to future use of the Site.	Score = 6 Higher score than Alternative S2 based on larger quantity of highly contaminated sediment (i.e., smear zone sediment) to be removed from the aquatic environment and the resultant greater degree of public acceptance. Score is moderated based on expected degree of public concern associated with on-site consolidation, in-place containment of underlying contamination, long-term effectiveness of engineered cap, and restrictions related to future use of the Site.	Score = 7 Lower score than Alternative S3 because less smear zone sediment is removed compared to Alternative S3 and therefore public acceptance is expected to be lower. General acceptance by stakeholders for preservation of sensitive eelgrass habitat suggests this alternative would score higher for this criterion than Alternative S2. Score is moderated based on expected degree of public concern associated with on-site consolidation, in-place containment of underlying contamination, long-term effectiveness of engineered cap, and restrictions related to future use of the Site.	Score = 8 Expected degree of public acceptance anticipated to be relatively high based on public preferences for contaminant removal; however, consolidation of most contaminated material on-site may remain a concern for the public.	Score = 9 Slightly higher than Alternative S5a based on anticipated higher relative degree of public acceptance of off-site treatment and disposal. Score moderated based on potential concerns about large amount of truck or rail trips to transport all waste off-site.

Notes:

AOC = area of contamination

ENR = enhanced natural recovery

MNR = monitored natural recovery

MTCA = Model Toxics Control Act

Table 9-15

Disproportionate Cost Analysis - Upland Alternatives

R.G. Haley Site
Bellingham, Washington

Alternatives	U1		U2		U3a		U3b		U3c		U4	
	Passive LNAPL Removal, Vertical Shoreline Barrier, Upland Cap		**PRB, Upland Cap**		**Nearshore *In Situ* Soil Solidification, Upland Cap**		**Expanded *In-Situ* Soil Solidification and Stabilization, Upland Cap**		**Soil Excavation, *In Situ Soil* Solidification and Stablilization, Upland Cap**		**Complete Removal**	
MTCA Evaluation Criteria												
Compliance with MTCA Threshold Criteria	Yes		Yes		Yes		Yes		Yes		Yes	
Reasonable Restoration Time Frame	Yes		Yes		Yes		Yes		Yes		Yes	
DCA Benefits Scores												
Criteria and Weighting Factor	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Protectiveness (30%)	4	1.2	5	1.5	6	1.8	7	2.1	8	2.4	9	2.7
Permanence (20%)	3	0.6	4	0.8	6	1.2	7	1.4	8	1.6	9	1.8
Long-Term Effectiveness (20%)	3	0.6	4	0.8	7	1.4	8	1.6	9	1.8	10	2.0
Management of Short-Term Risks (10%)	9	0.9	7	0.7	7	0.7	6	0.6	5	0.5	3	0.3
Technical and Administrative Implementability (10%)	8	0.8	6	0.6	8	0.8	7	0.7	6	0.6	5	0.5
Consideration of Public Concerns (10%)	3	0.3	4	0.4	5	0.5	6	0.6	7	0.7	9	0.9
Total Score	**30**	**4.4**	**30**	**4.8**	**39**	**6.4**	**41**	**7.0**	**43**	**7.6**	**45**	**8.2**
Disproportionate Cost Analysis (DCA)												
Estimated Cost[1]	$10,090,000		$10,710,000		$10,250,000		$21,050,000		$24,990,000		$167,600,000	
Ratio of Cost Compared to Lowest Cost Alternative[2]	1.0		1.06		1.0		2.09		2.33		16.35	
Relative Benefit/Cost Ratio (Total Weighted Score/(Cost/$5,000,000)	2.18		2.24		3.12		1.66		1.52		0.24	
Costs Disproportionate to Incremental Benefits[3]	No		No		No		Yes		Yes		Yes	
Practicability of Remedy based on Test of Disproportionate Cost[4]	Practicable		Practicable		Practicable		Not Practicable		Not Practicable		Not Practicable	
Remedy Permanent to Maximum Extent Practicable[5]	No		No		Yes							
Overall Alternative Ranking	3rd		2nd		1st							
Ratio of Benefit Compared to Most Permanent, Practicable Alternative[6]	0.1		0.8		1.0							

Notes

[1] Estimated costs are at FS level, with a range of +50% and -30%. See Appendix Q.

[2] Estimated Cost of Alternative/Estimated Cost of Alternative 1, the lowest cost Alternative.

[3] DCA Test per WAC 173-340-360(3)(e)(i) is defined as follows:"Costs are disproportionate to benefits if the incremental costs of the alternative over that of a lower cost alternative exceed the incremental degree of benefits achieved by the alternative over that of the lower cost alternative."

[4] An alternative is considered "Not Practicable" if it is disproportionately costly relative to the benefit achieved.

[5] The **practicable** alternatives are compared; the most permanent, practicable remedy is identified as the Preferred Alternative.

[6] Weighted Benefit of Practicable Alternative/Weighted Benefit of the Preferred Alternative, Alternative U3.

Table 9-16

Disproportionate Cost Analysis - Sediment Alternatives

RG Haley Site
Bellingham, Washington

Alternatives	S1		S2		S3		S4		S5a		S5b	
	Containment		**Upper Intertidal Sediment Removal and Amended Cap**		**Upper Intertidal Sediment Removal and Sand Cap**		**Intertidal/Shallow Subtidal Removal and Amended Cap**		**Complete Removal and Backfill with On-Site Consolidation**		**Complete Removal and Backfill with Off-Site Treatment/Disposal**	
Minimum Criteria												
Protection of Human Health and the Environment	Yes		Yes		Yes		Yes		Yes		Yes	
Compliance with ARARs	Yes		Yes		Yes		Yes		Yes		Yes	
Compliance with Sediment Cleanup Standards	Yes		Yes		Yes		Yes		Yes		Yes	
Use of Permanent Solutions	Yes		Yes		Yes		Yes		Yes		Yes	
Reasonable Restoration Time Frame	Yes		Yes		Yes		Yes		Yes		Yes	
Source Control	Yes		Yes		Yes		Yes		Yes		Yes	
Use of Sediment Recovery Zone	Not needed		Not needed		Not needed		Yes		Not needed		Not needed	
Compliance with Institutional Controls (e.g., ENR, MNR)	Yes		Yes		Yes		Yes		Yes		Yes	
Public Review	Yes		Yes		Yes		Yes		Yes		Yes	
Monitoring to Ensure Remedy Effectiveness	Yes		Yes		Yes		Yes		Yes		Yes	
Provision for Periodic Review	Yes		Yes		Yes		Yes		Yes		Yes	
DCA Relative Benefits Score												
Criteria	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Protectiveness (30%)	2	0.6	5	1.5	7	2.1	6	1.8	9	2.7	8	2.4
Permanence (20%)	2	0.4	5	1	7	1.4	6	1.2	8	1.6	9	1.8
Long-Term Effectiveness (20%)	3	0.6	4	0.8	6	1.2	5	1	8	1.6	9	1.8
Management of Short-Term Risks (10%)	9	0.9	8	0.8	7	0.7	6	0.6	5	0.5	4	0.4
Technical and Administrative Implementability (10%)	6	0.6	6	0.6	8	0.8	7	0.7	9	0.9	10	1
Consideration of Public Concern (10%)	3	0.3	5	0.5	6	0.6	7	0.7	8	0.8	9	0.9
Total Score	**25.0**	**3.4**	**33.0**	**5.2**	**41.0**	**6.8**	**37.0**	**6.0**	**47.0**	**8.1**	**49.0**	**8.3**
Disproportionate Cost Analysis (DCA)												
Estimated Cost[1]	$3,820,000		$5,140,000		$5,470,000		$6,640,000		$7,640,000		$12,180,000	
Ratio of Cost Compared to Lowest Cost Alternative[2]	1.0		1.3		1.4		1.7		2.0		3.2	
Relative Benefit /Cost (Total Weighted Score/(Cost/$5,000,000)	4.5		5.1		6.2		4.5		5.3		3.4	
Costs Disproportionate to Incremental Benefits[3]	No		No		No		Yes		Yes		Yes	
Practicability of Remedy based on Test of Disproportionate Cost[4]	Practicable		Practicable		Practicable		Not Practicable		Not Practicable		Not Practicable	
Remedy Permanent to Maximum Extent Practicable[5]	Yes		Yes		Yes							
Overall Alternative Ranking	3rd		2nd		1st							
Ratio of Benefit Compared to Most Permanent, Practicable Alternative[6]	0.5		0.8		1.0							

Notes

[1] Estimated costs are at FS level, with a range of +50% and -30%. See Appendix Q.

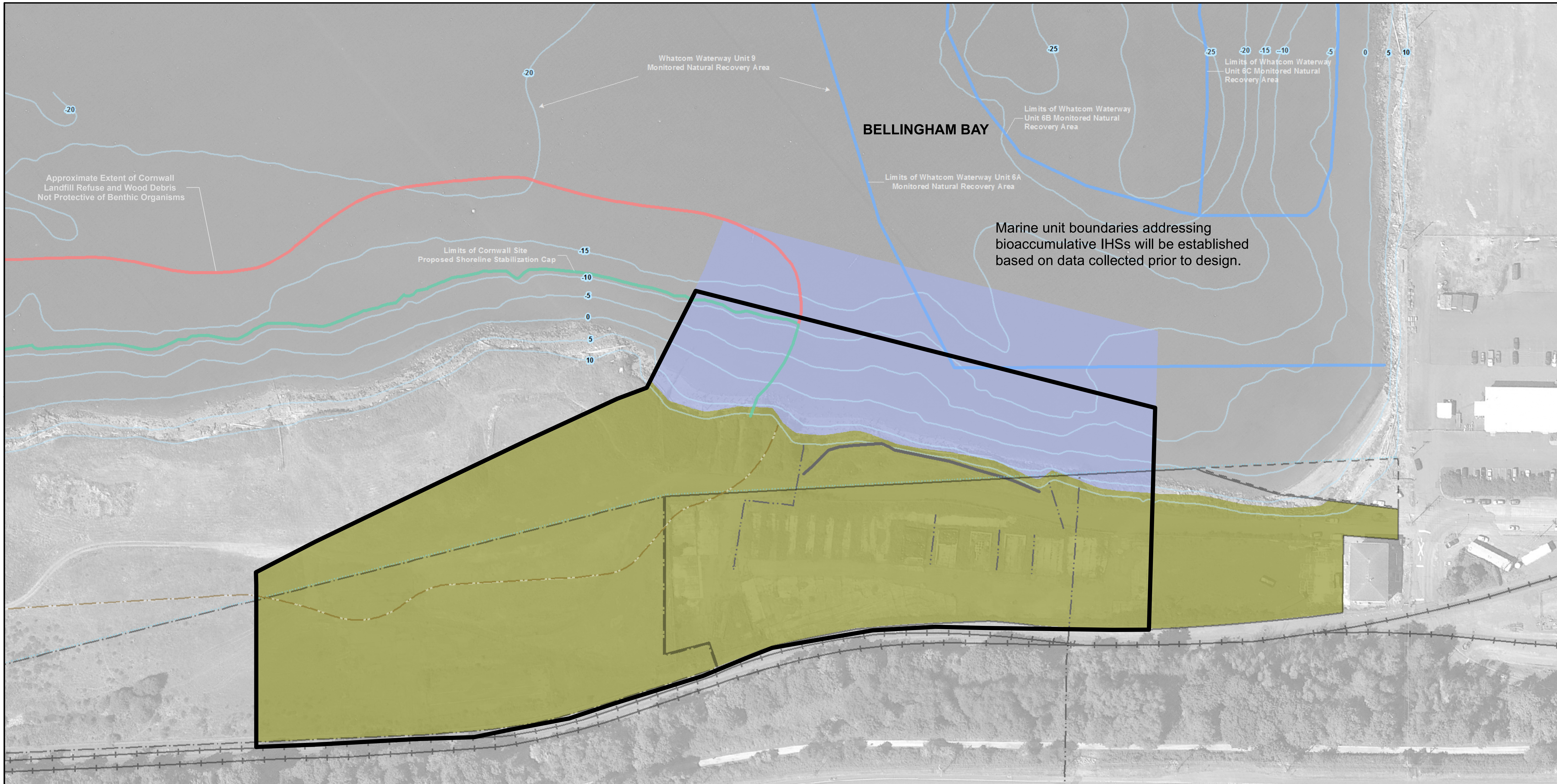
[2] Estimated Cost of Alternative/Estimated Cost of Alternative 1, the lowest cost Alternative.

[3] DCA Test per WAC 173-340-360(3)(e)(i) is defined as follows:"Costs are disproportionate to benefits if the incremental costs of the alternative over that of a lower cost alternative exceed the incremental degree of benefits achieved by the alternative over that of the lower cost alternative."

[4] An alternative is considered "Not Practicable" if it is disproportionately costly relative to the benefit achieved.

[5] The **practicable** alternatives are compared; the most permanent, practicable remedy is identified as the Preferred Alternative.

[6] Weighted Benefit of Practicable Alternative/Weighted Benefit of the Preferred Alternative, Alternative S3.



True North
Project North
W S N E
0 50 100
Feet

Reference: Aerial from Google Earth, August 2011.
Contour elevation displayed is referenced to NAVD88 vertical datum.

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document.
3. Refer to Figure 6-1 for identification of property lines and other upland features.
GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

City Owned Property, Former R.G. Haley International
Cornwall Property
Port of Bellingham Property
Inner Harbor Line
Sheet Pile Wall
Storm Drain
Cornwall Approximate Landward Boundary of Landfill Refuse

Marine Unit
Upland Unit
2014 Expanded AOC

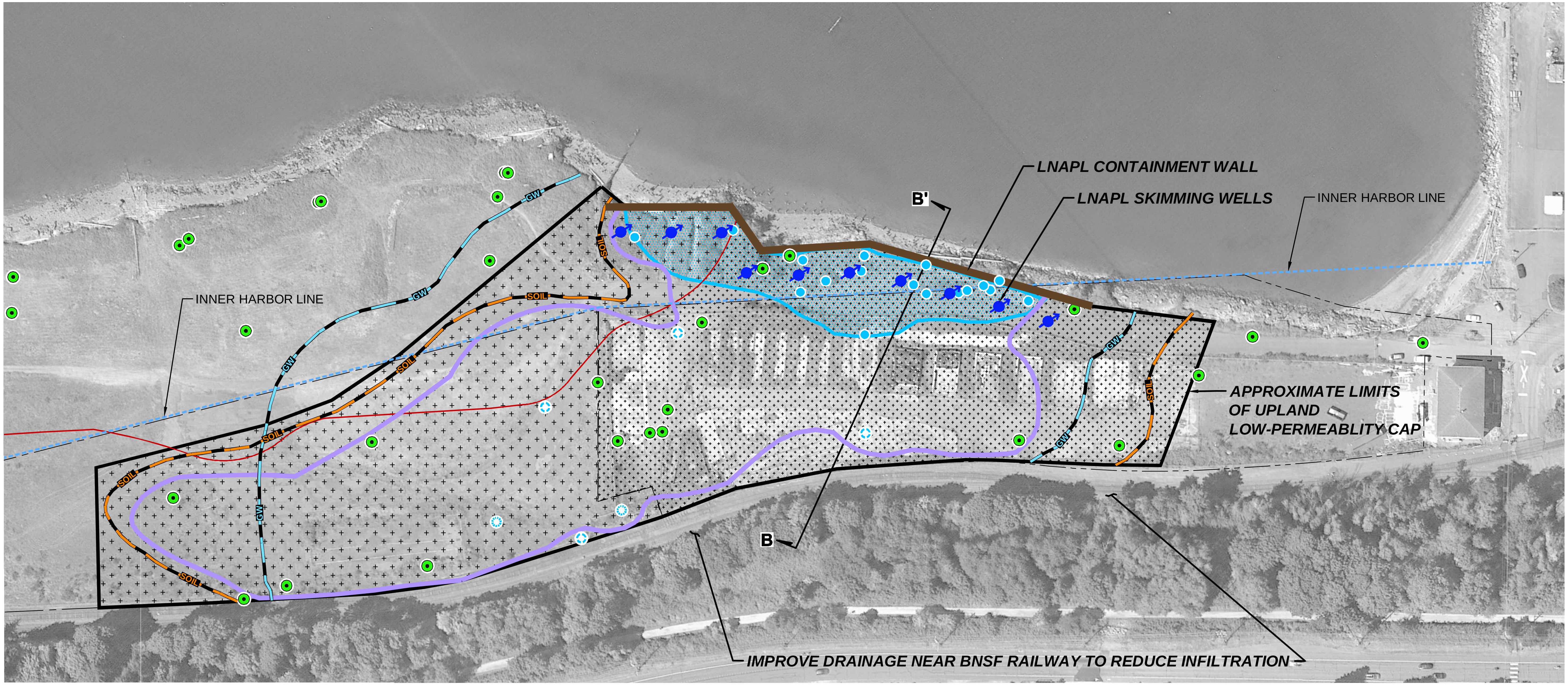
FS Site Units

R.G. Haley Site
Bellingham, Washington

GeoEngineers

Figure 9-1

Path: \\sea\projects\0\0356114\GIS\MXDs\Fig_9-1_SiteUnits.mxd Map Revised: 23 July 2015 cgonzales



Legend

A — A'	Cross Section Location
	City Owned Property, Former R.G. Haley International
	Cornwall Property
	Inner Harbor Line
	Potentially Mobile LNAPL at Shoreline
	Current Measurable LNAPL in Well
	Current Trace LNAPL in Well
	Historical LNAPL (Not Currently Present)
	LNAPL Never Observed
	Low Permeability Upland Cap (Haley-Cornwall Overlap Area)
	Low Permeability Upland Cap (Haley Only)
	Low Permeability LNAPL Containment Wall (Sheet Pile)
	In-Well LNAPL Skimmer (number and spacing conceptual only)
	Boundary of Cornwall Landfill Waste
SOIL	Boundary of Haley Soil Exceedances
GW	Boundary of Haley Groundwater Exceedances
	Boundary of Smear Zone

W E S N True North Project North

120 0 120
Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

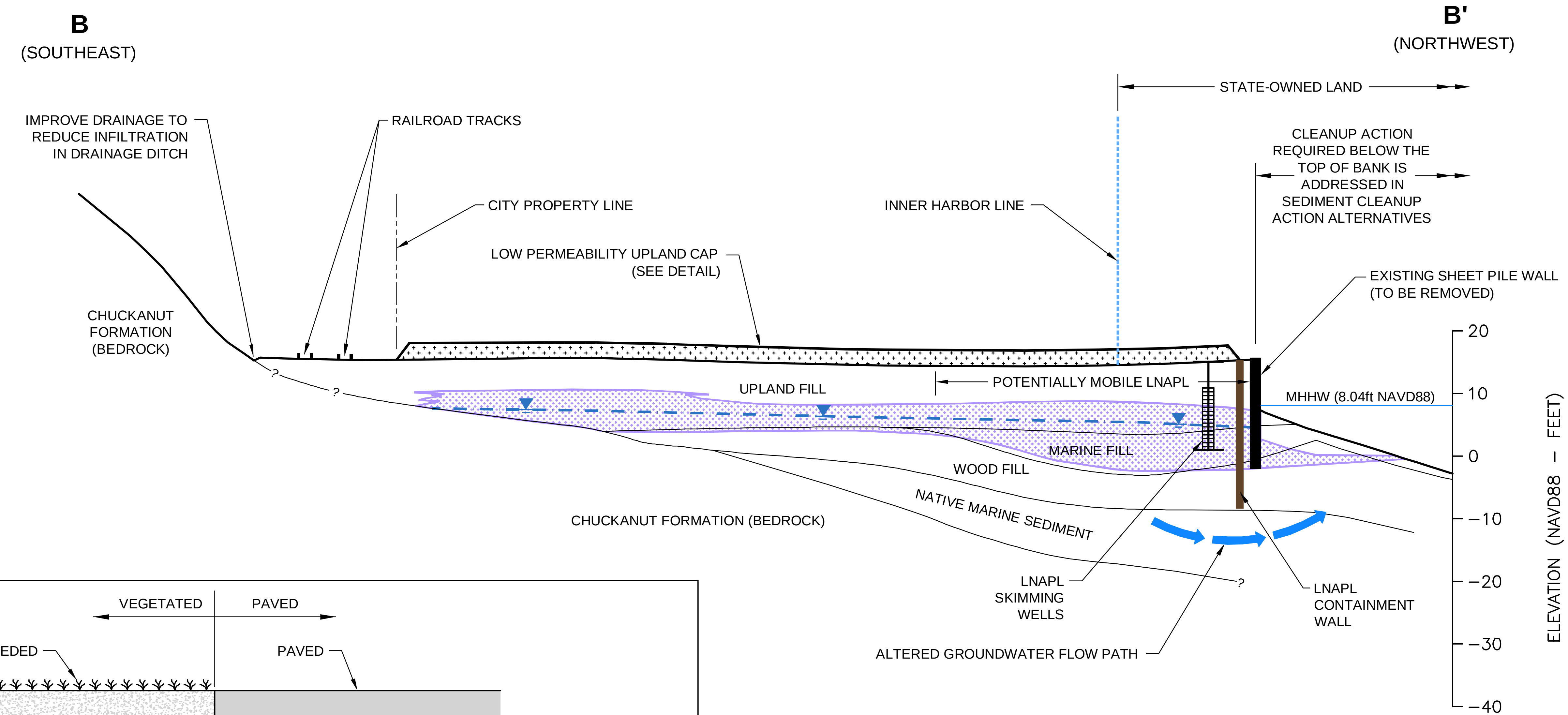
Reference: Base aerial photo from Google Earth Pro 2011.

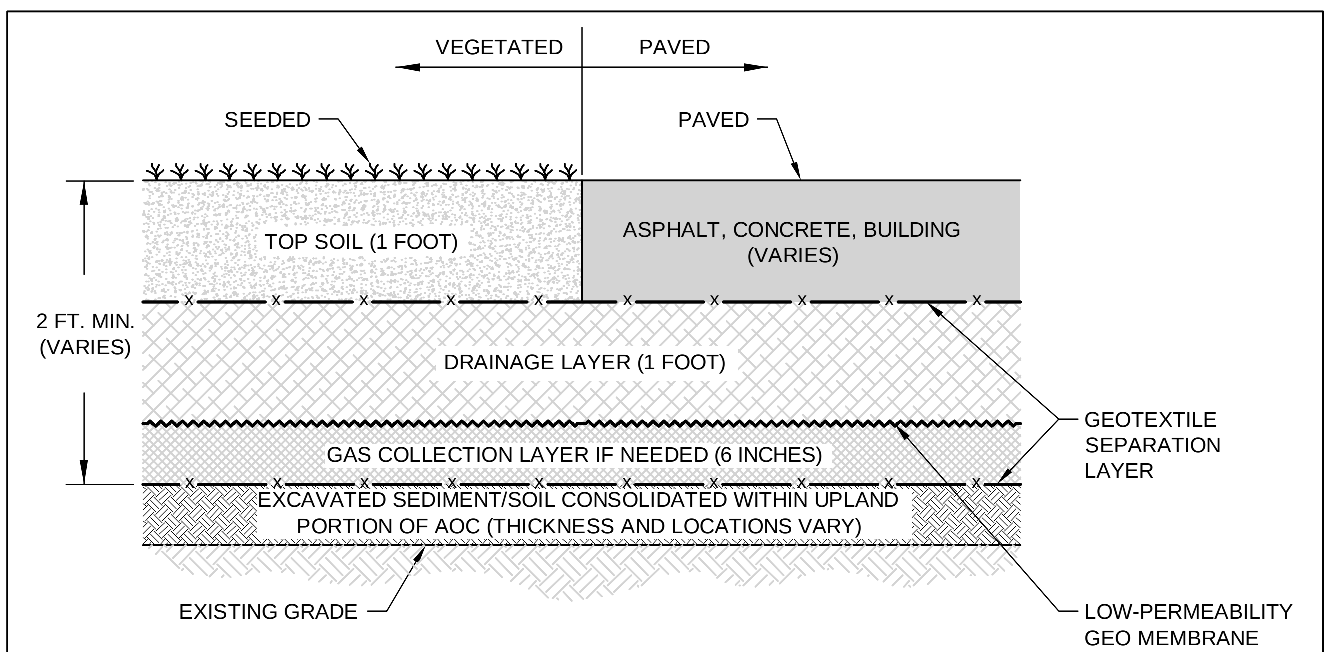
Upland Cleanup Action Alternative U1 Plan

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-2





Upland Low-Permeability Cap Detail (Typ.)

Legend

- LNAPL Skimming Well
- Groundwater Elevation in Shallow Wells on 8/9/2012 (High Tide)
- Screened Interval
- Approximate Extent of Petroleum Smear Zone
- Low Permeability Upland Cap
- LNAPL Containment Wall (Sheet Pile, Slurry Wall, or Other Type of Low Permeability Wall Type Constructed to Approximately 5-feet Below the Smear Zone)

HORIZONTAL SCALE: 1"= 40'
VERTICAL SCALE: 1"= 20'
VERTICAL EXAGGERATION: 2X

40 0 40
FEET

Upland Cleanup Action Alternative U1
Cross Section B-B'

R.G. Haley Site
Bellingham, Washington

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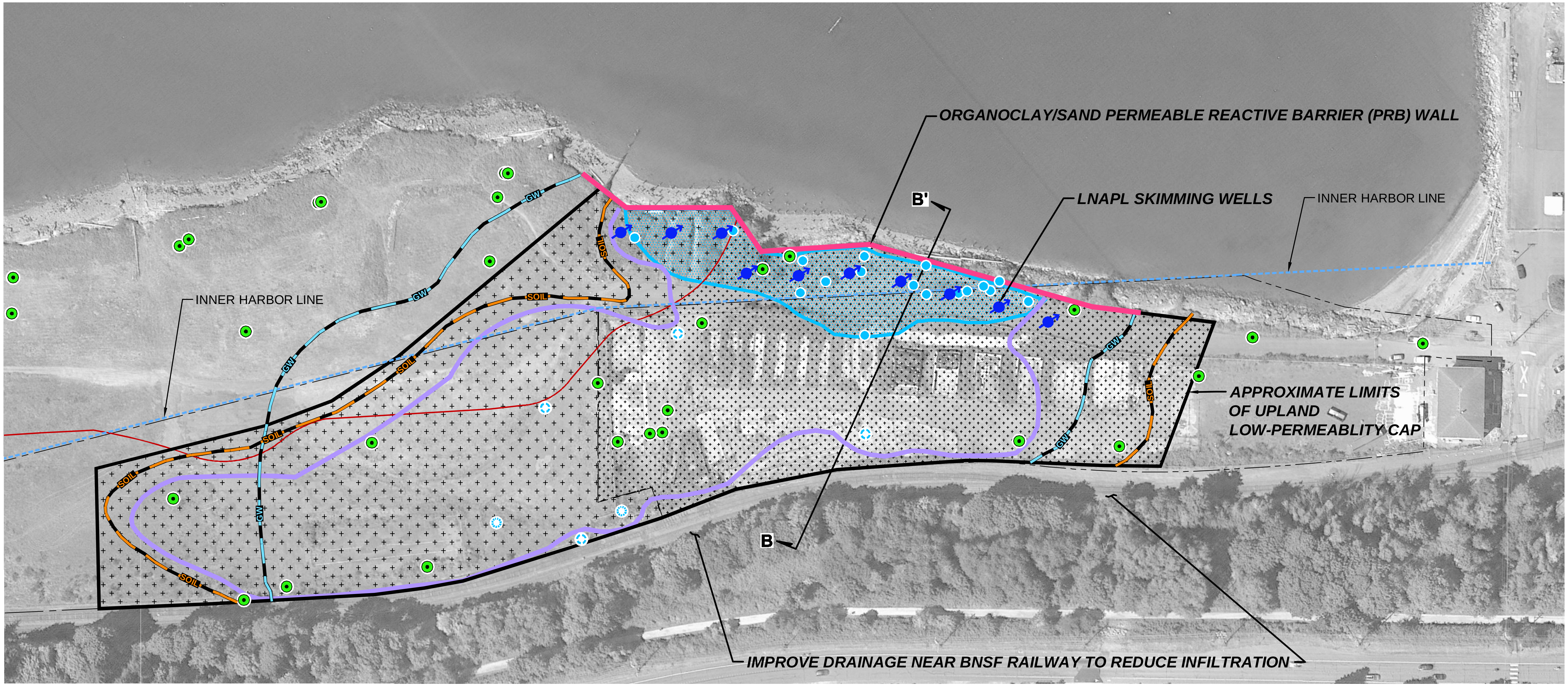
Figure 9-3

Notes

1. Directions given on cross section line refer to Project North.
2. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

P:\0\0356114\06\CAD\Task 2700 Feasibility Study\Upland Cleanup Alternative Figures\Figure 9-3 Upland Cleanup Action Alternative U1 Cross-Section A-A'.dwg\TAB:BB modified on Nov 24, 2014 - 1:04pm



Legend

A A'	Cross Section Location
	City Owned Property, Former R.G. Haley International
	Cornwall Property
	Inner Harbor Line
	Potentially Mobile LNAPL at Shoreline
	Current Measurable LNAPL in Well
	Current Trace LNAPL in Well
	Historical LNAPL (Not Currently Present)
	LNAPL Never Observed
	Low Permeability Upland Cap (Haley-Cornwall Overlap Area)
	Low Permeability Upland Cap (Haley Only)
	Organoclay/Sand Permeable Reactive Barrier (PRB) Wall
	In-Well LNAPL Skimmer (number and spacing conceptual only)
	Boundary of Cornwall Landfill Waste
SOIL	Boundary of Haley Soil Exceedances
GW	Boundary of Haley Groundwater Exceedances
	Boundary of Smear Zone

W S N E True North Project North

120 0 120

Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

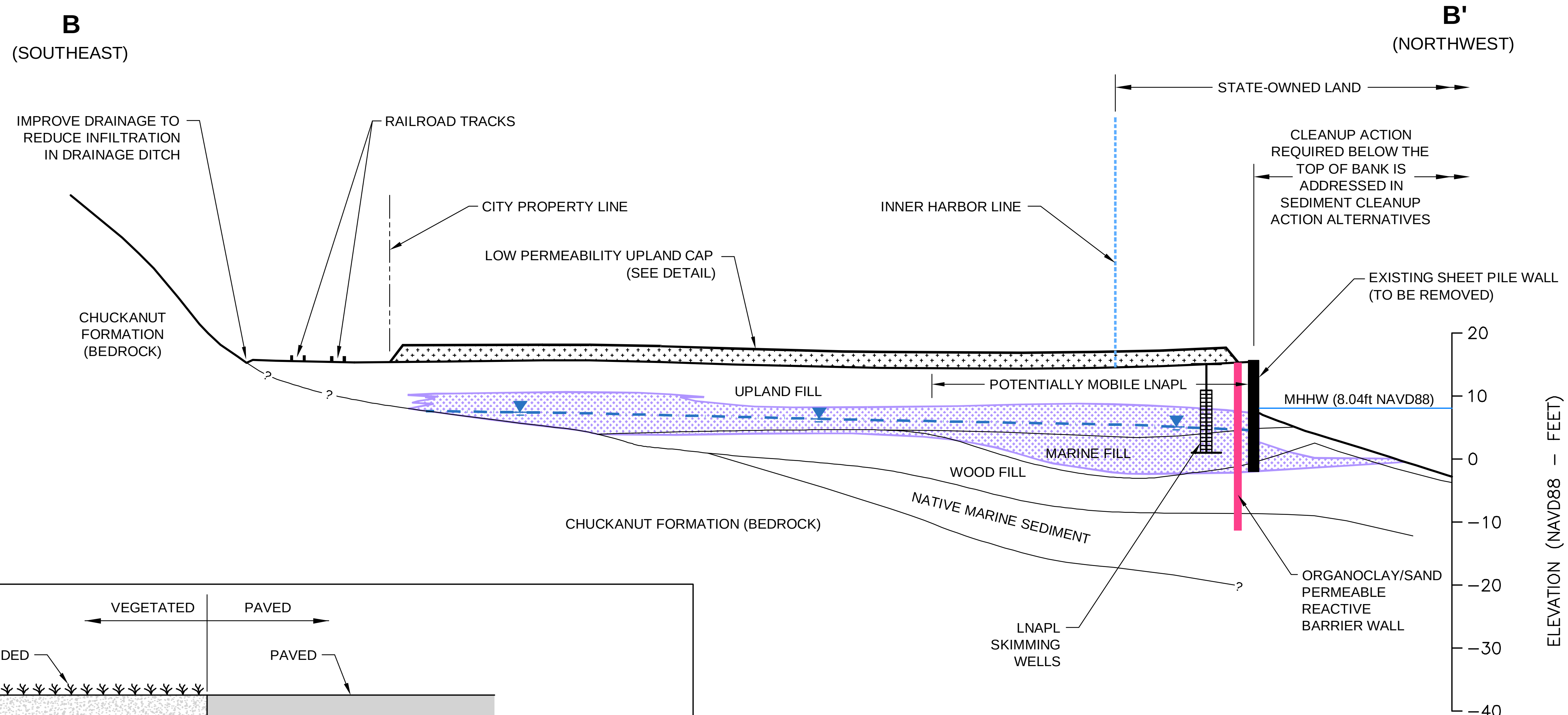
Upland Cleanup Action Alternative U2 Plan

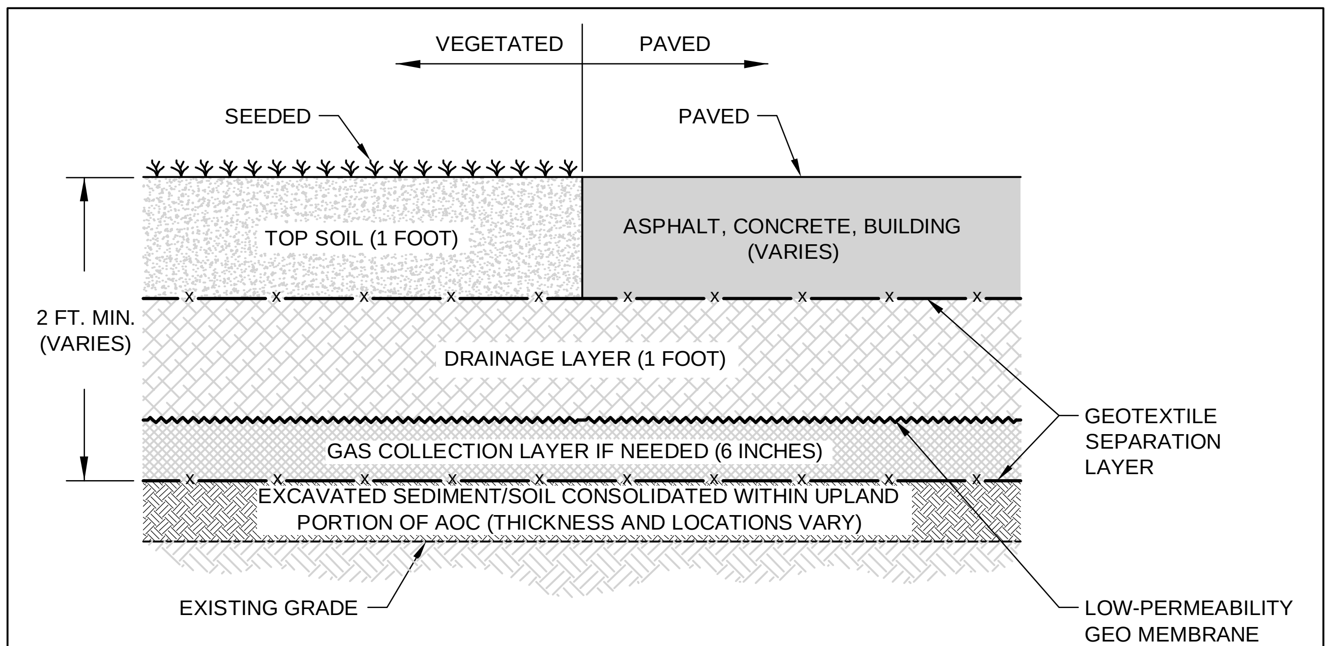
R.G. Haley Site
Bellingham, Washington

GeoEngineers

Figure 9-4

P:\0\0356114\06\CAD\Task 2700 Feasibilty Study\Upland Cleanup Alternative Figures\Figure 9-4 Upland Cleanup Action Alternative U2 Plan.dwg\TAB:Fig 9-1 modified on Sep 07, 2014 9:14am





Upland Low-Permeability Cap Detail (Typ.)

Legend

- LNAPL Skimming Well
- Groundwater Elevation in Shallow Wells on 8/9/2012 (High Tide)
- Screened Interval
- Approximate Extent of Petroleum Smear Zone
- Low Permeability Upland Cap
- Organoclay/Sand Permeable Reactive Barrier (PRB) Wall

Notes

1. Directions given on cross section line refer to Project North.
2. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

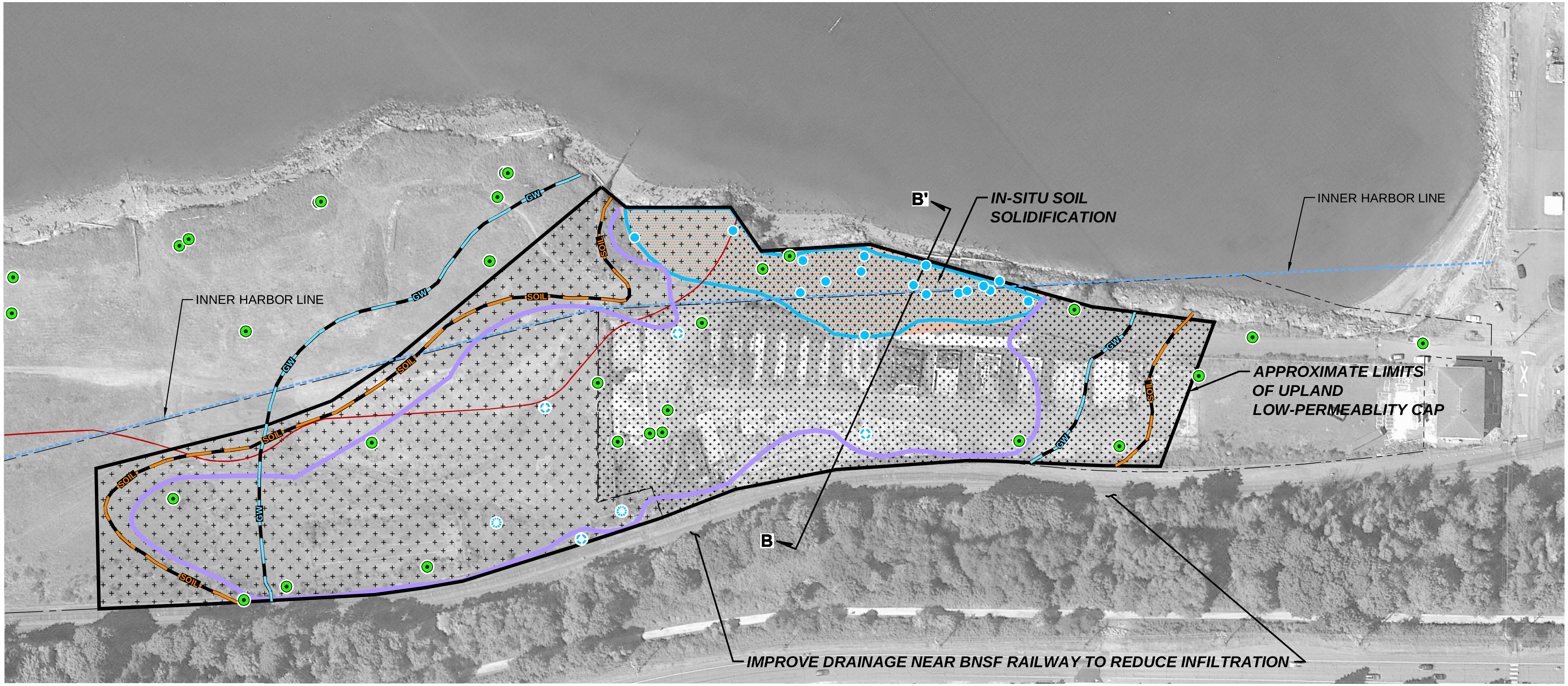
Upland Cleanup Action Alternative U2
Cross Section B-B'

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-5

P:\0\0356114\06\CAD\Task 2700 Feasibility Study\Upland Cleanup Alternative Figures\Figure 9-5 Upland Cleanup Action Alternative U2 Cross-Section A-A'.dwg\TAB:BB modified on Nov 24, 2014 - 1:07pm



Legend

A A'	Cross Section Location
	City Owned Property, Former R.G. Haley International
	Cornwall Property
	Inner Harbor Line
	Potentially Mobile LNAPL at Shoreline
	Current Measurable LNAPL in Well
	Current Trace LNAPL in Well
	Historical LNAPL (Not Currently Present)
	LNAPL Never Observed
	Low Permeability Upland Cap (Haley-Cornwall Overlap Area)
	Low Permeability Upland Cap (Haley Only)
	In-Situ Soil Solidification
	Boundary of Cornwall Landfill Waste
SOIL	Boundary of Haley Soil Exceedances
GW	Boundary of Haley Groundwater Exceedances
	Boundary of Smear Zone

W S N E True North Project North

120 0 120

Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

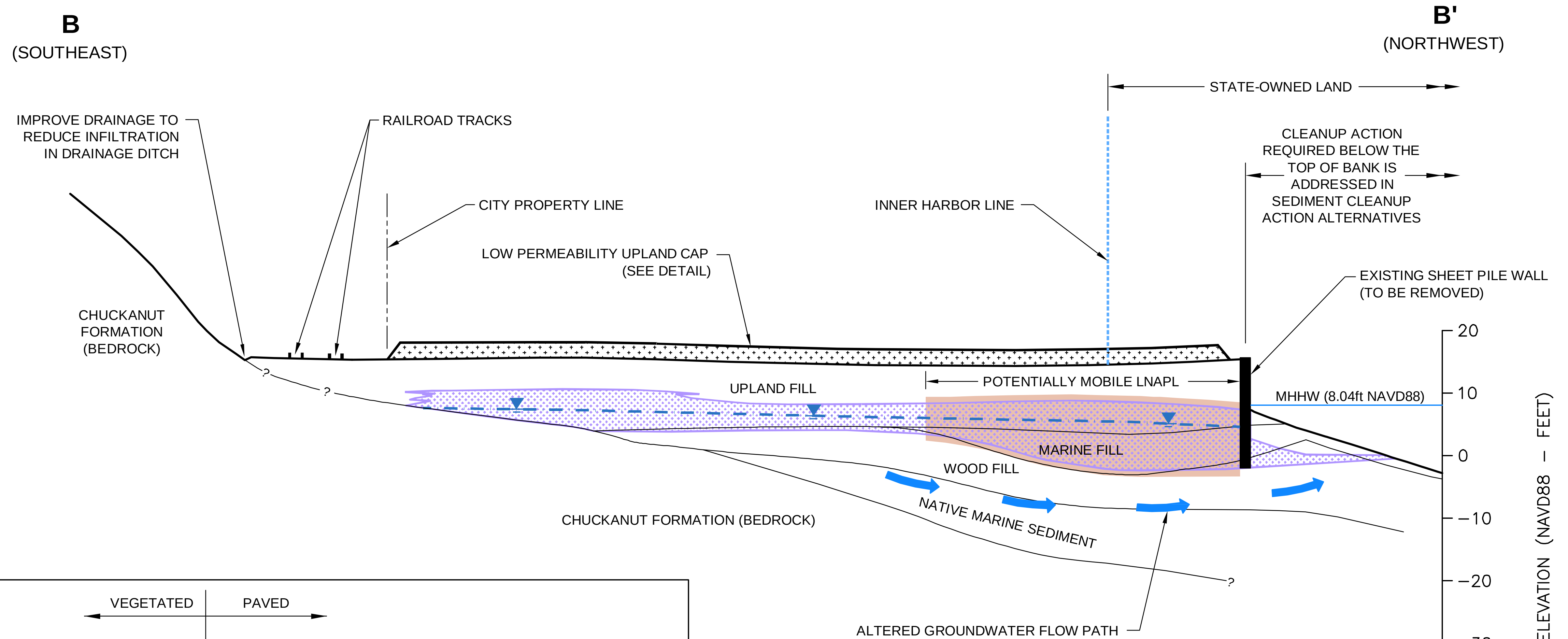
Upland Cleanup Action Alternative U3a Plan

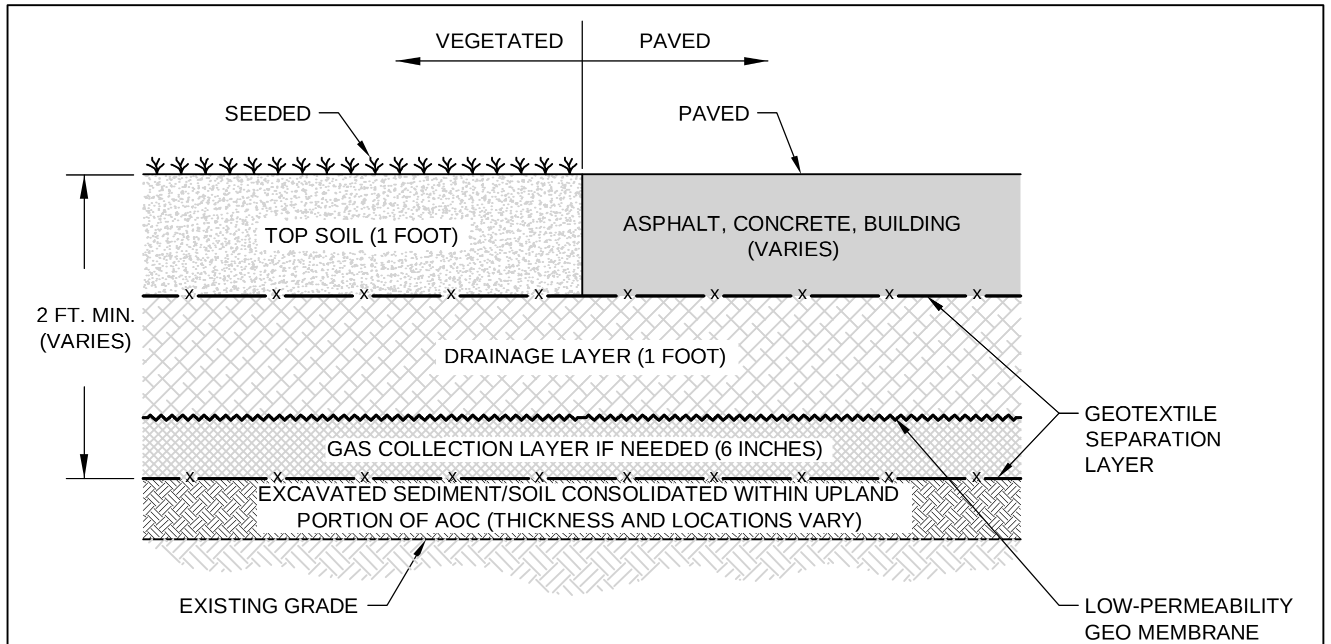
R.G. Haley Site
Bellingham, Washington

GeoEngineers

Figure 9-6

P:\0\0356114\06\CAD\Task 2700 Feasibility Study\Upland Cleanup Alternative Figures\Figure 9-6 Upland Cleanup Action Alternative U3a Plan.dwg\TAB:Fig 9-1 modified on Sep 04, 2014 - 9:00am





Upland Low-Permeability Cap Detail (Typ.)

Legend

- Approximate Extent of Petroleum Smear Zone
- Low Permeability Upland Cap
- In-Situ Soil Solidification

Notes

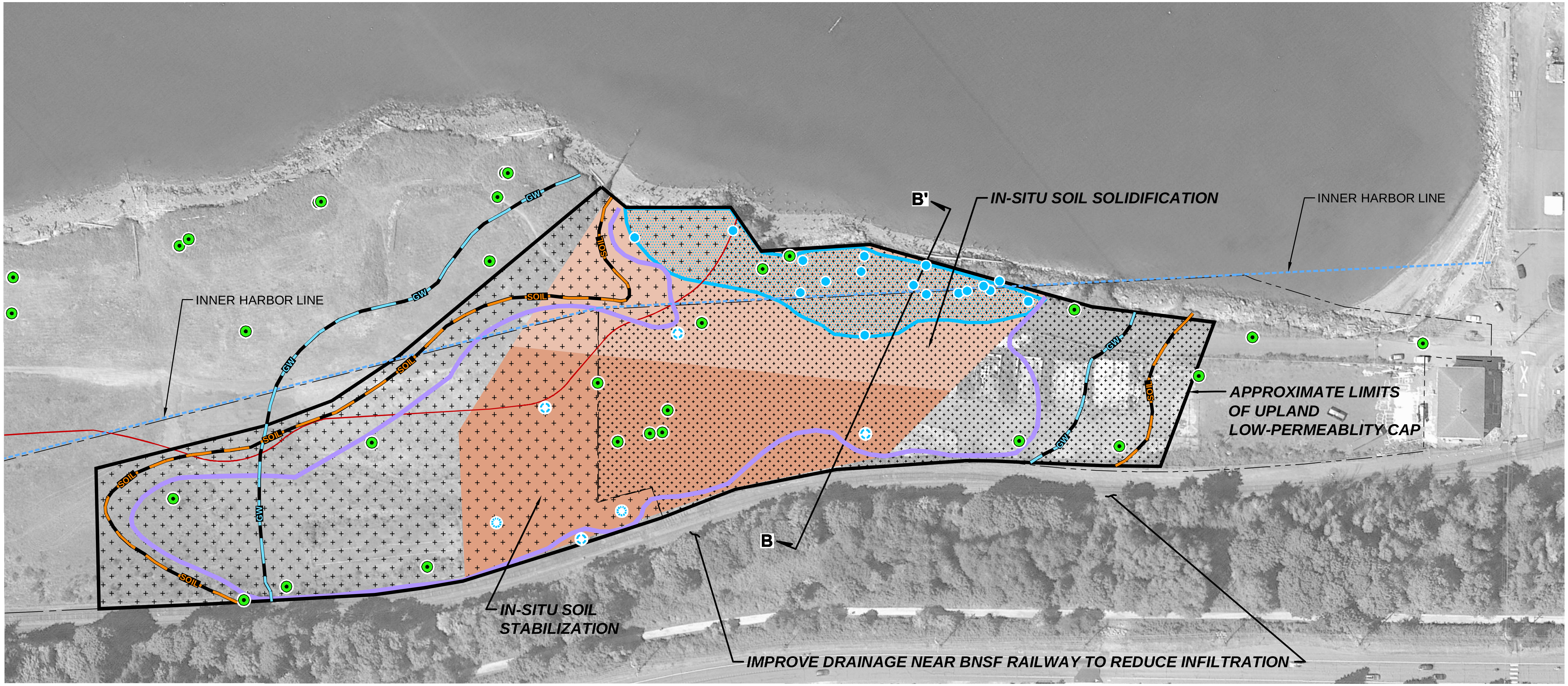
1. Directions given on cross section line refer to Project North.
2. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Upland Cleanup Action Alternative U3a
Cross Section B-B'

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-7



Legend

A A' — Cross Section Location

City Owned Property, Former R.G. Haley International

Cornwall Property

Inner Harbor Line

Potentially Mobile LNAPL at Shoreline

Current Measurable LNAPL in Well

Current Trace LNAPL in Well

Historical LNAPL (Not Currently Present)

LNAPL Never Observed

Low Permeability Upland Cap (Haley-Cornwall Overlap Area)

Low Permeability Upland Cap (Haley Only)

In-Situ Soil Solidification

In-Situ Soil Stabilization

Boundary of Cornwall Landfill Waste

SOIL — Boundary of Haley Soil Exceedances

GW — Boundary of Haley Groundwater Exceedances

Boundary of Smear Zone

W True North S N Project North E

120 0 120

Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

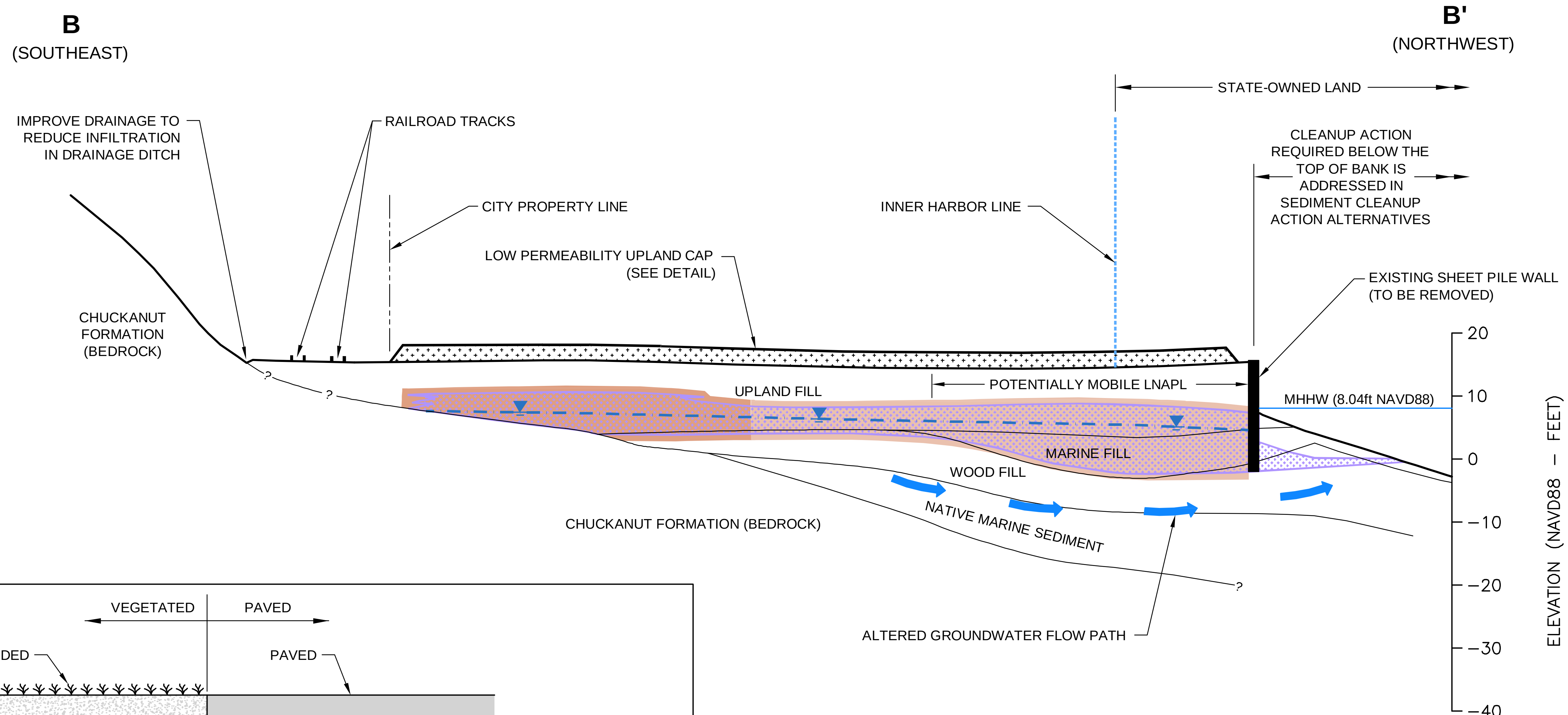
Upland Cleanup Action Alternative U3b Plan

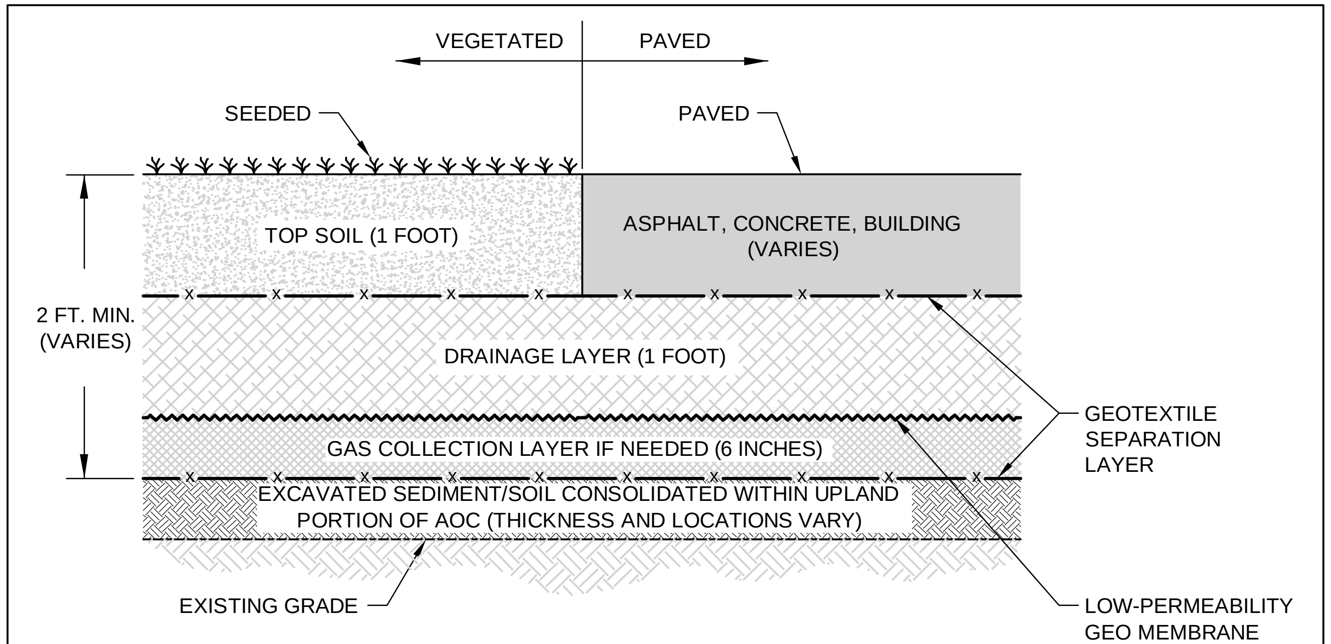
R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-8

P:\0\0356114\06\CAD\Task 2700 Feasibility Study\Upland Cleanup Alternative Figures\Figure 9-8 Upland Cleanup Action Alternative U3b Plan.dwg\TAB:Fig 9-1 modified on Sep 04, 2014 - 9:18am





Upland Low-Permeability Cap Detail (Typ.)

HORIZONTAL SCALE: 1"= 40'
VERTICAL SCALE: 1"= 20'
VERTICAL EXAGGERATION: 2X

40 0 40
FEET

Legend

- Approximate Extent of Petroleum Smear Zone
- Low Permeability Upland Cap
- In-Situ Soil Solidification
- In-Situ Soil Stabilization

Notes

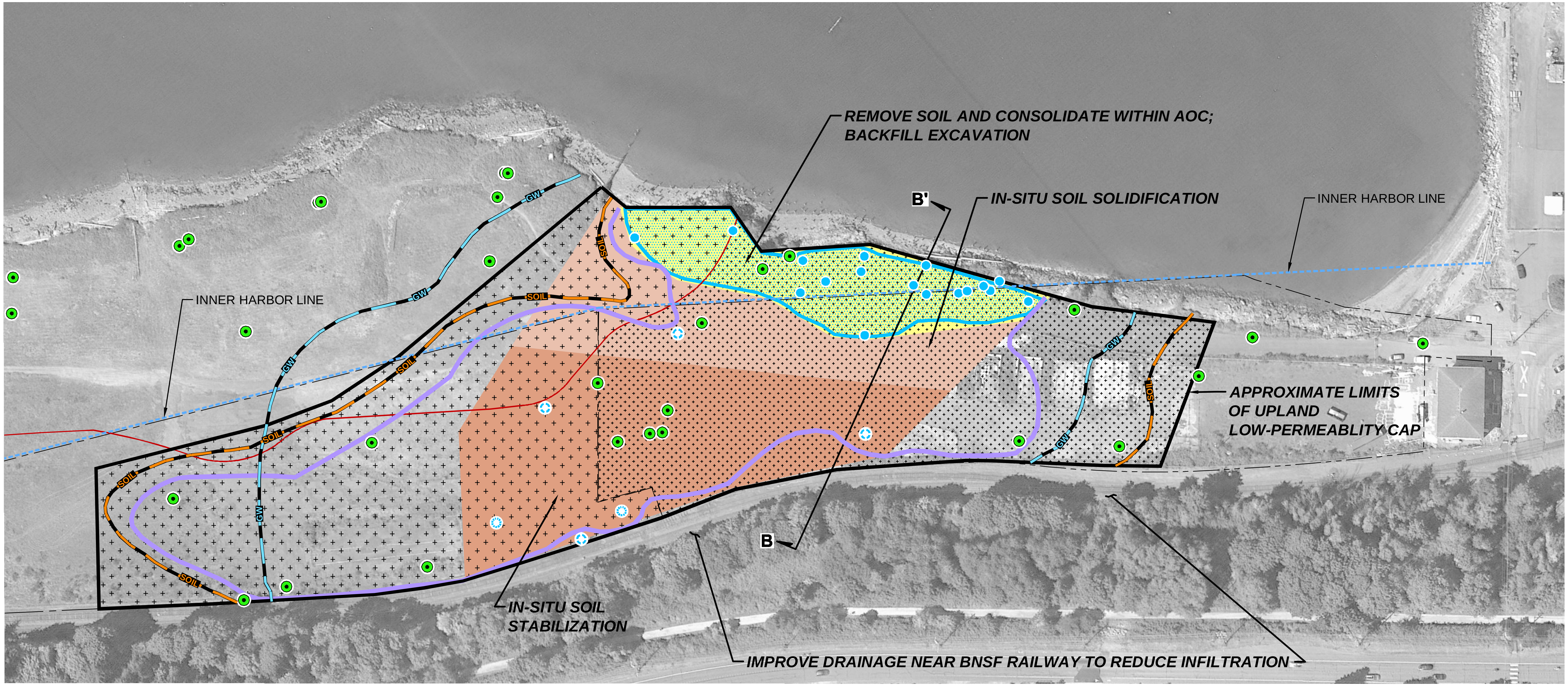
1. Directions given on cross section line refer to Project North.
2. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Upland Cleanup Action Alternative U3b Cross Section B-B'

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-9



Legend

A / A'	Cross Section Location
	City Owned Property, Former R.G. Haley International
	Cornwall Property
	Inner Harbor Line
	Potentially Mobile LNAPL at Shoreline
	Current Measurable LNAPL in Well
	Current Trace LNAPL in Well
	Historical LNAPL (Not Currently Present)
	LNAPL Never Observed
	Low Permeability Upland Cap (Haley-Cornwall Overlap Area)
	Low Permeability Upland Cap (Haley Only)
	In-Situ Soil Solidification
	In-Situ Soil Stabilization
	Removal and Backfill; Consolidate Excavated Soil within AOC
	Boundary of Cornwall Landfill Waste
SOIL	Boundary of Haley Soil Exceedances
GW	Boundary of Haley Groundwater Exceedances
	Boundary of Smear Zone

W E S N True North Project North

120 0 120

Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

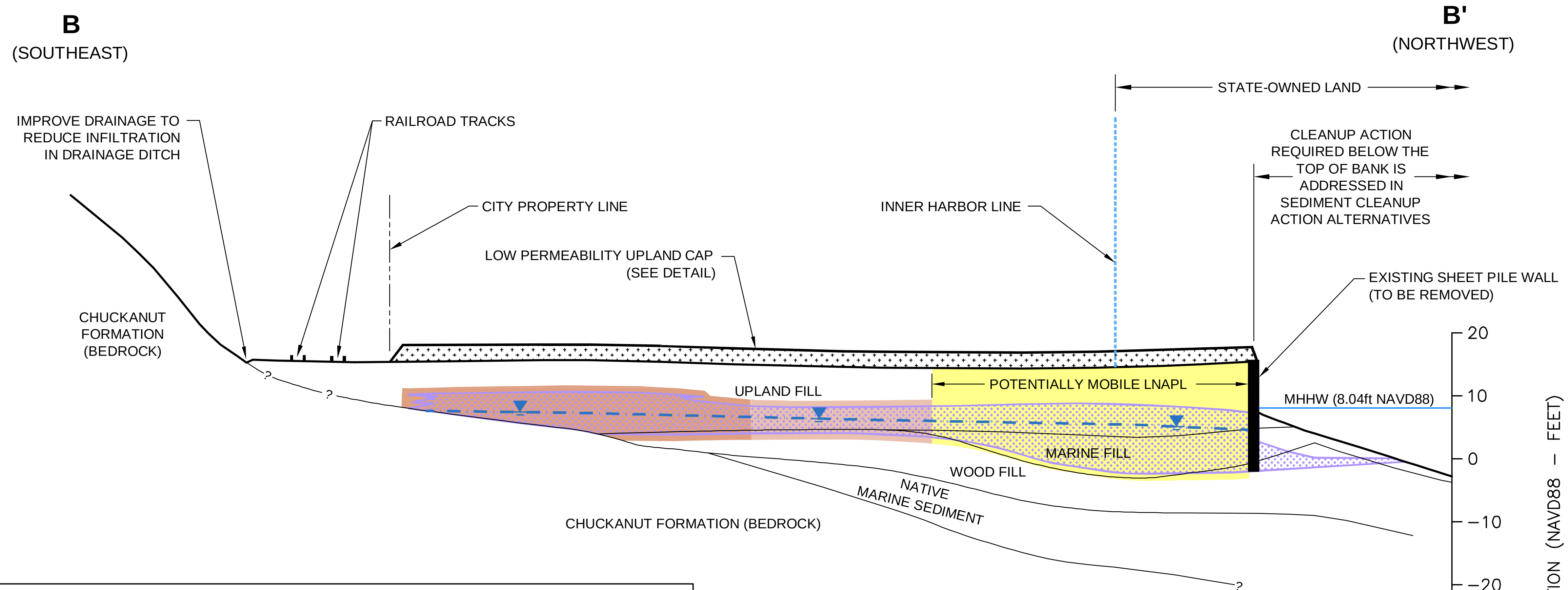
Upland Cleanup Action Alternative U3c

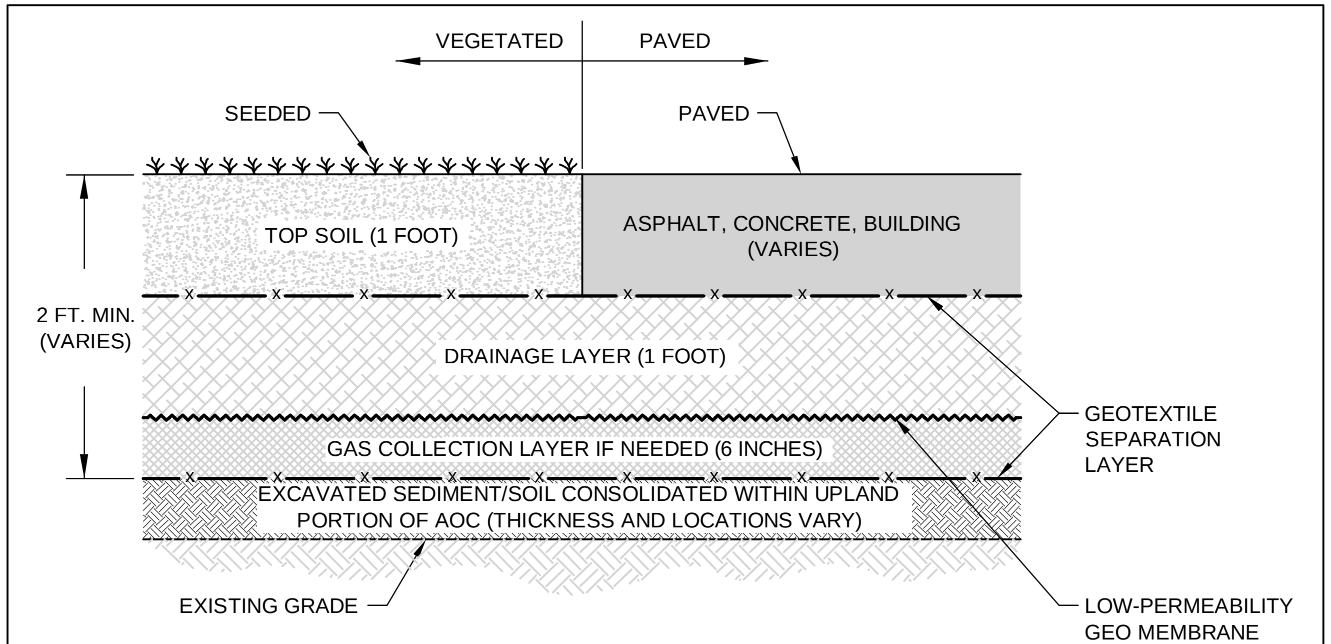
R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-10

P:\0\0356114\06\CAD\Task 2700 Feasibility Study\Upland Cleanup Alternative Figures\Figure 9-10 Upland Cleanup Action Alternative U3c Plan.dwg\TAB:Fig 9-1 modified on Dec 18, 2014 9:50am





Upland Low-Permeability Cap Detail (Typ.)

HORIZONTAL SCALE: 1"= 40'
VERTICAL SCALE: 1"= 20'
VERTICAL EXAGGERATION: 2X

40 0 40
FEET

Legend

- Approximate Extent of Petroleum Smear Zone
- Low Permeability Upland Cap
- In-Situ Soil Solidification
- In-Situ Soil Stabilization
- Removal and Backfill with Clean Imported Fill; Consolidate Excavated Soil within AOC

Notes

1. Directions given on cross section line refer to Project North.
2. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

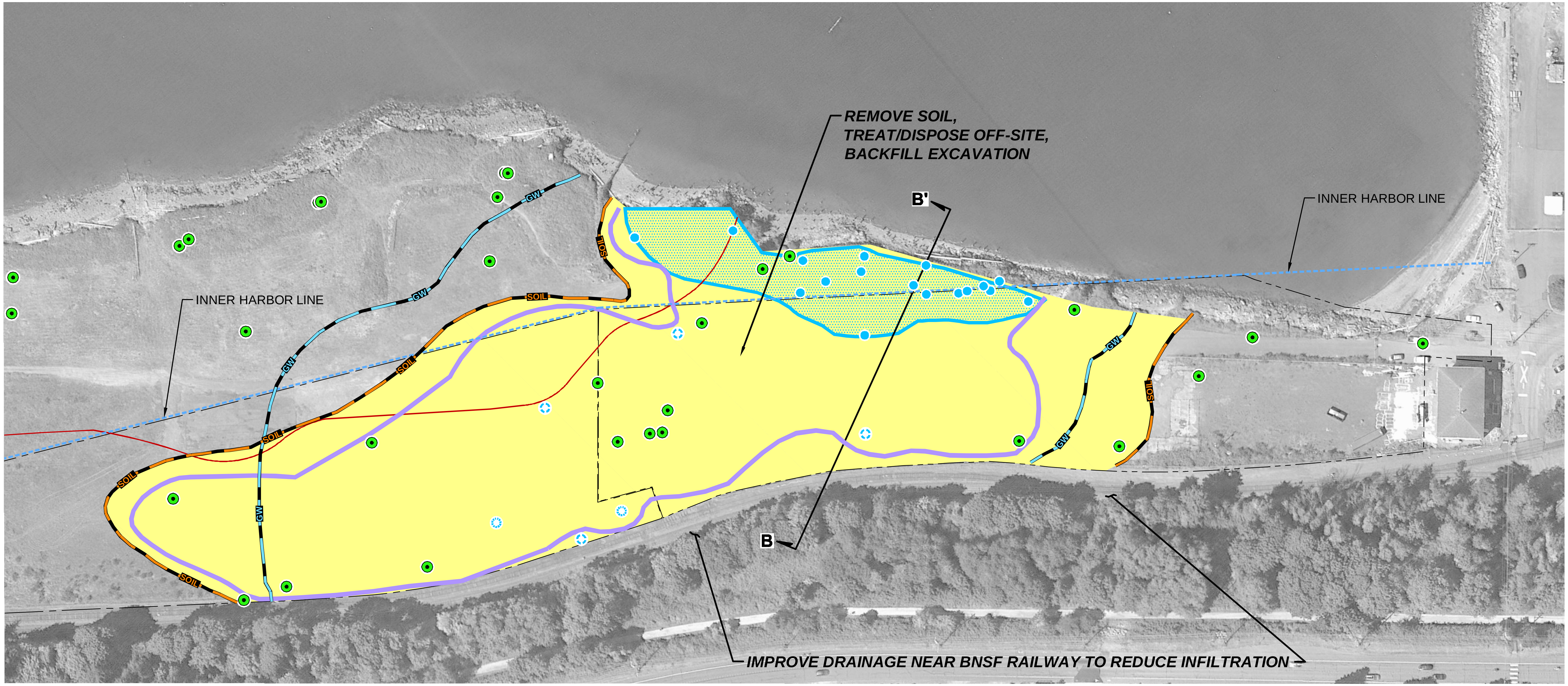
Upland Cleanup Action Alternative U3c
Cross Section B-B'

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

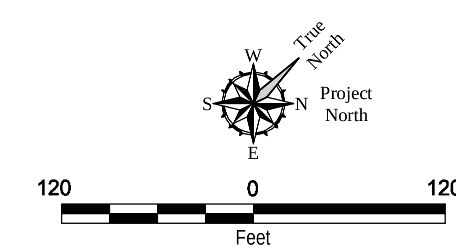
Figure 9-11

P:\0\0356114\06\CAD\Task 2700 Feasibility Study\Upland Cleanup Alternative Figures\Figure 9-11 Upland Cleanup Action Alternative U3c Cross-Section AA.dwg\TAB:BB modified on Dec 18, 2014 - 9:51am



Legend

A A'	Cross Section Location
— - - —	City Owned Property, Former R.G. Haley International
— - —	Cornwall Property
(blue dashed line)	Inner Harbor Line
(blue stippled area)	Potentially Mobile LNAPL at Shoreline
(solid blue dot)	Current Measurable LNAPL in Well
(dashed blue circle)	Current Trace LNAPL in Well
(dotted blue circle)	Historical LNAPL (Not Currently Present)
(green dot)	LNAPL Never Observed
(yellow area)	Removal and Backfill; Off-Site Treatment/Disposal
(red line)	Boundary of Cornwall Landfill Waste
SOIL	Boundary of Haley Soil Exceedances
GW	Boundary of Haley Groundwater Exceedances
(purple line)	Boundary of Smear Zone



Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

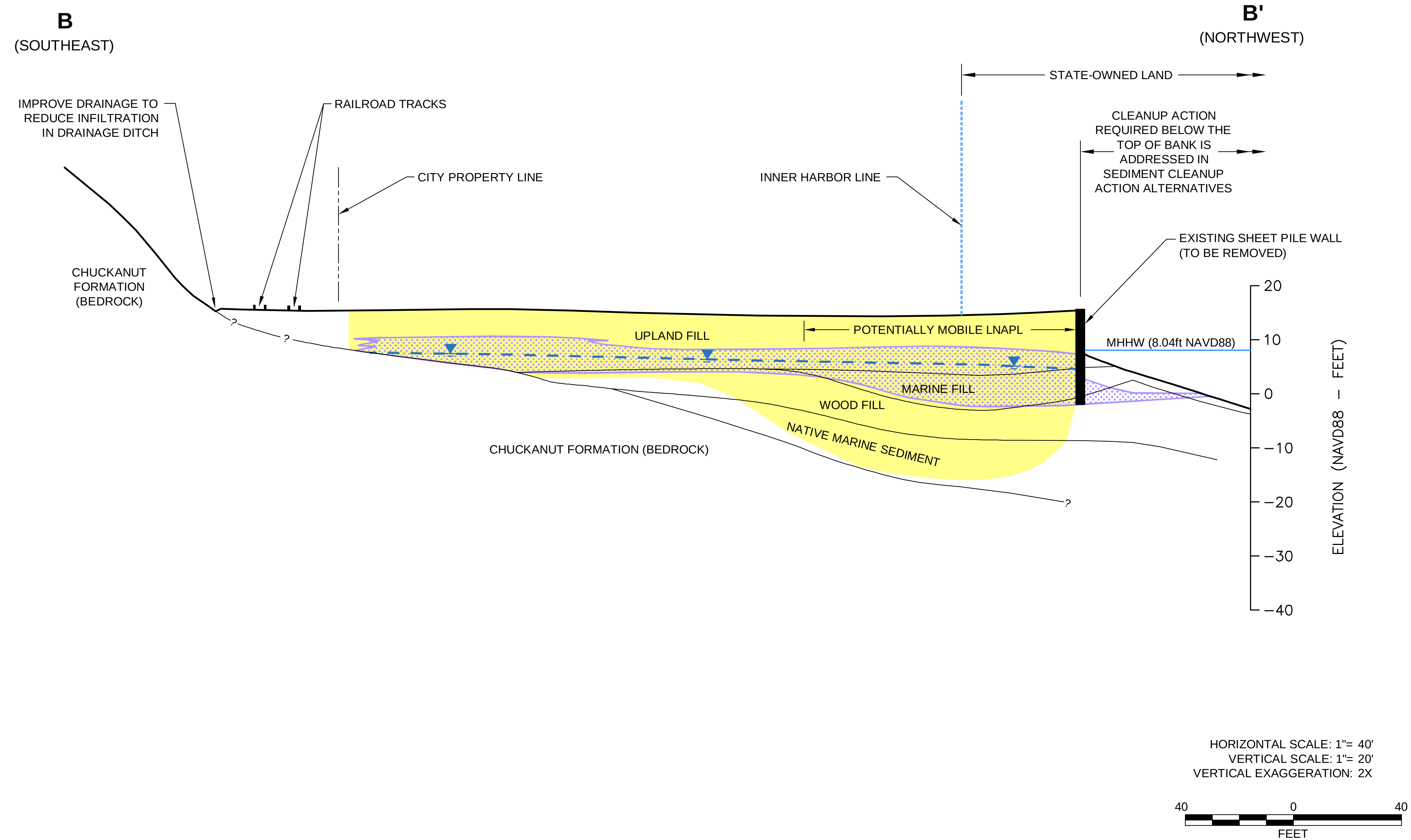
Upland Cleanup Action Alternative U4 Plan

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-12

P:\0\0356114\06\CAD\Task 2700 Feasibility Study\Upland Cleanup Alternative Figures\Figure 9-12 Upland Cleanup Action Alternative U4 Plan.dwg\TAB:Fig 9-1 modified on Sep 18, 2014 - 9:56am



Legend

- Approximate Extent of Petroleum Smear Zone
- Removal and Backfill with Clean Imported Fill; Off-Site Treatment/Disposal

Notes

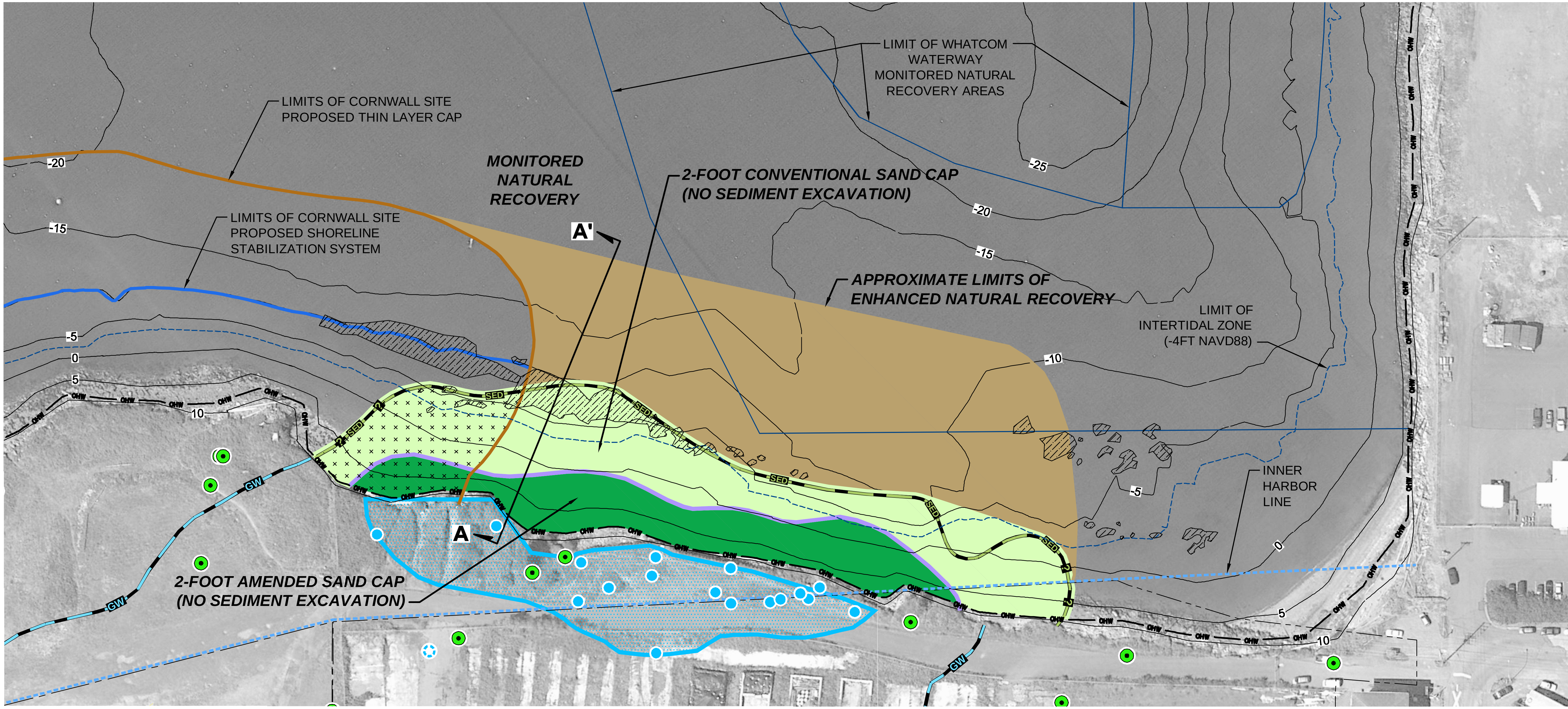
1. Directions given on cross section line refer to Project North.
2. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Upland Cleanup Action Alternative U4
Cross Section B-B'

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-13



Legend

- A — A' Cross Section Location
- City Owned Property, Former R.G. Haley International
- Cornwall Property
- Inner Harbor Line
- Potentially Mobile LNAPL at Shoreline
- Current Measurable LNAPL in Well
- Current Trace LNAPL in Well
- LNAPL Never Observed
- Haley-Cornwall Overlap Area
- Amended Sand Cap
- Conventional Sand Cap
- Note: Sand Caps are armored.
- Enhanced Natural Recovery
- SED Boundary of Haley Sediment SMS Benthic Toxicity Exceedances
- GW Boundary of Haley Groundwater Exceedances
- Smear Zone
- Eelgrass

W N S E True North Project North

100 0 100
Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

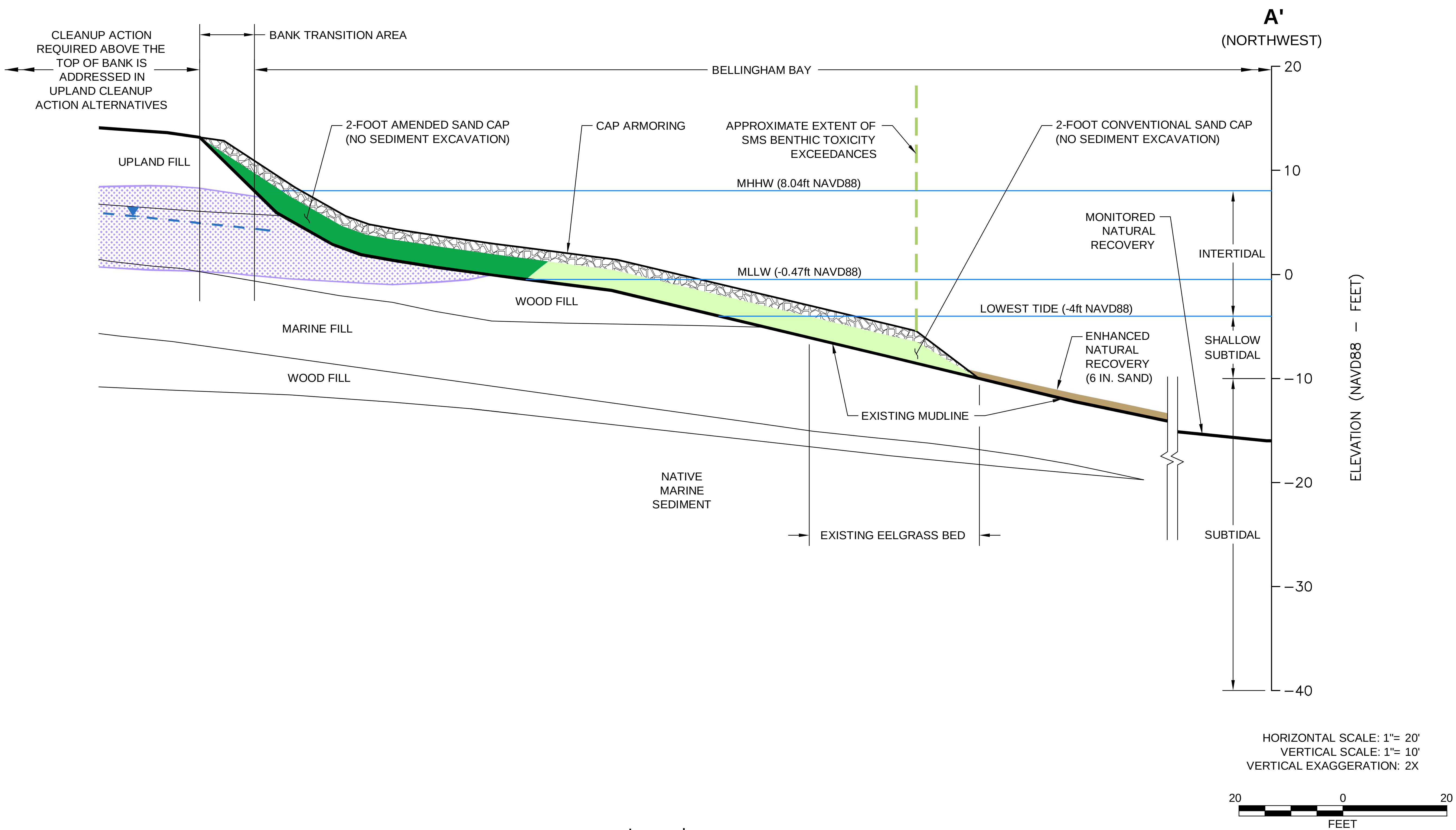
Reference: Base aerial photo from Google Earth Pro 2011.

Sediment Cleanup Action Alternative S1 Plan

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-14



Legend

- Smear Zone
- Amended Sand Cap
- Conventional Sand Cap
- Cap Armoring
- Enhanced Natural Recovery

Notes

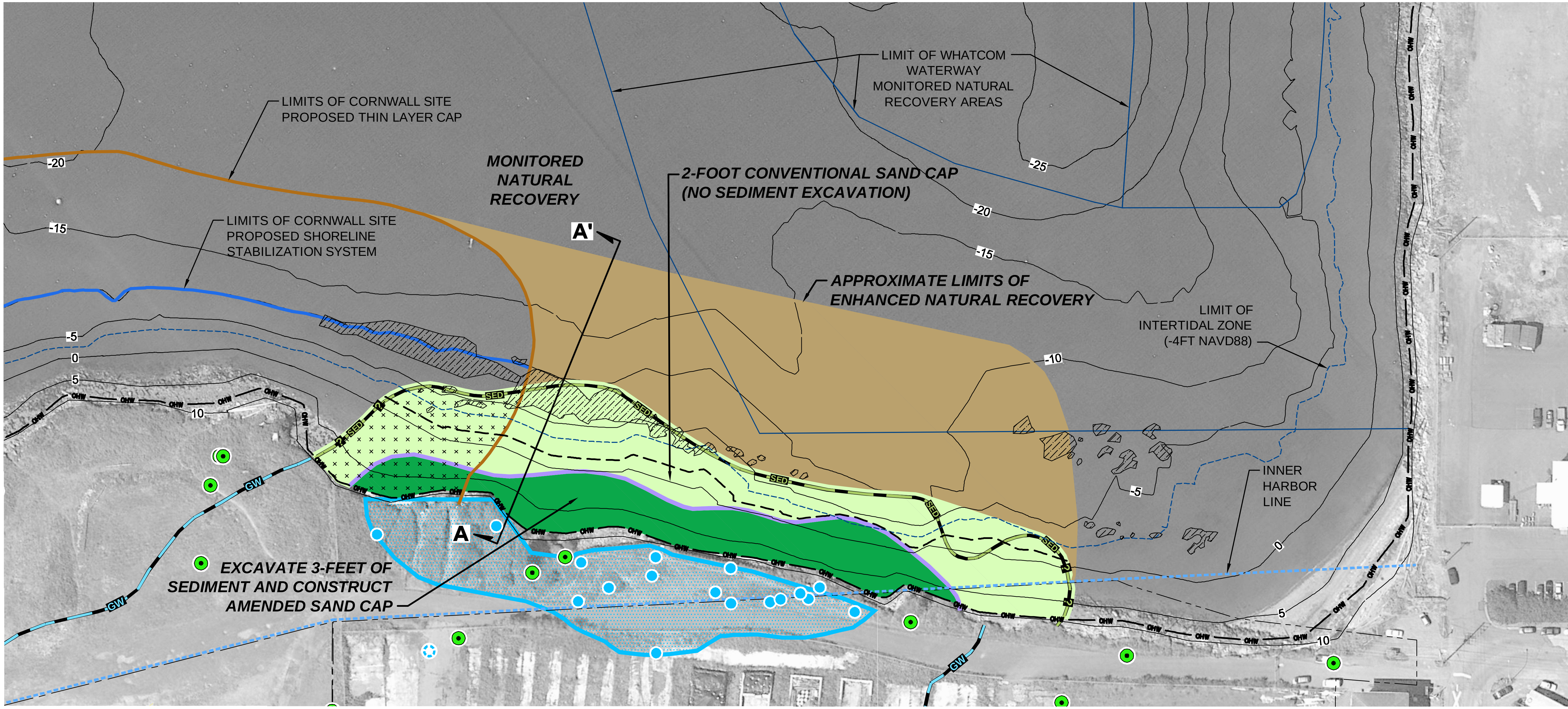
1. Directions given on cross section line refer to Project North.
2. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
3. Cleanup action for bank transition area depends on upland remedy selected.
4. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Sediment Cleanup Action Alternative S1
Cross Section A-A'

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-15



Legend

A A'	Cross Section Location
	City Owned Property, Former R.G. Haley International
	Cornwall Property
	Inner Harbor Line
	Potentially Mobile LNAPL at Shoreline
	Current Measurable LNAPL in Well
	Current Trace LNAPL in Well
	LNAPL Never Observed
	Haley-Cornwall Overlap Area
	Sediment Excavation Plus Amended Sand Cap
	Conventional Sand Cap
	Enhanced Natural Recovery
SED	Boundary of Haley Sediment SMS Benthic Toxicity Exceedances
GW	Boundary of Haley Groundwater Exceedances
	Smear Zone
	Extent of Sediment Removal
	Eelgrass

Note: Sand Caps are armored.

W S N E True North Project North

100 0 100
Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

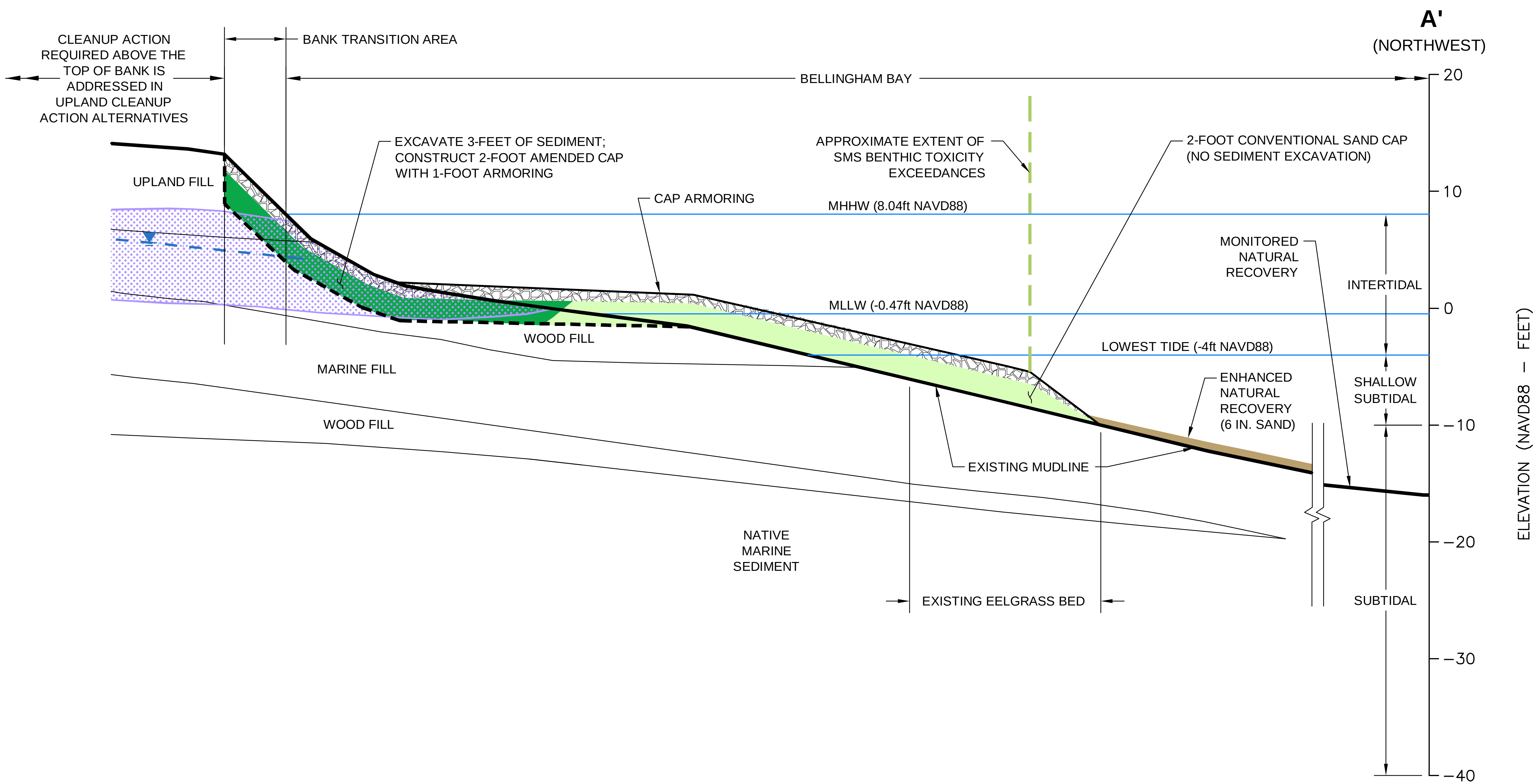
Sediment Cleanup Action Alternative S2 Plan

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-16

W:\Seattle\Projects\0\0356114\06\CAD\Task 2700 Feasibility Study\Sediment Cleanup Alternative Figures\Figure 9-16 Sediment Cleanup Action Alternative S2 Plan.dwg\TAB:Fig9-16 Modified on Mar 18, 2015 - 12:53pm



HORIZONTAL SCALE: 1"= 20'
VERTICAL SCALE: 1"= 10'
VERTICAL EXAGGERATION: 2X

20 0 20
FEET

Legend

- Smear Zone
- Base of Sediment Excavation
- Sediment Excavation Plus Amended Sand Cap
- Conventional Sand Cap
- Cap Armoring
- Enhanced Natural Recovery

Notes

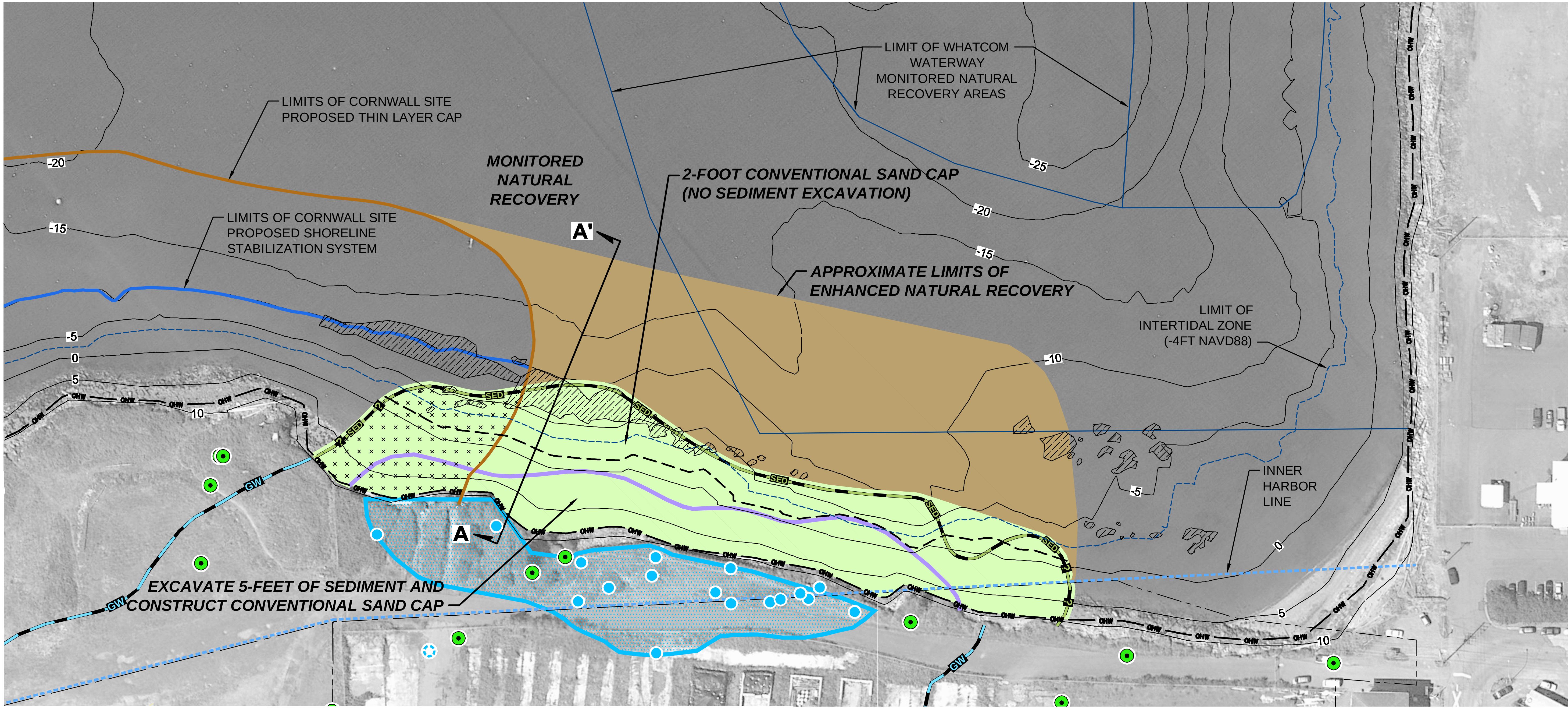
1. Directions given on cross section line refer to Project North.
2. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
3. Cleanup action for bank transition area depends on upland remedy selected.
4. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Sediment Cleanup Action Alternative S2
Cross Section A-A'

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-17



Legend

- A A' — Cross Section Location
- City Owned Property, Former R.G. Haley International
- Cornwall Property
- Inner Harbor Line
- Potentially Mobile LNAPL at Shoreline
- Current Measurable LNAPL in Well
- Current Trace LNAPL in Well
- LNAPL Never Observed
- Haley-Cornwall Overlap Area
- Sand Cap (Ranges in Thickness from 2-Feet to 5-Feet)
- Enhanced Natural Recovery
- Boundary of Haley Sediment SMS Benthic Toxicity Exceedances
- Boundary of Haley Groundwater Exceedances
- Smear Zone
- Extent of Sediment Removal
- Eelgrass

Note: Sand Cap is armored.

True North
Project North
W S N E

100 0 100
Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

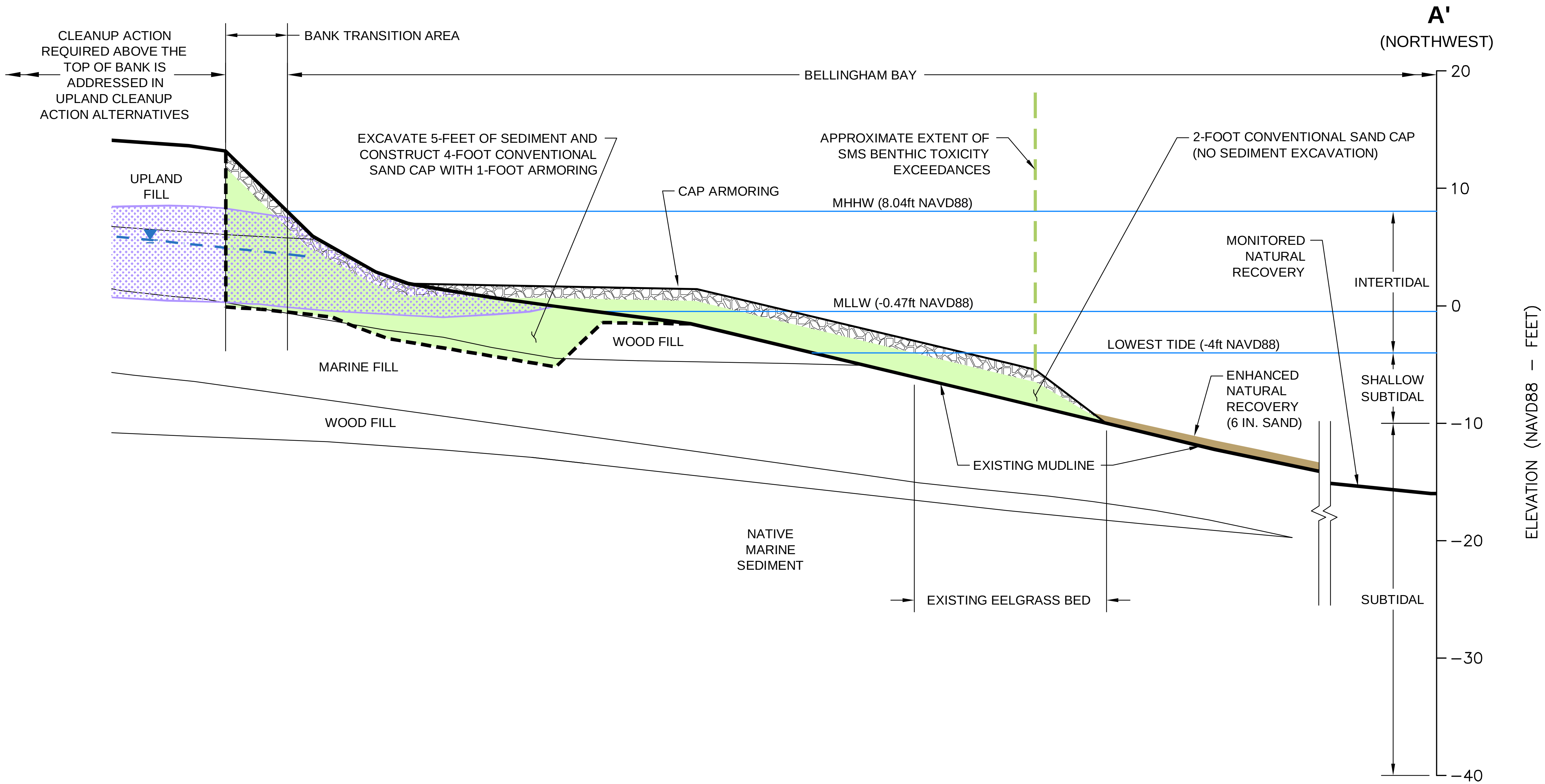
Sediment Cleanup Action Alternative S3 Plan

R.G. Haley Site
Bellingham, Washington

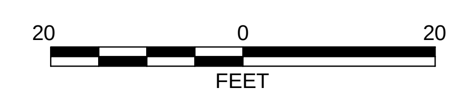
GeoEngineers

Figure 9-18

W:\Seattle\Projects\0\0356114\06\CAD\Task 2700 Feasibilty Study\Sediment Cleanup Alternative Figures\Figure 9-18 Sediment Cleanup Action Alternative S3 Plan.dwg\TAB:Fig9-18 Modified on Mar 18, 2015 - 12:55pm



HORIZONTAL SCALE: 1"= 20'
VERTICAL SCALE: 1"= 10'
VERTICAL EXAGGERATION: 2X



Legend

- Smear Zone
- Base of Sediment Excavation
- Sediment Excavation Plus Conventional Sand Cap (Ranges from 2-Feet to 5-Feet Thick)
- Cap Armoring
- Enhanced Natural Recovery

Notes

1. Directions given on cross section line refer to Project North.
2. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
3. Cleanup action for bank transition area depends on upland remedy selected.
4. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Sediment Cleanup Action Alternative S3
Cross Section A-A'

R.G. Haley Site
Bellingham, Washington

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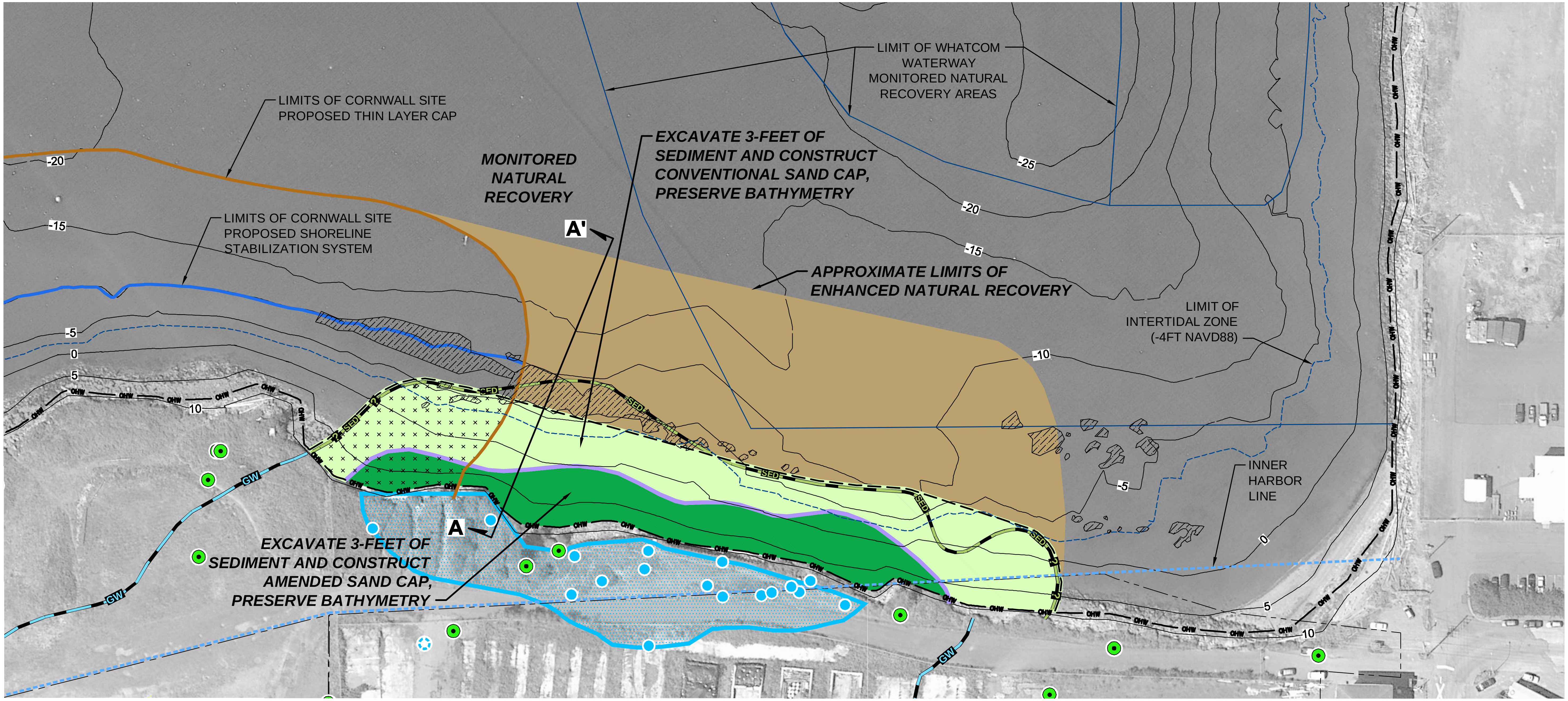
Figure 9-19



Legend

- Cross Section Location (A – A')
- City Owned Property, Former R.G. Haley International
- Cornwall Property
- Inner Harbor Line
- Potentially Mobile LNAPL at Shoreline
- Current Measurable LNAPL in Well
- Current Trace LNAPL in Well
- LNAPL Never Observed
- Haley-Cornwall Overlap Area
- Excavation Plus Amended Sand Cap
- Excavation Plus Conventional Sand Cap
- Note: Sand Caps are armored.
- Enhanced Natural Recovery
- Boundary of Haley Sediment SMS Benthic Toxicity Exceedances
- Boundary of Haley Groundwater Exceedances
- Smear Zone
- Extent of Sediment Removal
- Eelgrass

True North / Project North

100 0 100

Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

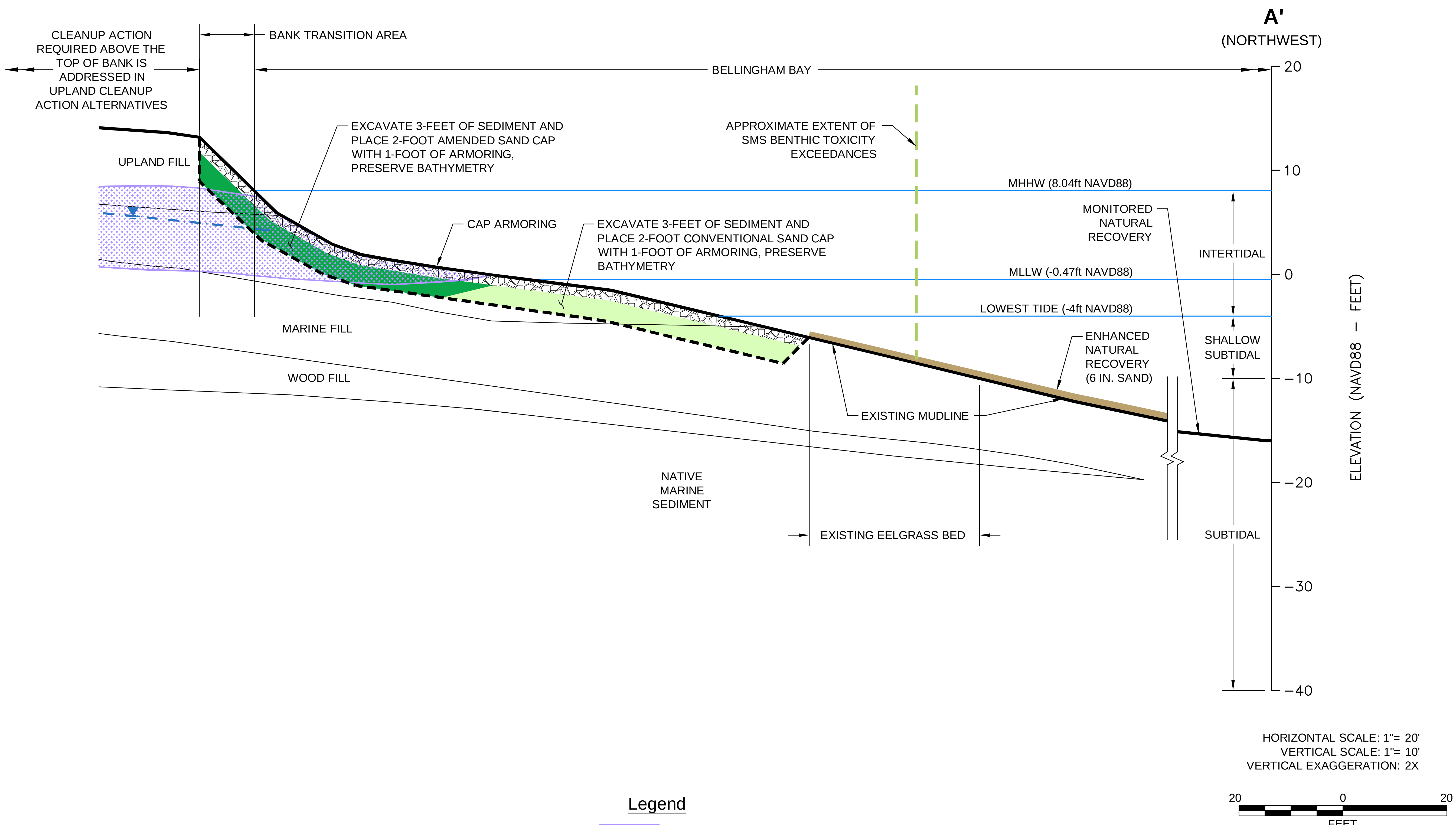
Sediment Cleanup Action Alternative S4 Plan

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-20

W:\Seattle\Projects\0\0356114\06\CAD\Task 2700 Feasibility Study\Sediment Cleanup Alternative Figures\Figure 9-20 Sediment Cleanup Action Alternative S4 Plan.dwg\TAB:Fig 9-20 Modified on Mar 18, 2015 - 12:58pm



Legend

- Smear Zone
- Base of Sediment Excavation
- Sediment Excavation Plus Amended Sand Cap
- Conventional Sand Cap
- Cap Armoring
- Enhanced Natural Recovery

Notes

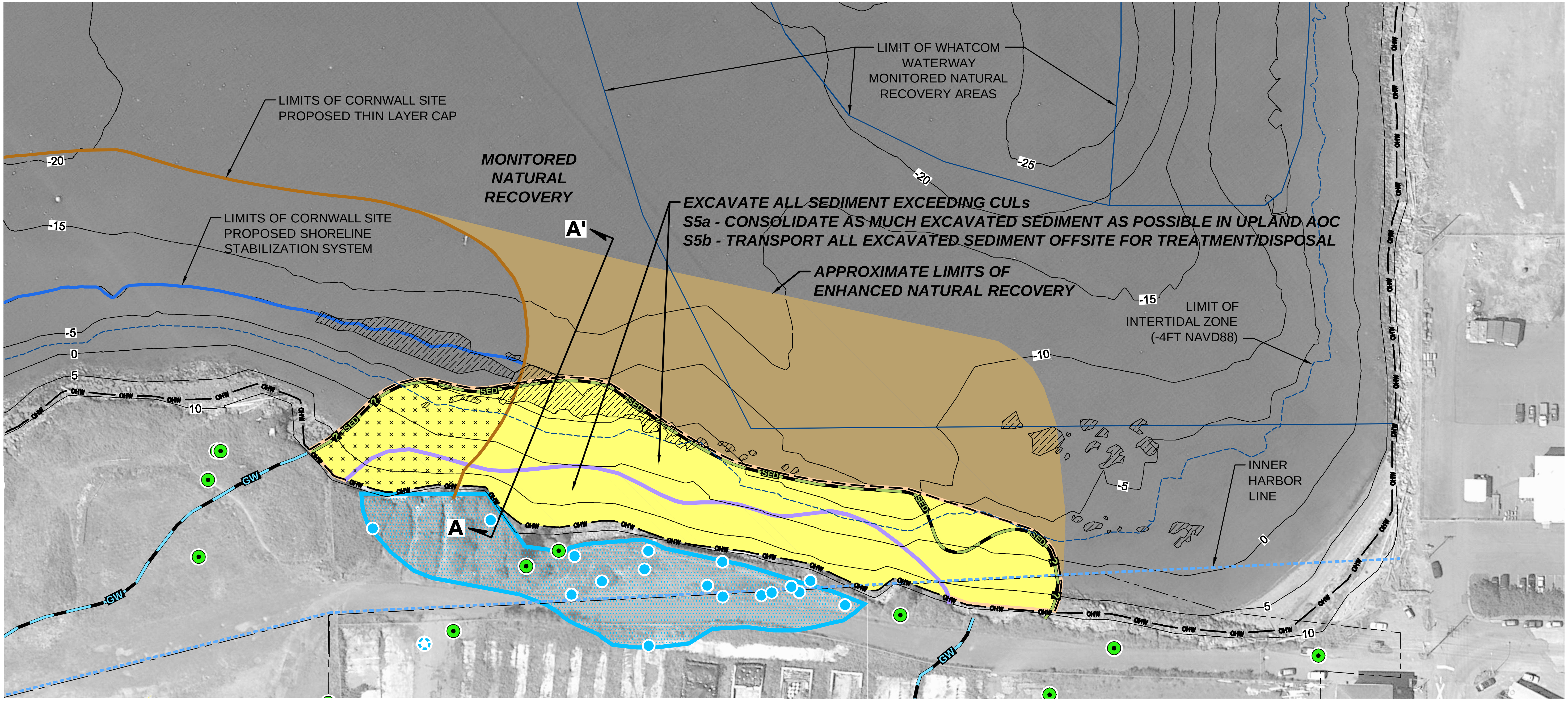
1. Directions given on cross section line refer to Project North.
2. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
3. Cleanup action for bank transition area depends on upland remedy selected.
4. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Sediment Cleanup Action Alternative S4
Cross Section A-A'

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-21



Legend

A A'	Cross Section Location
	City Owned Property, Former R.G. Haley International
	Cornwall Property
	Inner Harbor Line
	Potentially Mobile LNAPL at Shoreline
	Current Measurable LNAPL in Well
	Current Trace LNAPL in Well
	LNAPL Never Observed
	Haley-Cornwall Overlap Area
	Excavate Sediment Exceeding CULs, Backfill Excavation, with Armor
	Enhanced Natural Recovery
SED	Boundary of Haley Sediment SMS Benthic Toxicity Exceedances
GW	Boundary of Haley Groundwater Exceedances
	Smear Zone
	Extent of Sediment Removal
	Eelgrass

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

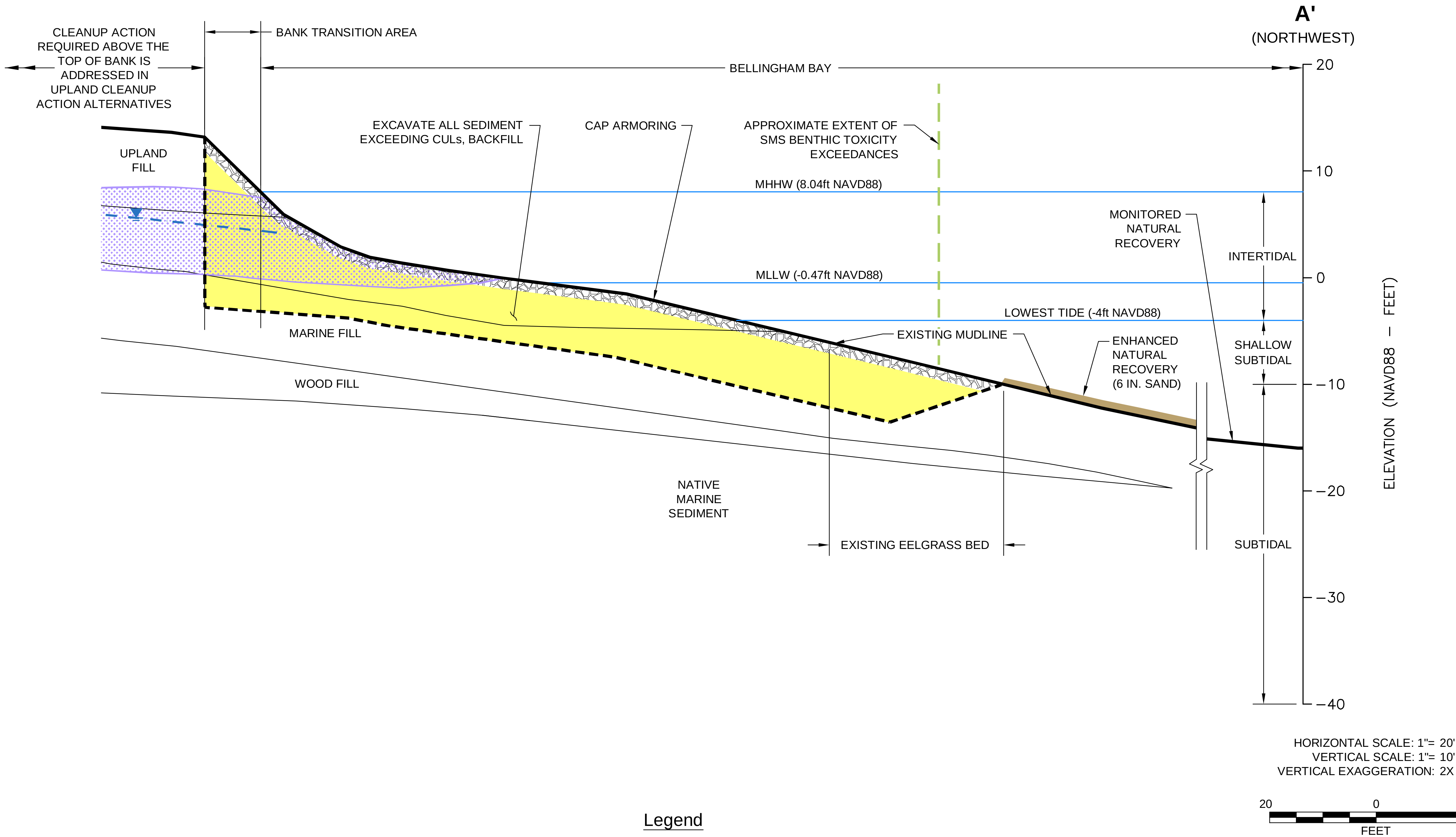
W:\Seattle\Projects\0\0356114\06\CAD\Task 2700 Feasibility Study\Sediment Cleanup Alternative Figures\Figure 9-22 Sediment Cleanup Action Alternative S5 Plan.dwg\TAB:Layout1 Modified on Mar 18, 2015 - 1:00pm

Sediment Cleanup Action Alternative S5a and 5b Plan

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-22



Legend

- Smear Zone
- Base of Sediment Excavation
- Excavate Sediment Exceeding CULs, Backfill Excavation
- Cap Armoring
- Enhanced Natural Recovery

Notes

1. Directions given on cross section line refer to Project North.
2. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
3. Cleanup action for bank transition area depends on upland remedy selected.
4. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Sediment Cleanup Action Alternative S5a and 5b Cross Section A-A'

R.G. Haley Site
Bellingham, Washington

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Figure 9-23

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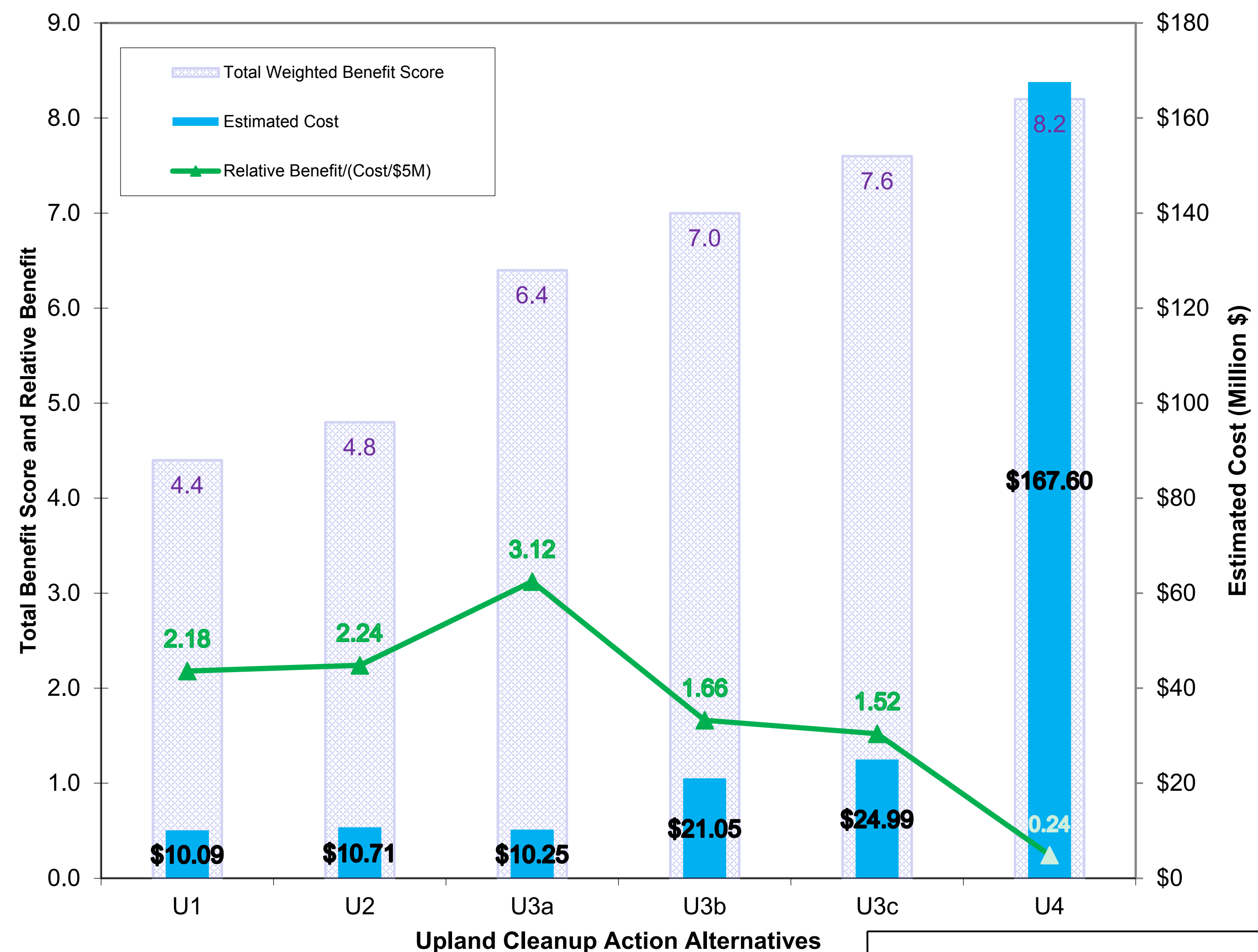
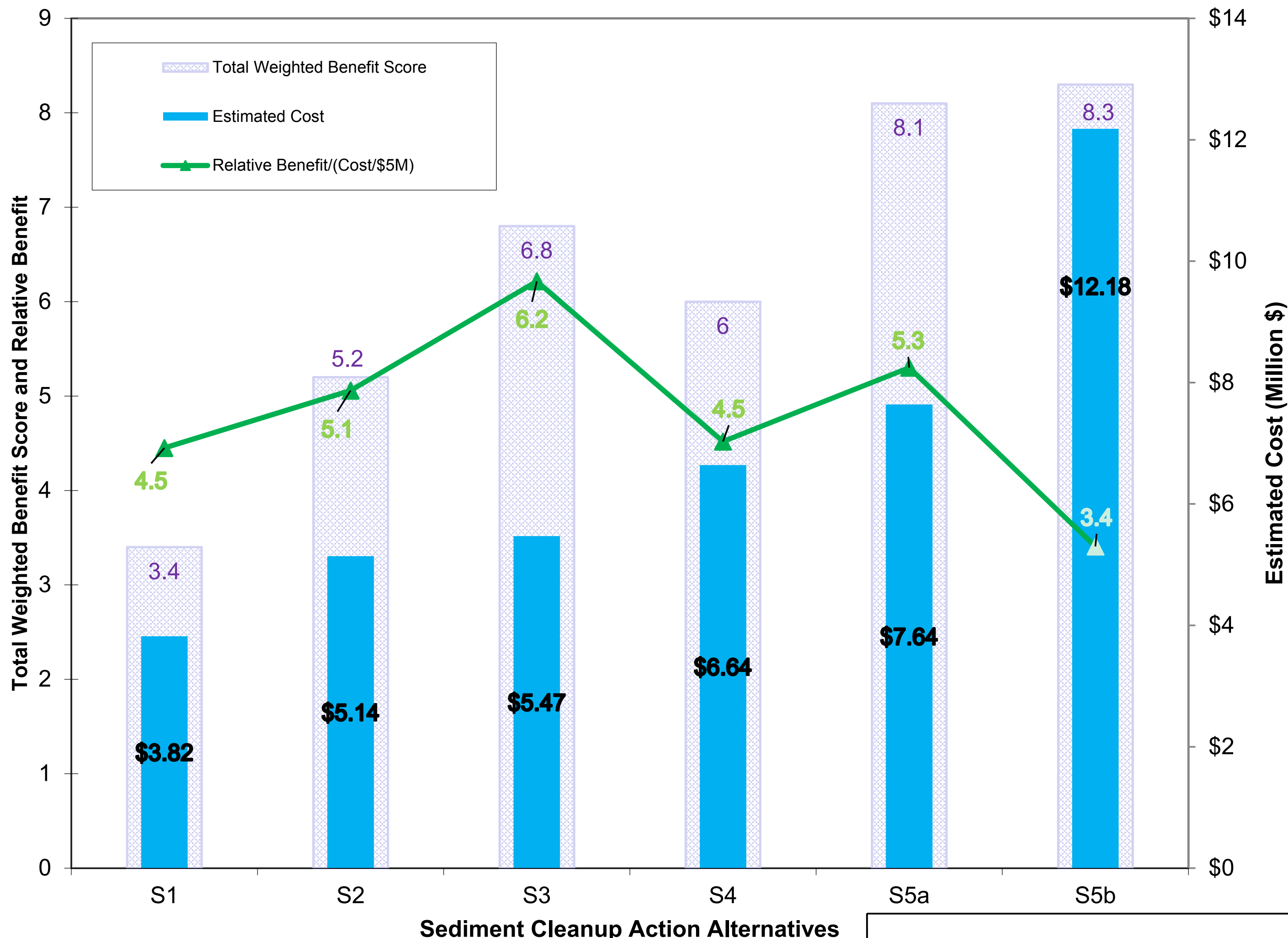


Disproportionate Cost Analysis - Upland

RG Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 9-24



Disproportionate Cost Analysis - Sediment

RG Haley Site
Bellingham, Washington

GeoEngineers

Figure 9-25

10.0 PREFERRED ALTERNATIVE

Preferred alternatives were identified separately for the upland and marine units of the Site based on the outcomes of each corresponding DCA conducted in accordance with MTCA (Section 9.6). The upland and sediment preferred alternatives will be designed as an integrated cleanup action, and are discussed in this section as a combined "preferred alternative." The final combined cleanup action for the Site will be selected in the CAP developed by Ecology.

10.1 Description of the Preferred Alternative

Alternative U3a "Nearshore *In Situ* Soil Solidification, Upland Cap" and Alternative S3 "Upper Intertidal Sediment Removal and Sand Cap" were identified as the alternatives that are permanent to the maximum extent practicable for the upland and marine units, respectively. The Site-wide, integrated preferred alternative is shown in Figures 10-1 through 10-3. The components of the combined preferred alternative are described below:

- The area of potentially mobile LNAPL and associated contaminated soil near the shoreline would be treated *in situ* using soil solidification methods. Treatability testing would be performed to determine the stabilizing reagent specifications for the soil solidification process. This FS assumes the solidification process would consist of a mixture of cement and organoclay. This element of the upland remedy would permanently immobilize and isolate potentially mobile LNAPL and soil contaminants in place, reducing contaminant leaching from soil and LNAPL to groundwater.
- Groundwater would flow below the solidified soil mass, through deeper soil where contaminant concentrations are lower or not present at detectable levels; this will enhance natural attenuation processes, resulting in reduced contaminant flux from the upland to marine units.
- A low-permeability, multi-layer cap over the entire upland area where soil exceeds cleanup levels would prevent direct contact and reduce stormwater infiltration. The cap layers would include (bottom to top) a separation layer, a gas-collection layer, a low-permeability geomembrane liner, a drainage layer, a separation geotextile and at least two feet of imported fill or topsoil that may be seeded or paved depending on Site redevelopment plans. The low-permeability cap would also provide passive subsurface vapor collection and venting to mitigate the accumulation of volatiles from LNAPL, soil, groundwater or landfill gases from refuse associated with the overlapping Cornwall Landfill site. Stormwater collection and treatment systems and upgradient drainage improvements also would be constructed to minimize infiltration of stormwater in recharge areas. In the event additional data are needed to refine the northern boundary of the low-permeability cap system and drainage controls, additional sampling would be conducted during the design phase.
- The shoreline bank would be recontoured as needed to integrate the upland and sediment remedies and provide structural continuity/transition between the Site units. Shoreline transition grading could be established to accommodate habitat restoration, shoreline access and water-dependent uses proposed as part of the future Cornwall Beach Park (Section 10.4).
- Existing Site features would be removed, as required, to construct the cleanup action including the existing sheet pile wall; the former Haley facility UST, surge tank and product piping; remnant

subsurface stormwater piping and outfalls; piling extending above the sediment surface; and large debris within the footprint of the active sediment remedy.

- LNAPL-impacted sediment in the upper intertidal zone would be excavated and removed from the marine unit; remaining contaminated sediment in this nearshore excavation area would be capped. The removed sediment would be managed on-site within the upland AOC to the maximum extent possible, after amending the sediment as needed to improve geotechnical suitability before the upland cap is constructed.
- The remaining area of SMS benthic toxicity exceedances, outside of the sediment excavation area, would be capped (no sediment removal). This capping area is located in the lower intertidal and shallow subtidal zones, which would not be expected to recover naturally. All sediment caps would be appropriately armored to withstand physical marine erosion processes, thereby reducing the risk of park visitors, net fishers, and benthic organisms directly contacting contaminated sediment. The caps also would be designed to provide for chemical isolation of underlying contaminants.
- Sediment in deeper subtidal areas with moderate contamination and more stable hydrodynamic conditions would utilize ENR (a thin sand layer) to achieve cleanup goals for bioaccumulative compounds. The ENR area would begin at the outer boundary of the capping area. The outer boundary of the ENR area would be established during remedial design, but for cost estimating purposes is conservatively assumed to extend to approximately -10 to -15 feet (NAVD88) (Sections 9.1.1.2 and 9.5.3) where dioxin/furan concentrations in sediment are greater than two times the cleanup level. ENR achieves risk reduction goals within a reasonable restoration timeframe.
- MNR would be utilized in subtidal areas seaward of the ENR area where low-level exceedances of bioaccumulative-based cleanup levels occur in sediment and are expected to naturally recover within a reasonable restoration timeframe.
- The footprint of the ENR and MNR areas will be refined after taking into account additional sediment analytical data that will likely be obtained to further evaluate concentrations of bioaccumulative compounds in the ENR/MNR areas. Finally, further evaluation of the anticipated effect of natural recovery in the ENR/MNR areas and interpretation of the Site data on a SWAC basis will be considered when determining the extent and location of the ENR and MNR areas.
- Institutional controls would be employed to prevent human activities that may damage the upland and sediment caps in the future and thus assure integrity of the remedy.
- Long-term monitoring and maintenance of the upland and sediment caps and natural recovery areas would be implemented. Periodic review of remedy performance and effectiveness would be established in conjunction with the monitoring program.

The estimated cost for the preferred alternative is $15,720,000. The estimated duration for treatability testing, design, permitting and construction of the upland preferred alternative is 2 to 3 years. Exposure pathways would be eliminated when construction of the remedy is completed and monitoring would confirm remedy effectiveness. The capped portions of the marine unit would achieve cleanup standards after construction is completed; construction is estimated to take two to three years following receipt of permits. Sediment cleanup standards in the ENR and MNR areas are anticipated to be achieved within 10 years following placement of the ENR layer.

10.2 Basis for Selection of the Preferred Alternative

The preferred alternatives for the upland and marine units were selected by comparing the relative benefit to the cost of each alternative, as described in MTCA (WAC 173-340-360[3][e]). The relative benefit for each alternative is represented by the sum of the weighted scores for each of the DCA criteria, as described in Section 9.6. The relative benefit/cost ratio was calculated by dividing the total weighted benefit score by the total cost for each alternative (to facilitate graphical presentation of the relative benefit/cost, the total cost of each alternative was divided by $5,000,000). The resulting relative benefit/cost ratio was plotted in Figures 9-24 and 9-25. As described in MTCA, the DCA test was used to determine if the cost of an alternative was disproportionate to its benefit: "Costs are disproportionate to benefits if the incremental costs of the alternative over that of a lower cost alternative exceed the incremental degree of benefits achieved by the alternative over that of the lower cost alternative." Using this method, Upland Alternative U3a and Sediment Alternative S3 achieved the highest level of relative benefit/cost and are permanent to the maximum extent practicable.

The preferred alternatives provide the optimum balance between cost, benefit and certainty associated with long-term performance. Alternatives for the upland unit and the marine unit that cost less than the corresponding preferred alternatives were identified; however, the less costly alternatives offer less relative benefit. Alternatives were identified that provide higher benefits compared to the preferred alternatives; however, the alternatives with higher benefits were determined to be disproportionately costly relative to the corresponding increased benefit.

10.3 Compatibility with Other Cleanup Actions

Significant portions of the Haley upland and marine units overlap with the Cornwall Landfill upland and marine units. In addition, portions of the Haley marine unit overlap with Whatcom Waterway sediment site Unit 9 and Whatcom Waterway site Unit 6C. The preferred alternative for the Haley Site can be entirely compatible with the Cornwall Landfill and Whatcom Waterway remedies in the areas of overlap. To be compatible; however, coordination will be required to assure protectiveness and maximize cost effectiveness. Coordination of design and construction phasing is discussed further below.

The Haley Site upland cleanup action and the Cornwall Landfill site upland cleanup action utilize several common elements that would be compatible and for which design will be coordinated and optimized; these elements include low-permeability caps, gas collection layers with venting to the surface, stormwater drainage improvements and controls to reduce infiltration, shoreline erosion protection, and environmental covenants that prevent incompatible uses. The conceptual cap profiles for the Haley and Cornwall Landfill sites differ somewhat; either conceptual design would be suitable for use in the overlap area except that coordination would be required to achieve a compatible finish grade that would assure cap integrity and meet stormwater management requirements for both sites. This will require coordination during design, particularly to account for the integration of excavated sediment (from the Haley marine unit) into the upland AOC.

The selected remedy for the Haley marine unit involves the removal of nearshore sediment and capping without significantly affecting bathymetry in the nearshore area. The current Cornwall Landfill sediment remedy utilizes capping and armoring of the shoreline without sediment removal, resulting in nearshore filling. The nearshore Haley sediment removal and capping action provides a chemical containment function that would not be provided by the Cornwall Landfill sediment remedy in the overlap area. As a result, the nearshore Haley sediment remedy would need to take precedence over the Cornwall remedy in the overlap area (Figure 10-1). The remedy designs would also need to be coordinated to merge grades at the point where the two caps coincide, and to integrate other design elements of the caps (e.g., armoring).

10.4 Integration of Preferred Alternative with Future Park Development

The City has recently completed the master plan for Cornwall Beach Park (City of Bellingham 2014), a proposed new 17-acre waterfront park that is proposed to be constructed on the upland and intertidal sediment areas associated with the Cornwall Landfill site and the Haley Site, as well as the Cornwall Cove pocket beach (also known as the Pine Street beach) to the north of the Haley Site. The City's conceptual park designs presented in the master plan were developed with input from the City, Port and cleanup consultants currently involved with the Cornwall Landfill site, as well as from the public. The design and implementation of the Haley Site cleanup and proposed park will be coordinated during future design, planning and permitting phases of both projects.

The preferred alternative for the Haley Site is consistent with the preliminary design concepts presented to date for the Cornwall Beach Park. Aspects of the cleanup planning and design that will be coordinated with park planning include the following:

- Design of the low-permeability upland cap will need to account for fill thickness to be placed over the upland cap for park grading, including the "viewing hill" where grades are anticipated to be raised more than 20 feet above the existing ground surface in places. Design considerations will include potential settlement and ambient venting for the gas collection system of the cap system.
- Institutional controls will specify that the low-permeability upland cap on the Haley Site should not be penetrated or compromised and will dictate measures to prevent exposure to underlying contaminants in the event that park construction methods or activities result in short-term modifications of the low-permeability cap.
- Wells used for compliance monitoring (locations not determined at this time) to monitor effectiveness of the cleanup action will need to be preserved through park construction and protected from park uses.
- Surface elevations in the upland unit on the Haley Site will be modified as a result of the low-permeability cap and consolidation of excavated contaminated sediment beneath the cap within the upland AOC. Modified grades will be established through remedial design.
- If future enclosed and occupied structures are constructed in connection with the park, such as coffee shop/concession or restrooms, the structures may require an under-slab vapor barrier and passive vapor collection/venting, depending on the cap gas-collection system design and structure locations in the upland unit.
- Waterfront uses for the proposed park include beach play areas, hand-carried watercraft launching, shoreline landscaping and habitat for aquatic organisms. The proposed sediment cap

design will need to consider future shoreline access and use, as well as issues related to eelgrass beds in the lower intertidal/shallow subtidal area.

- Institutional controls and environmental covenants for the marine unit will be developed with future park uses and activities in mind.
- Sediment cap design, particularly cap armoring, will need to consider future use of the shoreline by park users and the need for the surface material to be stable but compatible with habitat substrate requirements.

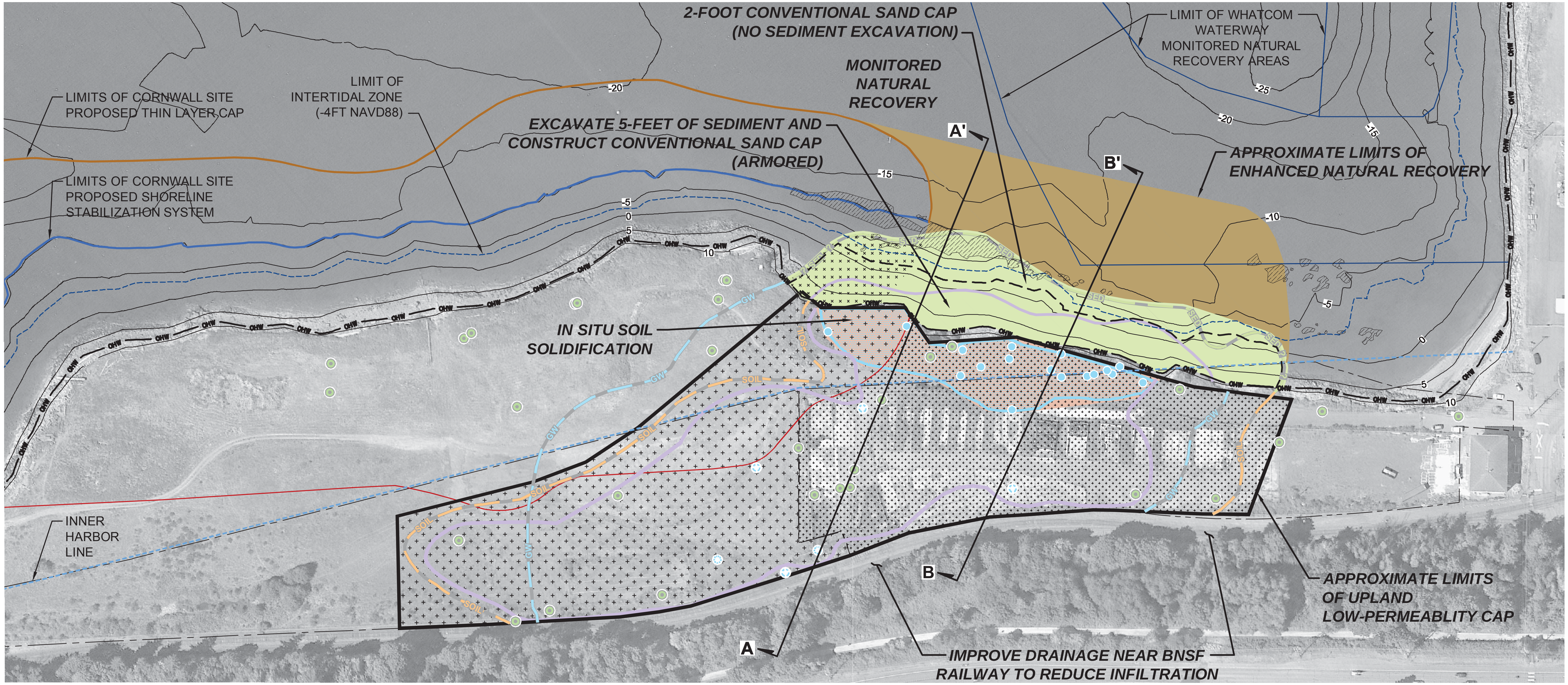
The transition from the upland remedy to the sediment remedy is expected to be designed in conjunction with final park design. The preferred cleanup action elements at the shoreline are not expected to prohibit future construction of park elements.

10.5 Remaining Steps in Site Cleanup Process

Additional steps are anticipated as part of the Haley Site cleanup. The RI/FS Report will undergo public review and comment. Ecology will respond to comments from the public and other stakeholders such as local, state and federal agencies and the RI/FS will be finalized. Ecology will then describe the proposed cleanup in the draft CAP, which will also be subject to public and agency review and comment along with the draft Consent Decree (CD) that will specify the remedy to be implemented at the Site and any other associated requirements.

Design of the remedy will begin after public comments are received on the draft CAP/CD and any necessary revisions are made to it. One component of the pre-design phase will be a treatability study to determine *in situ* solidification treatment parameters. Supplemental sampling to support remedy design will be conducted if the need for more information is identified.

Preliminary design of the full cleanup action will be documented in an Engineering Design Report (EDR), which is also subject to Ecology review. The Ecology-approved EDR will be used as the basis for environmental permit applications required for upland and in-water components of the project. Additional requirements for the project may be identified as part of the permit process, resulting in changes to the design or implementation (e.g., timing, sequencing, etc.). Following completion and approval of a final design, construction bid documents for selection of remediation contractors and suppliers will be prepared and the remedy will be constructed, with Ecology oversight. Following construction, an initial post-remedy monitoring event will be conducted to determine if the CAOs were achieved and to provide a baseline condition for evaluation of subsequent performance of the remedy.



Legend

A A'	Cross Section Location
	City Owned Property, Former R.G. Haley International
	Cornwall Property
	Inner Harbor Line
	Potentially Mobile LNAPL at Shoreline
	Current Measurable LNAPL in Well
	Current Trace LNAPL in Well
	Historical LNAPL (Not Currently Present)
	LNAPL Never Observed

PREFERRED ALTERNATIVE COMPONENTS

- Low-Permeability Upland Cap (Haley-Cornwall Overlap Area)
- Low-Permeability Upland Cap (Haley Only)
- In Situ Soil Solidification
- Haley-Cornwall Sediment Cap Overlap Area
- Conventional Sand Cap (Ranges in Thickness from 2-Feet to 5-Feet) Note: Sand Cap is Armored.
- Enhanced Natural Recovery
- Extent of Sediment Removal

- SOIL — Boundary of Haley Soil Exceedances
- GW — Boundary of Haley Groundwater Exceedances
- SED — Boundary of Haley Sediment SMS Benthic Toxicity Exceedances
- Boundary of Smear Zone
- Boundary of Cornwall Landfill Waste
- Eelgrass

True North · Project North · W S N E

150 0 150 Feet

Notes

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Base aerial photo from Google Earth Pro 2011.

Preferred Cleanup Action Alternative - Combined Upland and Sediment Components

R.G. Haley Site
Bellingham, Washington

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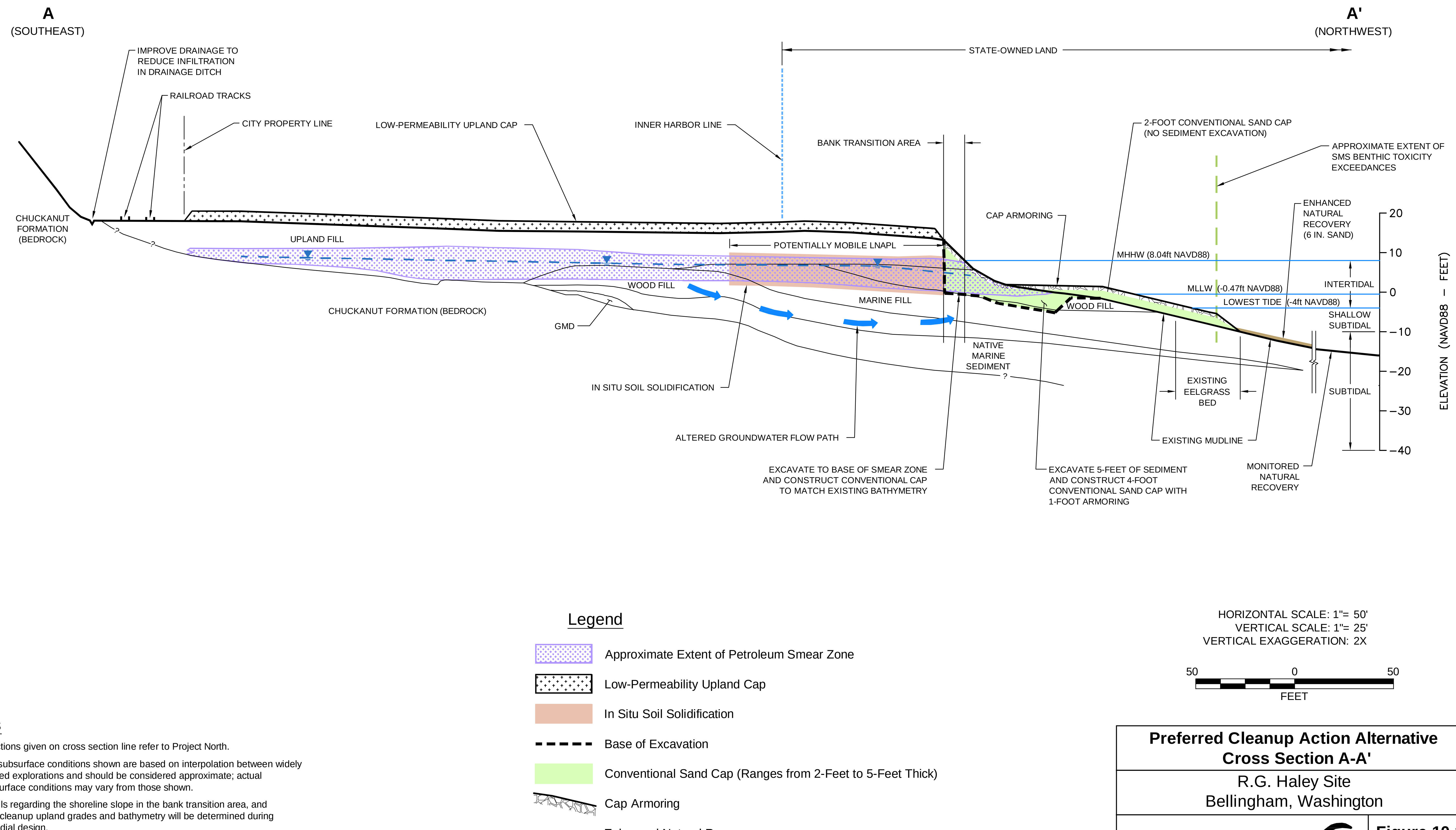
Figure 10-1 Plan



Notes

1. Directions given on cross section line refer to Project North.
2. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
3. Details regarding the shoreline slope in the bank transition area, and post-cleanup upland grades and bathymetry will be determined during remedial design.
4. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Preferred Cleanup Action Alternative Cross Section A-A'

R.G. Haley Site
Bellingham, Washington

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Figure 10-2 Section

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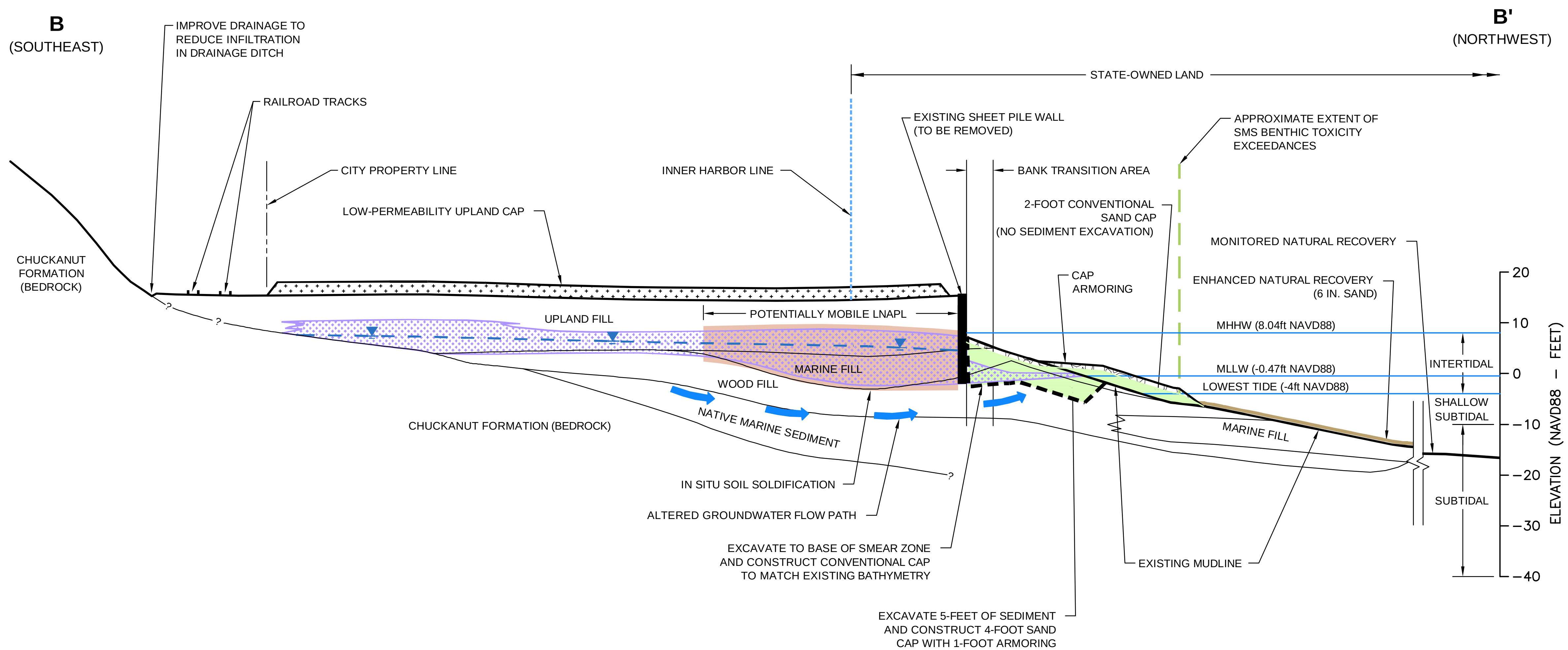

Legend

- Approximate Extent of Petroleum Smear Zone
- Low-Permeability Upland Cap
- In Situ Soil Solidification
- Base of Excavation
- Conventional Sand Cap (Ranges from 2-Feet to 5-Feet Thick)
- Cap Armoring
- Enhanced Natural Recovery

HORIZONTAL SCALE: 1"= 50'
VERTICAL SCALE: 1"= 25'
VERTICAL EXAGGERATION: 2X

50 0 50
FEET

Notes

1. Directions given on cross section line refer to Project North.
2. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
3. Details regarding the shoreline slope in the bank transition area, and post-cleanup upland grades and bathymetry will be determined during remedial design.
4. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document.

Preferred Cleanup Action Alternative
Cross Section B-B'

R.G. Haley Site
Bellingham, Washington

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Figure 10-3
Section

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[1] RSET members include U.S. Army Corps of Engineers (Portland, Seattle, and Walla Walla Districts and Northwestern Division), U.S. Environmental Protection Agency, Washington State Department of Ecology, Washington State Department of Natural Resources, Oregon Department of Environmental Quality, Idaho Department of Environmental Quality, NOAA Fisheries, and U. S. Fish and Wildlife Service.

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APPENDIX N
Area of Contamination (AOC)

Table of Contents

APPENDIX N. AREA OF CONTAMINATION (AOC)

EXHIBIT N-1

Department of Ecology Expanded AOC Definition

August 20, 2014

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
Northwest Regional Office • 3190 160th Ave SE • Bellevue, WA 98008-5452 • 425-649-7000
711 for Washington Relay Service • Persons with a speech disability can call 877-833-6341

August 20, 2014

Ms. Amy Kraham
City of Bellingham
210 Lottie Street
Bellingham, WA 98225

**Re: Expanded Area of Contamination Definition
R.G. Haley International Corporation Site**

Dear Ms. Kraham:

The Department of Ecology (Ecology) is approving the request in your July 21, 2014, letter to expand the boundaries of the existing Area of Contamination (AOC) at the R.G. Haley International Corporation Site (Site).

The AOC boundaries were originally established in a June 18, 2007, letter from Ecology, and subsequently modified in a July 8, 2013, letter. In these Ecology letters, the AOC was defined as the upland portion of the Site, plus a small intertidal area of the Site on the shoreline. The approved AOC expansion includes a larger upland area to the south and a larger intertidal/subtidal area along the Bellingham Bay shoreline. The enclosed Figure 1 shows the original and expanded boundaries of the AOC.

Contaminated soil and sediment that would otherwise need to be handled as a hazardous waste may be managed within the AOC in accordance with Ecology's 1991 *Area of Contamination* policy and with relevant EPA guidance.

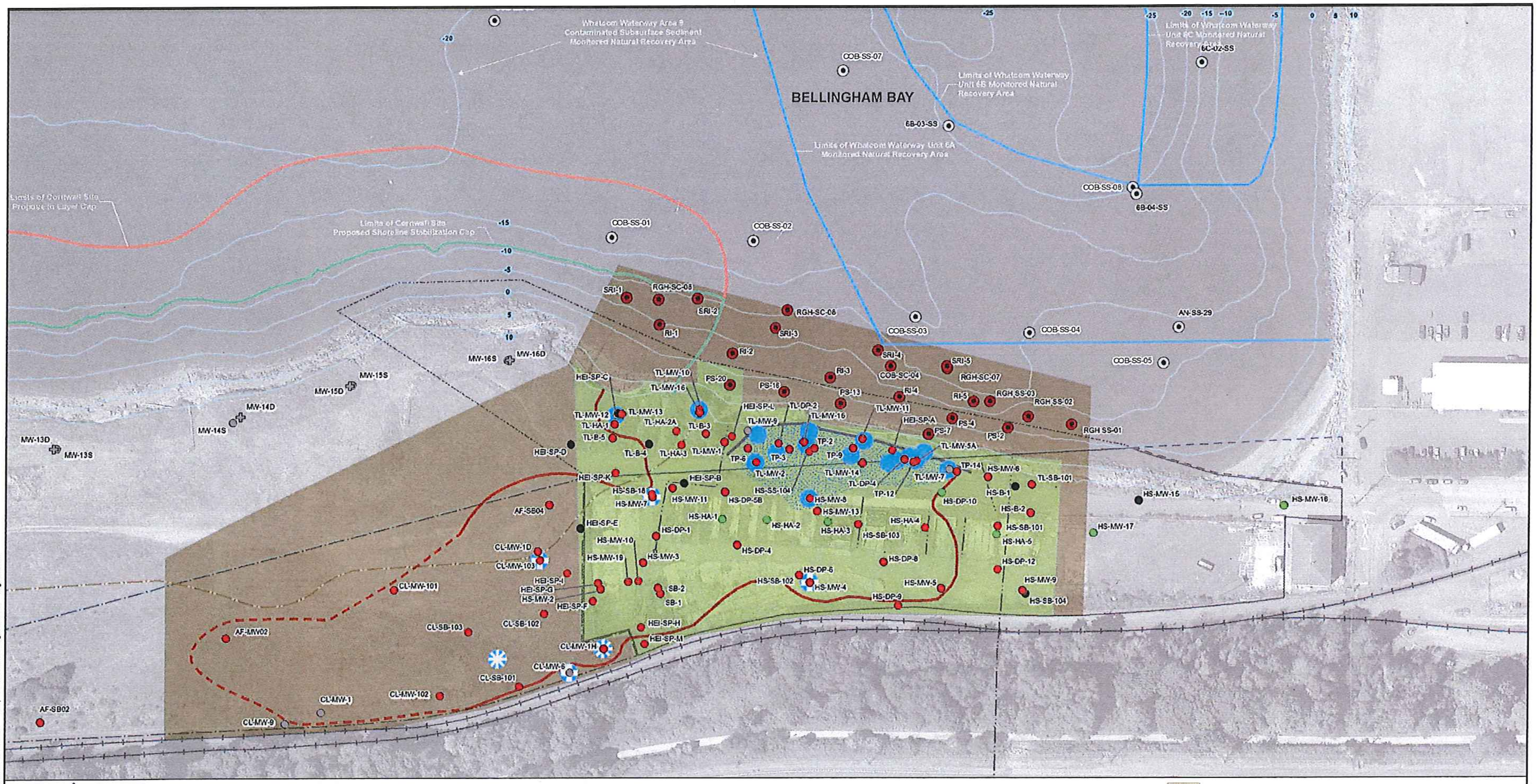
Your July 21 letter outlines restrictions on use of the AOC, and identifies some provisions of the Dangerous Waste Regulations that are likely to be relevant and appropriate for activities associated with managing contaminated soil and sediment within the AOC. The enclosed table provides a listing of some other provisions in the Dangerous Waste Regulations that may need to be considered further during the preparation of final cleanup documents for the Site, and implementation of the final cleanup.

Sincerely,

Mark Adams, LHG
Site Manager

Enclosure: Figure 1
Other Provisions of the Dangerous Waste Regulations to Consider

cc: Anne Powell, AAG, Ecology Division
Lucy McInerney, Ecology



- Existing Deep Monitoring Well
- Existing Shallow Monitoring Well
- City Owned Property, Former R.G. Haley International
- Cornwall Property
- Port of Bellingham Property
- Tideland Lease Area
- Inner Harbor Line
- Sheet Pile Wall
- Storm Drain
- Cornwall Approximate Landward Boundary of Landfill Refuse
- Estimated extent of petroleum smear zone (dashed portion based on Cornwall RI)

Soil Sample Results

- One or more soil samples exceed screening levels
- All soil samples analyzed less than screening levels
- Non-detect, PQL > screening level

Note: Symbol and color are shown for any exploration with soil sample IHS analytical result regardless of sample depth or date sampled. Existing monitoring wells with no soil sample data are shown in gray using the monitoring well symbols for deep and shallow monitoring wells.

- Measurable LNAPL in Well 2012/2013 and Earlier
- Trace LNAPL in Well 2012/2013 and Earlier
- LNAPL in Well Historical Only (2000-2007)
- LNAPL Plume

Sediment Samples

- Continuous contamination exceeds cleanup levels for chemical constituents

- 2014 Expanded AOC
- Former AOC

Reference: Aerial from Google Earth, August 2011. Contour elevation displayed is referenced to NAVD88 vertical datum.

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Path: \\sea\projects\0\0356114\GIS\MXDs\Fig_1_2014Expanded AOC.mxd Map Revised: 19 August 2014 cgonzales

2014 Expanded AOC

R.G. Haley Site
Bellingham, Washington

Figure 1

Other Provisions of the Dangerous Waste Regulations to Consider

Subsection	Title	Contents	Potentially Applicable Provisions
-145	*Spills and discharges into the environment*	Requirements for actions to be taken in case of a hazardous waste release into the environment	Certain notifications specified in case of a spill or discharge during remedial activities, as well as mitigation and control measures.
-280 (6)	*General requirements for dangerous waste management facilities*	Basic management and safety requirements at TSD facilities.	Safety and training provisions for handling and processing contaminated soil and sediment on-site.
-283	*Performance standards*	Performance standards for constructing, operating, and maintaining a dangerous waste facility	Performance standards
-310	*Security*	Measures to prevent unknowing or unauthorized access into the active area of a facility	Warning sign and barrier provisions
-320	*General inspection*	Periodic inspection requirements to assure dangerous waste constituents are not released to the environment	Owner responsibilities for periodic inspections and record keeping
-330	*Personnel Training*	Training requirements for facility personnel	A training program for facility personnel that teach dangerous waste management procedures, and response to potential emergencies.
-335	*Construction quality assurance program*	Requirements for a construction quality assurance (CQA) program for surface impoundments, waste piles, and landfills.	A CQA plan establishing a CQA program for construction activities.
-350	*Contingency plan and emergency procedures*	Measures to be taken to reduce risks in case of an emergency, such as a sudden release or a fire.	Contingency plan and emergency measures

-380	*Facility recordkeeping*	Requirements to maintain a written record of facility operations	Records on locations and quantities of dangerous waste maintained in the AOC, waste removal, waste analyses and determinations, emergency or unexpected incidents, required inspections, required monitoring, repairs or modifications to the waste containment system.
-395(6)	*Labeling for containers and tanks*	Labeling requirements	Labeling of tanks or containers containing dangerous waste
-610	*Closure and post-closure care*	Requirements for closure and for post-closure care	Performance standards, equipment decontamination, post-closure care, and a "notice in deed to property"
-645	*Releases from regulated units*	Requirements for monitoring, characterizing, and responding to a release to the uppermost aquifer	Reponses in case a release has been detected in ground water.
-665	*Landfills*	Design and operating requirements for facilities that dispose of dangerous waste in landfills, i.e., in or on land.	Design and operating requirements

EXHIBIT N-2
City of Bellingham AOC Request to Ecology
July 21, 2014

OFFICE OF THE CITY ATTORNEY
210 Lottie Street, Bellingham, WA 98225
Telephone: (360) 778-8270
Fax: (360) 778-8271

— COPY —

July 21, 214

Ecology NWRO
Attention: Mark Adams
3190 160th Ave SE
Bellevue, WA 98008-5452

RE: RG Haley Site Area of Contamination (AOC)
Amended Agreed Order 2186

Dear Mr. Adams:

Introduction

The City of Bellingham (City) requests that the Department of Ecology (Ecology) approve an expansion of the boundaries of the existing Area of Contamination (AOC) at the RG Haley Site ("Site"). The AOC was originally approved by Ecology, and its boundaries were subsequently expanded, as described in letters written by Ecology on June 18, 2007 and July 8, 2013. The 2007 letter stated that the AOC was designated for the purpose of "excavation, movement and treatment of contaminated materials." In 2013, the AOC area was expanded to include a portion of the intertidal zone, specifically where the 2013 Interim Action occurred ("Interim Action Area").

Ecology established an AOC Policy ("Policy") in August 1991; the Policy is applicable for MTCA cleanup sites under an Order or Decree. The RG Haley Site Remedial Investigation/Feasibility Study (RI/FS) is being performed under amended Agreed Order 2186, and future cleanup actions are expected to be conducted under a Consent Decree. The Policy states that moving dangerous waste within an AOC is not considered "generation" as defined by the Dangerous Waste Regulations (Chapter 173-303 WAC). The Policy further states that "containment, treatment and disposal of consolidated wastes within an AOC does not automatically trigger the dangerous waste regulations" and that Land Disposal Restrictions (LDRs) will not automatically become applicable at sites where dangerous wastes are being excavated, consolidated or moved within the defined AOC. Contaminated remediation waste associated with releases from the Haley wood treatment facility (i.e. soil, sediment and debris) are classified as F032-listed dangerous waste and subject to the LDRs unless managed within the boundaries of an AOC in accordance with the Policy.

The Policy only applies to areas within the designated AOC boundaries. The AOC is defined as "that portion of the site which contains continuous contamination." Site Managers are responsible for designating the AOC boundaries. An AOC may extend beyond a property boundary.

The remainder of this letter describes the proposed expansion of the AOC and anticipated remedial activities within this area including on-site waste management actions. It is important to note that some remediation-derived waste generated during Haley-related cleanup actions will likely be transported off-site for treatment and/or disposal. This waste, once removed from the AOC, would be subject to regulation as dangerous waste. This letter does not address any of the wastes that would be managed off-site.

Proposed Expansion of the AOC

The current boundary of the AOC is comprised of the footprint of former Haley operations in the upland and in the Interim Action Area (Figure 1). It is appropriate to expand the AOC boundaries based on supplemental investigation data that show a broader extent of F032-related constituents originating from historic Haley operations (Draft RI Report dated March 18, 2014). The proposed revised AOC boundary (Figure 1) is based on the footprint of continuous Haley-related soil and groundwater contamination that exceeds applicable MTCA cleanup levels, and sediment contamination that exceeds chemical and biological criteria based on protection of the benthic community.

The expanded AOC is proposed to include nearshore sediment because several alternatives being evaluated in the FS would incorporate excavated sediment into an integrated upland cap. The upland cap would, in turn, be integrated with features of the future Cornwall Beach Park (see conceptual preliminary master plan attached). This future City park, which is in the planning stages, will encompass the Haley Site and the adjacent (and overlapping) Cornwall Landfill Site.

The proposed AOC expansion also extends onto upland portions of the Cornwall Landfill Site. Remedial actions in this portion of the AOC will be conducted to address contaminants associated with both the Cornwall Landfill and Haley Sites. Capping has already been selected for this area as one component of the Cornwall remedy; the same action (capping) may be a component of the Haley remedy in this area. The Cornwall and Haley project teams will collaborate to develop a cap design for this portion of the AOC that achieves remedial action objectives for both Sites and is compatible with the future park design. The City is in a unique position to accomplish this as the owner of property comprising both Sites on the landward side of the inner harbor line. The City will initiate discussions with the Port of Bellingham (Port), which is leading cleanup efforts on the Cornwall Site, as soon as Ecology approves this request for expansion of the AOC.

Potential Waste Designations

In the absence of an AOC designation, remediation-derived wastes (e.g. soil, sediment and debris) associated with releases from the Haley wood treatment facility are classified as F032-listed dangerous waste if "generated." The F032 designation could have significant cost implications[1] because several polycyclic aromatic hydrocarbon (PAH) constituents are present in sediment at concentrations exceeding the LDR treatment standards (40CFR268.40) based on data collected during the RI. Similarly, some PAH, dioxin and furan constituents are present in upland soil at

[1] Costs for the off-site transport, treatment (incineration) and disposal for land-banned wastes from the Site could be as high as approximately $900/ton.

concentrations exceeding the alternative treatment standards[2]. Soil and sediment in some portions of the Site, if generated, also would designate as State-only dangerous waste based on the toxicity criteria. The soil and sediment would not likely designate as Extremely Hazardous Waste (EHW) based on State-only criteria. This contaminated media would not likely designate by characteristics as a state or federal dangerous waste.

If an expanded AOC is approved by Ecology, a broader range of remedial alternatives can be developed that would be considered "permanent to the maximum extent practicable" (WAC 173-340-360(3)). The City's proposed actions within the AOC are described below.

Proposed Waste Management Actions within the AOC

The FS for the Haley Site will describe the proposed remedial alternatives. Nearly all remedial alternatives will have an associated on-site waste management component. For purposes of developing and evaluating remedial alternatives, the City is anticipating that the dangerous waste regulations will not be applicable if the following general waste management actions are completed within the AOC:

- Excavated soil or sediment within the AOC will generally be managed and handled using methods that would not constitute RCRA "placement." EPA guidance regarding AOCs and LDRs[3] notes that the LDRs are triggered if a waste is "placed" in a land-based unit and indicates that the following do not constitute "placement:" consolidating waste within a single AOC, capping in-place, treating in-situ, or processing the waste within the AOC to improve its structural stability (but not in a separate tank).
- Contaminated soil within the AOC is anticipated to be capped in-place and/or treated in-situ to reduce contaminant toxicity and/or mobility.
- Consolidating excavated sediment in the upland cap (within the AOC) after processing it to improve structural stability for geotechnical purposes. Processing could include: dewatering the excavated sediment in a constructed area where fluids can be captured and managed as remediation wastewater; drying the excavated sediment by tilling with an excavator in a prepared area; and strengthening the excavated sediment by mixing with Portland cement using excavation equipment in a prepared area. Literature research indicates that it also may be necessary to add organoclay to the sediment to enable the Portland cement to effectively strengthen the sediment in the presence of organic contaminants. None of these sediment processing actions would be conducted in a tank or container.
- Consolidating the contents of drummed soil investigation wastes currently stored on-site within the existing AOC to be capped on-site with other remediation-derived waste.

As previously stated, the City is anticipating that the dangerous waste regulations will not be applicable to the cleanup actions described above if completed within the AOC. The Policy requires, however, that substantive requirements of the regulation still be met if it is determined that the

[2] The alternative soil treatment standards (40CFR268.49) are 10 times the Universal Treatment Standards (10xUTS) in 40CFR 268.48

[3] http://yosemite.epa.gov/osw/rcra.nsf/documents/221071ABC154700B85256611006BD9AE

regulation is relevant and appropriate to the Site or action. Proposed relevant and appropriate requirements from the DW regulation are summarized below.

Relevant and Appropriate Requirements

The Policy requires that substantive portions of relevant and appropriate requirements of the dangerous waste regulations be implemented in situations where remediation-derived waste is managed in an AOC. The criteria that are used to determine which portions of the dangerous waste regulations are relevant and appropriate at a MTCA cleanup site are presented in MTCA regulations, WAC 173-340-710(4). Based on the MTCA evaluation criteria, the City interprets the following subsections of WAC 173-303 to be the relevant and appropriate requirements to be implemented in connection with the excavation, movement and consolidation of remediation-derived wastes within the Haley AOC:

WAC 173-303 Subsection and Title	Contents	Relevant or Appropriate Provisions
-060 Notification and identification numbers	Requirements for EPA/state identification number	Identification number needed for waste transported off-site for treatment/disposal. City would be considered "generator;" however, waste consolidated within the AOC would not be considered "generated."
-200 Accumulating dangerous waste on-site	Procedures and requirements for on-site storage of dangerous waste	Drummed investigation-derived soil and other remediation derived waste if temporarily stored in the waste containment area is subject to the labelling, signage/security and inspection provisions of this section.
-630 Use and management of containers	Describes requirements for on-site containers used	Where used, requirements for labelling, compatibility, spill prevention, drainage and protection will be followed. Drummed soil cuttings from drilling may be consolidated within the AOC.
-900 Public involvement and participation	Requirements of Ecology for informing the public and responding to public concerns	Public notice and response can be accomplished through public comment periods associated with RI/FS and CD/CAP.

Note: The Policy indicates that when the Department determines that a law or regulation is relevant and appropriate as defined in WAC 173-340-710, only the substantive portions of these laws must be met.

Please let me know if you have questions concerning this request.

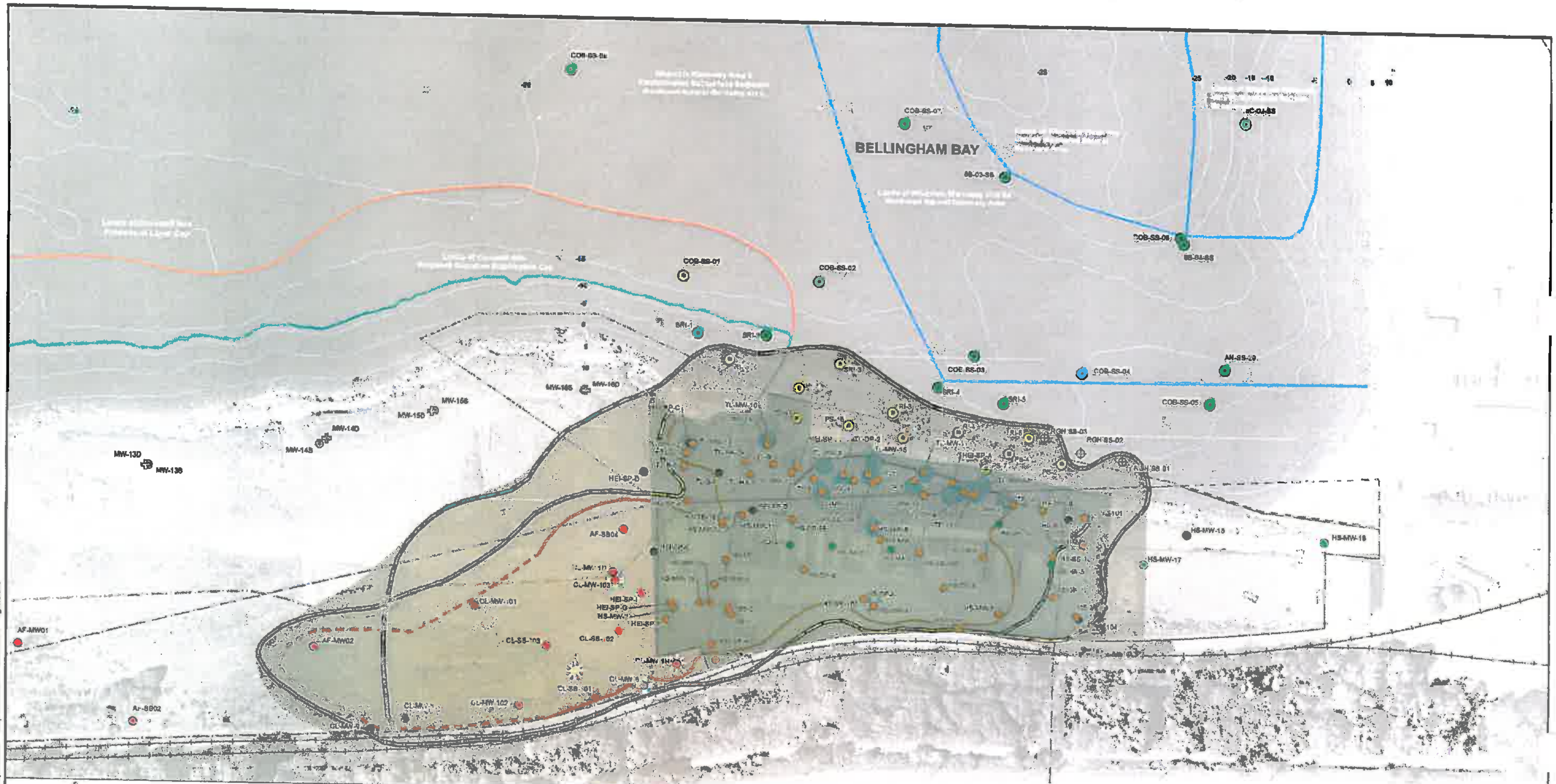
Sincerely,

Amy Kraham
Environmental Project Manager

cc: GeoEngineers

Attachments:

Figure 1 - Proposed AOC
Cornwall Beach Park - Proposed AOC Overlay
Ecology AOC determinations dated June 18, 2007 and July 8, 2013



Existing Deep Monitoring Well
Existing Shallow Monitoring Well
City Owned Property, Former R.G. Haley International
Cornwall Property
Port of Bellingham Property
Tideland Lease Area
Inner Harbor Line
Sheet Pile Wall
Storm Drain
Cornwall Approximate Landward Boundary of Landfill Refuse

Proposed AOC

Current AOC

Soil Sample Results

- One or more soil samples exceed screening levels
- All soil samples analyzed less than screening levels
- Non-detect, PQL > screening level
- Measurable LNAPL in Well 2012/2013 and Earlier
- Trace LNAPL in Well 2012/2013 and Earlier
- LNAPL in Well Historical Only (2000-2007)
- LNAPL Plume
- Estimated extent of petroleum smear zone (dashed portion based on Cornwall RI)

Sediment Sample Results

- Exceeds CSL/2LAET Chemical or Biological Criterion for One or More Site Contaminants
- Exceeds SQS/LAET Chemical or Biological Criterion for One or More Site Contaminants
- Meets Criteria
- Estimated footprint of all soil screening level exceedances
- Estimated footprint of all groundwater screening level exceedances
- Estimated footprint of sediment exceedances for SMS chemical and/or toxicity criteria

W S N E — True North — Project North

0 50 100 Feet

Reference: Aerial from Google Earth, August 2011. Contour elevation displayed is referenced to NAVD88 vertical datum.

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document.
3. Refer to Figure 6-1 for identification of property lines and other upland features.
GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Note:
Boundaries of impacted sediment may be modified in the FS to account for bioaccumulatives.

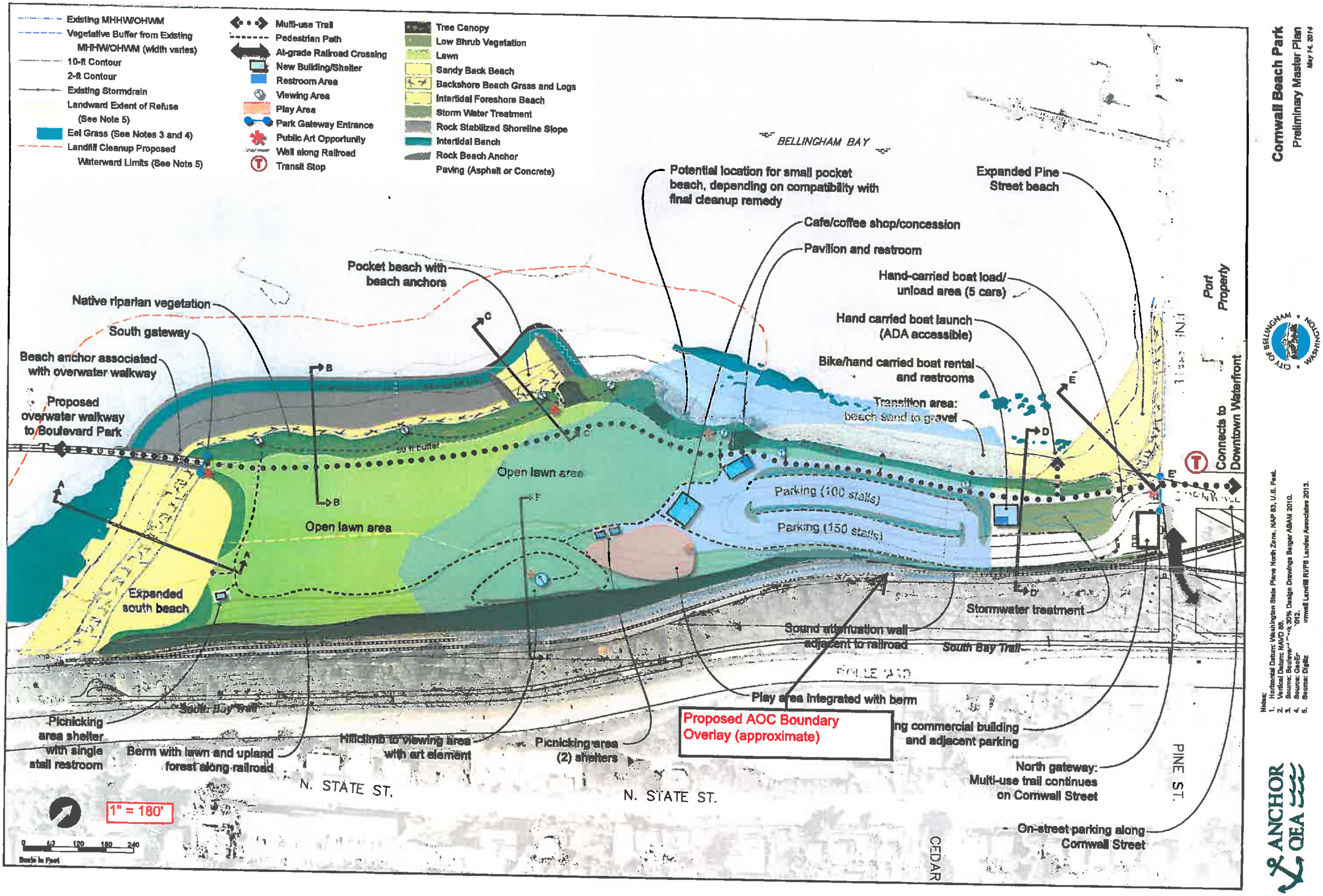
Proposed AOC

R.G. Haley Site
Bellingham, Washington

GeoEngineers

Figure 1

Path: \\sea\projects\0\0356114\GIS\MXDs\Fig_8-1_Total_Impact.mxd Map Revised: 17 June 2014 cgonzales


Existing MHHW/OHWM
Vegetative Buffer from Existing MHHW/OHWM (width varies)
10-ft Contour
2-ft Contour
Existing Stormdrain
Landward Extent of Refuse (See Note 5)
Eel Grass (See Notes 3 and 4)
Landfill Cleanup Proposed Waterward Limits (See Note 5)
Multi-use Trail
Pedestrian Path
At-grade Railroad Crossing
New Building/Shelter
Restroom Area
Viewing Area
Play Area
Park Gateway Entrance
Public Art Opportunity
Wall along Railroad
Transit Stop
Tree Canopy
Low Shrub Vegetation
Lawn
Sandy Back Beach
Backshore Beach Grass and Logs
Intertidal Foreshore Beach
Storm Water Treatment
Rock Stabilized Shoreline Slope
Intertidal Bench
Rock Beach Anchor
Paving (Asphalt or Concrete)
BELLINGHAM BAY
Potential location for small pocket beach, depending on compatibility with final cleanup remedy
Expanded Pine Street beach
Cafe/coffee shop/concession
Pavilion and restroom
Hand-carried boat load/ unload area (5 cars)
Hand carried boat launch (ADA accessible)
Bike/hand carried boat rental and restrooms
Transition area: beach sand to gravel
Pocket beach with beach anchors
Native riparian vegetation
South gateway
Beach anchor associated with overwater walkway
Proposed overwater walkway to Boulevard Park
Port Property
Connects to Downtown Waterfront
Open lawn area
Open lawn area
Parking (100 stalls)
Parking (150 stalls)
Expanded south beach
Stormwater treatment
Sound attenuation wall adjacent to railroad
South Bay Trail
Play area integrated with berm
Proposed AOC Boundary Overlay (approximate)
...ing commercial building and adjacent parking
North gateway: Multi-use trail continues on Cornwall Street
On-street parking along Cornwall Street
Picnicking area shelter with single stall restroom
Berm with lawn and upland forest along railroad
Hillclimb to viewing area with art element
Picnicking area (2) shelters
N. STATE ST.
N. STATE ST.
CEDAR
PINE ST.
1" = 180'
Scale in Feet
Cornwall Beach Park
Preliminary Master Plan
May 14, 2014
CITY OF BELLINGHAM • WASHINGTON
ANCHOR QEA

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
Northwest Regional Office • 3190 160th Avenue SE • Bellevue, Washington 98008-5452 • (425) 649-7000

June 18, 2007

Mr. Everett Billingslea
Douglas Management
P.O. Box 3757
Seattle, WA 98124-3757

Mr. James Miller
Mr. Jay Lucas
GeoEngineers, Inc.
600 Stewart Street, Suite 700
Seattle, WA 98101

Dear Mr. Billingslea, Mr. Miller, Mr. Lucas:

RE: *R.G. Haley International Corporation Site, Bellingham, WA*
Area of Contamination Designation

The Department of Ecology has received and reviewed your request for designation of an Area of Contamination at the RG Haley International Corporation Site in Bellingham, Washington. Since this site is under an Ecology MTCA Agreed Order for development of the Remedial Investigation/Feasibility Study documents, and ultimately will be under a MTCA Consent Decree for the final cleanup decision and action (as defined by Chapter 173-340 WAC), the Department of Ecology's Area of Contamination Policy shall apply.

The AOC policy stipulates how situations in which the excavation and movement of contaminated materials at sites being remediated under the Model Toxics Control Act, through order or decree, would not be considered generation or disposal of hazardous waste as defined by Chapter 173-303-WAC.

The site's draft RI/FS has been prepared and will soon undergo public review. The preferred alternative of enhanced soil agitation was intensely critiqued and a pilot study to further evaluate the effectiveness of the methodology was conducted early January 2007. I also consulted with Solid and Hazardous Waste staff at the Northwest Regional Office of Ecology. It has been determined appropriate to designate the upland property of the RG Haley site as an AOC for excavation, movement, and treatment of contaminated materials. As a visual aid, the proposed boundary of the AOC is depicted in the attached figure (submitted with GeoEgineers AOC letter dated 10/27/05).

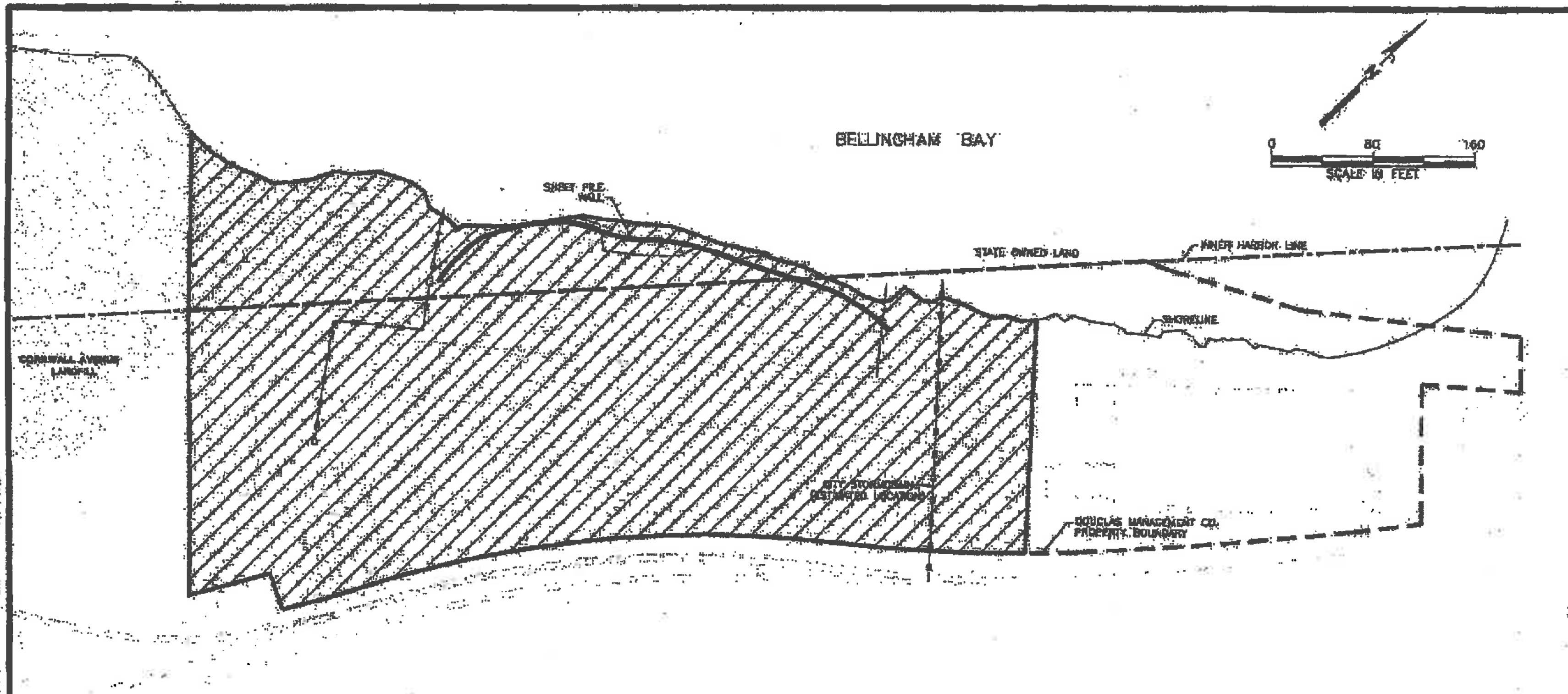
The AOC policy stipulates that it is necessary to comply with the statutory requirement that no EHW may be disposed of in Washington State. The Engineering Design Report, as required in the upcoming Cleanup Action Plan, shall provide the necessary criteria for treatment to at least DW levels. The AOC boundary is proposed and designation will be finalized in the development of the Cleanup Action Plan and Consent Decree for final Cleanup of the site, following public review and comment.

If you should have any questions, feel free to contact me at 425-649-4422, or via email at gcar461@ecy.wa.gov.

Sincerely,

Glynis A. Carrosino, Project Manager
Toxics Cleanup Program
Washington State Dept of Ecology
Northwest Regional Office

CC: Peter Adolphson, Ecology HQ
Brad Helland, Ecology NWRO
Charles San Juan, Ecology HQ
Lucy McInerney, Ecology NWRO
Phil Kovacs, Ecology NWRO
Kristie Carevich, Ecology AAG
Chuck Blumenfeld, Perkins Coie LLP



EXPLANATION:

- STORMDRAIN
- SHEETPILE BARRIER
- PROPOSED AREA OF CONTAMINATION BOUNDARY (AOC)
- UST UNDERGROUND STORAGE TANK
- ESTIMATED EXTENT OF UPLAND REFUSE BASED ON LANDAU ASSOCIATES, JANUARY 27, 2003, ECOLOGY REVIEW DRAFT RI/FS CORNWALL AVENUE LANDFILL, BELLINGHAM, WASHINGTON; FIGURE 3-8
- RIPRAP SHORELINE

Notes: 1. The locations of all features shown are approximate.
2. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

References: CAD files "R2000geoeng_holeybase50x" revised 07/28/04 by Pacific Survey & Engineering, Inc., file "Fig3-8" dated August 2002 by Landau Associates; and files "027500201T1M" and "027500201T1A" dated 03/29/04 by GeoEngineers.

GEOENGINEERS

PROPOSED AOC

FIGURE 1

SEAT\P:\0275002\01\CAD\T5\ECOL-027500201T5a.DWG JCL:MJF 10/25/05

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
Northwest Regional Office • 3190 160th Ave SE • Bellevue, WA 98008-5452 • 425-649-7000
711 for Washington Relay Service • Persons with a speech disability can call 877-833-6341

July 8, 2013

Ms. Amy Kraham
City of Bellingham
210 Lottie Street
Bellingham, WA 98225

Re: Updated Area of Contamination Definition
R.G. Haley International Corporation Site (the Site)

Dear Ms. Kraham:

The Department of Ecology (Ecology) is updating an Area of Contamination (AOC) "designation" originally established in a June 18, 2007, letter from Glynis Carrosino of Ecology. In that letter, the AOC was defined as the upland portion of the Site. Having an AOC allowed the movement and temporary storage of contaminated materials (wastes) at the Site, pending final cleanup.

With this letter, Ecology is enlarging the AOC to include a beach area within the Site that will be the location of an interim action. The beach area is shown on the attached figure. The interim action is anticipated to take place in the third quarter of 2013, and is designed to intercept oil seeping into the bay. Most of the work will involve placing absorbent/protective layers of material on the beach. Some contaminated materials may need to be moved or removed (e.g., large rocks) and some may be generated (e.g., decontamination fluids) during the interim action.

It should be noted that the City of Bellingham remains responsible to manage the wastes within the AOC in a manner that protects human health and the environment. In making determinations about such protection, Ecology will rely on its guidance document Interprogram Policy - Area of Contamination August 20, 1991.

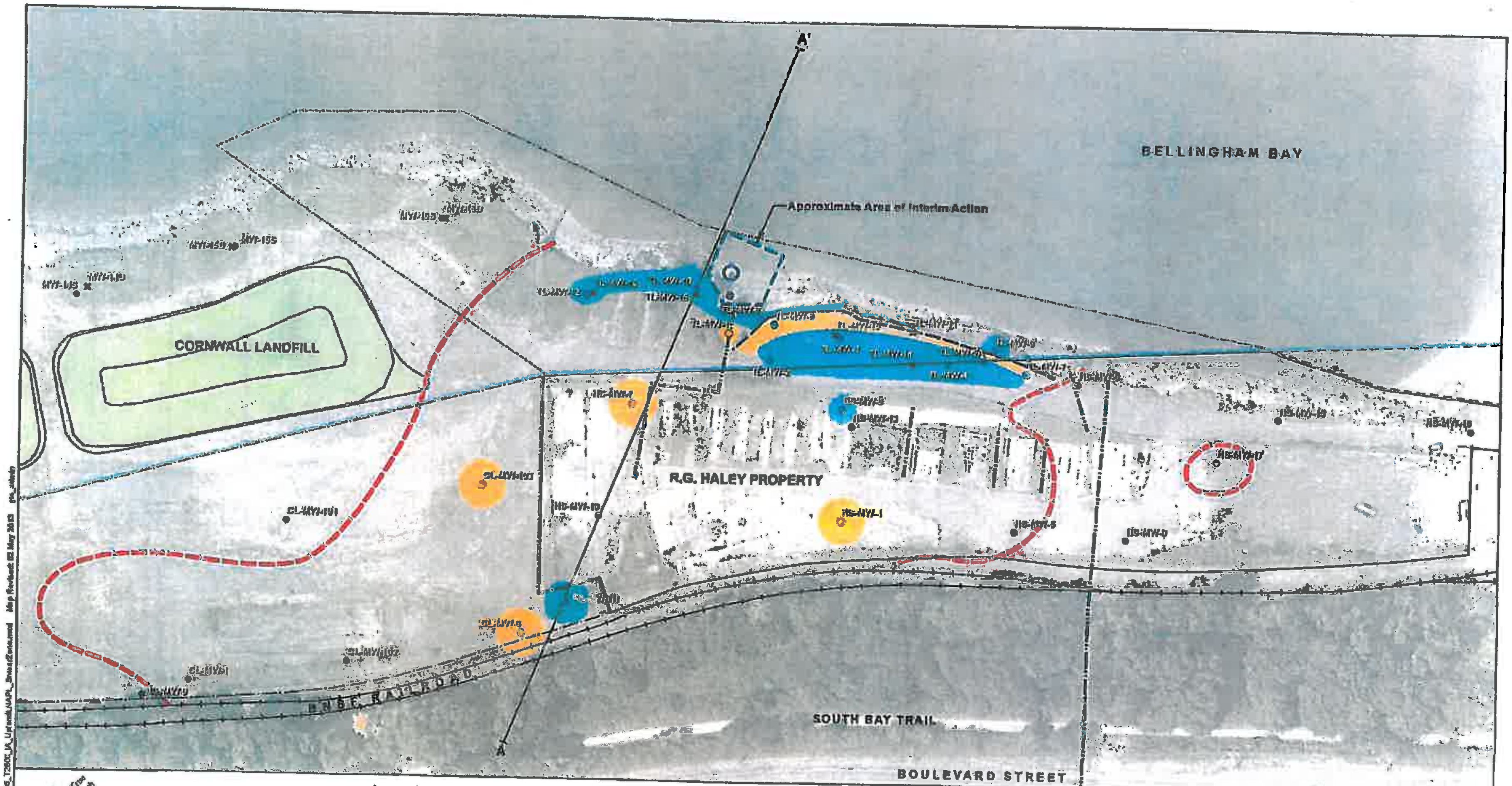
If you have any questions, please contact me at (425) 649-7107 or at mada461@ecy.wa.gov.

Sincerely,

Mark Adams, LHG
Site Manager

Enclosure (1)

cc: Kristie Elliot – Assistant Attorney General, Ecology Division
Lucy McInerney – Northwest Regional Office, Ecology



Legend

- Approximate Boundary of Interim Action Area
- Smear Zone Boundary in Soil
- Sheet Pile Wall
- Outfall
- Tideland Lease Area
- Inner Harbor Line
- Cross Section A-A'
- Deep Monitoring Well
- Shallow Monitoring Well
- Light Nonaqueous Phase Liquid (LNAPL) Emerging from Sediment (2012/2013)
- Measurable LNAPL (Current or Historical)
- Trace LNAPL (Current or Historical)
- Cornwall Interim Placement Area

Note: The lateral extent of the smear zone on the Cornwall Site is based on Figure 6-3 in the January 2013 Agency Review Draft of the RI report for Cornwall. For the purposes of this figure it is assumed that the smear zones on the Cornwall and Haley Sites are connected. The continuity of these smear zones will be further evaluated during completion of the R.G. Haley RI.

Reference: Aerial from Google Earth, August 2011.

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

LNAPL Locations and Interim Action Area

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 2

EXHIBIT N-3
Department of Ecology Updated AOC Definition
July 8, 2013

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
Northwest Regional Office • 3190 160th Ave SE • Bellevue, WA 98008-5452 • 425-649-7000
711 for Washington Relay Service • Persons with a speech disability can call 877-833-6341

July 8, 2013

Ms. Amy Kraham
City of Bellingham
210 Lottie Street
Bellingham, WA 98225

Re: Updated Area of Contamination Definition
R.G. Haley International Corporation Site (the Site)

Dear Ms. Kraham:

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It should be noted that the City of Bellingham remains responsible to manage the wastes within the AOC in a manner that protects human health and the environment. In making determinations about such protection, Ecology will rely on its guidance document Interprogram Policy - Area of Contamination August 20, 1991.

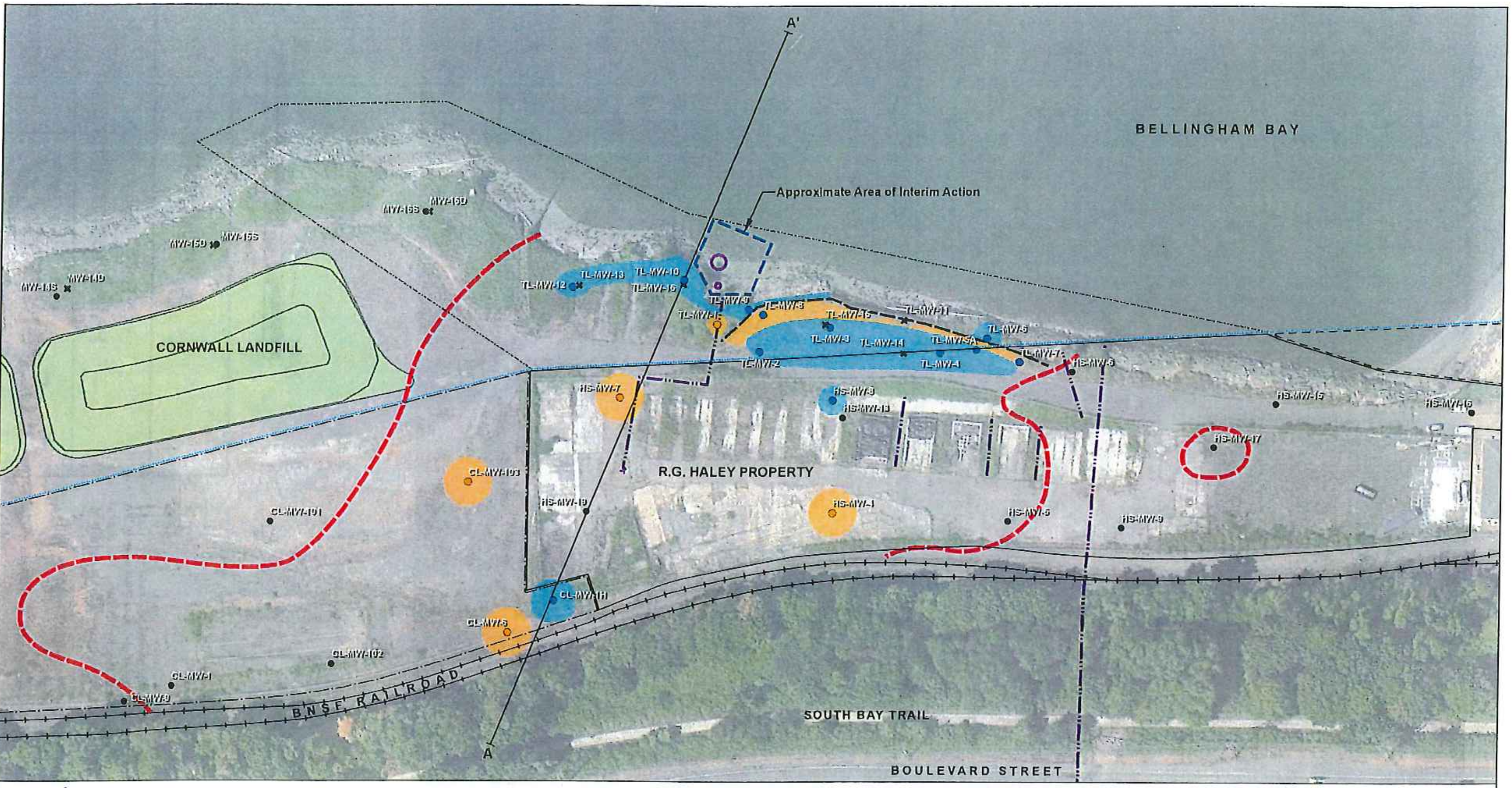
If you have any questions, please contact me at (425) 649-7107 or at mada461@ecy.wa.gov.

Sincerely,

Mark Adams, LHG
Site Manager

Enclosure (1)

cc: Kristie Elliot – Assistant Attorney General, Ecology Division
Lucy McInerney – Northwest Regional Office, Ecology



True North
Project North

0 100 200
Feet

Legend

- Approximate Boundary of Interim Action Area
- Smear Zone Boundary in Soil
- Sheet Pile Wall
- Outfall
- Tideland Lease Area
- Inner Harbor Line
- Cross Section A-A'
- Deep Monitoring Well
- Shallow Monitoring Well
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- Measurable LNAPL (Current or Historical)
- Trace LNAPL (Current or Historical)
- Cornwall Interim Placement Area

Note: The lateral extent of the smear zone on the Cornwall Site is based on Figure 6-3 in the January 2013 Agency Review Draft of the RI report for Cornwall. For the purposes of this figure it is assumed that the smear zones on the Cornwall and Haley Sites are connected. The continuity of these smear zones will be further evaluated during completion of the R.G. Haley RI.

Reference: Aerial from Google Earth, August 2011.

Notes:
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2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Path: W:\Seattle\Projects\0\0356114\GIS\035611406_T2600_IA_UplandLNAPL_SmearZone.mxd Map Revised: 02 May 2013 gis_admin

LNAPL Locations and Interim Action Area

R.G. Haley Site
Bellingham, Washington

GEOENGINEERS

Figure 2

EXHIBIT N-4
Department of Ecology Approval of AOC Designation
June 18, 2007

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
Northwest Regional Office • 3190 160th Avenue SE • Bellevue, Washington 98008-5452 • (425) 649-7000

June 18, 2007

Mr. Everett Billingslea
Douglas Management
P.O. Box 3757
Seattle, WA 98124-3757

Mr. James Miller
Mr. Jay Lucas
GeoEngineers, Inc.
600 Stewart Street, Suite 700
Seattle, WA 98101

Dear Mr. Billingslea, Mr. Miller, Mr. Lucas:

RE: *R.G. Haley International Corporation Site, Bellingham, WA*
Area of Contamination Designation

The Department of Ecology has received and reviewed your request for designation of an Area of Contamination at the RG Haley International Corporation Site in Bellingham, Washington. Since this site is under an Ecology MTCA Agreed Order for development of the Remedial Investigation/Feasibility Study documents, and ultimately will be under a MTCA Consent Decree for the final cleanup decision and action (as defined by Chapter 173-340 WAC), the Department of Ecology's Area of Contamination Policy shall apply.

The AOC policy stipulates how situations in which the excavation and movement of contaminated materials at sites being remediated under the Model Toxics Control Act, through order or decree, would not be considered generation or disposal of hazardous waste as defined by Chapter 173-303-WAC.

The site's draft RI/FS has been prepared and will soon undergo public review. The preferred alternative of enhanced soil agitation was intensely critiqued and a pilot study to further evaluate the effectiveness of the methodology was conducted early January 2007. I also consulted with Solid and Hazardous Waste staff at the Northwest Regional Office of Ecology. It has been determined appropriate to designate the upland property of the RG Haley site as an AOC for excavation, movement, and treatment of contaminated materials. As a visual aid, the proposed boundary of the AOC is depicted in the attached figure (submitted with GeoEgineers AOC letter dated 10/27/05).

The AOC policy stipulates that it is necessary to comply with the statuatory requirement that no EHW may be disposed of in Washington State. The Engineering Design Report, as required in the upcoming Cleanup Action Plan, shall provide the necessary criteria for treatment to at least DW levels. The AOC boundary is proposed and designation will be finalized in the development of the Cleanup Action Plan and Consent Decree for final Cleanup of the site, following public review and comment.

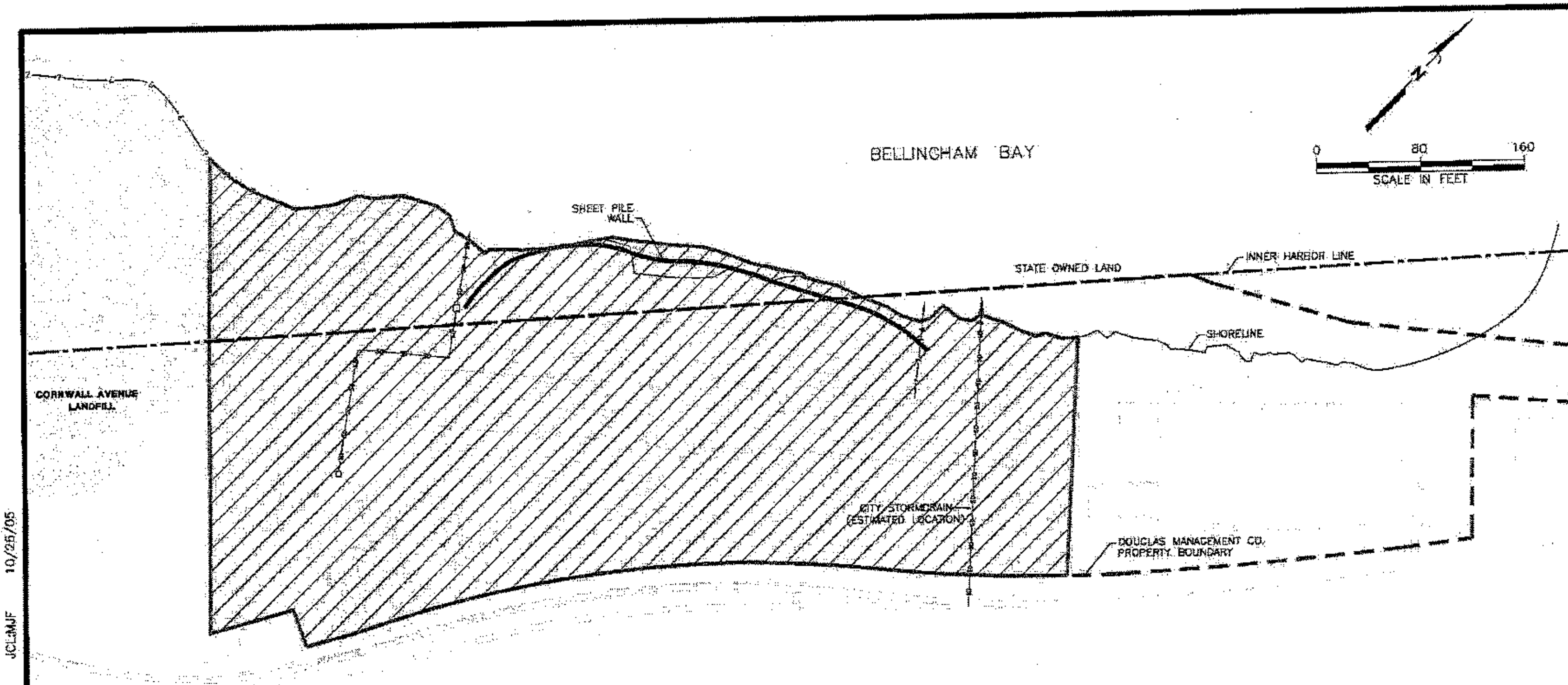
If you should have any questions, feel free to contact me at 425-649-4422, or via email at gcar461@ecy.wa.gov.

Sincerely,

Glynis A. Carrosino

Glynis A. Carrosino, Project Manager
Toxics Cleanup Program
Washington State Dept of Ecology
Northwest Regional Office

CC: Peter Adolphson, Ecology HQ
Brad Helland, Ecology NWRO
Charles San Juan, Ecology HQ
Lucy McInerney, Ecology NWRO
Phil Kovacs, Ecology NWRO
Kristie Carevich, Ecology AAG
Chuck Blumenfeld, Perkins Coie LLP



EXPLANATION:

- STORMDRAIN
- SHEETPILE BARRIER
- PROPOSED AREA OF CONTAMINATION BOUNDARY (AOC)
- UST — UNDERGROUND STORAGE TANK
- ESTIMATED EXTENT OF UPLAND REFUSE BASED ON LANDAU ASSOCIATES, JANUARY 27, 2003, ECOLOGY REVIEW DRAFT RI/FS CORNWALL AVENUE LANDFILL, BELLINGHAM, WASHINGTON, FIGURE 3-B
- RIPRAP SHORELINE

Notes:
1. The locations of all features shown are approximate.
2. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

References: CAD files "R2000geoeng_holeybase50x" revised 07/28/04 by Pacific Survey & Engineering Inc., file "Fig3-B" dated August 2002 by Landau Associates, and files "027500201T1LM" and "027500201T1A" dated 03/29/04 by GeoEngineers.

GEOENGINEERS

PROPOSED AOC

FIGURE 1

SEAT\P:\0275002\01\CAD\T5\ECOL-0275002011Sa.DWG JCL:MJF 10/25/05

APPENDIX O
Bioaccumulation Sediment Screening Levels

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APPENDIX O. BIOACCUMULATION SEDIMENT SCREENING LEVELS

1.0 INTRODUCTION

This technical appendix was prepared in connection with the Remedial Investigation and Feasibility Study (RI/FS) of the R.G. Haley Site (Site) in Bellingham, Washington to support the development of cleanup levels that address bioaccumulative pathways for people and aquatic organisms (fish, birds and mammals). Site-related bioaccumulative compounds detected in sediment samples within the area of investigation for the Site include polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), and dioxins/furans.

The Washington Department of Ecology's (Ecology) Sediment Management Standards (SMS; Chapter 173 204 WAC) do not provide risk-based cleanup levels for chemicals that pose risks to human and ecological receptors as a result of bioaccumulation. However, a basic framework for incorporating the bioaccumulation exposure pathway is provided in the recently adopted SMS Rule revision (effective September 2013).

According to the revised SMS Rule, sediment cleanup levels are defined as "the concentration or level of biological effects of a contaminant in sediment determined by the department to be protective of human health and the environment." Sediment cleanup levels are initially established at the sediment cleanup objective (SCO) and may be adjusted up to, but not to exceed, the cleanup screening level (CSL). The SCO and CSL are discussed in this appendix. Bioaccumulation risk-based sediment thresholds that are protective of human health and ecological receptors are two sets of criteria that are considered in the selection of SCOs and CSLs. In general, SCOs and CSLs for a chemical are set as the highest of the following levels:

- The lowest risk-based level protective of human health, benthic organisms, or ecological receptors;
- Background; or
- Practical quantitation limits (PQL).

Sediment criteria based on the protection of benthic organisms are included in Table 5-1 of the RI report and are not repeated in this appendix. However, the benthic sediment criteria are further evaluated in the FS for use as cleanup levels.

This appendix describes the overall approach for deriving bioaccumulation risk-based cleanup levels protective of human health and ecological receptors, natural and regional background concentrations, and identifying appropriate PQLs. The overall approach follows current Ecology and EPA published guidance on evaluating risks based on bioaccumulation and ingestion of seafood in Puget Sound and is consistent with the approach used at other sites in Bellingham Bay.

The approach used in this appendix to calculate sediment screening levels protective of the bioaccumulation pathway is based on Ecology's December 2013 draft Sediment Cleanup Users' Manual, referred to as SCUM II (Ecology 2013f). Ecology finalized the SCUM II guidance in March 2015 (Ecology 2015b). The final SCUM II guidance includes minor changes to the exposure assumptions used to calculate the human health risk-based bioaccumulation sediment levels. This appendix has not been revised to incorporate these minor changes because they would not affect the values selected as proposed sediment cleanup levels in Table 9-2, which are based on regional background sediment concentrations for Dioxin TEQ and cPAH TEQ, the practical quantitation limit for pentachlorophenol and protection of benthic organisms for the remaining indicator hazardous substances.

2.0 OVERALL APPROACH

The overall approach used to derive bioaccumulation sediment cleanup levels was to calculate bulk sediment concentrations that, if exceeded, would lead to elevated tissue concentrations in ecological receptors or seafood that, in turn, would pose an unacceptable risk to wildlife or people via consumption of fish and shellfish. Acceptable sediment concentrations are, therefore, set at levels that should not result in adverse effects to various receptors, assuming equilibrium partitioning between sediment and tissue. In Bellingham Bay, receptors of concern include tribal and recreational fishers, anadromous (e.g., salmonids) and non-anadromous (e.g., flatfish) fishes, aquatic-dependent mammals (e.g., otter) and birds (e.g., diving ducks).

The approach presented is generally consistent with approaches used to develop site-specific screening levels for the Whatcom Waterway and Harris Avenue Shipyard sites, which are nearby Bellingham Bay cleanup sites. The Whatcom Waterway approach is summarized in RETEC 2006. The Harris Avenue Shipyard screening level derivations are summarized in Attachment G-1 of the associated draft RI/FS (Floyd|Snider 2013).

3.0 EXISTING TISSUE THRESHOLDS AND SEDIMENT SCREENING LEVELS

Through efforts to address potential bioaccumulative effects, several regulatory programs (Ecology sediment management program, British Columbia contaminated sites program, and several regional dredged material management programs) in the Pacific Northwest have compiled tissue thresholds that should not result in adverse effects to ecological receptors or people and wildlife consuming seafood. Oregon Department of Environmental Quality (ODEQ) has also published generic (i.e., not site-specific) sediment criteria for several bioaccumulative contaminants based on acceptable tissue concentrations. The Puget Sound Dredged Material Management Program (DMMP) has identified sediment concentrations above which bioaccumulation may occur and which trigger additional evaluation steps prior to open water disposal of dredged sediment. Tissue thresholds and/or bioaccumulation sediment screening levels are found in the following:

- Washington State Draft Sediment Cleanup Users' Manual, referred to as SCUM II (Ecology 2013f)
- Sediment Evaluation Framework (SEF) for the Pacific Northwest (RSET 2009)
- Oregon State Guidance for Assessing Bioaccumulative Chemicals of Concern in Sediment (ODEQ 2007)
- Criteria for Managing Contaminated Sediment in British Columbia (Macfarlane et al. 2003)
- Puget Sound DMMP Users' Manual (USACE 2013)

Tissue thresholds compiled from these sources that are relevant for the Haley Site are summarized in attached Table O-1 (ecological receptors) and Table O-2 (human receptors); published sediment screening levels pertaining to bioaccumulation assessments are provided in Table O-3.

4.0 SEDIMENT CLEANUP OBJECTIVES

According to WAC 173-340-560(3), SCOs for a chemical are set as the highest of the following levels:

- The lowest risk-based level protective of human health (based on a cancer risk of 1 x 10^{-6} or a hazard quotient of 1), benthic organisms or ecological receptors. As noted previously, risk-based levels based on the protection of benthic organisms were included in the draft RI and are not included in this appendix.
- Natural background.
- Practical quantitation limits (PQLs).

4.1. Sediment Risk-Based Levels Protective of Human Health and Ecological Receptors

In order to calculate a bioaccumulation sediment cleanup level from an acceptable tissue concentration, the relationship between sediment and tissue at a site must be measured or predicted. Site-specific biota-sediment accumulation factors (BSAFs) are often used to estimate this relationship. Existing BSAFs published from other studies can be used at sites where site-specific data are not available. BSAFs are widely reported in the literature and have been compiled in an online database supported by EPA's Mid-Continent Division (EPA 2013). This database contains over 20,000 records collected primarily from Superfund sites and is organized by habitat type (e.g., estuarine, freshwater, etc.), species (typically fish and invertebrates), and chemical. Original sediment and tissue data upon which the BSAFs are based are also included in the database.

EPA's BSAF database was downloaded and evaluated for the presence of extreme values (outliers) using EPA's ProUCL® version 4.1 software for each chemical and taxonomic group (i.e., fish and shellfish); because of the limited marine data set, separate habitat values (i.e., freshwater versus marine) were not evaluated. Following removal of outliers, the 95th upper confidence limit (or non-parametric equivalent) was calculated using ProUCL for each chemical and taxonomic group, except for pentachlorophenol; no entries were found in EPA's BSAF data set for pentachlorophenol. BSAFs for pentachlorophenol were derived from average modeled values for invertebrates and demersal[1] fish from a study of contaminant loadings to Puget Sound (Ecology and Environment 2009).

BSAFs were available only for individual dioxin/furan congeners and individual carcinogenic PAHs (cPAHs). Screening levels for total mixtures of dioxins/furans and cPAHs were derived separately using BSAFs for individual compounds and the toxicity equivalent (TEQ) methodology (discussed below). BSAFs for individual compounds are presented in Table O-4.

[1] Demersal fish are those utilizing near-bottom habitats and that have greater contact with sediment than water-column species.

4.1.1. Human Health

Acceptable tissue concentrations in seafood consumed by people were derived using Part A of the Equations 1 and 2 below. These tissue concentrations were based on a 1 in 1 million excess cancer risk level for carcinogenic chemicals (that is, a 10^{-6} risk level) and a hazard quotient of 1 for non-carcinogenic chemicals. These target risk and hazard levels are consistent with levels used to derive Sediment Cleanup Objectives (SCO) in Ecology's updated SMS. The BSAFs identified in Table O-4 were then used to calculate sediment screening levels using Part B of Equations 1 and 2 and the tissue levels derived in Part A.

Carcinogens

$$Equation\ 1: CUL = \left\{\left(\frac{(CR \times BW \times AT \times UCF)}{(CPF_O \times FCR \times FDF \times EF \times ED)}\right) \times \left(\frac{(S_{foc})}{(SUF \times SL \times BSAF)}\right)\right\}$$

Part A (red): Calculates a risk-based tissue concentration

Part B (blue): Converts the risk-based tissue concentration to a risk-based sediment concentration

Non-carcinogens

$$Equation\ 2: CUL = \left\{\left(\frac{(HQ \times BW \times AT \times UCF \times RfDo)}{(FCR \times FDF \times EF \times ED)}\right) \times \left(\frac{(S_{foc})}{(SUF \times SL \times BSAF)}\right)\right\}$$

Part A (red): Calculates a risk-based tissue concentration

Part B (blue): Converts the risk-based tissue concentration to a risk-based sediment concentration

Where:

CUL = sediment cleanup level
CR = cancer risk
HQ = hazard quotient
BW = body weight
AT = averaging time
UCF = unit correction factor
CPF_o = cancer potency factor (oral)
RfD_o = oral reference dose
FCR = fish (and/or shellfish) consumption rate
FDF = fish (and/or shellfish) dietary fraction
SUF = site use factor
EF = exposure frequency
ED = exposure duration
BSAF = biota-sediment accumulation factor
SL = tissue fraction of lipid
S_{foc} = sediment fraction of organic carbon

Bioaccumulation sediment screening levels were calculated for two human receptors: (1) subsistence fisher – high exposure and, (2) subsistence fisher – low exposure. The purpose of calculating two screening levels for subsistence fishers was to provide a range of potential sediment screening levels. Screening levels were not calculated for other potential receptors (e.g., recreational fishers) because tribal fishers are expected to consume more fish/shellfish than other receptors. Only one parameter, fish/shellfish dietary fraction, was varied to provide the range of subsistence fisher exposures. This parameter is discussed below along with fish/shellfish consumption rates.

4.1.1.1. FISH/SHELLFISH CONSUMPTION RATES

Fish and shellfish ingestion rates for the subsistence fishers are based on the Tulalip tribal adult fish/shellfish consumption rates (Toy et al. 1996). Consistent with similar evaluations conducted for the Whatcom Waterway and Harris Avenue Shipyard sites, the fish/shellfish ingestion rates used are the 90th percentile Tulalip consumption rates for clams and mussels, crabs and bottom fish (RETEC 2006 and Floyd|Snider 2013). Salmon consumption was not included in the ingestion rate because salmon are migratory and exposure to Haley sediment is expected to be minimal. Consumption of pelagic fish was not included because these fish spend most of their time in the water column and are not in direct contact with sediment.

Fish/shellfish ingestion rates used for this evaluation are as follows:

- Dungeness Crab = 23.4 g/day
- Clams and mussels = 38.5 g/day
- Demersal fish = 7.8 g/day

4.1.1.2. FISH/SHELLFISH DIETARY FRACTION

The fish/shellfish dietary fraction refers to the proportion of a subsistence fisher's seafood diet that is gathered from a site or the general vicinity of a given site.

- Subsistence Fishers – High Exposure: The fish and shellfish dietary fractions for the subsistence fisher (high exposure) are 1 (i.e., 100 percent comes from the Site) for fish and shellfish. These values were selected to be consistent with the evaluations conducted for the Whatcom Waterway and Harris Avenue Shipyard sites. However, the 90th percentile fish and shellfish dietary fractions for the Tulalip Tribe and representing the fractions of fish and shellfish locally harvested are 0.72 and 0.98, respectively. These values were obtained from Tables 34 (fish) and 36 (shellfish) of Ecology's Fish Consumption Rate document (Ecology 2013g). Therefore, the use of a dietary fraction of 1 for fish and shellfish consumption may overestimate the actual amount of fish/shellfish consumed by tribal adults that were from the Haley area of investigation.
- Subsistence Fishers – Low Exposure: The fish and shellfish dietary fractions for the subsistence fisher (low exposure) assumed limited site use by subsistence fishers and fish. The intent of these "low exposure" values is to provide a low end range of dietary fraction values.

With the exception of fraction organic carbon (f_{oc}) and fish and shellfish lipid fraction, the remaining parameter assumptions and values followed Ecology SCUM II guidance and are presented in Table O-5. The site-specific f_{oc} of 0.028 is the median f_{oc} in surface sediment at the Haley site following the removal of outliers using ProUCL. Fish and shellfish lipid fraction values of 0.029 and 0.026, respectively are from EPA's KABAM Version 1.0 K_{ow} (based) Aquatic Bioaccumulation Model because no site-specific data are available.

4.1.2. Ecological Receptors

Bioaccumulation cleanup levels protective of ecological receptors were derived using Equation 3 below and acceptable tissue levels (ATL) (Table O-1) for aquatic or aquatic-dependent organisms, BSAF values for aquatic life and aquatic-dependent wildlife (Table O-4) and sediment fraction organic carbon and tissue fraction of lipid values (Table O-5). Bioaccumulation sediment cleanup levels were derived for aquatic life (fish, shellfish and other invertebrates) and aquatic-dependent wildlife (birds and mammals). Sediment cleanup levels for aquatic-dependent wildlife were derived to protect receptor populations and sensitive individuals. The acceptable tissue levels used for this evaluation were from the Sediment Evaluation Framework (RSET 2009), with the exception of the aquatic life (aquatic organisms) value for dioxins/furans, which was from ODEQ (2007).

$$Equation\ 3: CUL = \frac{ATL \times S_{foc}}{SL \times BSAF}$$

Where:

CUL = sediment cleanup level

ATL = acceptable tissue level

SL = tissue fraction of lipid

BSAF = biota-sediment accumulation factor

S_{foc} = sediment fraction of organic carbon

4.1.3. Dioxin and cPAH TEQ Calculations

Dioxins/furans and cPAHs are measured as individual congeners or chemicals, but are often regulated as a group. However, each constituent has different chemical properties affecting their bioavailability, toxicity, and transfer among environmental media. In an effort to derive sediment cleanup levels for dioxins/furans and cPAHs as groups, the fraction of individual dioxin and furan congeners and individual cPAHs in surface sediment (0 to 0.5 feet below mudline) relative to total dioxins/furans and total cPAHs, respectively, were used to calculate the dioxin TEQ and cPAH TEQ concentrations that are protective of human health and ecological receptors. This methodology assumes that the ratios of individual congeners and individual cPAHs, which are based on the exposure point concentration (EPC) for each congener and PAH, reflect the ratios of individual congeners and cPAHs that are present throughout surface sediment at the Site. This approach is conceptually similar to the approach used by Ecology to develop site-specific MTCA Method B cleanup levels for total petroleum hydrocarbons (another group of chemicals comprising individual constituents with differing chemical properties).

Similar to the sediment cleanup levels for non-carcinogenic PAHs and pentachlorophenol, the dioxin and cPAH TEQ cleanup levels are based on a carcinogenic risk of 1 in a million (that is, a 10^{-6} risk level).

4.2. Natural Background

Natural background values are considered in the development of SCOs. Ecology recently calculated 90th UTL natural background sediment values in the draft SCUM II guidance (Ecology 2013f). Ecology used data from the OSV Bold Study (DMMP 2009) and data from Ecology-approved reference sites and other Puget Sound sites that Ecology determined were "appropriately similar to reference sites in terms of anthropogenic impact." Ecology derived 90th UTLs for cPAH TEQ and dioxin TEQ of 16 µg/kg and 4 ng/kg, respectively; these values are included in Table O-6. There was not an equivalent value for pentachlorophenol; typically this chemical is not detected in reference areas in Puget Sound.

4.3. Practical Quantitation Limits

SMS specifies that the SCO for a given chemical shall not be set at a level below analytical PQLs. The PQLs listed in Table O-6 were obtained from Ecology's SCUM II guidance based on EPA 8270 low level methods (Ecology 2013f), except as discussed below.

PQLs were not available for cPAH TEQ, dioxin TEQ, or TPH because concentrations are reported as group sums, rather than individually analyzed constituents. Derived PQLs for these three sediment bioaccumulative chemicals of concern are explained below and are included in Table O-6.

- Dioxin TEQ: Ecology derived a PQL-based cleanup level of 5 ng/kg in Appendix F of the SCUM II guidance (Ecology 2013f).
- cPAH TEQ: Ecology recommended a PQL of 10 µg/kg (Ecology 2014d).
- TPH: The median PQL for the diesel fraction of TPH (NWTPH-Dx) of 45 mg/kg from Table F-1 of the Ecology's draft SCUM II guidance (Ecology 2013f) is used to represent the PQL for TPH as it is the primary contributor to the group sum.

4.4. Proposed Sediment Cleanup Objectives

The proposed SCOs for each chemical are presented in Table O-6. As noted above, the selected value is the highest of the following: (1) lowest risk-based value protective of human health or ecological receptors, (2) natural background, or (3) PQL.

5.0 PROPOSED CLEANUP SCREENING LEVELS

According to Chapter 173-340-560(4) WAC, CSLs for a chemical are set as the highest of the following levels:

- The lowest risk-based level protective of human health (based on a cancer risk of 1 x 10^{-5} or a hazard quotient of 1), benthic organisms or ecological receptors. As noted previously, risk-based levels based on the protection of benthic organisms were included in the draft RI and are not included in this appendix.
- Regional background.
- PQLs.

5.1. Sediment Risk-Based Levels Protective of Human Health and Ecological Receptors

The methods used to calculate risk-based CSLs for sediment are the same as those used to calculate risk-based SCOs, with one exception. For CSLs, the target cancer risk is 1 in 100,000 (that is, a 10^{-5}

risk level), rather than a cancer risk of 1 in a million (or 10^{-6} risk level). Human health CSLs based on noncarcinogenic effects and ecological receptor CSLs are the same values as the SCOs.

5.2. Regional Background

Chapter 173-204-560(5) WAC allows regional background concentrations to be considered as potential CSLs when the background concentrations are higher than both the risk-based levels and PQLs. Regional background values were recently derived for cPAHs, dioxins/furans and several other chemicals in Bellingham Bay (Ecology 2015); values were based on the 90:90 UTLs of chemical concentrations in surface sediment samples collected in an area Ecology determined to be a likely regional background area. Values are provided in Table O-7.

5.3. PQLs

The PQLs are the same for the development of SCOs and CSLs and were previously discussed in the SCO section of this appendix.

5.4. Proposed Cleanup Screening Levels

The proposed CSLs for each chemical are presented in Table O-7. As noted above, the selected value is the highest of the following: (1) lowest risk-based value protective of human health or ecological receptors, (2) regional background, or (3) PQLs.

Table O-1

Tissue Thresholds for Protection of Ecological Receptors

R.G. Haley Site

Bellingham, Washington

Bioaccumulative Chemical of Concern (mg/kg ww)	DMMP[1]	Sediment Evaluation Framework[2]					British Columbia[3]		Oregon Department of Environmental Quality[4]				
	Aquatic Life	Aquatic Life	Deep Water SI	Deep Water Population	Nearshore SI	Nearshore Population	Mammalian	Avian	Aquatic Organisms	Bird SI	Bird Populations	Mammal SI	Mammal Populations
PAHs													
1-methylnaphthalene	--	--	--	--	--	--	--	--	--	--	--	--	--
2-methylnaphthalene	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthene	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthylene	--	--	--	--	--	--	--	--	--	--	--	--	--
Anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(b)fluoranthene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(k)fluoranthene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--	--	--	--
Chrysene	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenzo(a,h)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluoranthene	8,400	19	7.4	36	3.8	19	--	--	19	--	--	190	950
Fluorene	--	--	790	3,900	410	2,000	--	--		--	--	--	--
Indeno(1,2,3-c,d)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Phenanthrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Pyrene	--	1.0	7.4	36	3.8	19	--	--	1.0	--	--	9,500	47,000
Phenols													
Pentachlorophenol	900	0.001	32	160	8.1	41	--	--	0.087	--	--	0.18	1.8
Dioxins/furans													
Dioxins TEQ	--	--	9.6E-07	2.6E-05	5.0E-07	8.5E-06	7.1E-07	4.8E-07	6.4E-06	8.0E-06	4.0E-05	5.8E-07	1.6E-05

Notes:

[1] DMMP—Dredged Material Management Program (USACE 2013)

[2] Sediment Evaluation Framework (RSET 2009)

[3] British Columbia Sediment Criteria (Macfarlane et al. 2003)

[4] Oregon Department of Environmental Quality - Sediment Bioaccumulation Screening Level Values (ODEQ 2007)

Shading indicates value was used to calculate bioaccumulation sediment cleanup level

PAHs = polycyclic aromatic hydrocarbons

SI = sensitive individual (e.g., endangered species)

TEQ = toxicity equivalent

mg/kg = milligram per kilogram

ww = wet weight

Table O-2

Tissue Thresholds for Protection of Human Receptors

R.G. Haley Site

Bellingham, Washington

Bioaccumulative Chemical of Concern (mg/kg ww)	Sediment Evaluation Framework[1]			Oregon Department of Environmental Quality[2]			
	General Population	Recreational Fishers	Subsistence Fishers	Carcinogens Recreational Fishers	Carcinogens Subsistence Fishers	Non-carcinogens Recreational Fishers	Non-carcinogens Subsistence Fishers
PAHs							
1-methylnaphthalene	--	--	--	--	--	--	--
2-methylnaphthalene	--	--	--	--	--	--	--
Acenaphthene	--	--	--	--	--	--	--
Acenaphthylene	--	--	--	--	--	--	--
Anthracene	--	--	--	--	--	--	--
Benzo(a)anthracene	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--	--	--
Benzo(b)fluoranthene	--	--	--	--	--	--	--
Benzo(k)fluoranthene	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--
Chrysene	--	--	--	--	--	--	--
Dibenzo(a,h)anthracene	--	--	--	--	--	--	--
Fluoranthene	52	16	4.8	--	--	160	20
Fluorene	52	16	4.8	--	--	--	--
Indeno(1,2,3-c,d)pyrene	--	--	--	--	--	--	--
Phenanthrene	--	--	--	--	--	--	--
Pyrene	3.9	12	3.6	--	--	120	15
Phenols							
Pentachlorophenol	0.025	0.0033	0.001	0.078	0.0096	120	15
Dioxins/furans							
Dioxins TEQ	2.3E-08	3.1E-09	9.2E-10	6.2E-08	7.6E-09	--	--

Notes:

[1] Sediment Evaluation Framework (RSET 2009)

[2] Oregon Department of Environmental Quality - Sediment Bioaccumulation Screening Level Values (ODEQ 2007)

PAHs = polycyclic aromatic hydrocarbons

TEQ = toxicity equivalent

mg/kg = milligram per kilogram

ww = wet weight

Table O-3

Sediment Thresholds Above Which Adverse Bioaccumulative Effects May Occur

R.G. Haley Site

Bellingham, Washington

Bioaccumulative Chemical of Concern (mg/kg dw)	DMMP[1]	Oregon Department of Environmental Quality[2]						
	Bioaccumulation Trigger	Bird SI	Bird Populations	Mammal SI	Mammal Populations	Marine Fish	Recreational Fishers	Subsistence Fishers
PAHs								
1-methylnaphthalene	--	--	--	--	--	--	--	--
2-methylnaphthalene	--	--	--	--	--	--	--	--
Acenaphthene	--	--	--	--	--	--	--	--
Acenaphthylene	--	--	--	--	--	--	--	--
Anthracene	--	--	--	--	--	--	--	--
Benzo(a)anthracene	--	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--	--	--	--
Benzo(b)fluoranthene	--	--	--	--	--	--	--	--
Benzo(k)fluoranthene	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--
Chrysene	--	--	--	--	--	--	--	--
Dibenzo(a,h)anthracene	--	--	--	--	--	--	--	--
Fluoranthene	4.6	--	--	360	1,800	37	510	62
Fluorene		--	--	--	--	--	--	--
Indeno(1,2,3-c,d)pyrene		--	--	--	--	--	--	--
Phenanthrene		--	--	--	--	--	--	--
Pyrene	11.98	--	--	18,000	90,000	1.9	380	47
Phenols								
Pentachlorophenol	0.504	--	--	0.33	3.3	0.17	0.25	0.030
Dioxins/furans								
Dioxins TEQ	1.0E-05	7.0E-07	3.5E-06	5.2E-08	1.4E-06	5.6E-07	9.1E-09	1.1E-09

Notes:

[1] DMMP—Dredged Material Management Program (USACE 2013)

[2] Oregon Department of Environmental Quality - Sediment Bioaccumulation Screening Level Values (ODEQ 2007)

PAHs = polycyclic aromatic hydrocarbons

SI = sensitive individual (e.g., endangered species)

TEQ = toxicity equivalent

mg/kg = milligram per kilogram

dw = dry weight

Table 0-4

Biota Sediment Accumulation Factors

R.G. Haley Site

Bellingham, Washington

Bioaccumulative Chemical of Concern	All Species[1]	Fish[1]	Shellfish[1]
PAHs			
1-methylnaphthalene	0.459	0.0109	0.528
2-methylnaphthalene	0.163	0.119	0.597
Acenaphthene	0.0538	0.0323	0.0544
Acenaphthylene	0.0202	0.0158	0.181
Anthracene	0.155	0.0089	0.113
Benzo(a)anthracene	0.036	0.0016	0.0449
Benzo(a)pyrene	0.0255	0.0002	0.0252
Benzo(b)fluoranthene[2]	0.002	0.0004	0.0148
Benzo(k)fluoranthene[2]	0.002	0.0004	0.0148
Benzo(g,h,i)perylene	0.0464	0.0008	0.0532
Chrysene	0.175	0.0018	0.226
Dibenzo(a,h)anthracene	0.0254	0.002	0.0459
Fluoranthene	0.1	0.0028	0.22
Fluorene	0.174	0.0225	0.208
Indeno(1,2,3-c,d)pyrene	0.0354	0.001	0.0426
Naphthalene	0.328	0.334	0.426
Phenanthrene	0.111	0.0067	0.123
Pyrene	0.133	0.002	0.159
Phenols			
Pentachlorophenol	0.274	0.134	0.384
Dioxins and Furans			
1,2,3,4,6,7,8-HpCDD	0.0089	0.00259	0.0162
1,2,3,4,6,7,8-HpCDF	0.0266	0.00488	0.0256
1,2,3,4,7,8,9-HpCDF	0.0135	0.0171	0.0143
1,2,3,4,7,8-HxCDD	0.0583	0.0301	0.0835
1,2,3,4,7,8-HxCDF	0.0739	0.017	0.0657
1,2,3,6,7,8-HxCDD	0.0656	0.0592	0.1
1,2,3,6,7,8-HxCDF	0.0719	0.0705	0.0678
1,2,3,7,8,9-HxCDD	0.0189	0.00643	0.0397
1,2,3,7,8,9-HxCDF	0.15	0.0039	0.0098
2,3,4,6,7,8-HxCDF	0.0379	0.0212	0.0413
1,2,3,7,8-PeCDD	0.224	0.224	0.217
1,2,3,7,8-PeCDF	0.814	0.906	0.966
2,3,4,7,8-PeCDF	0.23	0.278	0.219
2,3,7,8-TCDD	0.331	0.313	0.468
2,3,7,8-TCDF	0.342	0.287	0.36
OCDD	0.0295	0.00126	0.0207
OCDF	0.0156	0.0103	0.0125

Notes:

[1] BSAF values were derived from EPA's BSAF database (EPA 2013), except the pentachlorophenol, which was derived from Ecology and Environment (2009).

[2] BSAFs for benzo(b)fluoranthene and benzo(k)fluoranthene were combined, due to the small data set size. Results are uncertain.

PAHs = polycyclic aromatic hydrocarbons

Table O-5

Human Health Exposure Factors for Calculating Risk-Based Sediment Concentrations

R.G. Haley Site

Bellingham, Washington

Parameter	Parameter Name	Units	Subsistence Fisher	
			Low Exposure	High Exposure
CUL	cleanup level	chemical specific	chemical-specific	chemical-specific
CR	cancer risk	unitless	1.0E-06	1.0E-06
BW	body weight	kg	70	70
AT	averaging time	days	27,375 (75 years)	27,375 (75 years)
UCF	unit correction factor	g/kg	1,000	1,000
CPFo	cancer potency factor (oral)	mg/kg-day	chemical-specific	chemical-specific
FCR	fish and shellfish consumption rate[1]	g/day	61.9 for shellfish; 7.8 fish	61.9 shellfish; 7.8 fish
FDF	fish and shellfish dietary fraction[1]	fraction	0.05 for shellfish; 0.05 fish	1 for shellfish; 1 fish
EF	exposure frequency	days/year	365	365
ED	exposure duration	years	70	70
S_{foc}	fraction of sediment organic carbon[2]	fraction	site-specific; 0.028	site-specific; 0.028
SUF	site use factor for fish and shellfish	fraction	1 for shellfish; 1 for fish	1 for shellfish; 1 for fish
SL	representative lipid fraction for fish and shellfish[3]	fraction	0.026 for shellfish; 0.029 for fish	0.026 for shellfish; 0.029 for fish
BSAF	biota-sediment accumulation factor	g (ww) lipid-normalized tissue concentration/g (dw) organic carbon normalized sediment concentration	chemical-specific (from Table O-4)	chemical-specific (from Table O-4)

Notes:

[1] See text for a description on how these values were derived.

[2] Site-specific value for surface sediment at Haley

[3] From EPA's KABAM Version 1.0 Kow (based) Aquatic BioAccumulation Model

g/kg = gram per kilogram

mg/kg = milligram per kilogram

dw - dry weight

ww = wet weight

Table 0-6

Proposed Bioaccumulation Sediment Cleanup Objectives (SCO)

R.G. Haley Site

Bellingham, Washington

Bioaccumulative Chemical of Concern	Protective of People		Protective of Ecological Receptors			Modifying Factors		Proposed SCOs
	Subsistence Fishers - Low Exposure	Subsistence Fishers - High Exposure	Aquatic Life (Fish and Invertebrates)	Aquatic Dependent Wildlife (Individual Birds and Mammals)	Aquatic Dependent Wildlife (Bird and Mammal Populations)	Natural Background[1]	PQL[2]	
PAHs (µg/kg)								
2-methylnaphthalene	3,400,000	8,500	n/a	n/a	n/a	<RBCs	10	8,500
Acenaphthene	530,000,000	1,300,000	n/a	n/a	n/a	<RBCs	10	1,300,000
Acenaphthylene	170,000,000	430,000	n/a	n/a	n/a	<RBCs	10	430,000
Anthracene	>max	3,400,000	n/a	n/a	n/a	<RBCs	10	3,400,000
Benzo(a)anthracene	790	40	n/a	n/a	n/a	cPAH TEQ	10	cPAH TEQ
Benzo(a)pyrene	140	7.1	n/a	n/a	n/a	cPAH TEQ	10	cPAH TEQ
Benzofluoranthenes	2,400	120	n/a	n/a	n/a	cPAH TEQ	10	cPAH TEQ
Benzo(g,h,i)perylene	290,000,000	730,000	n/a	n/a	n/a	<RBCs	10	730,000
Chrysene	1,600	79	n/a	n/a	n/a	cPAH TEQ	10	cPAH TEQ
Dibenzo(a,h)anthracene	770	39	n/a	n/a	n/a	cPAH TEQ	10	cPAH TEQ
Fluoranthene	95,000,000	240,000	180,000	37,000	180,000	<RBCs	10	37,000
Fluorene	98,000,000	250,000	n/a	2,300,000	11,000,000	<RBCs	10	250,000
Indeno(1,2,3-c,d)pyrene	840	42	n/a	n/a	n/a	cPAH TEQ	10	cPAH TEQ
Naphthalene	22,000,000	55,000	n/a	n/a	n/a	<RBCs	10	55,000
Phenanthrene	>max	3,200,000	n/a	n/a	n/a	<RBCs	10	3,200,000
Pyrene	98,000,000	250,000	7,300	28,000	140,000	<RBCs	10	7,300
cPAH TEQ	130	6.6	n/a	n/a	n/a	16	10	19.4
Phenols (µg/kg)								
Pentachlorophenol	160	8.1	3.5	29,000	140,000	ND	100	100
Dioxins and Furans (ng/kg)								
Dioxins TEQ	1.7	0.087	55	2.8	48	4	5	5

Notes:

[1] Natural background values calculated as the 90/90 UTL from Ecology's SCUM II guidance (Table 11-1;Ecology 2013).

[2] Practical quantitation limits (PQLs) from Table F-1, SCUM II guidance (Ecology 2013) based on median PQL for EPA 8270 low level methods, unless otherwise noted. PQL for dioxin TEQ derived in Appendix F (Ecology 2013). PQL for cPAH TEQ recommended by Mark Adams, Ecology in an email to Amy Kraham, City of Bellingham, dated May 8, 2014 titled "Revisions to Bioaccumulative PQLs."

ND = not detected (68 of 70 samples were ND)

PAHs = polycyclic aromatic hydrocarbons

TEQ = toxicity equivalent

>max - risk based value is greater than 1,000,000,000 µg/kg

Shading indicates basis for proposed cleanup level

Table O-7

Proposed Bioaccumulation Cleanup Screening Levels (CSL)

R.G. Haley Site
Bellingham, Washington

Bioaccumulative Chemical of Concern	Protective of People		Protective of Ecological Receptors			Modifying Factors		Proposed CSLs
	Subsistence Fishers - Low Exposure	Subsistence Fishers - High Exposure	Aquatic Life (Fish and Invertebrates)	Aquatic Dependent Wildlife (Individual Birds and Mammals)	Aquatic Dependent Wildlife (Bird and Mammal Populations)	Regional Background[1]	PQL[2]	
PAHs (µg/kg)								
2-methylnaphthalene	3,400,000	8,500	n/a	n/a	n/a	n/a	10	8,500
Acenaphthene	530,000,000	1,300,000	n/a	n/a	n/a	n/a	10	1,300,000
Acenaphthylene	170,000,000	430,000	n/a	n/a	n/a	n/a	10	430,000
Anthracene	>max	3,400,000	n/a	n/a	n/a	n/a	10	3,400,000
Benzo(a)anthracene	7,900	400	n/a	n/a	n/a	n/a	10	cPAH TEQ
Benzo(a)pyrene	1,400	71	n/a	n/a	n/a	n/a	10	cPAH TEQ
Benzofluoranthenes	24,000	1,200	n/a	n/a	n/a	n/a	10	cPAH TEQ
Benzo(g,h,i)perylene	290,000,000	730,000	n/a	n/a	n/a	n/a	10	730,000
Chrysene	16,000	790	n/a	n/a	n/a	n/a	10	cPAH TEQ
Dibenzo(a,h)anthracene	7,700	390	n/a	n/a	n/a	n/a	10	cPAH TEQ
Fluoranthene	95,000,000	240,000	180,000	37,000	180,000	n/a	10	37,000
Fluorene	98,000,000	250,000	n/a	2,300,000	11,000,000	n/a	10	250,000
Indeno(1,2,3-c,d)pyrene	8,400	420	n/a	n/a	n/a	n/a	10	cPAH TEQ
Naphthalene	22,000,000	55,000	n/a	n/a	n/a	n/a	10	55,000
Phenanthrene	>max	3,200,000	n/a	n/a	n/a	n/a	10	3,200,000
Pyrene	98,000,000	250,000	7,300	28,000	140,000	n/a	10	7,300
cPAH TEQ	1,300	66	n/a	n/a	n/a	86	10	86
Phenols (µg/kg)								
Pentachlorophenol	1,600	81	3.5	29,000	140,000	n/a	100	100
Dioxins and Furans (ng/kg)								
Dioxins TEQ	17	0.87	55	2.8	48	15	5	15

Notes:

[1] Background values calculated as the 90:90 UTL of data from Bellingham Bay (Ecology 2015).

[2] Practical quantitation limits (PQLs) from Table F-1, SCUM II guidance (Ecology 2013) based on median PQL for EPA 8270 low level methods, unless otherwise noted. PQL for dioxin TEQ derived in Appendix F (Ecology 2013). PQL for cPAH TEQ recommended by Mark Adams, Ecology in an email to Amy Kraham, City of Bellingham, dated May 8, 2014 titled "Revisions to Bioaccumulative PQLs."

PAHs = polycyclic aromatic hydrocarbons

TEQ = toxic equivalent

n/a = not available

>max - risk based value is greater than 1,000,000,000 µg/kg

Shading indicates basis for proposed cleanup level

APPENDIX P
Soil Agitation Pilot Study

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APPENDIX P. SOIL AGITATION PILOT STUDY

Summary of 2007 Soil Agitation Pilot Test

Field and bench-level tests of enhanced soil agitation were performed in January 2007 to evaluate agitation as a remedial technology to remove LNAPL in the Haley upland soil (GeoEngineers 2007). A summary is presented below.

The field test utilized an auger or backhoe bucket to “mix” saturated smear zone soil within an open excavation near the shoreline (approximately 20 feet by 16 feet in plan dimensions), after removal of approximately 8 feet of overlying soil. The excavation was located near wells TL-MW-2 and RW-6 where the greatest thicknesses of in-well LNAPL had been observed. Fill encountered in the excavation included silty sand with gravel and construction debris, blocks of sandstone, concrete rubble, steel pipe and occasional wood debris. Smear zone soil included marine fill characterized as sand with silt and shells. Native marine fill was present in the excavation base below the smear zone soil, at approximately 11.5 feet below ground surface (bgs).

Saturated smear zone soil in the excavation (extending from approximately 8 to 12 feet bgs) was agitated for several hours over the course of three days using a 24-inch-diameter auger or backhoe bucket; the excavation was covered each night after agitation activities. A rotary-drum skimmer was placed in the lowest portion of the open excavation to remove the LNAPL as it accumulated on the water surface during the agitation activities. Water and oil removed by the skimmer were transferred to 55-gallon drums for storage and disposal.

An estimated 195 gallons of oil were liberated by soil agitation methods during the field test and collected by skimming. After the first day of soil agitation, the thickness of LNAPL on the groundwater surface in the excavation was 0.06 feet; after the second day of soil agitation, the LNAPL thickness was 0.03 feet. LNAPL removal effectiveness during the field test was limited based on the rotary skimmer employed. Field observations of excavation sidewall stability, wood fill, groundwater seepage, oil seepage and recovery were recorded during the field test. Soil sampling and analytical testing were also performed during the field testing as described below.

Two bench tests were performed on smear zone soil samples removed from the field test excavation. The bench tests were performed in the laboratory using hand tools (spoons, etc.) for mixing and oil collection; samples represented approximately 15 pounds of soil. Bench testing involved intermittently mixing each sample with tap water and allowing the mixture to rest before skimming oil from the water surface. The bench tests were conducted for 4 to 6 hours.

LNAPL removal effectiveness from enhanced agitation was evaluated through direct measurement of the quantity of recovered oil during the field test, comparison of pre-test and post-test diesel-range hydrocarbon concentrations in bench test soil samples, and comparison of pre-test and post-test free product mobility testing of field test soil samples from the excavation and bench test soil samples. The field and bench testing observations and results indicated that soil agitation would be expected to reduce diesel concentrations in soil by 70 to 90 percent, and post-treatment residual diesel concentrations to less than concentrations indicative of free product mobility.

February 20, 2007

Douglas Management Company
18000 International Boulevard, Suite 800
Seattle, Washington 98188

Attention: Everett Billingslea

Subject: Results of Field Pilot Test and Bench Test
Enhanced Agitation Remediation Technique
Former R.G. Haley Wood Treatment Site
Bellingham, Washington
Agreed Order No. DE 2186

1.0 INTRODUCTION

This document summarizes the results of pilot testing to evaluate the feasibility of enhanced agitation as a remedial method for the R.G. Haley International Corporation (Haley) wood treatment site (herein referred to as "Site"). A Work Plan for the pilot study was submitted for Ecology review on December 19, 2006. Ecology provided brief review comments and granted approval for conducting the pilot tests in a letter from Glynis Carrosino dated January 2, 2007. The field portion of the pilot test occurred from January 3 to January 5, 2007. The bench-scale testing occurred between January 8 and 10, 2007.

As discussed in the Work Plan, the overall goals of the pilot testing are to evaluate whether enhanced agitation of petroleum-contaminated soil could be effective in 1) eliminating the free product plume at the Site, and 2) preventing the mobility of residual hydrocarbons in soil as phase-separated free product after the conclusion of remedial actions.

2.0 FIELD TEST PROCEDURES AND OBSERVATIONS

The approximate location of the field test is shown in Figure 1. The test occurred within the mapped limits of the free product plume in the immediate vicinity of existing wells TL-MW-2 and RW-6. These wells were monitored intermittently during the test and were not damaged by the pilot test operations. GeoEngineers documented the field testing with numerous digital photographs. Photos of field operations are included at the end of this summary report on Photos 1 through 13 on Figures 1 through 7. Photos of the bench test are included on Photos 14 through 19 on Figures 7 through 10.

Field conditions necessitated some deviations from the Work Plan, primarily with regard to sampling of contaminated soil before and after the field test. The field test procedures, as actually implemented, are summarized below:

1. Place straw bale enclosures on two sides of the planned test excavation (one for temporary storage of relatively non-contaminated overburden soil, and the other for temporary storage of petroleum-contaminated soil from the smear zone). Place a liner of plastic sheeting on the floors and walls of each soil enclosure area.

2. Excavate approximately 93 cubic yards of overburden soil to a depth of 7.5 feet and stockpile this soil in the overburden stockpile area (Photo 1). In general, the overburden soil consisted of silty sand with gravel and construction debris, blocks of sandstone, concrete rubble, one steel pipe, and occasional wood debris.
3. Install a trench box measuring 20 feet long by 16 feet wide by 8 feet deep to the base of the overburden excavation (Photo 2). The north corner of the trench box encountered the top of a buried timber pile, limiting the depth of the trench box to 7.5 feet. The base of the trench box coincided with the depth of the water table in test area.
4. Excavate approximately 9 cubic yards of highly contaminated smear zone soil and place this soil in the contaminated material stockpile. The contaminated soil was removed from the central portion of the test excavation to a depth of about 9.5 feet below grade. The contaminated soil consisted of dark gray sand with silt and shells (dredged fill; SP-SM by Unified Soil Classification System). Groundwater with visible free product entered the excavation upon excavation of the “sump” in the central portion of the test excavation (Photo 3).
5. From the contaminated material stockpile, obtain smear zone soil samples for laboratory testing as follows:
    - **a.** Three tube samples (6 inches long by 2.4 inches diameter) for pre-agitation free product mobility testing using methods ASTM D425M, API RP 40 (Photo 4).
    - **b.** One pre-agitation composite jar sample (Pre-agitate 4) for analysis of diesel using Ecology Method NWTPH-Dx.
    - **c.** Two composite bulk samples (Pre-test 1 and Pre-test 2) for bench testing (Photo 5).
    - **d.** Note that sampling of organic-rich fill soil was anticipated in the Work Plan. No such soil was encountered within the sump excavation.
6. At the end of Day 1, the excavation was allowed to rest overnight. Steel plates were placed over the top of the excavation to prevent accidental entry into the excavation.
7. At the beginning of Day 2, the water table was approximately 8 feet below the ground surface, with 0.06 feet of free product on the water table (approximately 55 gallons based on the dimensions of the sump area).
8. Install a rotary drum skimmer in the excavation and remove accumulated free product to a vacuum truck (Photo 6).
9. Begin agitation of soil in the water using a 24-inch-diameter helical auger mounted on a tracked excavator. Recover free product from the water table using the rotary drum skimmer as product is liberated from the soil (Photo 7). The soil agitation occurred within the central portion of the sump and around the perimeter of the sump to a depth of about 3 feet below the water table (10.5 to 11.0 feet below ground surface).
10. Stop soil agitation with the auger periodically to allow oil to separate and accumulate on the water surface, for more effective removal by the skimmer.
11. In the afternoon of Day 2, the agitation method was changed from the helical auger to the bucket of the tracked excavator. It was found that the soil could be moved and mixed faster and deeper with the excavator bucket than the helical auger (Photo 8).
12. The excavator enlarged the sides of the sump and agitated soil to a depth of about 4.5 feet below the water table (12 feet below ground surface). Abundant wood debris was encountered at about 11 feet below grade. This wood became floating debris on the water surface, which inhibited the effectiveness of the skimmer (Photo 9). The excavator removed much of the wood debris from the water surface and placed it on the contaminated soil stockpile.

13. A unit of native silt with shells was encountered at a depth of about 11.5 feet below grade. The silt stuck to the teeth of the excavator bucket. Field screening indicated that the silt was not contaminated (Photo 10). A soil sample (Post-agitate 5) was obtained to confirm the field screening results by analytical testing.

14. Agitation of the silt layer created a mud slurry in the bottom of the sump (Photo 11). The viscosity of the muddy water inhibited the accumulation of oil on the water surface as free phase product. Furthermore, it was not possible to obtain post-agitation soil samples of the slurry. The field agitation program was terminated at 3 PM on Day 2.

15. At the end of Day 2, the excavation was allowed to rest overnight. Steel plates were placed over the top of the excavation to prevent accidental entry into the excavation.

16. At the start of Day 3, the water table was about 7.5 feet below ground surface, with about 0.03 feet of free product on the water surface.

17. Fluids in the vacuum truck from Day 2 were transferred to 55-gallon drums. A total of 199 gallons of product and water was transferred (Photo 12).

18. The rotary drum skimmer was used to remove the accumulated oil on the water surface. This fluid was also transferred to the 55-gallon drums. A total of 55 gallons of fluid were transferred from product recovery operations on Day 3.

19. The total volume of fluid recovered by the drum skimmer for Days 2 and 3 was 254 gallons. This fluid contained all oil that was liberated and recovered as a result of the sump excavation and agitating the smear zone using the auger and excavator bucket. However, oil contained in the contaminated soil stockpile was NOT agitated and is not included in this total.

20. Two fluid samples were obtained from the drums to estimate the relative percentage of oil and water in the recovered fluids. After settling overnight, the samples were examined visually. Both samples indicated that about 77 percent of the fluid recovered was oil and the remaining 23 percent was sediment-rich water (Photo 13). Using this ratio, approximately 195 gallons of oil was recovered during the field test.

21. Field equipment, including the trench box, was decontaminated with a pressure washer. Decon water and other wastewater from the site was returned to the excavation.

22. The excavation was backfilled with soil in the reverse order that the soil was excavated. Initial backfilling occurred over several days to allow water in the excavation to soak into adjacent soil and not spill out of the test excavation. Backfilling was further delayed by snow and freezing conditions in mid-January. Backfilling was completed on January 17, 2007.

23. Plastic sheeting and other test residuals were placed in existing containers under the on-site drying shed structures. Drums with recovered oil and water also remain at the Site.

During Day 2 of the field test (January 4), GeoEngineers' field representative was equipped with an air sampling device to evaluate potential airborne exposure to pentachlorophenol during soil agitation operations. Sampling was done for four continuous hours of exposure using OSHA 39 sampling protocols. The sampling pump circulated breathing zone air through three XAD-7 sampling tubes in series at an air volume of 0.2 L/min. After conclusion of the test, the sampling tubes were submitted under chain-of-custody to Galson Laboratories for quantification of pentachlorophenol.

3.0 BENCH TEST PROCEDURES AND OBSERVATIONS

Two bulk samples of hydraulic fill (sand with silt and shells) were returned to GeoEngineers' laboratory in Redmond, Washington for bench-scale testing of enhanced agitation. The testing for each sample was done sequentially (not simultaneously). All work occurred under a ventilated hood to prevent vapor exposures to laboratory workers. GeoEngineers documented the bench tests with numerous digital photographs. The test methodology is summarized below:

1. Remove approximately 15 pounds of soil from each sealed bulk sample and re-seal the sample containers. Place each 15-pound sample in a large stainless steel mixing bowl for two separate bench tests (Photo 14). Determine the wet weight of soil placed in each bowl.
2. Obtain pre-agitation soil samples (Pre-test 1 and Pre-test 2) from each bulk sample for analysis of diesel using Ecology Method NWTPH-Dx, then perform the following steps on each sample.
3. Slowly add tap water to the mixing bowl until the water level reaches the top of the soil in the bowl (Photo 15).
4. Gently mix the soil and water using a stainless steel spoon. Continue mixing until a considerable amount of oil covers the water surface (Photo 16).
5. Let the soil and water rest for 10 to 15 minutes and remove oil from the water surface using a turkey baster and/or a stainless steel spoon (Photo 17). Transfer the liquid to a large graduated cylinder to allow oil to separate from the water.
6. Repeat the soil agitation and oil recovery process for several hours, adding additional water as needed, until relatively little new oil appears on the water surface with continued agitation of the soil (Photo 18).
7. Drain excess water and oil from the test bowl and obtain post-agitation soil samples for laboratory testing as follows:
   a. Two tube samples (one from each test) for free product mobility testing using methods ASTM D425M, API RP 40.
   b. One jar sample for each test (Post-test 1 and Post-test 2) for analysis of diesel using Ecology Method NWTPH-Dx (two post-agitation samples total).
8. After overnight separation, determine the volume of oil recovered in the graduated cylinder for each bench test (Photo 19).
9. Transfer excess soil, water, product and test residuals to sealed buckets for return to the Site.

4.0 ANALYTICAL TEST RESULTS

A summary of soil analytical data for the pilot testing is presented on Table 1. Note that the sample of native silt from the base of the sump excavation for the pilot test (Post-agitate 5) was non-detect for diesel. This confirms that the lowest soil unit encountered during the test was below the depth of the smear zone (at least at the location of the field pilot test).

The most meaningful results for comparing the pre-agitation and post-agitation soil conditions are derived from the bench tests (Table 2). These data demonstrate substantial reductions in oil concentration resulting from soil agitation in water (94 percent reduction for the first bench test and 76 percent reduction for the second test). These concentration reductions are reasonably comparable to the concentration reductions calculated based on the volume of oil recovered during the two bench tests.

The air sampling for pentachlorophenol during the 4-hour exposure test resulted in no detection of pentachlorophenol, at a lower detection limit of 0.0038 mg/cu. meter.

5.0 FREE PRODUCT MOBILITY TEST RESULTS

Three samples of smear zone soil from the field pilot test, and two samples of smear zone soil from the bench test, were submitted to PTS Laboratories in Santa Fe Springs, California. The samples were tested to evaluate free product mobility using API RP 40 and ASTM D425M testing methods. In brief, this procedure uses a centrifuge to apply forces of 1,000 times the acceleration of gravity for a period of one hour to cylindrical soil core samples. Most of the fluids in the soil pore spaces drain from the samples in response to the centrifugal forces. The percentage of soil pore space volume occupied by oil and water are measured before and after the test. The results of the testing are summarized on Table 3.

The results of the free product mobility testing offer the following conclusions:

- For the pre-agitation field samples, the centrifuge reduced the amount of oil in soil pore spaces to residual amounts ranging from 2.8 percent to 5.8 percent of total pore volume. This residual amount is sometimes interpreted to be the "residual saturation" level for free product in soil. If these residual saturation values are converted from percentage pore space volume to mass concentrations, the residual oil concentrations would range from about 5,500 mg/kg to 11,000 mg/kg, with an average for the three pre-agitation field samples of 8,200 mg/kg.
- Based on the bench testing, the mass concentration of oil in soil after agitation ranged from 2,700 mg/kg to 8,200 mg/kg (Table 1), with an average for two post-agitation samples of 5,450 mg/kg. This suggests that the mass concentrations of oil following enhanced agitation on a bench scale are typically less than residual saturation concentrations for the dredge sand materials that were tested.
- The free product mobility testing indicated that the centrifuge process reduced the volume of oil in the soil pore space by 16 percent to 39 percent for the three pre-agitation samples obtained in the field. The bench testing of the same materials indicated 76 percent to 94 percent reductions in oil concentrations after agitation (see Section 4.0). This suggests that the agitation process is more effective in removing oil from the soil than subjecting the soil to centrifuge separation at 1,000 times the acceleration of gravity.

6.0 IMPLICATIONS OF PILOT TESTS TO FULL SCALE REMEDIATION

Pilot testing in the field and in the laboratory showed the potential for effective use of enhanced soil agitation for the full-scale remediation of the free product plume at the Site. Based on the results of the field and bench tests, a significant volume of free product could be removed from the free product plume using the enhanced agitation technology. The Draft RI/FS for the site (dated March 13, 2006) estimated that approximately 12,000 gallons of oil could be recovered from the planned remedial action area using enhanced soil agitation. Based on the results of the pilot testing, we now estimate that 20,000 to 30,000 gallons of oil can be recovered using this method (assuming smear zone thickness and characteristics similar to the pilot testing).

Residual concentrations of hydrocarbons in the soil zone treated by agitation are expected to have diesel concentrations that are reduced by 70 percent to 90 percent from pre-treatment conditions. The residual concentrations after backfilling (see additional discussion below) are expected to be less than the concentrations that support free product mobility. Furthermore, the residual hydrocarbon concentrations after soil agitation are expected to be low enough that natural attenuation processes can be relatively effective in furthering the reduction in residual oil concentrations after completion of the remedial action.

Pilot testing identified several obstacles to implementation of a full-scale enhanced soil agitation technology. Identified obstacles include:

- The presence of abandoned timber piles in the subsurface was confirmed in the free product plume portion of the Site.
- Wood debris exists in the smear zone area intended for enhanced soil agitation. Some of this wood debris floats to the surface of the water and inhibits effective recovery of oil from the surface of the water.
- Agitation of subsurface silt units produces a muddy slurry that inhibits the release of oil to the surface of the water.
- Excess water with minor amounts of free product remains in the remedial excavation area at the end of the agitation process.
- Backfilling is challenging with free water in the excavation.

Each of the difficulties described above is surmountable with appropriate planning and field controls. Possible methods to overcome these obstacles will be described in the Engineering Design Report. Based on the lessons learned from pilot testing, full-scale remedial actions could include the following components:

- Soil agitation may occur sequentially within relatively small cofferdams constructed inside the limits of the free product plume. Individual cofferdam cells would be constructed out of sheet piles recovered from the existing sheet pile wall at the site (after installation of a new Waterloo Barrier sheet pile wall).
- Rather than excavate a “sump” below the water table for soil agitation, water could be added to the cofferdam cells after the overburden soil is removed to the top of the smear zone. Using this method, it would not be necessary to remove any contaminated soil from the ground. The sheet piles bordering the cofferdams would minimize the potential for contaminant migration to or from adjacent areas during soil agitation.
- The timber piles in the planned area of remediation do not appear to be treated with creosote or other wood preservatives. Removal of these piles is not recommended because of the potential for creating a vertical pathway for the migration of contaminated groundwater. One option for addressing timber piles in the excavation is to cut the piles off at the base of the excavation and leave them in place below that depth. Alternatively, the full length of the piles could remain in place, and soil agitation could occur in the soil surrounding the uppermost portions of the piles.
- Soil agitation with the excavator bucket appears to be more efficient and effective that use of a helical auger.
- Floating wood debris in the soil agitation area likely can be managed effectively by direct removal. It may be necessary to remove the debris using a rake-like attachment to the arm of an excavator (tracked backhoe).
- Analytical testing at the location of the field pilot test revealed that the native silt unit at the base of the smear zone is not contaminated with oil. Smear zone agitation within the cofferdams should proceed gradually from shallow to deep to minimize disturbance of the silt unit and the associated creation of a mud slurry in the excavation. If silt units are encountered during soil agitation, they should be evaluated for the potential presence of oil contamination using field screening methods. If not contaminated, soil agitation should not extend into the silt layer.

- Excess water in the soil agitation area can be pumped to Baker tanks to allow for settling of suspended solids and separation of oil. After separation, this water can be used for soil agitation in the next cofferdam cell that will be treated.
- Soil admixture materials, such as fly ash, could potentially be added to the wet soil in each cofferdam cell after completion of agitation. With the addition of admixture material, soil strength should increase, soil permeability should decrease, and the potential mobility of residual oil in the soil should decrease.

7.0 CONCLUSION

The pilot test demonstrates the feasibility of enhanced agitation for addressing the free product plume area of the Site. The results of this pilot test will be incorporated into the Engineering Design Report and cost estimate for full scale remediation of the Site.

Sincerely,

GeoEngineers, Inc.

James A. Miller, P.E., L.HG.
Senior Principal

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Attachments: Table 1. Summary of Analytical Results
Table 2. Summary of Bench Testing Results
Table 3. Summary of Free Product Mobility Testing
Figures 1 through 10. Pilot Test Photos

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TABLE 1
SUMMARY OF ANALYTICAL RESULTS
ENHANCED AGITATION PILOT TESTING

Sample Name	Sample Depth (feet)	Sample Date	Sample Type	Diesel Concentration (mg/kg)	Comment
Pre-agitate 4	8-10	01/03/07	A	18,000	Dredge sand
Post-agitate 5	11.5	01/04/07	B	<25	Native silt
Pre-test 1	8-10	01/08/07	C	45,000	Dredge sand
Post-test 1	8-10	01/09/07	D	2,700	Dredge sand
Pre-test 2	8-10	01/09/07	C	35,000	Dredge sand
Post-test 2	8-10	01/09/07	D	8,200	Dredge sand

Notes:
A = Field sample before agitation in water
B = Field sample from below base of smear zone (not agitated)
C = Bench (lab) sample before agitation in water
D = Bench (lab) sample after agitation in water

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TABLE 2
SUMMARY OF BENCH TESTING RESULTS

Bench Test Number	Wet Sample Weight (lbs)	Oil Recovered (ml)	Concentration Reduction Based on Analytical Testing	Calculated Concentration Reduction Based on Oil Recovery[1,2]
1	15.50	233	42,300 mg/kg	33,200 mg/kg
2	17.46	227	26,800 mg/kg	28,800 mg/kg

Notes:

[1] Dry weight of in-place soil assumed at 112 pounds per cubic foot.

[2] Pre-test soil moisture content assumed at 17 percent.

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TABLE 3
SUMMARY OF FREE PRODUCT MOBILITY TESTING

Sample Name	Sample Type	Pore Volume Pre-centrifuge (%)		Pore Volume Post-centrifuge (%)		Fluid Pore Volume Reduction (%)	
		Water	Oil	Water	Oil	Water	Oil
Pre-agitate 1	A	39.8	6.9	9.8	5.8	75	16
Pre-agitate 2	A	30.4	4.6	9.6	2.8	68	39
Pre-agitate 3	A	31.9	5.2	8.2	3.9	74	25
Post-test 1	D	65.5	4.4	10.8	2.3	83	48
Post-test 2	D	58.2	5.8	11.6	3.0	80	48

Notes:

[1] Methods API RP 40 and ASTM D425M

[2] A = Field sample before agitation in water

[3] D = Bench (lab) sample after agitation in water

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PILOT TEST PHOTOS

Photo 1. Overburden stockpiling

Photo 2. Trench box in place

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FIGURE 1

Photo 3. Oil and water entering sump excavation

Photo 4. Preparation of soil sample for free product mobility testing

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FIGURE 2

Photo 5. Collecting bulk soil sample for bench testing

Photo 6. Rotary drum skimmer in operation

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FIGURE 3

Photo 7. Soil agitation using helical auger, with simultaneous oil recovery

Photo 8. Soil agitation using excavator bucket

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FIGURE 4

Photo 9. Wood debris in excavation

Photo 10. Native silt encountered below base of smear zone

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FIGURE 5

Photo 11. Slurry created by agitation of native silt unit

Photo 12. Transfer of recovered oil to drums

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FIGURE 6

Photo 13. Oil and sediment-laden water recovered during field pilot test

Photo 14. Soil in mixing bowl for bench test

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FIGURE 7

Photo 15. Addition of water to soil prior to bench-scale agitation

Site Photo 16. Agitation of soil with stainless steel spoon

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FIGURE 8

Photo 17. Removal of liberated oil from water surface in mixing bowl.

Photo 18. Water surface in mixing bowl at completion of agitation process

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FIGURE 9

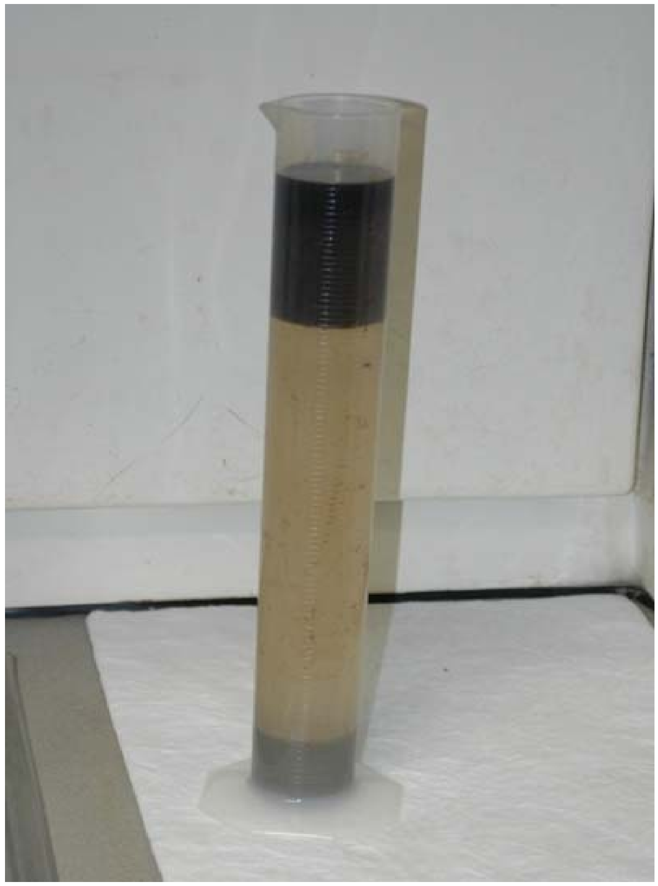

Photo 19. Graduated cylinder with oil recovered from soil during second bench test

APPENDIX Q
Cleanup Alternatives Cost Estimates

Table of Contents

APPENDIX Q. CLEANUP ALTERNATIVES COST ESTIMATES

Table Q-1

Summary of Cost Estimates for Remedial Alternatives

R.G. Haley Site

Bellingham, Washington

Alternative	Alternative Description	Capital Costs	O&M Costs (NPV)	Contingency (25%)	Total Cost
Upland Cleanup Action Alternatives (including costs for "Common Elements")					
U1	Passive LNAPL Removal, Vertical Shoreline Barrier, Upland Cap	$ 5,360,000	$ 2,710,000	$ 2,020,000	$ 10,090,000
U2	PRB, Passive LNAPL Removal, Upland Cap	$ 5,470,000	$ 3,100,000	$ 2,140,000	$ 10,710,000
U3a	Nearshore *In situ* Soil Solidification, Upland Cap	$ 6,730,000	$ 1,470,000	$ 2,050,000	$ 10,250,000
U3b	Expanded *In situ* Soil Solidification and Stabilization, Upland Cap	$ 15,370,000	$ 1,470,000	$ 4,210,000	$ 21,050,000
U3c	Soil Removal, *In situ* Soil Solidification and Stabilization, Upland Cap	$ 18,520,000	$ 1,470,000	$ 5,000,000	$ 24,990,000
U4	Complete Removal	$ 132,940,000	$ 1,140,000	$ 33,520,000	$ 167,600,000
Sediment Cleanup Action Alternatives					
S1	Containment	$ 2,410,000	$ 810,000	$ 600,000	$ 3,820,000
S2	Upper Intertidal Sediment Removal and Amended Cap	$ 3,240,000	$ 870,000	$ 1,030,000	$ 5,140,000
S3	Upper Intertidal Sediment Removal and Sand Cap	$ 3,470,000	$ 910,000	$ 1,090,000	$ 5,470,000
S4	Intertidal and Shallow Subtidal Sediment Removal and Amended Cap	$ 4,340,000	$ 970,000	$ 1,330,000	$ 6,640,000
S5a	Complete Removal and Backfill, Consolidate within Upland AOC	$ 5,600,000	$ 370,000	$ 1,490,000	$ 7,460,000
S5b	Complete Removal and Backfill, Off-Site Treatment Disposal	$ 9,370,000	$ 370,000	$ 2,440,000	$ 12,180,000

Notes:

Cost estimates prepared in general accordance with EPA guidance (EPA 2000a). Estimates represent order-of-magnitude with a range of -30 percent to +50 percent. Costs are in 2014 dollars.

Capital costs include indirect capital costs including remedial design and permitting, project management, construction management and construction mobilization which are all calculated as a percentage of the direct capital cost. Applicable sales taxes were not included but are within the order-of-magnitude range.

Restoration project costs for fill mitigation are included for Sediment Cleanup Action Alternatives S1, S2 and S3.

Long-term operation, monitoring, maintenance and inspection costs are presented as the Net Present Value (NPV) estimated over a 30 year period using a discount rate of 1.1% as specified by Ecology. Operation and Maintenance (O&M) costs include project management and construction management calculated as a percentage of the base O&M cost.

See Table Q-2 for acronyms and abbreviations used.

Table Q-2

Unit Costs Used for Detailed Cost Estimates

R.G. Haley Site
Bellingham, Washington

Item	Unit	Unit Cost (or units conversion ratio)	Notes (Basis for Estimated Unit Cost)
Direct Capital Costs			
General Site Construction Elements			
Upland earthwork temporary controls (erosion control, stormwater diversion, access controls)	LS	$ 75,000	Professional judgment and experience on other similar projects.
Post-construction upland survey	each	$ 25,000	Professional judgment and experience on other similar projects.
Post-construction marine survey	each	$ 50,000	Professional judgment and experience on other similar projects.
LNAPL Recovery			
Install LNAPL recovery wells	each	$ 5,000	Professional judgment and experience on other similar projects. Includes below-grade vault to house skimmer equipment.
Install LNAPL recovery skimmers and operation system	each	$ 7,500	Vendor quotes for equipment and labor to install (average of three different methodologies, one solar and two electrical).
Vertical Barriers/Treatment Walls			
Waterloo hydraulic barrier	sq. ft.	$ 63	Vendor quote + 25 percent contingency added to account for project complexity due to shoreline location.
Slurry/PRB wall (Dewind one-pass)	sq. ft.	$ 12	Vendor quote + 25 percent contingency added to account for project complexity due to shoreline location.
PRB wall (Dewind) fixed mobilization fee	LS	$ 75,000	Vendor quote. Represents additional cost to mobilize specialized equipment. Costs are in addition to unit cost/sf to install wall.
PRB media: Organoclay PM-199	lb	$ 1.58	Vendor quote. PRB incorporates granular organoclay mixed with sand. Quantities calculated based on ratio of 20 percent organoclay for a 2-foot wide PRB.
Bulk density of organoclay PM-199	lb/cy	1,350	Per Vendor. Averaged bulk densities for this product, which range between 1,188 and 1,512 lb/cy.
Sand portion of PRB	cy	$ 33	Professional judgment and experience on other similar projects. PRB comprises 80 percent sand and 20 percent granular organoclay.
Upland Soil Solidification and Stabilization			
Soil ISS treatability testing	LS	$ 100,000	Bench testing to evaluate treatability and design factors. Based on vendor estimate and estimated cost to develop plan and collect samples.
Soil bulk density	lb/cy	3,200	Average unit weight (in-place volume) based on prior testing; average accounts for differences in unit weights between unsaturated and saturated soil and varying quantities of wood fill.
ISS media cost: Organoclay SS-199	lb	$ 1.50	Vendor quote. ISS media usage ratio for Organoclay SS-199 assumed to be 1 percent organoclay by weight to 8 percent portland cement by weight. Actual use will depend on treatability tests.
ISS media cost: Portland cement	lb	$ 0.10	Contractor quote. Assumed average bulk density of 94 lb/cf for Portland cement.
ISS media cost: Organoclay PM-199	lb	$ 1.58	Vendor quote. Used for in situ stabilization (with no solidification). Granular Organoclay PM-199 has larger particle size (coarse sand) than the powdered form and can be used as ISS media without portland cement. Typical ratio is 1 to 3 percent by weight.
Shallow solidification or stabilization using an excavator	cy	$ 40	Vendor-provided average cost for stabilization mixing labor and equipment.
Deep solidification or stabilization using auger	cy	$ 70	
Handling of consolidated soil or sediment	cy	$ 5	Recent project experience. Handling of excavated soil and/or sediment, strengthening material as needed to allow consolidation within upland AOC under cap.

Item	Unit	Unit Cost (or units conversion ratio)	Notes (Basis for Estimated Unit Cost)
Excavation (Upland and Sediment)			
Soil excavation in upland up to top of shoreline bank	cy	$ 10	Estimate based on cost for similar recent completed projects. Includes screening and handling of oversized debris encountered during excavation and stockpiling material.
Temporary sheet pile during excavation	sq. ft.	$ 28	Contractor estimate. Quantities are full area of sheet pile (embedded and exposed).
Upland excavation dewatering and water handling - shallow shoreline excavation	LS	$ 50,000	Estimate for excavation dewatering and water handling for shallow (less than 15 feet bgs) upland smear zone excavation.
Upland excavation dewatering and water handling - deep shoreline excavation	LS	$ 200,000	Estimate for excavation dewatering and water handling for deep (greater than 15 feet bgs) upland excavation.
Sediment excavation using land-based excavation equipment	cy	$ 35	Contractor estimate. Excavate using equipment placed in upland; stockpile in upland. includes silt curtain for in-water BMP.
Shoring and/or coffer dam install for intertidal excavation	LS	$ 325,000	Estimate based on use of Portadam coffer dam system. Cost based on vendor quote for installation, dismantling, and 2-months rental.
Handling of water drained from excavated sediment	LS	$ 50,000	Estimate for collection, handling, and reuse of water drained from stockpiled excavated sediment. Assume water is reused on site for process water in the stabilization process.
Sediment removal by dredging (barge-mounted)	cy	$ 34	Estimate based on based on cost for similar recent completed projects. includes silt curtain for water quality control.
Water quality monitoring during dredging	day	$ 4,000	Water quality monitoring performed during dredging. Assume dredge rate of 250 cy/day to determine duration of monitoring.
Transport dredged sediment to Site upland and off-load for consolidation in upland or transport off-site for disposal.	ton/cy	$ 15	Estimate based on based on cost for similar recent completed projects.
Soil unit weight conversion (in-place volume)	ton/cy	1.6	Average unit weight (in-place volume) based on prior testing; average accounts for differences in unit weights between unsaturated and saturated soil and varying quantities of wood fill.
Sediment unit weight conversion (in-place volume)	ton/cy	1.5	Professional judgment. Average unit weight (in-place volume).
Transport/Disposal			
Handling and loading of excavated material	cy	$ 2	Professional judgment and experience on other similar projects.
Transport (truck) and dispose soil to Subtitle D landfill	ton	$ 65	Vendor quote for permitted facility in Wenatchee, Washington. Washington state refuse tax of 3.6 percent is not included.
Transport (truck) and dispose Soil at Subtitle C (hazardous waste) landfill	ton	$ 176	Vendor quote for permitted facility in Arlington, Oregon.
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	ton	$ 245	Disposal costs for debris encountered during stabilization and excavation of soil/sediment that is consolidated on site. Anticipated debris includes large woody debris (piles, logs) and larger landfill debris not likely to be solidified or stabilized in situ. Vendor quote for permitted facility in Arlington, Oregon.
Transport (truck), incinerate and dispose soil at hazardous waste facility in (Aragonite, Utah)	ton	$ 878	Vendor quote for permitted facilities in Aragonite, Utah. Basis for quote is $228/ton transport by truck and $650/ton for incineration and landfill disposal.
Transport (truck) and dispose liquid waste at Subtitle C (hazardous waste) landfill	gallon	$ 9	Vendor quote for permitted facilities in Aragonite, Utah.
Upland Backfilling and Capping			
Import, place, and compact backfill (pit run)	cy	$ 25	Recent project experience.
Rough grading for cap surface preparation	sq. yd.	$ 1	Recent project experience.
Cap - gas collection layer under geomembrane	sq. ft.	$ 1.50	Recent project experience. Includes labor and materials (pea gravel, etc).
Cap - geomembrane layer	sq. ft.	$ 0.60	Recent project experience. 40 mil thick PVC geomembrane.
Cap drainage layer - import, place, compact	cy	$ 20	Recent project experience. Type 17 Bank Run.
Cap surface - pavement	sq. yd.	$ 25	Recent project experience. 3 inch or 4 inch thick asphalt concrete pavement, including subgrade material and preparation.
Cap surface - topsoil	cy	$ 35	Recent project experience.
Hydroseed capped area	acre	$ 12,197	Recent project experience.

Item	Unit	Unit Cost (or units conversion ratio)	Notes (Basis for Estimated Unit Cost)
In-Water Backfilling and Capping			
Sediment debris sweep and disposal	acre	$ 40,000	Professional judgment and experience on other similar projects. Prepares existing surface for cap.
Enhanced natural recovery (ENR) layer	cy	$ 65	Contractor estimate. Assume placement in two separate thin lifts with 6-inch final thickness.
Intertidal sand backfill/cap	cy	$ 39	Contractor estimate. Sand cap placed in intertidal zone using upland-based equipment.
Subtidal sand backfill/cap	cy	$ 47	Contractor estimate.
Amended cap media: Organoclay PM-199	lb	$ 1.58	Vendor quote. Application rate varies; determined through cap modeling.
Prepare amended cap blend	cy	$ 5	Contractor estimate. Mix sand/organoclay blend in upland location to prepare for placement.
Rock armor	cy	$ 40	Contractor estimate.
6-inch fish mix in-fill on rock armor	cy	$ 27	Estimate based on recent completed project costs.
6-inch layer of pea gravel armor	cy	$ 27	Estimate based on recent completed project costs.
Restoration project costs for fill mitigation	acre	$ 280,000	Expected to be required for alternatives involving in water filling. Estimate based on similar project costs.
Stormwater Management			
Stormwater collection, treatment, and discharge system for capped areas.	LS	$ 250,000	Professional judgment based on recently completed projects.
Stormwater treatment	LS	$ 50,000	Professional judgment based on recently completed projects.
Stormwater discharge	LS	$ 100,000	Professional judgment based on recently completed projects.
Miscellaneous			
Decommission monitoring or recovery wells	each	$ 500	Professional judgment based on recently completed projects.
Groundwater compliance	each	$ 5,000	Methods for groundwater compliance TBD. Best professional judgment.
Net Present Value Multipliers			
Net Present Value Discount Rate	1.1%		Requested by Ecology based on February 2014 Memo from Lower Duwamish Waterway Group: Revised Cost Estimates for EPA's Proposed Plan Remedy for the Lower Duwamish Waterway (LDW) Using Updated Present Value Discount Rates
Net Present Value Multipliers for equal payment series	**Years**	**Equal Annual Payment Multiplier**	**Single Payment Multiplier**
	2	1.97	0.98
	3	2.94	0.97
	4	3.89	0.96
	5	4.84	0.95
	6	5.78	0.94
	7	6.70	0.93
	8	7.62	0.92
	9	8.52	0.91
	10	9.42	0.90
	15	13.76	0.85
	20	17.87	0.80
	25	21.75	0.76
	30	25.43	0.72
	35	28.92	0.68
	40	32.22	0.65
	45	35.34	0.61
	50	38.30	0.58
Annual Groundwater Monitoring			
Groundwater sampling labor	well	$ 500	Recent project costs.
Groundwater sample chemical analysis	well	$ 600	Recent project costs. Blended average cost.
Annual reporting	LS	$ 25,000	Recent project costs.

Item	Unit	Unit Cost (or units conversion ratio)	Notes (Basis for Estimated Unit Cost)
Upland Cap Monitoring and Maintenance			
Cap monitoring, maintenance, and reporting - annual cost	acre	$ 1,500	Best professional judgment.
Barrier Wall Monitoring and Maintenance			
Barrier wall inspection, maintenance, and reporting - annual cost	LS	$ 5,000	Best professional judgment.
30-year PRB repair/replacement event	%	50%	Replacement of organoclay media in PRB at end of 30-year life-cycle. Assume 50 percent of original PRB installation cost.
LNAPL Recovery Systems			
LNAPL recovery system operation, monitoring, reporting - annual cost	LS	$ 100,000	Professional judgment and experience on other similar projects
Off-site transport and disposal of recovered LNAPL as hazardous waste	gallon	$ 7.88	Vendor quotes. Represents $6.88/gallon for treatment/disposal plus transport cost of $1.00 gallon for a fully loaded 4,000 gallon tanker truck (approx. $4,000 per load).
Sediment Monitoring and O&M			
Sediment cap long-term monitoring and reporting	acre/event	$ 15,000	Best professional judgment. Assume cap sampling, survey, etc. and reporting.
ENR monitoring and reporting	acre/event	$ 5,000	Best professional judgment. Assume sampling, survey, etc. and reporting for ENR areas.
MNR monitoring and reporting	LS/event	$ 60,000	Best professional judgment. Assume sampling, survey, etc. and reporting for Haley MNR area.
Sediment cap area O&M (maintenance costs)	acre/event	$ 10,000	Best professional judgment. Includes periodic miscellaneous cap maintenance.
20-year cap/liner repair event	%	10%	Periodic major repair of cap. Based on percent of cap remedy capital costs.
Indirect Capital Costs			
Mobilization/demobilization, contractor submittals, etc.	% of TDC	10.0%	Indirect percentages based on EPA 2000 guidance (EPA, 2000. A Guide to Developing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. OSWER 9355.0-75) and recent project experience.
Remedial design, permitting	% of TDC	12.0%	
Project management (PM)	% of TDC	6.0%	
Construction management (CM)	% of TDC	8.0%	
Total Indirect Capital Costs	% of TDC	36.0%	Apply mobe, design/permitting, PM, and CM to sum of capital direct costs.
Indirect Costs - O&M Expenses			
Project management	% of TDC	10%	
Construction management	% of TDC	5.0%	
Total Indirect O&M Costs	% of TDC	15.0%	Apply PM and CM to sum of O&M direct costs.

Notes:

Costs shown represent labor, equipment and materials.

The following acronyms are used on Tables Q-2 through Q-16:

- TDC = total direct capital cost
- NPV = net present value
- cy = cubic yard
- sq. ft. = square foot
- sq. yd. = square yard
- LS = lump sum
- OR = Oregon
- UT = Utah

Table Q-3

Common Elements for all Upland Alternatives

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
UST and Surge Tank Removal	1	LS	$ 90,000	$ 90,000	Contractor estimate. Includes: pump-out, triple rinse, remove and transport UST and backfill with Type 17 backfill material.
Transport Surge Tank	2	load	$ 2,800	$ 5,600	Contractor estimate.
Disposal of Concrete Surge Tank (Macro-encapsulation)	40	cy	$ 245	$ 9,800	Contractor estimate. Disposal at Arlington OR permitted facility. Transport via roll-off box.
Disposal of Surge Tank and UST Contents and Rinsewater and Recovered Oil Accumulated On-site	26,000	gallon	$ 6.88	$ 178,880	Vendor quote (2009 cost estimate for disposal of P9 oily water increased by 25 percent).
Transport of Recovered Oil	10	load	$ 3,950	$ 39,500	Contractor estimate. Transport contents from surge tank, UST, and rinse water and oily water accumulated on site to permitted facility in Aragonite, UT for treatment/disposal. Assumes 4,000 gallons/load.
Remove Existing Sheet Pile Wall	3,200	sq. ft.	$ 28	$ 89,600	Contractor Estimate. Existing wall is approximately 400 feet long, average 8 feet high.
Remove Existing Storm Drain System as Needed	1	LS	$ 50,000	$ 50,000	Professional judgment.
Drainage Improvement along BNSF right-of-way	1	LS	$ 50,000	$ 50,000	Professional judgment.
Vapor Barrier, if needed, during construction of future structures	1	LS	$ 15,000	$ 15,000	Professional judgment.
Institutional Controls	1	LS	$ 25,000	$ 25,000	Professional judgment.
Direct Capital Cost Subtotal				**$ 553,380**	
Indirect Capital Cost		% of TDC	36.0%	**$ 199,217**	
Total Capital Cost (Direct and Indirect)				**$ 752,597**	
Total Cost of Common Elements (Present Worth)				**$ 752,597**	

Table Q-4

Alternative Cost Estimate - Alternative U1 Passive LNAPL Removal, Vertical Shoreline Barrier, Upland Cap

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Common Elements (From Table Q-3)					
Direct Capital Cost Subtotal				$ 553,380	
Indirect Capital Cost		% of TDC	36.0%	$ 199,217	
Total Capital Cost				**$ 752,597**	
Upland Soil					
Low Permeability Cap	**334,800**	**sq. ft.**			From CAD File, Area = 334,800 sq. ft.
Upland earthwork temporary controls (erosion control, stormwater diversion, access controls)	1	LS	$ 75,000	$ 75,000	
Rough grading for cap surface preparation	37,200	sq. yd.	$ 1	$ 37,200	
Cap - gas collection layer under geomembrane	334,800	sq. ft.	$ 2	$ 502,200	
Cap - geomembrane layer	334,800	sq. ft.	$ 1	$ 200,880	
Cap drainage layer - import, place, compact	12,400	cy	$ 20	$ 248,000	Assume 1-foot thick drainage layer.
Cap surface - pavement	11,132	sq. yd.	$ 25	$ 278,300	From Cornwall Beach Plan exhibit, paved area within Haley Site is approx 2.3-acre. Assume 3-inch base and 3-inch asphalt.
Cap surface - topsoil	8,389	cy	$ 35	$ 293,627	From Cornwall Beach Plan exhibit, vegetated area within Haley Site is approx 5.2-acre. Assume 1-foot thick topsoil, including placement.
Hydroseed capped area	5.2	acre	$ 12,197	$ 63,423	
Stormwater collection, treatment, and discharge system for capped areas.	1	LS	$ 250,000	$ 250,000	
Stormwater treatment	1	LS	$ 50,000	$ 50,000	
Stormwater discharge	1	LS	$ 100,000	$ 100,000	
Post-construction upland survey	1	each	$ 25,000	$ 25,000	
Direct Capital Cost Subtotal				$ 2,123,630	
Indirect Capital Cost		% of TDC	36.0%	$ 764,507	
Total Capital Cost				**$ 2,888,137**	
Vertical Low-Permeability Shoreline Barrier/Wall	14,030	sq. ft.			From Figure for Alternative U1, Length = 610-ft, Height = 23-ft
Waterloo hydraulic barrier	14,030	sq. ft.	$ 63	$ 876,875	
Direct Capital Cost Subtotal				$ 876,875	
Indirect Capital Cost		% of TDC	36.0%	$ 315,675	
Total Capital Cost				**$ 1,192,550**	
Passive LNAPL Recovery/Removal					
Install LNAPL recovery wells	25	each	$ 5,000	$ 125,000	25-foot spacing between wells placed behind 610 foot cutoff wall.
Install LNAPL recovery skimmers and operation system	25	each	$ 7,500	$ 187,500	
Direct Capital Cost Subtotal				$ 312,500	
Indirect Capital Cost		% of TDC	36.0%	$ 112,500	
Total Capital Cost				**$ 425,000**	
Upland Groundwater					
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Groundwater compliance	12	each	$ 5,000	$ 60,000	
Direct Capital Cost Subtotal				$ 73,500	
Indirect Capital Cost		% of TDC	36.0%	$ 26,460	
Total Capital Cost				**$ 99,960**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 5,358,244**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Operation & Maintenance Costs					
Upland Long Term Groundwater Monitoring					
Entire Upland Area - Groundwater Monitoring at 21 upland wells quarterly for year 0, annually for 10 years, followed by four 5-year events					
Groundwater sampling labor	32	well	$ 500	$ 15,750	Quantity based on 21 upland wells plus 50 percent additional samples for field qa/qc or other.
Groundwater sample chemical analysis	32	well	$ 600	$ 18,900	
Annual reporting	1	LS	$ 25,000	$ 25,000	
Direct Subtotal				$ 998,700	
Indirect O&M Costs		% of TDC	15.0%	$ 149,805	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,148,505**	
Present Value Subtotal (including Indirect Costs)				**$ 1,135,547**	
Soil - Capped Area					
Cap Monitoring and Maintenance	7.7	acre			
Cap monitoring, maintenance, and reporting - annual cost	7.7	acre	$ 1,500	$ 11,529	Annual monitoring for 30 years.
Direct Subtotal				$ 345,868	
Indirect O&M Costs		% of TDC	15.0%	$ 51,880	
Undiscounted Subtotal (including Indirect Costs)				**$ 397,748**	
Present Value Subtotal (including Indirect Costs)				**$ 337,218**	
Barrier Wall Monitoring and Maintenance	1.0	LS			
Barrier wall inspection, maintenance, and reporting - annual cost	1.0	LS	$ 5,000	$ 5,000	Annual monitoring for 30 years.
Direct Subtotal				$ 150,000	
Indirect O&M Costs		% of TDC	15.0%	$ 22,500	
Undiscounted Subtotal (including Indirect Costs)				**$ 172,500**	
Present Value Subtotal (including Indirect Costs)				**$ 146,249**	
LNAPL Recovery					
LNAPL recovery system operation, monitoring, reporting - annual cost	1	LS	$ 100,000	$ 100,000	Operate Recovery for 10 years.
Off-site transport and disposal of recovered LNAPL as hazardous waste	125	gallon	$ 8	$ 985	Assume 5 gallons/year for each well.
Direct Subtotal				$ 1,009,850	
Indirect O&M Costs		% of TDC	15.0%	$ 151,478	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,161,328**	
Present Value Subtotal (including Indirect Costs)				**$ 1,094,051**	
Total Undiscounted O&M Costs (30 Years)				**$ 2,880,080**	
Total Net Present Value of O&M Costs (30 Years)				**$ 2,713,065**	
Contingency (25 Percent of Total Cost)				**$ 2,017,827**	
Total Cost of Alternative (Present Worth)				**$ 10,089,136**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-5

Alternative Cost Estimate - Alternative U2, Permeable Reactive Barrier (PRB), Passive LNAPL Removal, Upland Cap

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Common Elements (From Table Q-3)					
Direct Capital Cost Subtotal				$ 553,380	
Indirect Capital Cost		% of TDC	36.0%	$ 199,217	
Total Capital Cost				**$ 752,597**	
Upland Soil					
Low Permeability Cap	**334,800**	**sq. ft.**			From CAD File, Area = 334,800 sq. ft.
Upland earthwork temporary controls (erosion control, stormwater diversion, access controls)	1	LS	$ 75,000	$ 75,000	
Rough grading for cap surface preparation	37,200	sq. yd.	$ 1	$ 37,200	
Cap - gas collection layer under geomembrane	334,800	sq. ft.	$ 2	$ 502,200	
Cap - geomembrane layer	334,800	sq. ft.	$ 1	$ 200,880	
Cap drainage layer - import, place, compact	12,400	cy	$ 20	$ 248,000	Assume 1-foot thick drainage layer.
Cap surface - pavement	11,132	sq. yd.	$ 25	$ 278,300	From Cornwall Beach Plan exhibit, paved area within Haley Site is approx 2.3-acre. Assume 3-inch base and 3-inch asphalt.
Cap surface - topsoil	8,389	cy	$ 35	$ 293,627	From Cornwall Beach Plan exhibit, vegetated area within Haley Site is approx 5.2-acre. Assume 1-foot thick topsoil, including placement.
Hydroseed capped area	5.2	acre	$ 12,197	$ 63,423	
Stormwater collection, treatment, and discharge system for capped areas.	1	LS	$ 250,000	$ 250,000	
Stormwater treatment	1	LS	$ 50,000	$ 50,000	
Stormwater discharge	1	LS	$ 100,000	$ 100,000	
Post-construction upland survey	1	each	$ 25,000	$ 25,000	
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Direct Capital Cost Subtotal				$ 2,137,130	
Indirect Capital Cost		% of TDC	36.0%	$ 769,367	
Total Capital Cost				**$ 2,906,497**	
Permeable Reactive Barrier (PRB) for Passive Groundwater Treatment at Shoreline	**710**	**ft.**			PRB Length = 710 ft, Height = 27 ft
PRB wall (Dewind) fixed mobilization fee	1	LS	$ 75,000	$ 75,000	
Slurry/PRB wall (Dewind one-pass)	19,170	sq. ft.	$ 12	$ 230,040	From Figure 9-U2: 710 ft long and 27 ft deep
PRB media: Organoclay PM-199	383,400	lb	$ 2	$ 605,772	PRB at 2 ft width, 27 ft depth, 710 ft length
Sand portion of PRB	1081	cy	$ 33	$ 35,409	PRB at 2 ft width, 27 ft depth, 710 ft length
Direct Capital Cost Subtotal				$ 946,221	
Indirect Capital Cost		% of TDC	36.0%	$ 340,639	
Total Capital Cost				**$ 1,286,860**	
Passive LNAPL Recovery/Removal Using Skimming Wells					
Install LNAPL recovery wells	25	each	$ 5,000	$ 125,000	25-ft spacing between wells.
Install LNAPL recovery skimmers and operation system	25	each	$ 7,500	$ 187,500	
Direct Capital Cost Subtotal				$ 312,500	
Indirect Capital Cost		% of TDC	36.0%	$ 112,500	
Total Capital Cost				**$ 425,000**	
Upland Groundwater					
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Groundwater compliance	12	each	$ 5,000	$ 60,000	
Direct Capital Cost Subtotal				$ 73,500	
Indirect Capital Cost		% of TDC	36.0%	$ 26,460	
Total Capital Cost				**$ 99,960**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 5,470,914**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Operation & Maintenance Costs					
Upland Long Term Groundwater Monitoring					
Entire Upland Area - Groundwater Monitoring at 21 upland wells quarterly for year 0, annually for 10 years, followed by four 5-year events					
Groundwater sampling labor	32	well	$ 500	$ 15,750	Quantity based on 21 upland wells plus 50 percent additional samples for field qa/qc or other.
Groundwater sample chemical analysis	32	well	$ 600	$ 18,900	
Annual reporting	1	LS	$ 25,000	$ 25,000	
Direct Subtotal				$ 1,073,700	
Indirect O&M Costs		% of TDC	15.0%	$ 161,055	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,234,755**	
Present Value Subtotal (including Indirect Costs)				**$ 1,135,547**	
Soil - Capped Area					
Cap Monitoring and Maintenance	7.7	acre			
Cap monitoring, maintenance, and reporting - annual cost	7.7	acre	$ 1,500	$ 11,529	Annual monitoring for 30 years.
Direct Subtotal				$ 345,868	
Indirect O&M Costs		% of TDC	15.0%	$ 51,880	
Undiscounted Subtotal (including Indirect Costs)				**$ 397,748**	
Present Value Subtotal (including Indirect Costs)				**$ 337,218**	
Barrier Wall Monitoring and Maintenance	1.0	LS			
Barrier wall inspection, maintenance, and reporting - annual cost	1.0	LS	$ 5,000	$ 5,000	Annual monitoring for 30 years.
30-year PRB repair/replacement event	$ 946,221	%	50%	$ 473,110	Assume replenishment/replacement of organoclay at 30-year lifespan. Assume replenishment costs 50% of PRB construction capital cost.
Direct Subtotal				$ 623,110.39	
Indirect O&M Costs		% of TDC	15.0%	$ 93,467	
Undiscounted Subtotal (including Indirect Costs)				**$ 716,577**	
Present Value Subtotal (including Indirect Costs)				**$ 538,104**	
LNAPL Recovery					
LNAPL recovery system operation, monitoring, reporting - annual cost	1	LS	$ 100,000	$ 100,000	Operate Recovery for 10 years.
Off-site transport and disposal of recovered LNAPL as hazardous waste	125	gallon	$ 8	$ 985	Assume 5 gallons/year for each well.
Direct Subtotal				$ 1,009,850	
Indirect O&M Costs		% of TDC	15.0%	$ 151,478	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,161,328**	
Present Value Subtotal (including Indirect Costs)				**$ 1,094,051**	
Total Undiscounted O&M Costs (30 Years)				**$ 3,510,407**	
Total Net Present Value of O&M Costs (30 Years)				**$ 3,104,920**	
Contingency (25 Percent of Total Cost)				**$ 2,143,959**	
Total Cost of Alternative (Present Worth)				**$ 10,719,793**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-6

Alternative Cost Estimate - Alternative U3a, Nearshore *In Situ* Soil Solidification, Upland Cap

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Common Elements (From Table Q-3)					
Direct Capital Cost Subtotal				$ 553,380	
Indirect Capital Cost		% of TDC	36.0%	$ 199,217	
Total Capital Cost				**$ 752,597**	
Upland Soil					
Low Permeability Cap	**334,800**	**sq. ft.**			From CAD File, Area = 334,800 sq. ft.
Upland earthwork temporary controls (erosion control, stormwater diversion, access controls)	1	LS	$ 75,000	$ 75,000	
Rough grading for cap surface preparation	37,200	sq. yd.	$ 1	$ 37,200	
Cap - gas collection layer under geomembrane	334,800	sq. ft.	$ 2	$ 502,200	
Cap - geomembrane layer	334,800	sq. ft.	$ 1	$ 200,880	
Cap drainage layer - import, place, compact	12,400	cy	$ 20	$ 248,000	Assume 1-foot thick drainage layer.
Cap surface - pavement	11,132	sq. yd.	$ 25	$ 278,300	From Cornwall Beach Plan exhibit, paved area within Haley Site is approximately 2.3-acre. Assume 3-inch base and 3-inch asphalt.
Cap surface - topsoil	8,389	cy	$ 35	$ 293,627	From Cornwall Beach Plan exhibit, vegetated area within Haley Site is approx 5.2-acre. Assume 1-foot thick topsoil, including placement.
Hydroseed capped area	5.2	acre	$ 12,197	$ 63,423	
Stormwater collection, treatment, and discharge system for capped areas.	1	LS	$ 250,000	$ 250,000	
Stormwater treatment	1	LS	$ 50,000	$ 50,000	
Stormwater discharge	1	LS	$ 100,000	$ 100,000	
Post-construction upland survey	1	each	$ 25,000	$ 25,000	
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Direct Capital Cost Subtotal				$ 2,137,130	
Indirect Capital Cost		% of TDC	36.0%	$ 769,367	
Total Capital Cost				**$ 2,906,497**	
In-Situ Solidification Near Shoreline	**15,278**	**cy**			Area = 37,500 sq. ft., Avg. solidification thickness = 11 feet
Soil ISS treatability testing	1	LS	$ 100,000	$ 100,000	
ISS media cost: Organoclay SS-199	488,889	lb	$ 1.50	$ 733,333	
ISS media cost: Portland cement	3,911,111	lb	$ 0.10	$ 391,111	
Shallow solidification or stabilization using an excavator	15,278	cy	$ 40	$ 611,111	
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	1,333	ton	$ 245	$ 326,667	Assume 25 percent of soil in area where solidification overlaps Cornwall landfill limits is debris that is macroencapsulated for transport and disposal.
Import, place, and compact backfill (pit run)	833	cy	$ 25	$ 20,833	Replace disposed debris with backfill.
Direct Capital Cost Subtotal				$ 2,183,056	
Indirect Capital Cost		% of TDC	36.0%	$ 785,900	
Total Capital Cost				**$ 2,968,956**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Upland Groundwater					
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Groundwater compliance	12	each	$ 5,000	$ 60,000	
Direct Capital Cost Subtotal				$ 73,500	
Indirect Capital Cost		% of TDC	36.0%	$ 26,460	
Total Capital Cost				**$ 99,960**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 6,728,009**	
Operation & Maintenance Costs					
Upland Long Term Groundwater Monitoring					
Entire Upland Area - Groundwater Monitoring at 21 upland wells quarterly for year 0, annually for 10 years, followed by four 5-year events					
Groundwater sampling labor	32	well	$ 500	$ 15,750	Quantity based on 21 upland wells plus 50 percent additional samples for field qa/qc or other.
Groundwater sample chemical analysis	32	well	$ 600	$ 18,900	
Annual reporting	1	LS	$ 25,000	$ 25,000	
Direct Subtotal				$ 1,073,700	
Indirect O&M Costs		% of TDC	15.0%	$ 161,055	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,234,755**	
Present Value Subtotal (including Indirect Costs)				**$ 1,135,547**	
Soil - Capped Area					
Cap Monitoring and Maintenance	7.7	acre			
Cap monitoring, maintenance, and reporting - annual cost	7.7	acre	$ 1,500	$ 11,529	Annual monitoring for 30 years.
Direct Subtotal				$ 345,868	
Indirect O&M Costs		% of TDC	15.0%	$ 51,880	
Undiscounted Subtotal (including Indirect Costs)				**$ 397,748**	
Present Value Subtotal (including Indirect Costs)				**$ 337,218**	
Total Undiscounted O&M Costs (30 Years)				**$ 1,632,503**	
Total Net Present Value of O&M Costs (30 Years)				**$ 1,472,765**	
Contingency (25 Percent of Total Cost)				**$ 2,050,194**	
Total Cost of Alternative (Present Worth)				**$ 10,250,968**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-7

Alternative Cost Estimate - Alternative U3b, Expanded *In Situ* Soil Solidification and Stabilization, Upland Cap

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Common Elements (From Table Q-3)					
Direct Capital Cost Subtotal				$ 553,380	
Indirect Capital Cost		% of TDC	36.0%	$ 199,217	
Total Capital Cost				**$ 752,597**	
Upland Soil					
Low Permeability Cap	**334,800**	**sq. ft.**			From CAD File, Area = 334,800 sq. ft.
Upland earthwork temporary controls (erosion control, stormwater diversion, access controls)	1	LS	$ 75,000	$ 75,000	
Rough grading for cap surface preparation	37,200	sq. yd.	$ 1	$ 37,200	
Cap - gas collection layer under geomembrane	334,800	sq. ft.	$ 2	$ 502,200	
Cap - geomembrane layer	334,800	sq. ft.	$ 1	$ 200,880	
Cap drainage layer - import, place, compact	12,400	cy	$ 20	$ 248,000	Assume 1-foot thick drainage layer.
Cap surface - pavement	11,132	sq. yd.	$ 25	$ 278,300	From Cornwall Beach Plan exhibit, paved area within Haley Site is approx 2.3-acre. Assume 3-inch base and 3-inch asphalt.
Cap surface - topsoil	8,389	cy	$ 35	$ 293,627	From Cornwall Beach Plan exhibit, vegetated area within Haley Site is approx 5.2-acre. Assume 1-foot thick topsoil, including placement.
Hydroseed capped area	5.2	acre	$ 12,197	$ 63,423	
Stormwater collection, treatment, and discharge system for capped areas.	1	LS	$ 250,000	$ 250,000	
Stormwater treatment	1	LS	$ 50,000	$ 50,000	
Stormwater discharge	1	LS	$ 100,000	$ 100,000	
Post-construction upland survey	1	each	$ 25,000	$ 25,000	
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Direct Capital Cost Subtotal				$ 2,137,130	
Indirect Capital Cost		% of TDC	36.0%	$ 769,367	
Total Capital Cost				**$ 2,906,497**	
In-Situ Solidification Expanded Footprint	**28,333**	**cy**			Soil Solidification Area = 85,000 sq. ft., Avg solidification thickness = 9 feet
ISS media cost: Organoclay SS-199	906,667	lb	$ 1.50	$ 1,360,000	
ISS media cost: Portland cement	7,253,333	lb	$ 0.10	$ 725,333	
Shallow solidification or stabilization using an excavator	28,333	cy	$ 40	$ 1,133,333	Assume 10 ft depth for soil mixing
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	3,852	ton	$ 245	$ 943,704	Assume 25 percent of soil in area where solidification overlaps Cornwall landfill limits is debris that is macroencapsulated for transport and disposal.
Import, place, and compact backfill (pit run)	2,407	cy	$ 25	$ 60,185	Replace disposed debris with backfill.
Direct Capital Cost Subtotal				$ 4,222,556	
Indirect Capital Cost		% of TDC	36.0%	$ 1,520,120	
Total Capital Cost				**$ 5,742,676**	
In-Situ Stabilization by Organoclay Adsorption at Additional Upgradient Locations	**21,185**	**cy**			Soil Stabilization Area = 88,000 sq. ft., Avg thickness = 6.5 feet
ISS media cost: Organoclay PM-199	2,033,778	lb	$ 1.58	$ 3,213,369	
Shallow solidification or stabilization using an excavator	21,185	cy	$ 40	$ 847,407	
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	963	ton	$ 245	$ 235,926	Assume 25 percent of soil in area where stabilization overlaps Cornwall landfill limits is debris that is macroencapsulated for transport and disposal.
Import, place, and compact backfill (pit run)	602	cy	$ 25	$ 15,046	Replace disposed debris with backfill.
Direct Capital Cost Subtotal				$ 4,311,749	
Indirect Capital Cost		% of TDC	36.0%	$ 1,552,229	
Total Capital Cost				**$ 5,863,978**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Upland Groundwater					
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Groundwater compliance	12	each	$ 5,000	$ 60,000	
Direct Capital Cost Subtotal				$ 73,500	
Indirect Capital Cost		% of TDC	36.0%	$ 26,460	
Total Capital Cost				**$ 99,960**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 15,365,707**	
Operation & Maintenance Costs					
Upland Long Term Groundwater Monitoring					
Entire Upland Area - Groundwater Monitoring at 21 upland wells quarterly for year 0, annually for 10 years, followed by four 5-year events					
Groundwater sampling labor	32	well	$ 500	$ 15,750	Quantity based on 21 upland wells plus 50 percent additional samples for field qa/qc or other.
Groundwater sample chemical analysis	32	well	$ 600	$ 18,900	
Annual reporting	1	LS	$ 25,000	$ 25,000	
Direct Subtotal				$ 1,073,700	
Indirect O&M Costs		% of TDC	15.0%	$ 161,055	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,234,755**	
Present Value Subtotal (including Indirect Costs)				**$ 1,135,547**	
Soil - Capped Area					
Cap Monitoring and Maintenance	7.7	acre			
Cap monitoring, maintenance, and reporting - annual cost	7.7	acre	$ 1,500	$ 11,529	Annual monitoring for 30 years.
Direct Subtotal				$ 345,868	
Indirect O&M Costs		% of TDC	15.0%	$ 51,880	
Undiscounted Subtotal (including Indirect Costs)				**$ 397,748**	
Present Value Subtotal (including Indirect Costs)				**$ 337,218**	
Total Undiscounted O&M Costs (30 Years)				**$ 1,632,503**	
Total Net Present Value of O&M Costs (30 Years)				**$ 1,472,765**	
Contingency (25 Percent of Total Cost)				**$ 4,209,618**	
Total Cost of Alternative (Present Worth)				**$ 21,048,090**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-8

Alternative Cost Estimate - Alternative U3c, Soil Removal, *In Situ* Soil Solidification and Stabilization, Upland Cap

R.G. Haley Site

Bellingham, Washington

Description	Quantity: Number	Quantity: Unit	Cost: Unit Cost	Cost: Total Cost	Notes
Capital Costs (Direct and Indirect)					
Common Elements (From Table Q-3)					
Direct Capital Cost Subtotal				$ 553,380	
Indirect Capital Cost		% of TDC	36.0%	$ 199,217	
Total Capital Cost				**$ 752,597**	
Upland Soil					
Low Permeability Cap	**334,800**	**sq. ft.**			From CAD File, Area = 334,800 sq. ft.
Upland earthwork temporary controls (erosion control, stormwater diversion, access controls)	1	LS	$ 75,000	$ 75,000	
Rough grading for cap surface preparation	37,200	sq. yd.	$ 1	$ 37,200	
Cap - gas collection layer under geomembrane	334,800	sq. ft.	$ 2	$ 502,200	
Cap - geomembrane layer	334,800	sq. ft.	$ 1	$ 200,880	
Cap drainage layer - import, place, compact	12,400	cy	$ 20	$ 248,000	Assume 1-foot thick drainage layer.
Cap surface - pavement	11,132	sq. yd.	$ 25	$ 278,300	From Cornwall Beach Plan exhibit, paved area within Haley Site is approximately 2.3-acre. Assume 3-inch base and 3-inch asphalt.
Cap surface - topsoil	8,389	cy	$ 35	$ 293,627	From Cornwall Beach Plan exhibit, vegetated area within Haley Site is approx 5.2-acre. Assume 1-foot thick topsoil, including placement.
Hydroseed capped area	5.2	acre	$ 12,197	$ 63,423	
Stormwater collection, treatment, and discharge system for capped areas.	1	LS	$ 250,000	$ 250,000	
Stormwater treatment	1	LS	$ 50,000	$ 50,000	
Stormwater discharge	1	LS	$ 100,000	$ 100,000	
Post-construction upland survey	1	each	$ 25,000	$ 25,000	
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Direct Capital Cost Subtotal				$ 2,137,130	
Indirect Capital Cost		% of TDC	36.0%	$ 769,367	
Total Capital Cost				**$ 2,906,497**	
Excavate Contaminated Soil within limits of Mobile LNAPL and Consolidate within AOC					
Soil excavation in upland up to top of shoreline bank	24,667	cy	$ 10	$ 246,667	Area = 37,000 sq. ft., Average Excavation Thickness = 18 ft.
Temporary sheet pile during excavation	18,250	sq. ft.	$ 28	$ 511,000	Temporary sheet pile used to excavate at shoreline
Upland excavation dewatering and water handling - shallow shoreline excavation	1	LS	$ 50,000	$ 50,000	
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	3,947	ton	$ 245	$ 966,933	Assume 10 percent of excavated soil is debris that is macroencapsulated for transport and disposal.
Handling of consolidated soil or sediment	22,200	cy	$ 5	$ 111,000	Handling of excavated soil in upland AOC.
Shallow solidification or stabilization using an excavator	15,278	cy	$ 40	$ 611,111	Avg. solidification thickness = 11 feet. Overburden soil assumed to not require solidification. Assume excavated soil is spread thin enough to mix stabilization material using an excavator.
ISS media cost: Organoclay SS-199	488,889	lb	$ 1.50	$ 733,333	
ISS media cost: Portland cement	3,911,111	lb	$ 0.10	$ 391,111	
Import, place, and compact backfill (pit run)	24,667	cy	$ 25	$ 616,667	Assume backfill to original grade with clean import material
Direct Capital Cost Subtotal				$ 4,237,822	
Indirect Capital Cost		% of TDC	36.0%	$ 1,525,616	
Total Capital Cost				**$ 5,763,438**	
In-Situ Solidification Expanded Footprint	**47,000**	**sq. ft.**			Soil Solidification Area = 47,000 sq. ft.
ISS media cost: Organoclay SS-199	557,037	lb	$ 1.50	$ 835,556	
ISS media cost: Portland cement	4,456,296	lb	$ 0.10	$ 445,630	
Shallow solidification or stabilization using an excavator	17,407	cy	$ 40	$ 696,296	Assume solidification is shallow enough to be done by an excavator.
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	1,333	ton	$ 245	$ 326,667	Assume 25 percent of soil in area where solidification overlaps Cornwall landfill limits is debris that is macroencapsulated for transport and disposal.
Direct Capital Cost Subtotal				$ 2,304,148	
Indirect Capital Cost		% of TDC	36.0%	$ 829,493	
Total Capital Cost				**$ 3,133,641**	

Description	Quantity Number	Quantity Unit	Cost Unit Cost	Cost Total Cost	Notes
In-Situ Stabilization by Organoclay Adsorption at Additional Upgradient Locations	21,185	cy			Soil Stabilization Area = 88,000 sq. ft., Avg thickness = 6.5 ft.
ISS media cost: Organoclay PM-199	2,033,778	lb	$ 1.58	$ 3,213,369	
Shallow solidification or stabilization using an excavator	21,185	cy	$ 40	$ 847,407	Assume soil mixing is shallow enough to be done by an excavator.
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	963	ton	$ 245	$ 235,926	Assume 25 percent of soil in area where stabilization overlaps Cornwall landfill limits is debris that is macroencapsulated for transport and disposal.
Import, place, and compact backfill (pit run)	602	cy	$ 25	$ 15,046	Replace disposed debris with backfill
Direct Capital Cost Subtotal				$ 4,311,749	
Indirect Capital Cost		% of TDC	36.0%	$ 1,552,229	
Total Capital Cost				**$ 5,863,978**	
Upland Groundwater					
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Groundwater compliance	12	each	$ 5,000	$ 60,000	
Direct Capital Cost Subtotal				$ 73,500	
Indirect Capital Cost		% of TDC	36.0%	$ 26,460	
Total Capital Cost				**$ 99,960**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 18,520,111**	
Operation & Maintenance Costs					
Upland Long Term Groundwater Monitoring					
Entire Upland Area - Groundwater Monitoring at 21 upland wells quarterly for year 0, annually for 10 years, followed by four 5-year events					
Groundwater sampling labor	32	well	$ 500	$ 15,750	Quantity based on 21 upland wells plus 50 percent additional samples for field qa/qc or other.
Groundwater sample chemical analysis	32	well	$ 600	$ 18,900	
Annual reporting	1	LS	$ 25,000	$ 25,000	
Direct Subtotal				$ 1,073,700	
Indirect O&M Costs		% of TDC	15.0%	$ 161,055	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,234,755**	
Present Value Subtotal (including Indirect Costs)				**$ 1,135,547**	
Soil - Capped Area					
Cap Monitoring and Maintenance	7.7	acre			
Cap monitoring, maintenance, and reporting - annual cost	7.7	acre	$ 1,500	$ 11,529	Annual monitoring for 30 years
Direct Subtotal				$ 345,868	
Indirect O&M Costs		% of TDC	15.0%	$ 51,880	
Undiscounted Subtotal (including Indirect Costs)				**$ 397,748**	
Present Value Subtotal (including Indirect Costs)				**$ 337,218**	
Total Undiscounted O&M Costs (30 Years)				**$ 1,632,503**	
Total Net Present Value of O&M Costs (30 Years)				**$ 1,472,765**	
Contingency (25 Percent of Total Cost)				**$ 4,998,219**	
Total Cost of Alternative (Present Worth)				**$ 24,991,095**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-9

Alternative Cost Estimate - Alternative U4, Complete Removal

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Common Elements (From Table Q-3)					
Direct Capital Cost Subtotal				$ 553,380	
Indirect Capital Cost		% of TDC	36.0%	$ 199,217	
Total Capital Cost				**$ 752,597**	
Upland Soil					
Excavate Contaminated Soil using Conventional Methods					
Soil excavation in upland up to top of shoreline bank	187,074	cy	$ 10	$ 1,870,741	0'-5' (BGS) = 296,970 sq. ft. @ 5 Ft. depth 5'-10' (BGS) = 304,510 sq. ft. @ 5 ft. depth 10'-15' (BGS) = 212,150 sq. ft. @ 5 Ft. depth > 15' (BGS) = 89,350 sq. ft. @ 11 Ft. depth
Upland excavation dewatering and water handling - deep shoreline excavation	1	LS	$ 200,000	$ 200,000	
Transport (truck) and dispose liquid waste at Subtitle C (hazardous waste) landfill	403,200	gallon	$ 9	$ 3,628,800	Assume 2 weeks of dewatering deeper excavation near shoreline at 20 gallons per minute.
Handling and loading of excavated material	187,074	cy	$ 2	$ 374,148	
Transport (truck) and dispose soil to Subtitle D landfill	123,739	ton	$ 65	$ 8,043,052	0'-5' (BGS) = 102,970 sq. ft. @ 5 ft. Depth 5'-10' (BGS) = 100,280 sq. ft. @ 5 ft. depth 10'-15' (BGS) = 104,700 sq. ft. @ 5 Ft. depth > 15' (BGS) = 49,850 sq. ft. @ 11 Ft. depth
Transport (truck) and dispose Soil at Subtitle C (hazardous waste) landfill	58,601	ton	$ 176	$ 10,313,861	5'-10' (BGS) = 85,130 sq. ft. @ 5 ft. depth 10'-15' (BGS) = 25,750 sq. ft. @ 5 ft. depth > 15' (BGS) = 39,500 sq. ft. @ 11 Ft. depth
Transport (truck), incinerate and dispose soil at hazardous waste facility in (Aragonite, Utah)	116,978	ton	$ 878	$ 102,706,489	0'-5' (BGS) = 194,000 sq. ft. @ 5 Ft. depth 5'-10' (BGS) = 119,100 sq. ft. @ 5 ft. depth 10'-15' (BGS) = 81,700 sq. ft. @ 5 Ft. depth
Import, place, and compact backfill (pit run)	187,074	cy	$ 25	$ 4,676,852	Assume backfill to original grade with clean import material
Post-construction upland survey	1	each	$ 25,000	$ 25,000	
Direct Capital Cost Subtotal				$ 131,838,942	
Indirect Capital Cost	1	LS	$ 250,000	$ 250,000	Use lump sum indirect cost rather than multiplier due to the high proportion of direct capital cost associated with transport and disposal.
Total Capital Cost				**$ 132,088,942**	
Upland Groundwater					
Decommission monitoring or recovery wells	27	each	$ 500	$ 13,500	
Groundwater compliance	12	each	$ 5,000	$ 60,000	
Direct Capital Cost Subtotal				$ 73,500	
Indirect Capital Cost		% of TDC	36.0%	$ 26,460	
Total Capital Cost				**$ 99,960**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 132,941,499**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Operation & Maintenance Costs					
Upland Long Term Groundwater Monitoring					
Entire Upland Area - Groundwater Monitoring at 21 upland wells quarterly for year 0, annually for 10 years, followed by four 5-year events					
Groundwater sampling labor	32	well	$ 500	$ 15,750	Quantity based on 21 upland wells plus 50 percent additional samples for field qa/qc or other.
Groundwater sample chemical analysis	32	well	$ 600	$ 18,900	
Annual reporting	1	LS	$ 25,000	$ 25,000	
Direct Subtotal				$ 1,073,700	
Indirect O&M Costs		% of TDC	15.0%	$ 161,055	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,234,755**	
Present Value Subtotal (including Indirect Costs)				**$ 1,135,547**	
Total Undiscounted O&M Costs (30 Years)				**$ 1,234,755**	
Total Net Present Value of O&M Costs (30 Years)				**$ 1,135,547**	
Contingency (25 Percent of Total Cost)				**$ 33,519,262**	
Total Cost of Alternative (Present Worth)				**$ 167,596,308**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

For the purposes of developing cost estimates for this alternative, assumptions regarding remediation waste characterization, designation and treatment/disposal assumptions were made based on interpretation of site characterization data for representative samples and based on regulatory and landfill requirements. The key assumptions include the following:

- Remediation-derived wastes associated with releases from the Haley wood treatment facility are classified as F032-listed dangerous waste if "generated." In addition, remediation waste from some portions of the Site would also designate as a toxic criteria dangerous waste under the "state-only" toxicity criteria. Remediation waste from the Site does not designate as Extremely Hazardous Waste (EHW) based on state-only criteria, or state or federal characteristic waste.
- Federal and state Land Disposal Restrictions (LDRs) require that if concentrations of F032 constituents in remediation-derived soil waste exceed the alternative treatment standards[1], the waste must be incinerated before it can be disposed in a landfill. The nearest incineration facility for dioxin-contaminated soil is in Aragonite, Utah. Contaminated soil can be directly disposed (without treatment) in a Subtitle C landfill if concentrations of F032 constituents are less than the alternative treatment standards. The nearest Subtitle C landfill is in Arlington, Oregon.
- Contaminated soil can be directly disposed in Subtitle D landfill if approved under a Contained-In-Determination (CID) from Ecology. Ecology indicated that a CID may be applicable for soil with concentrations of F032 constituents less than the alternative treatment standards, and other petroleum and PAH constituents and dioxin/furan congeners that are not F032 constituents but are likely to be present based on the source of contamination, are less than alternative treatment standards or MTCA Method C cleanup levels[2] . Ecology CID approvals and related conditions of the determination are made on a case-by-case basis. Assumptions for FS costing were based on conditions that Ecology commonly requires under a CID. For example, Ecology typically requires that the remediation waste must be direct loaded into trucks or roll-off containers for transport to the landfill (e.g. off-loading and reloading is not allowed) and that this waste be disposed at a specified Subtitle D landfill. The nearest Subtitle D landfills are Roosevelt, Washington and Arlington, Oregon. A CID request is typically evaluated based on data provided for in-place samples that are representative of the material to be excavated and disposed.
- Excavated soil from the surface to 5 feet bgs within the footprint of the former Haley facility operations would require incineration due to the presence of dioxins/furans and/or PAHs at concentrations greater than the corresponding alternative treatment standards for F032 constituents in remediation waste (soil). Excavated soil from the surface to 5 feet bgs on the Cornwall property, south of the footprint of the former Haley facility operations, requires incineration where landfill refuse is present. Because the Cornwall property had a different site use than the Haley property during the period of Haley wood treatment operations, it was assumed for the FS costing that contaminant concentrations in the upper 5 feet of soil on the Cornwall property where landfill refuse is not present, would meet Ecology conditions for a CID such that excavated soil in the upper 5 feet would be eligible for disposal at a Subtitle D landfill under a CID.
- The 5 to 15 feet bgs zone corresponds to the smear zone where residual LNAPL (mobile and immobile) is present. In areas where LNAPL exceeds residual saturation as represented by trace or measureable LNAPL in monitoring wells, or the concentrations of dioxins/furans and/or PAHs in soil are greater than the corresponding alternative treatment standards for F032 constituents, it is assumed incineration would be required. Where concentrations of dioxins/furans and/or PAHs in soil are less than the corresponding alternative treatment standards for F032 constituents, remediation waste (soil) does not require incineration and the soil would be disposed at a Subtitle C landfill unless concentrations of all constituents are low enough to meet CID criteria.
- Adjacent to the shoreline where LNAPL accumulates in monitoring wells, concentrations of F032 constituents in soil greater than 15 feet bgs (generally below the smear zone) are less than the corresponding alternative treatment standards for F032 constituents and remediation waste (soil) can be direct disposed at a Subtitle C facility. The remaining areas where soil below 15 feet bgs exceeds cleanup levels and concentrations of F032 meet CID criteria, contaminated soil can be disposed at a Subtitle D landfill in accordance with conditions of a CID.

[1] Treatment standards are the threshold values above which dangerous waste requires treatment (incineration in the case of dioxins/furans and other organics) before it can be disposed at an approved landfill facility. 40 CFR 268.48 lists the universal treatment standards (UTS) for hazardous constituents in wastewater and non-wastewater. 40 CFR 268.49 allows for alternative treatment standards for remediation-derived contaminated soil. The alternative treatment standards are 10 times higher than the non-wastewater constituent concentrations in 40 CFR 268.48.

[2] Personal Communication, Dean Yasuda, Washington State Department of Ecology, June 2014

Table Q-10

Alternative Cost Estimate - Alternative S1, Containment

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Smear Zone/Upper Intertidal					
Amended Sand Cap	**24,000**	**sq. ft.**			Area = 24,000 sq. ft.
Sediment debris sweep and disposal	1	acre	$ 40,000	$ 22,039	
Intertidal sand backfill/cap	2,222	cy	$ 39	$ 86,667	Placement of sand cap, assume 25 percent contingency to account for transition to outer cap area.
Amended cap media: Organoclay PM-199	497,778	lb	$ 1.58	$ 786,489	Assume 7% application of organoclay to amend sand cap.
Prepare amended cap blend	2,222	cy	$ 5	$ 11,111	
Rock armor	889	cy	$ 40	$ 35,556	Assume 1-foot thick armor layor
6-inch fish mix in-fill on rock armor	444	cy	$ 27	$ 12,000	Assume 6-inch layer of fish mix
Restoration project costs for fill mitigation	0.52	acre	$ 280,000	$ 144,330	Assume capped area requires mitigation in the form of completing a restoration project.
Direct Capital Cost Subtotal				$ 1,076,152	
Indirect Capital Cost		% of TDC	36.0%	$ 387,415	
Total Capital Cost				**$ 1,463,567**	
Lower Intertidal/Shallow Subtidal					
Unamended Sand Cap	**48,000**	**sq. ft.**			Area = 48,000 sq. ft.
Subtidal sand backfill/cap	4,444	cy	$ 47	$ 208,889	Assume 2-ft thick sand cap plus 25 percent consolidation
Rock armor	1,778	cy	$ 40	$ 71,111	Assume 1-foot thick armor layor
6-inch fish mix in-fill on rock armor	889	cy	$ 27	$ 24,000	Assume 6-inch layer of fish mix
Restoration project costs for fill mitigation	1.0	acre	$ 280,000	$ 288,660	Assume capped area requires mitigation in the form of completing a restoration project.
Direct Capital Cost Subtotal				$ 592,660	
Indirect Capital Cost		% of TDC	36.0%	$ 213,358	
Total Capital Cost				**$ 806,017**	
Subtidal ENR Area					
Placement of Thin (6-inch) Layer of Sand	**85,000**	**sq. ft.**			Area = 85,000 sq. ft.
Enhanced natural recovery (ENR) layer	1,574	cy	$ 65	$ 102,315	Assume 6-inch sand thickness placed in two lifts.
Direct Capital Cost Subtotal				$ 102,315	
Indirect Capital Cost		% of TDC	36.0%	$ 36,833	
Total Capital Cost				**$ 139,148**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 2,408,732**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Operation & Maintenance COSTS					
Marine Area O&M					
Sediment Cap Monitoring					
Sediment cap long-term monitoring and reporting	1.7	acre/event	$ 15,000	$ 24,793	Monitoring cap areas after year 1, 3, and 5 followed by five additional 5 year events for a total of 8 events over 30 years. **The total monitoring and reporting costs over 8 events is included in the Direct Subtotal row below.**
Sediment cap area O&M (maintenance costs)	1.7	acre/event	$ 10,000	$ 16,529	Perform O&M on cap/liner areas every 5 years for 30 years (6 EVENTS). **The total maintenance costs over 4 events is included in the Direct Subtotal row below.**
ENR monitoring and reporting	2	acre/event	$ 5,000	$ 10,000	Unit cost is shown per acre for 1 event. Assumptions for monitoring include 2 acres of ENR area after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
MNR monitoring and reporting	1	LS/event	$ 60,000	$ 60,000	Lump sum event cost for performing monitoring across limits of Haley MNR area. Monitoring is assumed to occur after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
20-year cap/liner repair event	$ 2,269,584	%	10%	$ 226,958	Assume 10 percent of sediment cap/liner capital costs for completion of repairs at 20-year timeframe.
Direct Subtotal				$ 804,479	
Indirect O&M Costs		% of TDC	15.0%	$ 120,672	
Undiscounted Subtotal (including Indirect Costs)				**$ 925,151**	
Present Value Subtotal (including Indirect Costs)				**$ 809,062**	
Total Undiscounted O&M Costs (30 Years)				**$ 925,151**	
Total Net Present Value of O&M Costs (30 Years)				**$ 809,062**	
Contingency (25 Percent of Total Cost)				**$ 602,183**	
Total Cost of Alternative (Present Worth)				**$ 3,819,977**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-11

Alternative Cost Estimate - Alternative S2, Upper Intertidal Sediment Removal and Amended Cap

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Smear Zone/Upper Intertidal					
Excavate Intertidal Sediment to Accommodate Cap					
Sediment excavation using land-based excavation equipment	3,667	cy	$ 35	$ 128,333	Remove 3-feet of sediment from top of bank to approximately existing elevation +2 feet NAVD. Approximately 23,000 sq. ft. of 3-foot excavation. Grade Removal out to existing elevation -1.5 feet NAVD. Approximately 20,000 SF of area grading from 3 feet to no removal.
Shoring and/or coffer dam install for intertidal excavation	1	LS	$ 325,000	$ 325,000	Assume use of coffer dam system to excavate intertidal sediment in dry conditions.
Handling of water drained from excavated sediment	1	LS	$ 50,000	$ 50,000	
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	1,100	ton	$ 245	$ 269,500	Assume 20 percent of excavated sediment is debris that is macroencapsulated for transport and disposal.
Handling of consolidated soil or sediment	2,933	cy	$ 5	$ 14,667	Assume 80 percent of excavated sediment is transferred to upland for consolidation into upland AOC.
ISS media cost: Organoclay SS-199	88,000	lb	$ 1.50	$ 132,000	Stabilize excavated sediment similar to upland alternatives.
ISS media cost: Portland cement	704,000	lb	$ 0.10	$ 70,400	
Shallow solidification or stabilization using an excavator	2,933	cy	$ 40	$ 117,333	Assume excavated soil is spread thin enough to mix stabilization material using an an excavator.
Placement of Organoclay Amended Sand Cap	**24,000**	**sq. ft.**			Area of Amended Sand Cap = 24,000 sq. ft.
Intertidal sand backfill/cap	1,778	cy	$ 39	$ 69,333	Placement of sand cap following mix with amendment, assume 2-foot thick cap across 24,000 sq. ft.
Amended cap media: Organoclay PM-199	398,222	lb	$ 1.58	$ 629,191	Assume 7 percent application of organoclay to amend sand cap.
Prepare amended cap blend	1,778	cy	$ 5	$ 8,889	
Rock armor	889	cy	$ 40	$ 35,556	Assume 1-foot thick armor layor
6-inch fish mix in-fill on rock armor	444	cy	$ 27	$ 12,000	Assume 6-inch layer of fish mix
Placement of Intertidal Unamended Sand Cap	**17,000**	**sq. ft.**			Area of Intertidal Unamended Sand Cap = 17,000 sq. ft.
Intertidal sand backfill/cap	1,259	cy	$ 39	$ 49,111	Placement of sand cap in intertidal areas not capped with amended sand cap, down to approximately elevation -1 feet NAVD. Assume 2-foot thick cap across 17,000 sq. ft.
Rock armor	630	cy	$ 40	$ 25,185	Assume 1-foot thick armor layor
6-inch fish mix in-fill on rock armor	315	cy	$ 27	$ 8,500	Assume 6-inch layer of fish mix
Direct Capital Cost Subtotal				$ 1,944,999	
Indirect Capital Cost		% of TDC	36.0%	$ 700,199	
Total Capital Cost				**$ 2,645,198**	
Lower Intertidal/Shallow Subtidal					
Unamended Sand Cap	**27,000**	**sq. ft.**			Area of unamended sand cap below approximately elevation -1 feet NAVD. Area = 27,000 sq. ft.
Subtidal sand backfill/cap	2,500	cy	$ 47	$ 117,500	Assume 2-ft thick sand cap plus 25 percent consolidation
Rock armor	1,000	cy	$ 40	$ 40,000	Assume 1-foot thick armor layor
6-inch fish mix in-fill on rock armor	500	cy	$ 27	$ 13,500	Assume 6-inch layer of fish mix
Restoration project costs for fill mitigation	0.58	acre	$ 280,000	$ 162,371	Assume capped area requires mitigation in the form of completing a restoration project.
Direct Capital Cost Subtotal				$ 333,371	
Indirect Capital Cost		% of TDC	36.0%	$ 120,014	
Total Capital Cost				**$ 453,385**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
ENR Area					
Thin Layer Sand Cap	85,000	sq. ft.			Area = 85,000 sq. ft.
Enhanced natural recovery (ENR) layer	1,574	cy	$ 65	$ 102,315	Assume 6-inch sand thickness
Direct Capital Cost Subtotal				$ 102,315	
Indirect Capital Cost		% of TDC	36.0%	$ 36,833	
Total Capital Cost				**$ 139,148**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 3,237,731**	
Operation & Maintenance Costs					
Marine Area O&M					
Sediment Cap Monitoring					
Sediment cap long-term monitoring and reporting	1.6	acre/event	$ 15,000	$ 23,416	Monitoring cap areas after year 1, 3, and 5 followed by five additional 5 year events for a total of 8 events over 30 years. **The total monitoring and reporting costs over 8 events is included in the Direct Subtotal row below.**
Sediment cap area O&M (maintenance costs)	1.6	acre/event	$ 10,000	$ 15,611	Perform O&M on cap/liner areas every 5 years for 30 years (6 EVENTS). **The total maintenance costs over 4 events is included in the Direct Subtotal row below.**
ENR monitoring and reporting	2.0	acre/event	$ 5,000	$ 10,000	Unit cost is shown per acre for 1 event. Assumptions for monitoring include 2 acres of ENR area after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
MNR monitoring and reporting	1	LS/event	$ 60,000	$ 60,000	Lump sum event cost for performing monitoring across limits of Haley MNR area. Monitoring is assumed to occur after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
20-year cap/liner repair event	$ 3,098,583	%	10%	$ 309,858	Assume 10% of sediment cap/liner capital costs for completion of repairs at 20-year timeframe.
Direct Subtotal				$ 870,850	
Indirect O&M Costs		% of TDC	15.0%	$ 130,628	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,001,478**	
Present Value Subtotal (including Indirect Costs)				**$ 869,408**	
Total Undiscounted O&M Costs (30 Years)				**$ 1,001,478**	
Total Net Present Value of O&M Costs (30 Years)				**$ 869,408**	
Contingency (25 Percent of Total Cost)				**$ 1,026,785**	
Total Cost of Alternative (Present Worth)				**$ 5,133,923**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-12

Alternative Cost Estimate - Alternative S3, Upper Intertidal Sediment Removal and Sand Cap

R.G. Haley Site
Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Smear Zone/Upper Intertidal Exceedance Area					
Excavate Intertidal Sediment to Accommodate Cap					
Sediment excavation using land-based excavation equipment	7,700	cy	$ 35	$ 269,500	Remove 5-feet of sediment from top of bank to approximately existing elevation 0 feet NAVD to accommodate armored cap thickness. Remove additional wedge of deeper sediment to complete smear zone removal. From C3D calcs, excavation volume approximately 7,700 cy.
Shoring and/or coffer dam install for intertidal excavation	1	LS	$ 325,000	$ 325,000	Assume use of coffer dam system to excavate intertidal sediment in dry conditions.
Handling of water drained from excavated sediment	1	LS	$ 50,000	$ 50,000	
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	2,310	ton	$ 245	$ 565,950	Assume 20 percent of excavated sediment is debris that is macroencapsulated for transport and disposal.
Handling of consolidated soil or sediment	6,160	cy	$ 5	$ 30,800	Assume 80 percent of excavated sediment is transferred to upland for consolidation into upland AOC.
ISS media cost: Organoclay SS-199	184,800	lb	$ 1.50	$ 277,200	Stabilize excavated sediment similar to upland alternatives.
ISS media cost: Portland cement	1,478,400	lb	$ 0.10	$ 147,840	
Shallow solidification or stabilization using an excavator	6,160	cy	$ 40	$ 246,400	Assume excavated soil is spread thin enough to mix stabilization material using an an excavator.
Placement of Intertidal Unamended Sand Cap	**41,000**	**sq. ft.**			Area of Intertidal Unamended Sand Cap = 41,000 sq. ft.
Intertidal sand backfill/cap	6,074	cy	$ 39	$ 236,889	Placement of 4-foot sand cap in intertidal areadown to approximately elevation -1 feet NAVD. Assume 4-foot thick cap across 41,000 sq. ft.
Rock armor	1,519	cy	$ 40	$ 60,741	Assume 1-foot thick armor layor
6-inch fish mix in-fill on rock armor	759	cy	$ 27	$ 20,500	Assume 6-inch layer of fish mix
Direct Capital Cost Subtotal				$ 2,230,820	
Indirect Capital Cost		% of TDC	36.0%	$ 803,095	
Total Capital Cost				**$ 3,033,915**	
Lower Intertidal/Shallow Subtidal Exceedance Area					
Unamended Sand Cap	**31,000**	**sq. ft.**			Area of unamended sand cap below approximately elevation -1 feet NAVD. Area = 31,000 sq. ft.
Subtidal sand backfill/cap	2,870	cy	$ 47	$ 134,907	Assume 2-ft thick sand cap plus 25 percent consolidation
Rock armor	1,148	cy	$ 40	$ 45,926	Assume 1-ft thick armor layer
6-inch fish mix in-fill on rock armor	1,148	cy	$ 34	$ 39,037	Assume 6-inch layer of fish mix
Restoration project costs for fill mitigation	0.67	acre	$ 280,000	$ 186,426	Assume capped area requires mitigation in the form of completing a restoration project.
Direct Capital Cost Subtotal				$ 219,870	
Indirect Capital Cost		% of TDC	36.0%	$ 79,153	
Total Capital Cost				**$ 299,024**	
ENR Area					
Thin Layer Sand Cap	**85,000**	**sq. ft.**			**Area = 85,000 sq. ft.**
Enhanced natural recovery (ENR) layer	1,574	cy	$ 65	$ 102,315	Assume 6-inch sand thickness
Direct Capital Cost Subtotal				$ 102,315	
Indirect Capital Cost		% of TDC	36.0%	$ 36,833	
Total Capital Cost				**$ 139,148**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 3,472,087**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Operation & Maintenance Costs					
Marine Area O&M					
Sediment Cap Monitoring					
Sediment cap long-term monitoring and reporting	1.7	acre/event	$ 15,000	$ 24,793	Monitoring cap areas after year 1, 3, and 5 followed by five additional 5 year events for a total of 8 events over 30 years. **The total monitoring and reporting costs over 8 events is included in the Direct Subtotal row below.**
Sediment cap area O&M (maintenance costs)	1.7	acre/event	$ 10,000	$ 16,529	Perform O&M on cap/liner areas every 5 years for 30 years (6 EVENTS). **The total maintenance costs over 4 events is included in the Direct Subtotal row below.**
ENR monitoring and reporting	2.0	acre/event	$ 5,000	$ 10,000	Unit cost is shown per acre for 1 event. Assumptions for monitoring include 2 acres of ENR area after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
MNR monitoring and reporting	1	LS/event	$ 60,000	$ 60,000	Lump sum event cost for performing monitoring across limits of Haley MNR area. Monitoring is assumed to occur after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
20-year cap/liner repair event	$ 3,332,938	%	10%	$ 333,294	Assume 10 percent of sediment cap/liner capital costs for completion of repairs at 20-year timeframe.
Direct Subtotal				$ 910,815	
Indirect O&M Costs		% of TDC	15.0%	$ 136,622	
Undiscounted Subtotal (including Indirect Costs)				$ 1,047,437	
Present Value Subtotal (including Indirect Costs)				**$ 907,317**	
Total Undiscounted O&M Costs (30 Years)				**$ 1,047,437**	
Total Net Present Value of O&M Costs (30 Years)				**$ 907,317**	
Contingency (25 Percent of Total Cost)				**$ 1,094,851**	
Total Cost of Alternative (Present Worth)				**$ 5,474,254**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-13

Alternative Cost Estimate - Alternative S4, Intertidal and Shallow Subtidal Sediment Removal and Amended Cap

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Smear Zone/Upper Intertidal Exceedance Area					
Excavate Intertidal Sediment to Accommodate Cap	**39,000**	**sq. ft.**			Area of excavation above elevation 0 feet NAVD = 39,000 sq. ft.
Sediment excavation using land-based excavation equipment	4,333	cy	$ 35	$ 151,667	Remove 3-feet of sediment from top of bank to approximately existing elevation 0 feet NAVD. Approximately 39,000 sq. ft. of 3-foot excavation.
Shoring and/or coffer dam install for intertidal excavation	1	LS	$ 325,000	$ 325,000	Assume use of coffer dam system to excavate intertidal sediment in dry conditions.
Handling of water drained from excavated sediment	1	LS	$ 50,000	$ 50,000	
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	1,300	ton	$ 245	$ 318,500	Assume 20 percent of excavated sediment is debris that is macroencapsulated for transport and disposal.
Handling of consolidated soil or sediment	3,467	cy	$ 5	$ 17,333	Assume 80 percent of excavated sediment is transferred to upland for consolidation into upland AOC.
ISS media cost: Organoclay SS-199	104,000	lb	$ 1.50	$ 156,000	Stabilize excavated sediment similar to upland alternatives.
ISS media cost: Portland cement	832,000	lb	$ 0.10	$ 83,200	
Shallow solidification or stabilization using an excavator	3,467	cy	$ 40	$ 138,667	Assume excavated soil is spread thin enough to mix stabilization material using an an excavator.
Placement of Organoclay Amended Sand Cap	**24,000**	**sq. ft.**			Area of Amended Sand Cap = 24,000 sq. ft.
Intertidal sand backfill/cap	1,778	cy	$ 39	$ 69,333	Placement of sand cap following mix with amendment, assume 2-foot thick cap across 24,000 sq. ft.
Amended cap media: Organoclay PM-199	398,222	lb	$ 1.58	$ 629,191	Assume 7% application of organoclay to amend sand cap.
Prepare amended cap blend	1,778	cy	$ 5	$ 8,889	
Rock armor	889	cy	$ 40	$ 35,556	Assume 1-foot thick armor layer
6-inch fish mix in-fill on rock armor	444	cy	$ 27	$ 12,000	Assume 6-inch layer of fish mix
Placement of Intertidal Unamended Sand Cap	**17,000**	**sq. ft.**			Area of Intertidal Unamended Sand Cap = 17,000 sq. ft.
Intertidal sand backfill/cap	1,259	cy	$ 39	$ 49,111	Placement of sand cap in intertidal areas not capped with amended sand cap, down to approximately elevation 0 feet NAVD. Assume 2-foot thick cap across 17,000 sq. ft.
Rock armor	630	cy	$ 40	$ 25,185	Assume 1-foot thick armor layer
6-inch fish mix in-fill on rock armor	315	cy	$ 27	$ 8,500	Assume 6-inch layer of fish mix
Direct Capital Cost Subtotal				$ 2,078,132	
Indirect Capital Cost		% of TDC	36.0%	$ 748,127	
Total Capital Cost				**$ 2,826,259**	
Lower Intertidal/Shallow Subtidal					
Dredge Intertidal Sediment to Accommodate Cap	**29,000**	**sq. ft.**			Area of dredging below elevation 0 feet NAVD = 29,000 sq. ft.
Sediment removal by dredging (barge-mounted)	3,867	cy	$ 34	$ 131,467	Dredge 3-feet of sediment from elevation 0 to outer limit of benthic toxicity. Assume 20 percent overdredge.
Water quality monitoring during dredging	16	day	$ 4,000	$ 64,000	Water quality monitoring during dredging.
Handling of water drained from excavated sediment	1	LS	$ 50,000	$ 50,000	
Transport dredged sediment to Site upland and off-load for consolidation in upland or transport off-site for disposal.	3,867	ton/cy	$ 15	$ 58,000	Transporting and off-loading from barge to upland.
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	580	ton	$ 245	$ 142,100	Assume 10 percent of excavated sediment is debris that is macroencapsulated for transport and disposal.
Handling of consolidated soil or sediment	3,480	cy	$ 5	$ 17,400	Assume 90 percent of excavated sediment is transferred to upland for consolidation into upland AOC.
ISS media cost: Organoclay SS-199	104,400	lb	$ 1.50	$ 156,600	Stabilize excavated sediment similar to upland alternatives.
ISS media cost: Portland cement	835,200	lb	$ 0.10	$ 83,520	
Shallow solidification or stabilization using an excavator	3,480	cy	$ 40	$ 139,200	Assume excavated soil is spread thin enough to mix stabilization material using an an excavator.

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Placement of Lower Intertidal to Subtidal Unamended Sand Cap	**26,500**	**sq. ft.**			Area of Lower Intertidal to Subtidal Unamended Sand Cap = 26,500 sq. ft.
Subtidal sand backfill/cap	2,454	cy	$ 47	$ 115,324	Placement of sand cap in lower intertidal and subtidal areas. Assume 2-foot thick cap across 26,500 sq. ft. plus 25 percent consolidation.
Rock armor	981	cy	$ 40	$ 39,259	Assume 1-foot thick armor layer
6-inch fish mix in-fill on rock armor	491	cy	$ 27	$ 13,250	Assume 6-inch layer of fish mix
Direct Capital Cost Subtotal				$ 1,010,120	
Indirect Capital Cost		% of TDC	36.0%	$ 363,643	
Total Capital Cost				**$ 1,373,763**	
ENR Area					
Thin Layer Sand Cap	**85,000**	**sq. ft.**			Area = 85,000 sq. ft.
Enhanced natural recovery (ENR) layer	1,574	cy	$ 65	$ 102,315	Assume 6-inch sand thickness
Direct Capital Cost Subtotal				$ 102,315	
Indirect Capital Cost		% of TDC	36.0%	$ 36,833	
Total Capital Cost				**$ 139,148**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 4,339,171**	
Operation & Maintenance Costs					
Marine Area O&M					
Sediment Cap Monitoring					
Sediment cap long-term monitoring and reporting	1.5	acre/event	$ 15,000	$ 23,244	Monitoring cap areas after year 1, 3, and 5 followed by five additional 5 year events for a total of 8 events over 30 years. **The total monitoring and reporting costs over 8 events is included in the Direct Subtotal row below.**
Sediment cap area O&M (maintenance costs)	1.5	acre/event	$ 10,000	$ 15,496	Perform O&M on cap/liner areas every 5 years for 30 years (6 EVENTS). **The total maintenance costs over 4 events is included in the Direct Subtotal row below.**
ENR monitoring and reporting	2.0	acre/event	$ 5,000	$ 10,000	Unit cost is shown per acre for 1 event. Assumptions for monitoring include 2 acres of ENR area after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
MNR monitoring and reporting	1	LS/event	$ 60,000	$ 60,000	Lump sum event cost for performing monitoring across limits of Haley MNR area. Monitoring is assumed to occur after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
20-year cap/liner repair event	$ 4,200,023	%	10%	$ 420,002	Assume 10 percent of sediment cap/liner capital costs for completion of repairs at 20-year timeframe.
Direct Subtotal				$ 978,928	
Indirect O&M Costs		% of TDC	15.0%	$ 146,839	
Undiscounted Subtotal (including Indirect Costs)				**$ 1,125,767**	
Present Value Subtotal (including Indirect Costs)				**$ 969,150**	
Total Undiscounted O&M Costs (30 Years)				**$ 1,125,767**	
Total Net Present Value of O&M Costs (30 Years)				**$ 969,150**	
Contingency (25 Percent of Total Cost)				**$ 1,327,080**	
Total Cost of Alternative (Present Worth)				**$ 6,635,400**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-14

Alternative Cost Estimate - Alternative S5a, Complete Removal, Consolidate within Upland AOC

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Smear Zone/Upper Intertidal					
Excavate Contaminated Sediment and Dispose Off-Site	**38,000**	**sq. ft.**			Area of excavation above elevation 0 feet NAVD = 38,000 sq. ft.
Sediment excavation using land-based excavation equipment	10,600	cy	$ 35	$ 371,000	Remove 6-feet of sediment from top of bank to approximately existing elevation 0 feet NAVD. Remove additional wedge of deeper sediment to complete smear zone removal. From C3D calcs, excavation volume approximately 10,600 cy.
Shoring and/or coffer dam install for intertidal excavation	1	LS	$ 325,000	$ 325,000	Assume use of coffer dam system to excavate intertidal sediment in dry conditions.
Handling of water drained from excavated sediment	1	LS	$ 50,000	$ 50,000	
Handling and loading of excavated material	5,300	cy	$ 2	$ 10,600	
Transport (truck) and dispose soil to Subtitle D landfill	7,950	ton	$ 65	$ 516,750	Assume 50 percent of excavated intertidal sediment can be disposed of as non-hazardous waste at a Subtitle D landfill.
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	1,590	ton	$ 245	$ 389,550	Assume 20 percent of excavated sediment to be consolidated in upland AOC is debris that is macroencapsulated for transport and disposal.
Handling of consolidated soil or sediment	4,240	cy	$ 5	$ 21,200	Assume 80 percent of remaining excavated sediment is transferred to upland for consolidation into upland AOC.
ISS media cost: Organoclay SS-199	127,200	lb	$ 1.50	$ 190,800	Stabilize excavated sediment being consolidated in AOC similar to upland alternatives
ISS media cost: Portland cement	1,017,600	lb	$ 0.10	$ 101,760	
Shallow solidification or stabilization using an excavator	4,240	cy	$ 40	$ 169,600	Assume excavated sediment is spread thin enough to mix stabilization material using an an excavator.
Intertidal sand backfill/cap	10,600	cy	$ 39	$ 413,400	
Rock armor	1,407	cy	$ 40	$ 56,296	Assume 1-foot thick armor layer required to protect shoreline
6-inch fish mix in-fill on rock armor	704	cy	$ 27	$ 19,000	Assume 6-inch layer of fish mix
Direct Capital Cost Subtotal				$ 2,634,956	
Indirect Capital Cost	1	LS	$ 250,000	$ 250,000	Use lump sum indirect cost rather than multiplier due to the high percentange of cost associated with disposal.
Total Capital Cost				$ 2,884,956	
Lower Intertidal/Shallow Subtidal					
Dredge Contaminated Sediment and Dispose Off-Site	**35,000**	**sq. ft.**			Area of dredging below elevation 0 feet NAVD = 35,000 sq. ft.
Sediment removal by dredging (barge-mounted)	9,333	cy	$ 34	$ 317,333	Dredge 6-feet of sediment from elevation 0 feet NAVD to outer limit of benthic toxicity. Assume 20 percent overdredge.
Water quality monitoring during dredging	38	day	$ 4,000	$ 152,000	Water quality monitoring during dredging.
Handling of water drained from excavated sediment	1	LS	$ 50,000	$ 50,000	
Transport dredged sediment to Site upland and off-load for consolidation in upland or transport off-site for disposal.	9,333	ton/cy	$ 15	$ 140,000	
Handling and loading of excavated material	4,200	cy	$ 2	$ 8,400	
Transport (truck) and dispose soil to Subtitle D landfill	6,300	ton	$ 65	$ 409,500	Assume 45 percent of dredged subtidal sediment can be disposed of as non-hazardous waste at a Subtitle D landfill.

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Macroencapsulate, transport (truck), and dispose of contaminated debris at Subtitle C (hazardous waste) landfill	1,540	ton	$ 245	$ 377,300	Assume 20 percent of excavated sediment to be consolidated in upland AOC is debris that is macroencapsulated for transport and disposal.
Handling of consolidated soil or sediment	4,107	cy	$ 5	$ 20,533	Assume 80 percent of remaining excavated sediment is transferred to upland for consolidation into upland AOC.
ISS media cost: Organoclay SS-199	123,200	lb	$ 1.50	$ 184,800	Stabilize excavated sediment being consolidated in AOC similar to upland alternatives.
ISS media cost: Portland cement	985,600	lb	$ 0.10	$ 98,560	
Shallow solidification or stabilization using an excavator	4,107	cy	$ 40	$ 164,267	Assume excavated sediment is spread thin enough to mix stabilization material using an an excavator.
Subtidal sand backfill/cap	9,333	cy	$ 47	$ 438,667	
Direct Capital Cost Subtotal				$ 2,361,360	Use lump sum indirect cost rather than multiplier due to the high proportion of cost associated with transport and disposal.
Indirect Capital Cost	1	lump sum	$ 250,000	$ 250,000	
Total Capital Cost				$ 2,611,360	
Subtidal ENR Area					
Thin Layer Sand Cap	**85,000**	**sq. ft.**			Area = 85,000 sq. ft.
Enhanced natural recovery (ENR) layer	1,574	cy	$ 65	$ 102,315	Assume 6-inch sand thickness
Direct Capital Cost Subtotal				$ 102,315	
Indirect Capital Cost				$ -	Assume limited additional indirect costs above other project elements.
Total Capital Cost				**$ 102,315**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 5,598,631**	
Operation & Maintenance Costs					
Marine Area O&M					
Sediment Cap Monitoring					
ENR monitoring and reporting	5.0	acre/event	$ 5,000	$ 24,757	Unit cost is shown per acre for 1 event. Assumptions for monitoring include 2 acres of ENR area after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
MNR monitoring and reporting	1	LS/event	$ 60,000	$ 60,000	Lump sum event cost for performing monitoring across limits of Haley MNR area. Monitoring is assumed to occur after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
Direct Subtotal				$ 339,027	
Indirect O&M Costs		% of TDC	15.0%	$ 50,854	
Undiscounted Subtotal (including Indirect Costs)				**$ 389,881**	
Present Value Subtotal (including Indirect Costs)				**$ 371,445**	
Total Undiscounted O&M Costs (30 Years)				**$ 389,881**	
Total Net Present Value of O&M Costs (30 Years)				**$ 371,445**	
Contingency (25 Percent of Total Cost)				**$ 1,492,519**	
Total Cost of Alternative (Present Worth)				**$ 7,462,595**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

Table Q-15

Alternative Cost Estimate - Alternative S5b, Complete Removal, Off-Site Treatment/Disposal

R.G. Haley Site

Bellingham, Washington

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Capital Costs (Direct and Indirect)					
Smear Zone/Upper Intertidal					
Excavate Contaminated Sediment and Dispose Off-Site	**38,000**	**sq. ft.**			Area of excavation above elevation 0 feet NAVD = 38,000 sq. ft.
Sediment excavation using land-based excavation equipment	10,600	cy	$ 35	$ 371,000	Remove 6-feet of sediment from top of bank to approximately existing elevation 0 feet NAVD. Remove additional wedge of deeper sediment to complete smear zone removal. From C3D calcs, excavation volume approximately 10,600 cy.
Shoring and/or coffer dam install for intertidal excavation	1	LS	$ 325,000	$ 325,000	Assume use of coffer dam system to excavate intertidal sediment in dry conditions.
Handling of water drained from excavated sediment	1	LS	$ 50,000	$ 50,000	
Handling and loading of excavated material	10,600	cy	$ 2	$ 21,200	
Transport (truck) and dispose soil to Subtitle D landfill	7,950	ton	$ 65	$ 516,750	Assume 50 percent of excavated intertidal sediment can be disposed of as non-hazardous waste at a Subtitle D landfill.
Transport (truck) and dispose Soil at Subtitle C (hazardous waste) landfill	3,975	ton	$ 176	$ 699,600	Assume 25 percent of excavated intertidal sediment requires disposal at RCRA C landfill without treatment.
Transport (truck), incinerate and dispose soil at hazardous waste facility in (Aragonite, Utah)	3,975	ton	$ 878	$ 3,490,050	Assume 25 percent of excavated intertidal sediment requires treatment by incineration prior to disposal.
Intertidal sand backfill/cap	10,600	cy	$ 39	$ 413,400	
Rock armor	1,407	cy	$ 40	$ 56,296	Assume 1-foot thick armor layer required to protect shoreline
6-inch fish mix in-fill on rock armor	704	cy	$ 27	$ 19,000	Assume 6-inch layer of fish mix
Direct Capital Cost Subtotal				$ 5,887,000	
Indirect Capital Cost	1	LS	$ 250,000.00	$ 250,000	Use lump sum indirect cost rather than multiplier due to the high percentange of cost associated with disposal.
Total Capital Cost				**$ 6,137,000**	
Lower Intertidal/Shallow Subtidal					
Dredge Contaminated Sediment and Dispose Off-Site	**35,000**	**sq. ft.**			Area of dredging below elevation 0 feet NAVD = 35,000 sq. ft.
Sediment removal by dredging (barge-mounted)	9,333	cy	$ 34	$ 317,333	Dredge 6-feet of sediment from elevation 0 feet NAVD to outer limit of benthic toxicity. Assume 20 percent overdredge.
Water quality monitoring during dredging	38	day	$ 4,000	$ 152,000	Water quality monitoring during dredging
Handling of water drained from excavated sediment	1	LS	$ 50,000	$ 50,000	
Transport dredged sediment to Site upland and off-load for consolidation in upland or transport off-site for disposal.	9,333	ton/cy	$ 15	$ 140,000	
Handling and loading of excavated material	9,333	cy	$ 2	$ 18,667	
Transport (truck) and dispose soil to Subtitle D landfill	6,300	ton	$ 65	$ 409,500	Assume 45 percent of dredged subtidal sediment can be disposed of as non-hazardous waste at a Subtitle D landfill
Transport (truck) and dispose Soil at Subtitle C (hazardous waste) landfill	7,700	ton	$ 176	$ 1,355,200	Assume 55 percent of dredged subtidal sediment requires disposal at RCRA C landfill without requiring treatment prior to disposal.
Transport (truck), incinerate and dispose soil at hazardous waste facility in (Aragonite, Utah)	0	ton	$ 878	$ -	
Subtidal sand backfill/cap	9,333	cy	$ 47	$ 438,667	
Direct Capital Cost Subtotal				$ 2,881,367	
Indirect Capital Cost	1	LS	$ 250,000	$ 250,000	Use lump sum indirect cost rather than multiplier due to the high proportion of cost associated with transport and disposal.
Total Capital Cost				**$ 3,131,367**	

Description	Quantity		Cost		Notes
	Number	Unit	Unit Cost	Total Cost	
Subtidal ENR Area					
Thin Layer Sand Cap	85,000	sq. ft.			Area = 85,000 sq. ft.
Enhanced natural recovery (ENR) layer	1,574	cy	$ 65	$ 102,315	Assume 6-inch sand thickness
Direct Capital Cost Subtotal				$ 102,315	
Indirect Capital Cost				$ -	Assume limited additional indirect costs above other project elements.
Total Capital Cost				**$ 102,315**	
TOTAL CAPITAL COSTS (Direct and Indirect)				**$ 9,370,681**	
Operation & Maintenance Costs					
Marine Area O&M					
Sediment Cap Monitoring					
ENR monitoring and reporting	5.0	acre/event	$ 5,000	$ 24,757	Unit cost is shown per acre for 1 event. Assumptions for monitoring include 2 acres of ENR area after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
MNR monitoring and reporting	1	LS/event	$ 60,000	$ 60,000	Lump sum event cost for performing monitoring across limits of Haley MNR area. Monitoring is assumed to occur after year 1, 3, 5, and 10. **The total monitoring and reporting cost total for the 4 events is included in the Direct Subtotal row below.**
Direct Subtotal				$ 339,027	
Indirect O&M Costs		% of TDC	15.0%	$ 50,854	
Undiscounted Subtotal (including Indirect Costs)				**$ 389,881**	
Present Value Subtotal (including Indirect Costs)				**$ 371,445**	
Total Undiscounted O&M Costs (30 Years)				**$ 389,881**	
Total Net Present Value of O&M Costs (30 Years)				**$ 371,445**	
Contingency (25 Percent of Total Cost)				**$ 2,435,532**	
Total Cost of Alternative (Present Worth)				**$ 12,177,658**	

Notes:

Present worth calculated using equal series present worth analysis where i = 1.1 %

For the purposes of developing cost estimates for Alternatives S5a and S5b, remediation waste characterization, designation and treatment/disposal assumptions were made based on interpretation of Site characterization data and based on regulatory and landfill requirements. Treatment/disposal costs for excavated sediment transported off site were based on comparison of sediment sample chemical analytical data to treatment standards and waste designation criteria. Key assumptions include the following:

- Remediation-derived sediment waste associated with releases from the Haley wood treatment facility would be classified as F032-listed dangerous waste if "generated." Remediation-derived sediment waste would not be designated as state or federal characteristic waste or EHW based on state-only criteria. Federal and state land disposal restrictions (LDRs) would apply to remediation-derived sediment waste. If concentrations of F032 constituents exceed the treatment standards[1], the waste would need to be incinerated before it could be disposed. Contaminated sediment would be directly disposed (without treatment) in a Subtitle C landfill if concentrations of F032 constituents are less than the treatment standards. Similar to requirements for contaminated soil, under certain conditions, contaminated sediment can be directly disposed in Subtitle D landfill if approved under a CID from Ecology.

- For purposes of costing alternatives for the FS, the zones proposed for sediment excavation (removal) were subdivided into 2-foot thick layers relative to the depth below the mudline to calculate a corresponding quantity of sediment for removal from that zone and subarea. Chemical analytical data for sediment samples representative of each of the subarea were reviewed relative to treatment standards applicable for the three disposal options: incineration/disposal at Subtitle C landfill, direct disposal at Subtitle C landfill, and disposal at Subtitle D landfill in accordance with a CID from Ecology. Each sediment sample was assumed to represent an area of equal volume. The percentage of samples meeting treatment standards for each disposal option was applied to the sediment quantity for that respective zone and subarea. This percentage-based waste profiling approach to estimate quantities for treatment and disposal at different facilities is reasonable for FS cost estimating assumptions. However, it should be noted that waste profiling approaches applicable for upland soil may not be appropriate for sediment because sediment excavation methodologies are significantly different.

[1] The industrial waste treatment standards for listed waste are specified in 40 CFR268.40. Ecology has indicated these treatment standards apply to remediation-derived sediment waste.

APPENDIX R
Sediment Cap Modeling

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APPENDIX R. SEDIMENT CAP MODELING

1.0 INTRODUCTION

This appendix summarizes sediment cap modeling conducted to support the development and evaluation of cleanup action alternatives for the R.G. Haley Site (Site) feasibility study (FS). A model was developed to evaluate design concepts for cleanup alternatives that would meet the cleanup action objectives for the marine unit. Specifically, cap designs utilizing varying thicknesses and amendment types and amendment quantities were evaluated using the cap model to determine the efficacy of confining or attenuating contamination in the nearshore portion of the marine unit, where upland groundwater likely discharges to Bellingham Bay. Tables R-1 through R-4 referenced below are provided on pages R-8 through R-10.

2.0 SITE CONDITIONS

Site conditions utilized for the model are presented in the remedial investigation (RI) and FS. Contaminated media at the Site include upland soil and groundwater and marine sediment. Light non-aqueous phase liquid (LNAPL) is present in the upland, including the petroleum smear zone where LNAPL is present at residual saturation and upland areas adjacent to the shoreline where LNAPL concentrations are greater than residual saturation and LNAPL is potentially mobile. The petroleum smear zone extends into the upper intertidal portion of the marine unit. Groundwater is present in the upland within native marine sediment, wood fill and marine sediment fill that is present above a relatively shallow, impermeable layer (Chuckanut formation, RI Figure 4-5). Groundwater recharge is primarily from precipitation that infiltrates through unpaved areas in the upland. Flows are generally towards Bellingham Bay, although subsurface features, including the existing sheet pile wall near the shoreline, alter the patterns and depth at which groundwater currently discharges to the bay. In general, groundwater is anticipated to upwell through the sediment to the bay within approximately 125 feet of the shoreline measured from the ordinary high water (OHW) line. Additional details concerning the groundwater hydrology at the Site are presented in the RI (Section 4.2).

The Site conditions relevant to the sediment cap modeling effort include the following:

- Properties and concentrations of contaminants that are the primary risk drivers in upland groundwater and in sediment;
- Estimated groundwater flow rates at the existing sediment mudline (RI Section 4.0 and Appendix H), referred to as the upwelling rate;
- Surface sediment organic carbon concentrations; and
- Hydrodynamic conditions that affect natural deposition of clean sediment (i.e., deposition from the Nooksack River).

2.1. Approach

The nearshore sediment, where active remedies were evaluated in the FS, represents the main portion of the marine unit impacted by Site-related contamination. The nearshore area has been divided into two zones: the intertidal zone and the shallow subtidal zone. The intertidal zone ranges from approximately +10 to -4 feet NAVD88 and the shallow subtidal ranges from -4 to -15 feet NAVD88. The deeper subtidal zone extends into Bellingham Bay but was not considered in the cap model. The upper intertidal zone, above approximately-elevation 0 feet NAVD88, contains residual LNAPL and is referred to as the intertidal smear zone (FS, Figures 9-14 and 9-15 of the FS). The portion of the intertidal zone below elevation 0 feet NAVD88 is referred to as the lower intertidal zone.

Modeling of cap performance using different design parameters for the upper intertidal zone was completed for the excavation and capping scenarios associated with the sediment cleanup action alternatives evaluated in the FS. Deposition of clean sediment originating from the Nooksack River was assumed to not occur in the upper intertidal zone due to the higher energy environment resulting from wind or wave-generated currents. Fine-grained capping material placed in the high energy environment in the upper intertidal zone would need to be armored by larger material to ensure cap stability. The effect of the armor layer was not evaluated as part of the cap modeling process since would contribute primarily to cap stability rather than chemical isolation.

Modeling within the lower intertidal/shallow subtidal zone was completed to determine the distance from the shoreline (relative to the OHW) at which the groundwater upwelling rate is low enough to enable the transition from an amended cap designed to enhance attenuation/chemical confinement of contaminants in groundwater discharging through the cap, to a conventional cap comprised of sand that has not been amended. To be conservative the cap design assumptions for the lower intertidal/shallow subtidal zone were based on no excavation or dredging of contaminated sediment, and no deposition of clean sediment within the modeled area.

3.0 METHODOLOGY

3.1. Selection of Model Indicator Hazardous Substances

A number of contaminants were identified in the RI as indicator hazardous substances (IHS) for groundwater, soil and sediment including total petroleum hydrocarbons, dioxins/furans (expressed as the dioxin TEQ), individual polycyclic aromatic hydrocarbons (PAHs), carcinogenic PAHs (cPAHs, expressed as the TEQ), and pentachlorophenol. The cap model was initially used to perform a sensitivity analysis to select a subset of IHSs for use in evaluating cap design parameters. The partitioning coefficients, upland groundwater concentrations, sediment concentrations, and cleanup levels for each IHS were used as inputs to the model using consistent cap design assumptions (e.g., cap thickness, amount of organic carbon, etc.) to evaluate which IHS requires the most conservative cap design. The result of the sensitivity analysis indicated that 2-methylnapthalene and pentachlorophenol are the contaminants that would require the most conservative cap design under all cap conditions evaluated in the FS, and were therefore selected for subsequent use in the model. TPH was also included in subsequent analyses, to account for groundwater flowing through the sediment smear zone under a subset of scenarios with limited or no sediment removal.

3.2. Model

The transient sediment cap model, CAPSIM© Version 2.7b (Dr. David Lampert, Xiaolong Shen and Dr. Danny Reible 2012), was used to analyze cap performance for the potential cap scenarios included in the sediment cleanup alternatives. The model was set up and verified by Dr. Reible using a model run for a conventional sand cap and an amended sand cap.

Model input parameters include measured and calculated existing conditions and sediment cap properties affecting the contaminant fate and transport processes. These input parameters are summarized in Table R-1, and consist of estimated groundwater upwelling velocity, porewater concentrations, organic carbon, chemical-specific organic carbon partitioning coefficient, diffusivity, hydrodynamic dispersivity, porosity, bulk density, bioturbation depth, cap thickness, cap amendment type and amount, cap porosity, cap bulk density, cap organic carbon, cap organic carbon partitioning coefficient, cap partitioning coefficient, cap hydrodynamic dispersivity, and for alternatives utilizing activated carbon amendment, the Freundlich coefficients. It was assumed that cleanup levels would need to be met within the biologically active zone (the sediment point of compliance under SMS) and that the cap would need to physically and chemically confine contamination over the long-term. A duration of 100 years was used for the model runs.

Using the input parameters described above, the model calculated both porewater and sediment concentrations for the modeled IHSs at the specified depth (biologically active zone) and time duration (100 years). By comparing the output parameters (porewater and sediment concentrations) to the cleanup levels at the point of compliance (which collectively comprise the cleanup standards), the cap thickness and amendment percentages could be adjusted and the model run iteratively to identify cleanup alternatives that would meet cleanup standards.

Several assumptions and estimates were necessary in order to model the complex fate and transport processes in the sediment. The assumptions are listed below and additional details are provided on pages R-5 through R-8. In general, where different inputs could be applied, the more conservative (more protective) value was used.

1. All upland cleanup action alternatives include a low-permeability cap that would significantly decrease stormwater infiltration and thus groundwater upwelling rates in the intertidal and shallow subtidal zones. The groundwater model used to estimate upwelling rates was based on a 95-percent estimated reduction of stormwater infiltration within the capped area. Considering the contributions of infiltration in upgradient and crossgradient uncapped areas and groundwater flow from the underlying Chuckanut formation, the resulting estimated reduction of groundwater discharge to the marine environment is approximately 70 percent.
2. An average upwelling rate was used for each sediment zone (upper intertidal zone, lower intertidal, and shallow subtidal). Actual upwelling rates would be expected to vary with distance away from the shoreline, but for the analysis of various alternatives, an average rate for each of the three zones was expected to adequately account for variabilities.
3. To determine the porewater concentrations to be used as the model input parameters, the 95 percent upper confidence limit (UCL) of the mean of 2-methylnapthalene and pentachlorophenol concentrations in upland groundwater were compared to the theoretical porewater concentrations calculated using mean sediment sample concentrations, conservative estimates of the fraction of organic carbon (Foc) in sediment, and chemical partitioning coefficients. Whichever concentrations were higher, were used in the cap model as input parameters for 2-methylnapthalene and pentachlorophenol concentrations.

4. The single most conservative contaminant concentration for each sediment zone was assumed to represent the entire zone, although the highest concentrations of the available sample data are not representative of average concentrations across larger areas.
5. Fractions of organic carbon for in situ sediment and sand cap materials were assumed based on existing Site sediment data and values used for similar projects and available capping material in the Puget Sound area.
6. It was assumed that capped areas would not be subject to natural recovery (i.e., no deposition of clean material) or experience erosion or consolidation of underlying sediment or cap material over the 100-year evaluation period.
7. It was assumed that there would be no natural degradation of the organic contaminants (i.e., decay rate equal to zero).
8. For amended cap scenarios, a two-layer model was used with the cap amendment material being placed as a first layer and unamended sand cap material as a second layer. This allowed the properties of each material to be modeled explicitly, although when a cap is constructed, amendment material would be mixed into the sand cap material based on the required amendment percentage (determined by model results).
9. The boundary conditions included the assumption that the overlying water (Bellingham Bay) and the capping material had an initial IHS concentration of zero.
10. The point of compliance for the porewater concentration was assumed to be at a depth 6 cm below the sediment-water interface. The explanation of this assumption is included in the second bullet of the "Point of Compliance" section below.
11. Other sediment and sand cap properties including hydrodynamic dispersivity, porosity, bulk density, and bioturbation depth were estimated based on literature and material vendor information.

3.3. Groundwater Upwelling Rates and Cap Zone Delineation

To determine where a conventional sand cap would meet the cleanup standards without adsorptive amendments, the CAPSIM model was used to calculate the maximum allowable upwelling velocity where a 2-foot thick conventional sand cap could be used as part of a cleanup alternative. Based on this calculated maximum upwelling velocity, the groundwater flow model was used to determine the approximate distance from the shoreline at which groundwater discharges at that upwelling velocity. This distance was used to determine the limit below which a 2-foot thick conventional sand cap would meet cleanup standards, and above which an amended or thicker cap would be required to attenuate contaminants in discharging groundwater.

Based on this analysis, the boundary where the upwelling velocity is low enough to allow a 2-foot conventional cap is approximately 65 feet from the shoreline (Table R-4), which corresponds to the approximate distance that the upper intertidal smear zone extends from the shoreline in most areas of the Site. Based on this result, the lowest elevation of the sediment smear zone was used as the boundary between the area where an amended or thicker conventional sand cap is necessary to isolate underlying sediment contamination and the area where upwelling rates and contaminant concentrations could be confined by a conventional 2-foot cap.

Using linear averaging between the maximum allowable upwelling boundary and the shoreline, the model input for upwelling velocity within the amended or thick cap zone was determined, and used to calculate the required cap thickness and amendment percentage (Table R-3).

3.4. Porewater Concentrations

Limited sediment porewater data were available to represent Site conditions. Therefore, porewater concentrations were estimated based on upland groundwater concentrations and theoretical porewater concentrations, as follows:

- Upland groundwater data (particularly those wells closest to the shoreline) used in the model were based on samples collected between 2000 and 2012 (RI, Section 3.0). The 2-methylnapthalene concentration data set included 21 samples and the pentachlorophenol data set included 22 concentrations. Several sample data points were removed from the data set because they would not be considered representative of post-cleanup upland conditions under any of the upland cleanup alternatives. The results that were removed either are spatial/statistical outliers or would be addressed as part of the upland cleanup. The 95 percent UCL of the mean concentrations of the remaining upland groundwater samples was then calculated and used to represent the potential porewater concentrations based on upland groundwater.
- To estimate the theoretical porewater concentrations, it was assumed that equilibrium between the sediment and porewater is achieved prior to discharging through the cap. As a conservative assumption, the theoretical porewater concentrations were calculated using maximum sediment concentrations, the average sediment organic carbon content, and contaminant-specific partitioning coefficients (see Table R-1 for the parameter values used in the calculations).

The two concentrations (i.e., empirical versus estimated) were compared, and the highest, and therefore most conservative, value was used to ensure that the model accounted for the highest potential concentration in upwelling groundwater entering the cap.

3.5. Fraction of Organic Carbon and Partitioning Coefficients

Total organic carbon concentrations in sediment at the Site were reviewed to evaluate the Foc to be used as the input parameter for the cap model. Total organic carbon concentrations for samples collected from the upper intertidal smear zone ranged from less than 1 percent to 67 percent with an average of 15.6 percent. The Foc used in the cap model was reduced to 5 percent to be more conservative and to account for the effect of LNAPL and the variability of organic material in existing sediment.

The linear Kd-specified sorption isotherm was used for the sand cap. When using this method, the model uses a Kd input parameter that was calculated based on the Foc in the cap material and the organic carbon partitioning coefficient of the chemical being modeled. Based on professional judgment and a review of other cap design projects, including the Lower Duwamish Waterway Feasibility Study (AECOM 2012), a baseline Foc value of 1 percent was assumed for the conventional sand cap material. A value of 1 percent is considered to be conservative as there is the potential to use material with higher natural organic carbon concentrations as cap material.

The linear Kd-specified sorption isotherm was also used to evaluate the use of organoclay amendment in the cap design. The Kd value for granular organoclay was provided by CETCO, an organoclay product vendor, and the Foc was back-calculated. The Freundlich sorption isotherm was used to evaluate an activated carbon amendment in place of the linear Kd-specified method, due to activated carbon's unique sorption process. Freundlich constants for 2-methylnaphthalene were provided by Dr. Reible; Freundlich constants for pentachlorophenol were estimated using literature reviews and conservative professional judgment.

3.6. Intertidal Sediment Excavation and Removal

The cap model was run for a range of cleanup alternatives that included varying amounts of contaminated sediment excavation and removal and capping. The alternatives that were evaluated include the following:

- No sediment removal;
- Removal of 2 feet of contaminated sediment followed by capping with 2-feet of conventional sand cap material;
- Removal of 4 feet of contaminated sediment followed by capping with 4-feet of conventional sand cap material;
- Removal of all sediment within the intertidal smear zone (i.e., to approximately 0 feet NAVD88) followed by capping with between 2-feet and 5-feet of conventional sand cap material to achieve original grade.

The excavation alternatives above influenced the maximum sediment concentrations and influenced the calculated theoretical porewater concentration for some chemicals used as input parameters in the model. As shown in Table R-1 below, the 95 percent UCL of the upland groundwater concentrations was higher than the maximum theoretical equilibrium concentration based on sediment concentrations for 2-methylnapthalene, and lower for pentachlorophenol. Therefore, the intertidal excavation conditions did not affect porewater concentrations of 2-methylnapthane, but had a significant effect on pentachlorophenol (because the maximum sediment concentration controlled the estimated porewater concentration for pentachlorophenol). Use of the upland groundwater concentration for 2-methylnaphthalene in determining cap performance is likely a very conservative input considering that most upland alternatives are expected to significantly reduce the groundwater concentrations of the IHSs.

3.7. Cap Amendment or Thickness Requirements

Two sand cap amendment compounds and a thicker conventional sand cap (greater than 2 feet) were each modeled for feasibility analysis. The thicker conventional sand cap was modeled using 1 to 3 percent Foc (i.e., representing a range of Focs in imported and natural sources of capping material) and variable thicknesses. Organoclay and activated carbon amendments were also modeled independently using sand conservatively assuming almost no carbon (i.e., used an Foc of 0.03 percent), and variable percentages of the amendment compound. Upwelling rates were averaged over the amended cap modeling area to account for a higher percentage of amendment (by weight) closer to the shoreline, and a lower percentage (by weight) of amendment at lower elevations. The cap amendment parameters are listed in Table R-3 below.

3.8. Point of Compliance

Sediment cap performance was evaluated to determine if the cleanup standards could be achieved for the following:

- Protection of sediment at the bottom of the biologically active zone. In Bellingham Bay this is assumed to be 12 cm below the sediment-water interface; contaminant concentrations at this point represent maximum benthic organism exposure prior to bioturbation and mixing.
- Protection of surface water using porewater concentrations at 6 cm below the sediment-water interface (i.e., mid-point of the bioturbation layer) to represent the sediment-surface water interface. This approach is conservative because less mixing with overlying surface would occur at this depth. In addition, the model requires a separate point of compliance from a boundary condition (since the contaminant concentration in surface water was set to zero as a boundary condition at the sediment-water interface, this boundary could not be used as the point of compliance for porewater).
- A cap lifespan of 100 years from time of construction.

The modeled contaminant concentrations at these points were compared to their respective cleanup levels to determine performance.

4.0 INPUT PARAMETERS

Table R-1 and R-2 summarize the model input parameters used when running the multiple amended cap scenarios summarized in Table R-3, and when identifying the maximum allowable upwelling rate where a 2-foot sand cap would meet cleanup standards (Table R-4).

TABLE R-1. EXISTING CONDITIONS

Sediment Properties		2-Methylnapthalene	Pentachlorophenol	Total Petroleum Hydrocarbons
Groundwater upwelling Velocity (cm/yr)		181.6		
Estimated Porewater Concentration	95% UCL (µg/L)	110	0.71	--
	Maximum theoretical[1] (µg/L)	96.85	159.32	625,000
Fraction Organic Carbon, f_{OC}		0.05		
Organic Carbon Partition Coefficient, K_{OC} (L/kg)		2,478	590	2,700,800
Diffusivity (cm2/s)		7.78x10-6	6.10x10-6	--
Hydrodynamic Dispersivity (cm)		1		
Porosity (decimal fraction)		0.5		
Bulk Density (g/cm3)		1.5		
Bioturbation Depth (cm)		12		
Benthic boundary layer mass transfer coefficient (cm/hr)		2.37		
Porewater Cleanup Level (µg/L)		15	3	250
Sediment Cleanup Level		670 ug/kg	100 ug/kg	260 mg/kg

Notes:

[1] Theoretical concentrations are based on contaminant partitioning coefficient and maximum sediment concentration at the depths corresponding to the alternatives. Maximum theoretical porewater concentrations shown occurred at sediment surface.

TABLE R-2. CAP MATERIAL PROPERTIES

Cap Material Properties		2-Methylnapthalene	Pentachlorophenol	Total Petroleum Hydrocarbons
Sand	Porosity (decimal fraction)	0.4		
	Bulk Density (g/cm^3)	1.6		
	Fraction Organic Carbon, f_{OC}	0.01		
	Organic Carbon Partition Coefficient, K_{OC} (L/kg)	2,478	590	2,700,800
	Partitioning Coefficient, K_d (L/kg)	24.78	5.9	27,008
	Hydrodynamic Dispersivity (cm)	1		
Organoclay	Porosity (decimal fraction)	0.5		
	Bulk Density (g/cm^3)	0.8		
	Octanol-Water Partition Coefficient, K_{OW} (L/kg)	3.86	5.09	7.23
	Partitioning Coefficient, K_d (L/kg)	14,621	437,522	161,800,000
	Hydrodynamic Dispersivity (cm)	1		
Activated Carbon	Porosity	0.4		
	Bulk Density (g/cm^3)	1.6		
	Freundlich, K_F ($ug/kg/(\mu g/L)^N$)	$7.25x10^6$	$7.25x10^6$	--
	Freundlich, N=1/n	0.42	0.42	--
	Hydrodynamic Dispersivity (cm)	1		

TABLE R-3. AMENDED CAP OR THICK CONVENTIONAL SAND CAP MODELING SCENARIOS

Cap	Amendment Type/Quanitity	Contaminant	Upwelling Velocity (cm/yr)	Porewater Concentration (µg/L)	F_{OC}	K_d	Meets Cleanup Standard ?
5-foot Sand	--	pentachlorophenol	181.6	0.71	0.01	5.9	Yes
5-foot Sand	--	2-methylnaphthalene	181.6	110	0.03	74.34	Yes
2-foot Sand	0.3% Organoclay	pentachlorophenol	181.6	159.32	0.0003	0.177	Yes
2-foot Sand	7% Organoclay	2-methylnaphthalene	181.6	110	0.0003	0.743	Yes
2-foot Sand	0.8% Activated Carbon	pentachlorophenol	181.6	159.32	0.0003	0.177	Yes
2-foot Sand	3% Activated Carbon	2-methylnaphthalene	181.6	100	0.0003	0.743	Yes

Note:

Bolded entry indicates the more conservative capping scenario necessary to meet cleanup standards for both indicator chemicals used in the cap model.

TABLE R-4. ALLOWABLE UPWELLING RATE (TO IDENTIFY WHERE THE THICK SAND CAP MAY TRANSITION TO THE 2-FOOT SAND CAP)

Alternative	Most Conservative IHS	Upland Groundwater Concentration (µg/L)	F_{OC}	K_d	Allowable Upwelling Rate (cm/yr)	Approximate Distance from the Shoreline where 2-foot Sand Cap Meets Cleanup Standards (ft)
S1	2-Methylnapthalene	110	0.01	24.78	21.5	65
S2	2-Methylnapthalene	110	0.01	24.78	21.5	65
S3	2-Methylnapthalene	110	0.01	24.78	21.5	65
S4	2-Methylnapthalene	110	0.01	24.78	21.5	65
S5a and S5b	2-Methylnapthalene	110	0.01	24.78	21.5	65

5.0 CONCLUSIONS

Modeling was used to determine where capping, assuming varying thicknesses and degree/type of amendments, could effectively confine underlying contamination and address groundwater transport of site-related compounds in the marine unit. The results of the modeling include the following:

- The maximum allowable upwelling velocity where a 2-foot thick sand cap would be sufficient to meet cleanup standards was spatially defined for each alternative. For each alternative the approximate distance from the shoreline where a 2-foot unamended sand cap becomes effective is approximately equal to the limit of the upper intertidal zone. Therefore, the smear zone boundary was used to delimit where the thick or amended sand cap versus the 2-foot conventional sand cap could be applied.

The potential for groundwater transport of site-related contamination (either from the upland or underlying sediment) between the shoreline and the smear zone boundary needs to be addressed as part of the sediment remedy. Using the input parameters summarized in this appendix, either a 5-foot thick conventional sand cap with a minimum Foc of 3 percent or a 2-foot thick sand cap amended with 7 percent organoclay or 3 percent activated carbon material, would be necessary to achieve cleanup standards in this zone.