Remedial Investigation and Feasibility Study

Gas Works Park Site
Seattle, Washington

for
Puget Sound Energy and the City of Seattle

January 2023

GeoEngineers
Earth Science + Technology

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2101 4th Avenue, Suite 950
Seattle, Washington 98121
206.728.2674

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Prepared for:

Puget Sound Energy
PO Box 97034 BEL11
Bellevue, Washington 98009-9734

Attention: Sara Leverette

Seattle Public Utilities
PO Box 34018
700 5th Avenue, Suite 4900
Seattle, Washington 98124-4018

Attention: Pete Rude

Seattle Parks and Recreation
300 Elliott Avenue West, Suite 100
Seattle, Washington 98119

Attention: David Graves

Prepared by:

GeoEngineers, Inc.
2101 4th Avenue, Suite 950
Seattle, Washington 98121
206.728.2674

Chris Bailey

Chris Bailey
Senior Environmental Engineer

Neil Morton
Senior Environmental Scientist

N A Musgrove

Nancy Musgrove
Environmental Scientist

John Herzog, LG, PhD
Senior Principal

Dan Baker, LG, LHG
Principal

ZAS:CLB:NAM:NFM:DMB:tln:leh

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ACRONYM AND ABBREVIATION LIST

%Pv	percent pore volume
2D	two-dimensional
3D	three-dimensional
AC	activated carbon
AKART	all known available and reasonable methods of treatment
ALU	ambient Lake Union
AO	Agreed Order
AOI	Area of Investigation
ARI	Analytical Resources, Inc.
AS/SVE	air sparging/soil vapor extraction
ATCO	American Tar Company
atm-m^3/mol	atmosphere-cubic meters per mole
Ballard Locks	Hiram M. Chittenden Locks
BAZ	biologically active zone
bgs	below ground surface
bml	below mudline
BMPs	best management practices
BSAFs	biota-sediment accumulation factors
BTEX	benzene, toluene, ethylbenzene, xylenes
C1	commercial-zoned
CAP	Cleanup Action Plan
CASRN	Chemical Abstract Service registry number
CD	1999 Consent Decree
cfd	cubic feet per day
CFR	Code of Federal Regulations
City	City of Seattle
CM	Conservancy Management
cm	centimeters
cm^2	square centimeters
cm/sec	centimeter per second
cm/year	centimeters per year

CN	Conservancy Navigation
COCs	contaminants of concern
COPC	contaminants of potential concern
COS	City of Seattle datum
cPAH	carcinogenic PAHs
CPOC	conditional point of compliance
CRM	Candidate Remedial Measure
CSL	cleanup screening level
CSM	conceptual site model
CSOs	combined sewer/stormwater overflows
CULs	cleanup levels
CW	Conservancy Waterway
CWA	Clean Water Act
cy	cubic yards
DCA	disproportionate cost analysis
DMMP	Dredged Material Evaluation and Disposal Procedures User Manual
DNAPL	dense nonaqueous phase liquid
DO	dissolved oxygen
DPD	Seattle Department of Planning and Development (became SDCI)
dw	dry weight
Ecology/ECY	Washington State Department of Ecology
ECRT	electro-chemical reduction technology
EIM	Environmental Information Management
ENR	Enhanced Natural Recovery
EPRI	Electric Power Research Institute
EPA	United States Environmental Protection Agency
ESA	Endangered Species Act
ESA	Eastern Sediment Area
ESRI	Environmental Systems Research Institute
EVS	Earth Volumetric Studio
feet/day or ft/day	feet per day
FFS	Focused Feasibility Study

FIPS	Federal Information Processing Standard
foc	fraction organic carbon
FOD	frequency of detection
FS	feasibility study
FSBD	Feasibility Study Bridging Document
ft^3/day	cubic feet per day
g/mol	grams per mole
GAC	granulated activated carbon
GIS	geographic information system
gpm	gallons per minute
GPS	global positioning system
GWMAs	groundwater management areas
GWPS	Gas Works Park Site
Haag	Richard Haag Associates, Inc.
Harbor Patrol	Seattle Police Harbor Patrol
HDPE	high-density polyethylene
HPA	hydraulic project approval
HPAH	high molecular weight PAH
HQ	hazard quotient
H:V	horizontal to vertical
I-5	Interstate-5
IA	Interim Action
IB	Industrial Buffer
IC	Industrial Commercial
IDW	Inverse Distance Weighting
JARPA	Joint Aquatic Resource Permit Application
L/kg	liters per kilogram
LIF	laser-induced fluorescence
LNAPL	light nonaqueous phase liquid
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
mg/kg	milligrams per kilogram

mg/L	milligrams per liter
µm	micrometer
mm Hg	millimeters mercury
MCL	maximum contaminant level
Metro	Municipality of Metropolitan Seattle
mg dw	milligrams dry weight
MGP	manufactured gas plant
MLS	multi-level sampler
MNA	monitored natural attenuation
MNR	Monitored Natural Recovery
MTCA	Model Toxics Control Act
NAD 83	North American Datum of 1983
NAPL	nonaqueous phase liquid
NAVD88	North American Vertical Datum of 1988
NEPA	National Environmental Policy Act
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
OC	Organoclay
OHW	ordinary high water
OHWM	ordinary high water mark
OSHA	Occupational Safety and Health Act
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCP	pentachlorophenol
PLPs	potentially liable parties
POTWs	publicly owned-treatment works
PQL	practical quantitation limit
PRB	permeable reactive barrier
PSE	Puget Sound Energy
RCRA	Resource Conservation and Recovery Act

RCW	Revised Code of Washington
RETEC	RETEC Group, Inc.
RI	remedial investigation
RL	reporting limit
RSLs	Regional Screening Levels
SAP	sampling and analysis plan
SCO	sediment cleanup objective
SCSD	Supplement to the Cleanup Standards Document
SCU	sediment cleanup unit
SCUM	Sediment Cleanup User's Manual
SEPA	State Environmental Policy Act
Ship Canal	Lake Washington Ship Canal
Shipyard	Northlake Shipyard
SLs	screening levels
SMA	sediment management area
SMC	Seattle Municipal Code
SMS	Sediment Management Standards
South Yard	Lake Union South Yard
SPR	Seattle Parks and Recreation
SPU	Seattle Public Utilities
State	State of Washington
SVOCs	semivolatile organic compounds
SWAC	surface area-weighted average concentration
TarGOST®	Tar-specific Green Optical Screening Tool
TEE	terrestrial ecological evaluation
TEQ	toxic equivalent concentrations
TOC	total organic carbon
TPAH	total polycyclic aromatic hydrocarbons
TPH	total petroleum hydrocarbons
UCM	unresolved complex mixture
UIC	Underground Injection Control
UM	Urban Maritime

USACE	United States Army Corps of Engineers
USC	United States Code
USCG	United States Coast Guard
USGS	United States Geological Survey
USTs	underground storage tanks
UV	ultraviolet
VOCs	volatile organic compound
WAC	Washington Administrative Code
WDAHP	Washington State Department of Archaeology and Historic Preservation
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WISHA	Washington Industrial Safety and Health Act
WNG	Washington Natural Gas
WRIA	Water Resources Inventory Area
WSA	Western Sediment Area
XRF	x-ray fluorescence
ZVI	zero-valent iron

1.0 INTRODUCTION

This remedial investigation and feasibility study (RI/FS) for the Gas Works Park Site (GWPS) addresses contamination from a former manufactured gas plant (MGP), a tar refinery and other historical industrial activities on Lake Union in Seattle, Washington (Figure 1-1). The RI/FS report has been prepared for Puget Sound Energy (PSE) and the City of Seattle (City) under a 2005 Agreed Order (No. DE 2008 [as amended]) with the Washington Department of Ecology (Ecology).

The GWPS includes the upland and sediment portion of the area of investigation (AOI) (Figure 1-2) defined in legal agreements[1] with Ecology. The AOI was developed to encompass areas of elevated contamination associated with the historical MGP, tar refining or other upland activities. The RI describes the nature and extent of chemical contamination in sediment and offshore groundwater within the AOI based on current Ecology regulations and guidance,[2] while retaining soil and upland groundwater cleanup levels from the 1999 Consent Decree (CD) and Cleanup Action Plan (CAP) for characterizing upland media. The RI also identifies how people and ecological receptors could be exposed to the contamination. The FS uses the RI findings to develop and evaluate a range of remedial alternatives to address the contamination, identifying a preferred alternative that protects human health and the environment and is permanent to the maximum extent practicable.

Contamination in the upland area has been largely addressed through a variety of previous cleanup actions described in Section 2, Summary of Investigations and Cleanup Actions, although a small area of uncapped bank soil remains and an area of shoreline arsenic-impacted groundwater requires further evaluation in the FS. The adjacent contaminated sediment area in Lake Union requires cleanup.

The RI:

- Summarizes the history, investigations, and cleanup actions performed to date and current environmental conditions within the AOI and surrounding area.
- Compiles and evaluates usable data.
- Summarizes human health and ecological risk evaluations performed and screening levels (SLs) used, including upland soil and groundwater cleanup levels established in a 1999 Consent Decree.
- Updates the nature, extent, and risks (to human health and ecological health) of contamination by comparing contaminant concentrations with soil and upland groundwater cleanup levels from the 1999 CD/CAP and current applicable screening levels for offshore groundwater and sediment.
- Evaluates the sources, characteristics, and transport of contaminants.
- Presents the current understanding of conditions in a conceptual site model (CSM).
- Identifies the locations and contaminants to be addressed by the remedial alternatives evaluated in the FS.

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[1] The legal agreements that define the AOI are the 1999 Consent Decree and the 2005 Agreed Order (see Section 1.3 for details).

[2] The Model Toxics Control Act, the Sediment Management Standards and associated guidance form the basis of the remedial investigation evaluations.

The FS:

- Describes cleanup objectives.
- Defines sediment management areas.
- Identifies and screens remedial technologies.
- Assembles remedial technologies into remedial alternatives.
- Evaluates the remedial alternatives, including a determination of the alternative that is permanent to the maximum extent practicable.
- Identifies a preferred remedial alternative.

Collectively, the RI/FS will be used by Ecology to select a cleanup action that will be documented in a draft CAP. The draft CAP will be reviewed by the public and other stakeholders prior to becoming final.

This RI/FS report was prepared consistent with the requirements of the Model Toxics Control Act (MTCA; Chapter 70A 305 Revised Code of Washington [RCW]) and applicable regulations (Washington Administrative Code [WAC] 173-340) and the Sediment Management Standards (SMS; WAC 173-204).

Sections 1 through 8 are part of the RI report; Sections 9 through 14 are part of the FS report. RI/FS references are included in Section 15. A notation has been placed in the header to delineate the RI and FS sections.

The appendices in this RI/FS report contain supporting information and document results of investigations and evaluations used in the main body of the report. However, some appendices were completed under outdated administrative and regulatory approaches. As a result, not all of the information they contain will comport with the main body of the RI/FS report.

1.1. Site Description

The AOI addressed by this RI/FS is defined in the 2005 Agreed Order (as amended; Ecology 2005a, 2013, and 2017a, b), which combines the upland portion of the GWPS defined in a 1999 Consent Decree (Ecology 1999) with the contaminated sediment area associated with historical upland industrial activities (see Section 1.3, Regulatory History). The upland and sediment portions of the AOI are separated by the ordinary high-water mark (OHWM[3]) as shown in Figure 1-2 and described below.

The AOI is the geographic area that is being evaluated in this RI/FS. The AOI comprises the upland Gas Works Park and Harbor Patrol properties and adjacent sediment as defined in Agreed Order No. DE 2008.

The GWPS is the name of the site and for the purposes of this report refers to the same geographic area as the AOI.

1.1.1. Upland Portion

The upland portion of the AOI is about 21 acres landward of the OHWM and includes Gas Works Park, portions of Waterways 19 and 20, and Seattle Police Harbor Patrol (Harbor Patrol) (Figure 1-2). It is bordered by industrial, commercial, and residential properties.

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[3] The OHWM is at an elevation of 22 feet USACE Locks Datum.

The Gas Works Park property is owned by the City and managed by Seattle Parks and Recreation. It consists of open grassy areas, a high grassy knoll known as Kite Hill (Figure 1-2), landscaping, historical industrial structures, and more than 2,000 feet of shoreline. Features of the shoreline include riprap, a concrete bulkhead along the southern shoreline known as the Prow, and low banks covered with blackberry and other invasive or opportunistic plants. A narrow gravel and mud beach is seasonally present at the base of the shoreline bank except in the riprap and bulkheaded areas. Signage and dense vegetation limit, but do not prevent, access to the shoreline. Waterway 19, owned by the State of Washington and managed by the Department of Natural Resources (WDNR), borders the northeast boundary of Gas Works Park and separates the park from an adjacent marina. A portion of the upland area of Waterway 19 is within the AOI.

The Harbor Patrol upland property west of the park is fenced, with two buildings, a storage bunker, a fueling station, and a paved parking lot (Figure 1-2). The property is owned by the City and managed by the Department of Finance and Administrative Services (FAS). Harbor Patrol uses the property is a base for all water-related emergency response along the 200 miles of shoreline within the City, the entire Lake Union, and portions of Puget Sound and Lake Washington. Harbor Patrol provides support to any other agency requesting assistance at a waterway. Harbor Patrol also uses the adjacent upland portion of the state-owned Waterway 20 (Figure 1-3), subject to WDNR Waterway Use Permit No. 20-089981. Harbor Patrol temporarily stores debris and other objects retrieved from the lake on the property and a boat ramp is located on the property. The upland portion of Waterway 20 is outside of the AOI.

The majority of the upland portion of the AOI has been remediated through a variety of previous cleanup actions described in Section 2. As described in Section 2, the majority of the upland is capped (see Figure 2-7).

1.1.2. Sediment Portion

The 56-acre sediment portion of the AOI is waterward of the OHWM and incorporates most of the aquatic portion of Waterway 19, all of the aquatic portion of Waterway 20 and the lake bottom adjacent to Metro's[4] Lake Union South Yard (South Yard), Harbor Patrol, and Gas Works Park (Figure 1-3). This area of North Lake Union is also part of the Lake Washington Ship Canal (Ship Canal), which links Lake Washington with Puget Sound. Over-water features within the AOI are associated with the western portion of Gas Works Park Marina that extends into Waterway 19, the Harbor Patrol property, Metro's South Yard and the eastern-most portion of the Northlake Shipyard. Both the shipyard and the marina have additional over-water structures immediately adjacent to the AOI.

- Gas Works Park Marina: over-water structures include floating boat houses and a series of docks providing moorage for floating homes and boats. The marina property is privately owned; however, residents at the Marina lease three small parcels at the southern end of the marina property from WDNR (Lease Numbers 20-013648, 20-A79485, and 20-B12133).
- Harbor Patrol: over-water structures include a boathouse, pile-supported piers, a floating dock, and a log boom. These over-water structures are on city-owned aquatic property and state-owned aquatic property subject to a use permit and lease between the City and WDNR (Aquatic Waterway Use Permit No. 20-08991 and Lease No. 20-009624).

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[4] Metro is the former Municipality of Metropolitan Seattle, a multi-jurisdictional sewerage and transportation agency that became part of King County in 1993.

- Metro Lake Union South Yard: over-water structures include two piers linked by a shoreside wharf. Structures fall within the King County property boundary.
- Northlake Shipyard: over-water structures include a wharf and fixed and floating piers. Most structures fall within four parcels owned by the state and leased from WDNR, three that are outside of the AOI and one that is within the AOI and waterward of the Metro South Yard (Lease No. 20-A12992). The remainder of the structures fall within the shipyard property boundary.

The sediment portion of the AOI was designated in the 2005 Agreed Order and identifies an area of sediment that contains hazardous substances, primarily polycyclic aromatic hydrocarbons (PAHs)[5], that are associated with releases from historical upland industrial activities. The sediment portion of the AOI will be managed as a sediment cleanup unit (SCU) in accordance with the SMS. This is discussed further in the FS.

1.2. Past and Present Ownership

The upland portion of the AOI has been developed since approximately 1907. The ownership history is summarized below:

- The Seattle Gas Light Company acquired most of the present-day Gas Works Park in 1905, except for certain properties on the western portion, for construction and operation of an MGP.
- A northwestern parcel was sold to the City in 1910 and later leased by the American Tar Company (ATCO).
- Most of the City-owned portion of the property that now houses Harbor Patrol was owned by Murray-Francis Marine before 1929. The property was sold to Paramount Briquetting in 1929, which sold it to the City in 1962.
- The City received the legal title to the Gas Works Park property in 1973, following a 10-year purchase period[6].

Current property ownership is mapped on Figure 1-3. Although the City owns almost all of the upland portion of the AOI, the State of Washington (State)[7] owns the upland portion of Waterway 19 that falls within the AOI.

The State owns most of the sediment portion of the AOI, except for the following:

- Small parcels owned by the City and King County[8].
- The parcel forming the eastern boundary of Waterway 19 is owned by Gas Works Park Marina.

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[5] PAHs are a large group of related chemicals that have both natural and manufactured sources. Over time, regulations have shifted the emphasis to a specific subset of PAHs—carcinogenic PAHs—for the protection of human health and the environment.

[6] The City purchased the upland property from PSE's predecessor through a series of contracts between 1962 and 1973.

[7] Aquatic lands owned by the State of Washington are managed by the Washington Department of Natural Resources (WDNR).

[8] Property records indicate that the shoreland portions (between the shoreline and the Harbor Line) of most of the Gas Works Park parcels were deeded to Seattle Light Company in 1909 (WDNR Index Map D-047). Additional shorelands southeast of the park were acquired by Washington Natural Gas (WNG) in 1962. The westernmost parcel was sold to the City in 1910; other parcels were transferred as part of the final sale to the City. King County owns the in-water portion of the Metro Lake Union (South Yard) property.

1.3. Regulatory History

The GWPS has a long and complex regulatory history requiring various actions at the site. Multiple environmental investigations associated with Gas Works Park and adjacent properties (including Lake Union) have been performed since the 1970s in response to regulatory requirements and legal agreements. Gas Works Park was evaluated for inclusion on the United States Environmental Protection Agency (EPA) National Priorities List (NPL) in the 1980s. In 1996, Ecology and EPA signed a Deferral Agreement (Appendix 1A) that deferred consideration of the Site for listing on the NPL while Ecology oversees cleanup activities under its regulatory authority. Since then, under various legal agreements, Ecology has directed environmental investigations, studies, cleanup action planning, and remedial actions conducted by PSE and the City. Ecology has also implemented a remedial action.

The key regulatory events and activities that have occurred at the GWPS since 1996 are shown on Figure 1-4. The regulatory drivers and agreements associated with investigation and cleanup at the GWPS are discussed further below. Regulatory boundaries are shown on Figure 1-2.

- 1997 Agreed Order – Required preparation of a focused feasibility study (FFS) and a Cleanup Action Plan (CAP) related to upland contaminated media (Ecology 1997).
- 1999 Consent Decree – Established the framework to complete cleanup actions on the upland portion of the AOI, including MTCA-compliant cleanup levels (CULs) for soil and groundwater. Sediment remediation and full analysis of the upland-to-sediment pathways were deferred to occur later under a separate MTCA legal agreement.
    - The 1999 Consent Decree (Ecology 1999) was amended in 2005 to incorporate an updated CAP, which addressed cleanup of undeveloped areas of the park.
- 2005 Agreed Order – Defined a 56-acre area of sediment, contaminated primarily with PAHs, associated with historical industrial upland activities, and required preparation of an RI/FS report for this sediment area (Ecology 2005a).
    - In March 2013, the 2005 Agreed Order was amended to combine the upland area remediated under the 1999 Consent Decree with the sediment area to create a single AOI, which is the focus of this RI/FS (Ecology 2013).
    - The 2005 Agreed Order was further amended in 2017. The second amendment (April 2017) addressed the installation of groundwater monitoring wells and treatment infrastructure for a planned interim action to reduce arsenic in groundwater in the Play Area portion of the park (Ecology 2017a). The third amendment (October 2017) called for operation and monitoring of that treatment system (Ecology 2017b).

1.4. Operational History

The GWPS history reflects the evolution of the Puget Sound region. Formerly territory occupied by three indigenous communities (the Duwamish, Hachooabsh, and Shilsholes), the area surrounding North Lake Union was settled by non-natives in the mid- to late-1800s. The first industries were associated with sawmills and forest products that supported small farms and homesteads in the area. In 1891, Wallingford and other communities on the north side of Lake Union were annexed by the City. In 1907, construction of an MGP was completed in the upland to supply fuel for the growing population. Other industries (e.g., tar refining, bulk fuel storage, shipbuilding) followed, operating along the North Lake Union shoreline adjacent to the MGP. Lake Union was a major barge route for coal mined in eastern King County, timber, and other raw or manufactured materials.

A summary of the MGP operations from 1907 onward are discussed in the following sections, along with historical information about other industrial activities that occurred on or adjacent to the upland portion of AOI. Historical features associated with the GWPS are shown on Figure 1-5. Additional detail on the operational history is provided in Appendix 1B.

1.4.1. MGP Operations

Before natural gas was widely available, combustible gas was produced from coke, coal, and oil at MGPs throughout the United States (EPA 1988). These MGPs, often called gasworks or town gas plants, provided fuel to the towns in which they operated and were instrumental in the early development of many communities. The MGP constructed by the Seattle Gas Light Company on the eastern side of what was then known as Brown's Point operated from 1907 to 1956 and was known as the Lake Station MGP. The Trans Mountain Pipeline began providing natural gas to the Seattle area in 1954, thus decreasing demand for manufactured gas, which led to the plant closure in 1956 (Sabol et al. 1988). The MGP was placed in standby mode in 1956; tanks were added to the facility for storage of natural gas until the property transferred to the City in 1973.

Three gas manufacturing processes were used over the life of plant operations. Raw materials used in the manufacture of gas varied depending on the manufacturing process, but generally consisted of coal, oil, and water. Byproducts differed by manufacturing process but also included commercially valuable products such as tar, coke, lampblack, and light oil that were either reused as fuels or sold to other industries. Tar, one of the most valuable products produced by all of the gasification processes at the MGP, was used for a variety of purposes and refined into a variety of products. Tars (primarily coal tar) were sold to manufacturers of creosote, pitch, and roofing materials[9]. ATCO and other tar refiners purchased tars from the MGP. Tar was also shipped off-site via rail or water (see the tar loading dock on the eastern shoreline shown on Figure 1-5).

Manufactured gases typically contained impurities and needed to be cleaned prior to delivery. Auxiliary processes (e.g., cooling and scrubbing) were used to remove the small amounts of free carbon (e.g., lampblack), tar, light oil, sulfur, ammonia, and other contaminants that were present in the gas. Many of these purification processes also created products that had high commercial value and were resold. Lampblack, along with some tar, was used to create briquettes for resale or reuse as boiler fuel. Light oils, including benzene and toluene, were recovered during the cooling process and further refined and then sold.

Sulfur constituted the largest volume of waste in the MGP processes (Ahlquist 1954). Initially, sulfur was removed by passing the gases through wood shavings coated with hydrated iron oxide in a series of purifier boxes. A later process improved removal by introducing the gases to a recirculating sodium thioarsenate solution, which bound the sulfur (the Thylox purification process). Oxygen bubbled through the solution, displacing the elemental sulfur precipitate, which was skimmed off, dewatered in a Kelly filter press, and then disposed of afterwards. After Thylox purification, a final process to remove the remaining sulfur relied on passing the gases through purifier boxes.

All byproducts generated by the MGP processes that could not be reused or sold were typically delivered to off-site landfills. However, based on historical research (see Appendix 1B) and results of site-specific environmental explorations, some of the MGP wastes (e.g., cinders, brick, concrete, clinker, ash), raw materials, products, and byproducts (e.g., coke, tar, lampblack, coal) were spilled or released. The United

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[9] Information compiled from individual Brown's Directories from 1914 to 1937.

States Geological Survey (USGS) and others have described a Gas Works Deposit—a fill layer that can contain agglomerate, lampblack, oil, tar, ash, cinders, brick, wood, concrete, or other material—as being present below ground surface (bgs) at the park (Sabol et al. 1988). Land regrading and park development activities performed in the mid-1970s redistributed MGP raw materials, products, byproducts, and wastes contained in the fill.

The main processes (heating, cooling, tar removal, and initial purification) took place in the east and south-central area of the present-day park. The removal, refining, and storage of light oil (including benzene) took place in the southeast area (south of the Play Barn). The Thylox purification system operated in the east-central area. Purifier boxes containing iron-oxide-coated wood chips were located in the southeast area. Lampblack was stored in a large area in the south-central area, south/southwest of the Cracking Towers.

Three docks formerly along the eastern shoreline are identified on Figure 1-5 (north to south) as the lake suction dock, tar loading dock, and oil dock. The lake suction dock appears to have been constructed by 1919 (Sanborn Fire Insurance 1919) and was used to provide cooling water to the MGP. The tar loading dock, used for offloading and shipping commercial products from the MGP, was first evident on a 1927 United States Army Corps of Engineers (USACE) “lake conditions” map. In 1937, the MGP received a permit from the USACE to install three dolphins along the eastern shoreline to guide navigation for oil tankers delivering raw material (USACE 1937); the oil dock was likely constructed at this time.

At least six outfalls conveyed surface runoff, steam boiler blowdown water, condensed steam, and cooling water from multiple MGP sources to the lake (Figure 1-5). Some discharges were filtered before entering surface waters (Foster 1943). Historical MGP-related outfalls are depicted in Figure 1-5 (additional information is provided in Appendix 1B).

1.4.2. Other On-site Industries

Many types of non-MGP industrial activities have historically occurred in the upland: tar refining, boatbuilding and boat repair, municipal waste incineration, municipal landfilling, light oil refining, chemical manufacturing, briquetting operations, fuel storage and sales, shingle milling, coal and gravel storage, and barge and tug operations. Most of these activities took place in the western portion of the AOI upland. Tar-refining operations took place over the longest period (1907 until the mid-1960s at ATCO) and had a significant impact on conditions in the western portion of the AOI (both upland and sediment). Additional information about on-site activities for these former facilities is provided in Appendix 1B; potential impacts of other industrial activities were assessed as part of site-wide investigations and are described as part of the nature and extent evaluation (Section 5) and in the CSM (Section 7).

1.4.3. Adjacent Lake Union Industries

Other areas of Lake Union were similarly industrialized during the same period as the MGP operation and contributed to the level of contamination found in the lake today. Marine commerce, which began in 1911, was significantly expanded by the completion of the Ship Canal in 1916. By the 1920s, urbanization and industrial production established Lake Union as a “working lake,” with over half the shoreline acreage used for manufacturing operations and industries, including boat works and maritime-related industries, engine repair facilities, machine shops, asphalt companies, oil storage and fueling operations, lumber and plywood mills, log rafting, and bulk materials storage and transport. Many facilities discharged wastes to the lake (Foster 1943; WPCC 1946; WPCC 1958).

The 1943 publication (Foster 1943) for the State of Washington Pollution Control Commission also describes spills into Lake Union from fueling facilities and oil loss at other facilities. Spills during barge unloading of raw materials and products (e.g., coal, petroleum, and gravel) were also reported.

Lake Union also received discharges from combined sewer/stormwater overflows (CSOs), private sewage outfalls, and public and private storm drains serving the urbanizing area. Between 1943 and 1977, the number of City and King County CSO outfalls that discharged to Lake Union nearly doubled, from 10 to 19 (Tomlinson et al. 1977). New storm drain pipes and outfalls were also added, such as those carrying runoff from Interstate-5 (I-5). Fewer CSOs discharge to Lake Union today and discharge volumes have decreased over the last five decades through construction of treatment plants and ongoing improvements to wastewater infrastructure.

As a hub for historical marine and boating activities, Lake Union also received waste[10] from marinas, boats, and houseboats (Foster 1943; Tomlinson et al. 1977) for decades. In Ecology's online Permitting and Reporting Information System database, 11 permitted discharges to Lake Union were found, of which 7 were associated with shipbuilding, repair, and maintenance. The nature of development has broadened to include more marinas, houseboats, offices, restaurants, and shoreline residences.

In recent history, facilities adjacent to the MGP included Harbor Patrol (still operational and part of the GWPS), a shipyard (still active today), a bulk petroleum storage facility, a tar products manufacturer, and a marina (still operational).

Additional information about industries near the AOI, associated cleanups, and long-term monitoring results can be found in Section 1.4.4 and in Appendix 1B.

1.4.4. Adjacent MTCA Cleanup Sites

MTCA cleanup sites located in the general vicinity of the GWPS are shown on Figure 1-6.

1.4.4.1. Northlake Shipyard

The Northlake Shipyard is located north and west of the AOI boundary and has been operating since at least 1956. There have been numerous complaints about, and investigations related to, unpermitted discharges to the lake from the shipyard throughout its history. In 1985, the federal government filed a civil complaint under the federal Clean Water Act (CWA) and Refuse Act and later charged the shipyard with dumping used sandblasting material (which typically contains heavy metals and tributyltin), paint chips, tar, rust, solvents, spilled liquids, and grease and oil into Lake Union. Eventually, the shipyard entered into an agreement with the EPA to clean up the site; this agreement was later transferred to Ecology. The shipyard funded a trust allowing the State to conduct a site cleanup. Ecology conducted an interim action to remove sandblast grit released during past shipyard operations. The interim action included dredging 8,300 cubic yards of sandblast grit contaminated sediment; removing 23 tons of scrap metal and 20 pilings; and backfilling the dredged area with clean sand. The interim action at the North Lake Shipyard was completed in early 2014 (Hart Crowser 2014).

The footprint of the dredge area is shown Figure 1-6. In addition, lake-wide maps, including Figure 5-18 (cPAHs), Figure 5-19A (total PAH [TPAH]), Figure 5-20 (arsenic), and Figures 5E-2 through 5E-16 (additional

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[10] Typical wastes from these sources included oils and grease, fuels, anti-fouling chemicals, and sewage

sediment COCs) show the footprint of the dredged area and illustrate the distribution of contaminants in surface sediment in the vicinity of the shipyard.

1.4.4.2. Metro Lake Union

West and northwest of the AOI upland is the former Chevron Bulk Fueling Terminal that is composed of two separate parcels formerly referred to as the North and South Yards of the Metro Lake Union facility. The South Yard parcel is owned by King County and the upland portion is leased by the Center for Wooden Boats. The South Yard parcel borders the AOI west of Waterway 20. Overwater structures related to the South Yard are located within the AOI sediment area. From 1925 to 1982, the South Yard was used as a petroleum products distribution terminal (Ecology 1998). The former North Yard consisted of the tank farm that stored gasoline and gasoline distillates, fuel oil, refined oil, lubricating oils, and diesel oil until 1992, when Metro decommissioned the aboveground tanks. Although not immediately adjacent to the AOI, subsurface fuel distribution pipes extended from the North Yard to the lakeshore and daylighted beneath fueling docks that are within the sediment portion of the AOI. A draft CAP for the site (Foster and Wheeler 1998), an exhibit to a 1998 consent decree for the site (Ecology 1998), lists historical occupants of the South Yard as Puget Sound Sheet Metal Works, a tannery, an oil and asphalt warehouse, and California Spray and Chemical Company (a predecessor of Chevron), which historically produced lead arsenate insecticide spray (Applied Geotechnology 1993). The Schultz Distributing Company also occupied the South Yard from the late 1970s to early 1980s. According to a 1991 Ecology memo, ‘Ecology staff indicate that Schultz Distributing has contributed to contamination on a number of sites through their operational practices’ (Ecology 1991).

Separate cleanup actions were implemented in the former North and South Yards between 1988 and 2015 to address contaminated soil and groundwater in the uplands. Metro conducted a cleanup under a 1998 Consent Decree that included tank and pipe demolition and disposal, localized soil excavation, bioremediation of soil and groundwater, and long-term groundwater monitoring. The 1998 Consent Decree was limited to the upland (former North and South Yards) and did not address sediment[11]. Additional excavations occurred in 2014 and 2015 in the former North Yard as part of the redevelopment by Touchstone Corporation under a 2007 Prospective Purchaser Consent Decree.

1.4.4.3. Former Nortar

The former ATCO[12] facility relocated immediately north of Gas Works Park on North Northlake Way in the mid-1960s (Figure 1-6). Renamed Nortar in the late 1990s, the company continued to manufacture roofing products and formulated wood preservatives for about 20 years until the late 1980s (Equipoise Corporation 1999). After conducting a MTCA-compliant site hazard assessment in 1997, Ecology added the site to the list of Hazardous Sites and Confirmed and Suspected Contaminated Sites because soil and groundwater had been impacted by releases of petroleum hydrocarbons, pentachlorophenol (PCP) and PAHs. Although the site does not border the shoreline, its stormwater discharged to Lake Union via a municipal outfall located in Waterway 20.

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[11] The 1998 Consent Decree further states that “any future action concerning or related in any way to the sediments in Lake Union shall be addressed in a document other than this Decree, and this Decree shall not be amended or interpreted to address the sediments in Lake Union” (Part V, 4).

[12] ATCO operated at the GWPS until the mid-1960s before moving operations. See Appendix 1B for more information.

1.4.4.4. Waterway 20 Upland

Ecology added the Waterway 20 upland area to the list of Confirmed and Suspected Contaminated Sites in 2021 based on a soil investigation completed by the City of Seattle FAS in 2016 (Herrera 2016). Carcinogenic PAHs were detected in soil at concentrations greater than the MTCA Method A soil cleanup level. The 2016 soil investigation report did not include a discussion of site history. The City of Seattle FAS, as licensee (WDNR Aquatic Waterway User Permit No. 20-089981), is investigating the upland portion of Waterway 20 with WDNR oversight.

1.5. Property Redevelopment and Park Construction

Gas manufacturing at the former MGP terminated in 1956. In 1962, the City entered into an agreement with Washington Natural Gas (WNG) to purchase the MGP property over time. From 1962 to 1970, the City used the western portion of the upland to stockpile material generated from construction along I-5, the Safeco building in the University District, and other off-site areas. The stockpile became known as the Great Mound and was later reconfigured as Kite Hill (Ecology 2000; Sabol et al. 1988; Parks and Recreation 1984). The Great Mound was partially constructed on property where a municipal landfill and refuse incinerator historically operated. The MGP plant was located east of this area, but a portion of Great Mound footprint was used by the MGP for lamp black storage.

A master plan for Gas Works Park was drafted by Richard Haag Associates, Inc. (Haag) and approved by the City in 1971 (Haag 1971). WNG began dismantling plant structures in accordance with the purchase agreement. In 1972, Haag amended the demolition strategy to retain the six Cracking Towers (oil gas generators), light-oil absorber, boiler house, and machine building (Play Barn) (Parks and Recreation 1984; Haag 1973a).

Demolition, including targeted excavation and off-site disposal of contaminated soil, continued until July 1974. The fate of former MGP structures, researched as part of the RI historical source evaluation, is presented in Appendix 1C.

In 1976, the majority of the park was regraded as part of the landscape design. Areas west and north of the Cracking Towers were sculpted into their current topographic form and the northeastern and eastern shoreline were regraded. The Great Mound was regraded to the general current topography[13] of Kite Hill using soil stockpiled on-site (Parks and Recreation 1984; Haag 1975).

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[13] Kite Hill was regraded and capped with clean soil in late 2014.

2.0 SUMMARY OF INVESTIGATIONS AND CLEANUP ACTIONS

The City, PSE, EPA, and Ecology have investigated and monitored the presence of contaminants within the AOI over several decades. The first site-specific investigations to evaluate environmental conditions in the upland began in 1971 as part of park development; many other investigations have followed. In 1997, investigations to support cleanup planning for the upland began. Following selection of a remedy in the 1999 Consent Decree, upland cleanup commenced, and construction was completed by 2001, followed by long-term monitoring.

A summary of investigations performed in the upland and sediment portions of the AOI is provided in Tables 2-1 (upland) and 2-2 (sediment); additional detail on specific investigations can be found in Table 2C-1 in Appendix 2C. The locations and types of explorations are shown on Figure 2-1 (soil), Figure 2-2 (groundwater), and Figures 2-3 through 2-6 (sediment). Figure 2-3 shows the location of all sediment samples; Figures 2-4 through 2-6 show subsets of sediment samples and are discussed below.

Cleanup actions performed to date in upland areas of the AOI are primarily related to park development and requirements of the 1999 Consent Decree. Previous upland cleanup actions and maintenance activities are listed in Table 2-3 and summarized in this section.

2.1. Previous Investigations

The type and breadth of previous investigations are summarized below:

- Site-wide investigations – Investigations of the extent of site-related contamination have included over 390 explorations[14] in the upland (Figure 2-1) and over 420 explorations in the sediment (Figure 2-4). The sampling density and areal coverage in the sediment portion of the AOI increased over time, as shown in the time-series graphics provided in Figure 2-5. Observational (e.g., sheen, odor, soil or sediment characteristic) and quantitative non-chemical measurements (e.g., groundwater elevations, topography, bathymetry) were made as part of other explorations supporting nonaqueous phase liquid (NAPL), geologic, hydrogeologic, geotechnical, and source evaluations. The quantitative non-chemical data were used to support development of the conceptual site models in the RI and development of cleanup action alternatives in the FS.
- Groundwater characterization – Analytical and physical data from more than 80 monitoring wells (deep, shallow, and multi-depths) have been collected from 1986 to December 2020 (Figure 2-2). Well construction details are presented in Table 3J-1 of Appendix 3J. Multiple rounds of slug tests, pump tests, and water level measurements in selected wells (Table 3J-2 in Appendix 3J) have been conducted to characterize the upland groundwater and support development of a three-dimensional (3D) model of hydrogeologic conditions (Appendix 3F).
- Geology – A site-wide geologic CSM (Section 3.2.4 and Appendix 3B) was developed from geologic data obtained from more than 150 of the explorations in the upland and more than 250 explorations in the sediment. Physical properties of soil and sediment were established based on vane shear, cone penetrometer tests, triaxial tests, bearing plate tests, sieve analyses, and standard penetration tests. Geotechnical sampling locations in sediment area shown in Figure 2-6.

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[14] An exploration is a unique location where environmental conditions were assessed. One or more samples were collected at most explorations (for example, soil samples collected at multiple depths within a soil boring).

- Physical conditions – Site-specific Lake Union surveys to map bathymetry, evaluate substrate conditions and debris distribution, and estimate sedimentation rates have been conducted (see Appendix 2C, Table 2C-1).
- Magnitude and spatial extent of contamination in environmental media – Analytical data have been collected from soil (over 400 samples), groundwater (over 400 samples), sediment (over 700 samples), offshore groundwater, porewater, air, NAPL, tar, and catch basin solids. These data supported evaluations of the nature and extent of contamination, geologic and hydrogeologic conditions, risks to people and ecological receptors, fate and transport of contaminants, natural attenuation of groundwater contamination, and the potential for natural recovery of sediment.
- Extent of NAPL and tar – Field observations from more than 200 explorations in the upland and 350 explorations in Lake Union sediment were used to map areas impacted by NAPL or tar (see Figure 5-26B and Appendix 5F). NAPL mapping and characterization techniques also included thickness gauging, laser-induced fluorescence probing (Tar-specific Green Optical Screening Tool [TarGOST®]), ultraviolet (UV) photography and petrophysical testing of soil cores, and NAPL recovery testing. Site-specific surveys to identify potential NAPL or tar seeps and characterize tar occurrences in sediment have also been conducted.
- Source characterization – Many data types (e.g., geophysical, petrophysical, UV photography, fluorescence, historical maps, and photos) were used to determine if any original sources remained (e.g., subsurface piping, tanks) and to identify areas impacted by historical sources (see Appendices 1A, 1B and 5F).

Many investigations have been conducted during the last 40 years in the upland and sediment areas of the AOI, as noted in Tables 2-1 and 2-2. The locations and types of upland explorations are presented on Figures 2-1 and 2-2; Figures 2-3 through 2-6 provide similar information for the AOI sediment area.

Many other special or highly focused studies have also been conducted; most of the resulting data were incorporated into the comprehensive RI data set (Appendix 5A). Additional detail about previous investigations is provided in Appendices 2C (broader studies) and 2D (special studies).

The City has also conducted investigations to evaluate the need for potential source control measures to protect a future sediment remedy. The GWPS storm drain system (underground pipes, catch basins and outfalls) includes outfalls that discharge from the park and Harbor Patrol as well as outfalls in Waterway 19 and Waterway 20 that capture stormwater from the upland portion of the GWPS and off-property areas, as shown on Figure 6B-1 of Appendix 6B. Storm drain source evaluations are summarized in Section 6.7; details are provided in Appendix 6B.

2.2. Previous Upland Cleanup and Remedial Actions

Previous cleanup work in the upland falls into the categories listed below. See Table 2-3 and Figure 2-7 for details.

- Independent remedial actions
- Cleanup actions conducted under the 1999 Consent Decree
- Interim actions conducted under 1997 and 2005 Agreed Orders

These previous upland cleanup and remedial actions are discussed below; additional detail is provided in Table 2-3. Figure 2-8 shows the current “state of the site.”

2.2.1. Independent Remedial Actions

Independent remedial actions were conducted prior to the 1999 Consent Decree and were primarily associated with the demolition of the MGP and redevelopment as a park. One exception was a diesel tank that was decommissioned at the Harbor Patrol property in 1999.

Most of the MGP facility was demolished between 1973 and 1976 (details are provided in Appendices 1A and 1B). As part of demolition and redevelopment activities, contaminated soil was excavated and disposed of off-site. Contaminated soil at the former facility was excavated to a depth of 1.5 feet to 8 feet bgs (Figure 2-9), including the area around the former water gas relief holders, Cracking Towers, the light-oil plant, various tar wells and tar separators, tar and oil storage tanks, lampblack storage areas, and the former Kelly filter (see Appendix 1C, Figure 1B-1 and Table 1B-1 for the fate of specific buildings and structures associated with excavation areas). The upland was extensively regraded (both cutting and filling) using redistributed contaminated soil and clean material that had been stockpiled at the upland (Figure 1A-6 of Appendix 1B shows excavation (cut) and fill contours). During regrading, the ground surface was lowered (cut) up to 33 feet or raised (filled) up to 27 feet[15]. As a result of these actions, contamination in shallow fill is no longer tied to the location of former points of release or underlying soil.

Demolition plans from 1973 (Haag 1973b) show a concrete burial area in the northwest section of the upland. Materials (rubble and soil) containing “trace amounts of sodium arsenate and sodium thioarsenate” from the Thylox purification facility were also buried on-site (Hart Crowser 2012a) in an excavated area near the base of Kite Hill. Additional details on demolition and excavation during park development are provided in Appendix 1B.

Approximately 41,000 cubic yards of soil was excavated during park development (Haag 1997). The volume of excavated material that remained on-site is uncertain. Some of this material was reused as fill (Hart Crowser 2012a), including for Kite Hill construction[16]; the rest was transported off-site for disposal.

In 1976, the areas west and north of the Cracking Towers were sculpted into their current topographic form, and the northeastern and eastern shoreline were regraded. The Great Mound[17], an on-site soil stockpile, was regraded to the general current topography of Kite Hill (Parks and Recreation 1984; Haag 1975). This regrading phase also included filling of the landscaping berms and tilling. The net change in grade from 1973 to 1976 (Figure 1A-6) shows the degree to which soil/fill was redistributed during property redevelopment.

After regrading, a layer of soil, sawdust, and dewatered biosolids was tilled into the soil throughout the Park to encourage the breakdown of contaminants and control dust (Richard 1983; Parks and Recreation 1984), often mixing deeper contaminated soil with these surface materials (Hart Crowser 2012a). This tilled surface was then covered with 2 inches of hydroseeded topsoil. A more detailed description of park development cleanup actions is presented in Appendix 1B.

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[15] The net cut and fill contours shown on Figure 1A-6 of Appendix 1BA were developed by comparing topographic surveys from 1973 and 1976.

[16] Contaminated soil was typically covered by up to 6 feet of cleaner material (Hart Crowser 2012b).

[17] From 1962 to 1970, the City used the western portion of the upland to stockpile thousands of cubic yards of material generated from construction along I-5, the Safeco building in the University District, and other off-site areas. The off-site material was assumed to be clean based on the sources of the material; however, there is no documentation confirming the fill material quality.

2.2.2. 1999 Consent Decree Cleanup Actions

The 1999 Consent Decree and CAP (Parametrix 1999) in the upland required both specific cleanup actions and maintaining the integrity and protectiveness of the remedy over time.

2.2.2.1. Cleanup Actions

Cleanup actions required by the 1999 Consent Decree included capping (Figure 2-7), groundwater treatment, groundwater monitoring, and implementation of institutional controls. Listed below are the specific cleanup actions that have been completed in the upland under the 1999 Consent Decree by the City and PSE; locations of these cleanup actions are shown in Figure 2-7:

- Shallow tar associated with observed or suspected tar seeps was excavated and backfilled with clean material in upland areas in 1997.
- Fencing was improved around the Cracking Tower. Signage regarding site hazards to visitors was also installed.
- Recovery wells were installed in the southeast corner of the park and oil was removed prior to construction of the air sparging/soil vapor extraction (AS/SVE) groundwater treatment system in this area.
- Placing a vegetated soil cover (cap) over about 5.7 acres of unpaved open areas of the park – In 2000-2001, a geotextile barrier was placed over contaminated soil, followed by a 12- to 18-inch-thick vegetated soil cap (ThermoRETEC 2001).
- Placing a vegetated soil cap over about 2 acres in the northwest corner of the park – In 2005, the northwest corner of the park was regraded and capped (a 1-foot thick minimum vegetated cap was placed over a geotextile barrier per the 1999 Consent Decree), thus making a previously closed area of the park publicly accessible (Parks and Recreation 2005). The cap thickness varied from 1 to 4 feet per the Seattle Parks and Recreation grading plan.
- Installing an in-situ groundwater treatment system involving air sparging and soil vapor extraction and an impermeable liner beneath the vegetated soil cap in the southeastern corner of the park – The AS/SVE operated from 2001 to 2006. Benzene concentrations declined enough from 2000 to 2010 to meet the remediation level (EcoCompliance 2007–2009). Monitoring well OBS-1 (the compliance monitoring point) met the cleanup level in 2013 (data are provided in Section 5, Nature and Extent of Contamination).
- Monitored groundwater natural attenuation (MNA) in the western portion of the upland – Monitoring was initiated in 2000 and extended to 2010 (ThermoRETEC 2000). Most wells have exhibited a decline in concentrations over time; concentrations in the remaining wells are stable (no change in magnitude over time). These data indicate that the naphthalene plume is shrinking and meets the remediation level in shoreline compliance monitoring wells (AMEC 2010; data are provided in Section 5, Nature and Extent of Contamination).
- Maintaining engineered and institutional controls within Gas Works Park – These controls limit park users' exposure to contaminants and include maintenance of soil caps, fencing, signage, and irrigation.
- Recording restrictive covenants – Restrictive covenants were recorded for the Gas Works Park and Harbor Patrol properties to prohibit cap disturbance, groundwater withdrawal, and structure removal (e.g., Play Barn and Cracking Towers), or any other action that could cause a new release of contamination or expose people or environmental receptors to contamination, without prior written approval from Ecology (see Appendix 2E).

The details of the cleanup work performed under the 1999 Consent Decree are presented in the Construction Completion Report, Volumes 1 and 2 (ThermoRETEC 2001).

2.2.2.2. Long-term Monitoring and Maintenance Activities

To ensure the integrity of the upland remedy, the 1999 Consent Decree required that monitoring (including inspections) and maintenance of remedy elements be conducted, including:

- Removal and treatment of tar seeps as they occur
- Development of an irrigation plan to maintain the vegetated soil caps
- Inspection and maintenance of the soil caps
- Maintenance or improvement (as needed) of fencing around the Cracking Towers
- Maintenance of public warning signs

Specific monitoring and maintenance activities that have been conducted are described below.

The City inspects the capped upland and uncapped shoreline areas of Gas Works Park weekly to monthly (depending on the season) to identify residual tar seeps and ensure performance of prior remedies. When encountered, tar is excavated and back-filled to grade with clean material. In 2007, tar was removed by hand in sediment near the OHWM along the eastern shoreline and excavated in the northeastern area of the upland (Figure 2-7). In all but one case, tar was completely removed; these areas were then covered with clean fill to grade (Floyd|Snider 2008a). Where tar was not completely removed at one location in the shoreline bank, the area was capped with a foot of clean backfill.

In 2008, two tar seeps were removed from the gully east of Kite Hill and one additional tar seep in the eastern shoreline area was partially excavated. All three excavations within or adjacent to the filled portion of Waterway 19 and were back-filled to grade with clean material. Tar removal and backfilling was performed by Seattle Parks & Recreation (Floyd|Snider 2008b) (Figure 2-7). Seattle Parks and Recreation personnel have not observed additional tar seeps in the last 13-14 years. Additional maintenance was performed on the eroding eastern shoreline, including covering the liner near the previous air sparging area in 2010 and adding large boulders to stabilize the shoreline. Seattle Parks and Recreation has historically placed gravel in beach areas on several occasions as part of its ongoing maintenance activities under the 1999 Consent Decree requirements; there is no record of additional placement since 2010.

Ecology conducted additional upland maintenance activities to reduce erosion and runoff of contaminated surface soil and potential human exposure to contaminated surface soil in the northeast corner of the upland by placing a soil cap that varied in thickness, from approximately 6 inches to 3 feet, across a 0.5-acre area in fall of 2012 (Figure 2-7) (Hart Crowser 2012b; ILIAD 2012).

Upon discovery of elevated carcinogenic polycyclic aromatic hydrocarbon (cPAH)[18] concentrations in shallow soils at Kite Hill by Ecology, the City and PSE implemented a maintenance project in compliance with the 1999 Consent Decree in late summer 2014. The purpose of the project was to eliminate the

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[18] Carcinogenic PAHs are a subset of the PAHs that were analyzed for as part of Ecology's 2011 investigation of park conditions.

potential for erosion and entrainment of contaminated surface soil by surface water runoff to the lake. The project eliminated human exposure to contaminated surface soil.

The maintenance activities in 2014 removed approximately 970 tons of surface soil from Kite Hill and an adjacent (east) drainage swale and installed a vegetated soil cap (see Figure 2-7) over an approximately 5-acre area. Grading was performed to improve drainage across the Kite Hill area and relieve ponding in localized areas. Damaged paths were replaced with new gravel and asphalt to improve (flatten) the grade. The design of the vegetated soil cap included geotextile and a gravel drainage layer to improve subsurface structural integrity and drainage. The vegetated soil cap is otherwise similar to the vegetated caps elsewhere at the GWPS.

2.2.3. 1997 and 2005 Agreed Order Interim Actions

2.2.3.1. 1997 Agreed Order

Prior to the 1999 Consent Decree, the City and PSE removed 2,500 gallons of tar from a partially buried tank discovered within the cracking tower area (see Underground Relief Holder Scrubber Tank in Figure 2-7). This action occurred under the 1997 Agreed Order with Ecology.

2.2.3.2. 2005 Agreed Order (as amended)

During a 2013 supplemental investigation (summarized in Appendix 2A), elevated arsenic was found in deep groundwater (MW-36D) downgradient of the Thylox process area (current Play Area). In response, between 2014 and 2016, additional investigations characterized the plume and evaluated remedial options. This culminated in an interim action (authorized in two 2017 amendments to the 2005 AO[19]) to treat arsenic in groundwater beneath the Play Area.

The interim action was completed between 2016 and 2020 and is documented in the Play Area Interim Action Construction Completion Report (GeoEngineers 2022). The interim action used an in-situ chemical fixation technology to neutralize high-pH groundwater and add iron, the combination of which was shown in treatability testing to break down thioarsenates and promote the formation of stable mineral precipitates of arsenic, iron, and sulfide. Injection wells were screened within the groundwater where elevated dissolved arsenic and high pH conditions reside. Over three events completed between 2017 and 2019, an iron sulfate reagent was introduced to fill and outwash groundwater through the injection wells to trigger arsenic precipitation and reduce dissolved arsenic concentrations in the plume beneath the Play Area upgradient of the shoreline. Each injection event was followed by groundwater performance monitoring throughout the Play Area.

The results of the performance monitoring completed during the interim action is documented in the Play Area Interim Action Monitoring Report (GeoEngineers 2021). The interim action resulted in significant reduction of dissolved arsenic within the Play Area, but arsenic remains above preliminary cleanup levels within the Play Area, as well as downgradient of the Play Area outside the limits of the interim action.

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[19] 2005 Agreed Order 2nd Amendment (April 2017) and 2005 Agreed Order 3rd Amendment (October 2017).

3.0 ENVIRONMENTAL SETTING

Information regarding the project environmental setting (both regional and site-specific) is provided in support of evaluations and data interpretation performed in the RI. Information discussed includes climate, environmental conditions in the surrounding urban environment, geology, seismic conditions, hydrogeology, hydrology, physical conditions, natural resources, land use, the built environment, infrastructure and historic/cultural resources.

3.1. Regional Environmental Setting

The GWPS is located on Lake Union within the urban environment of Seattle, Washington. Lake Union is a working lake that forms part of the Ship Canal, which was constructed in the early 1900s to support marine shipping and commerce. The overall setting is within the central Puget Sound Basin in Western Washington. Puget Sound contributes to the temperate maritime climate of the region and thus affects the amount of rainfall the area might receive and major weather/storm patterns. Physical features of the basin were formed during periods of glaciation and ice retreat, which affected site-specific geologic and hydrogeological conditions.

3.1.1. Climate

Climate is examined in an RI/FS because of its potential effect on site-specific conditions. As part of the Puget Sound region, Lake Union is affected predominantly by weather formed over the ocean and transported by prevailing onshore flows (Mass 2013). Temperatures and precipitation in the region are moderate, although periodic extremes can occur. Strong frontal systems and oceanic storms can cause high winds and heavy rainfall in late fall and winter, which can exacerbate erosion along unprotected shorelines and increase the volume of urban runoff. Snowfall can occur in winter but tends to be of limited duration and accumulation.

Average temperatures range from 36°F (January) to 73°F (August) and average annual rainfall is 34 inches[20], with 70 percent of the yearly precipitation falling from October through March. According to the Climate Impacts Group (2015), the Puget Sound region will likely experience increasing air and water temperatures, reduced snow accumulations in the mountains, and declining summer precipitation. These conditions will affect lowland lakes such as Lake Union in the following ways:

- Water temperatures will increase, or periods of warm water will last longer.
- Lakes will stratify earlier in the summer.
- Productivity, particularly of phytoplankton, will likely increase and/or the timing of blooms will be altered, thus affecting lake ecosystems.

The incremental increases in air and water temperatures are not expected to result in changes to subsurface NAPL transport behavior.

Sea level rise, an outcome of climate change, is unlikely to affect Lake Union because its levels are controlled by the Hiram M. Chittenden Locks (Ballard Locks).

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[20] Average temperatures and precipitation from http://www.usclimatedata.com/climate.php?location=USWA0395. The information is current as of July 2022.

3.1.2. Environmental Conditions in the Seattle Urban Environment

The GWPS is situated in an urban environment with a long history of industrial use. Over the last 100 years, both locally and in the broader Puget Sound basin, human activities have influenced soil, groundwater, air, surface water, and sediment quality.

Many chemical constituents have been widely distributed by broad-scale transport processes (e.g., wind, water currents), which, in turn, have affected the ambient conditions for environmental media. The generalized conditions in the local area are therefore important to consider while characterizing the nature and extent of contamination for a given site and in the evaluation of the cleanup area and the potential for recontamination. GWPS-related contaminants for which information exists about ambient concentrations are discussed below.

3.1.2.1. Soil Chemistry

Limited data are available to characterize contaminant concentrations in urban Seattle soil, except for cPAHs and a few other contaminants. In 2011, Ecology analyzed surface soil samples from six neighborhoods[21] in Seattle for cPAHs (Hart Crowser 2011). Average concentrations of cPAHs ranged from 260 to 680 micrograms per kilogram (µg/kg), expressed as the sum of toxic equivalent concentrations[22] (TEQ), in neighborhoods draining to the Ship Canal (i.e., Ballard, Capitol Hill and Ravenna).

Typical concentrations of metals in Seattle area soil have not been characterized; however, background metal concentrations in soil from non-urban areas have been established by Ecology (Ecology 1994) using shallow subsurface soil collected from around the state. Currently, 7 milligrams per kilogram (mg/kg) arsenic is identified as a background concentration in soil[23].

3.1.2.2. Groundwater Quality

No characteristic concentrations have been established for inorganic groundwater constituents in Seattle; organic compounds would not naturally occur in groundwater. Concentrations of arsenic in wells from the Puget Sound lowlands region range up to 76 micrograms per liter (µg/L) based on data collected from 2003 to 2010 (Washington Department of Health Drinking Water Division Sentry database).

3.1.2.3. Surface Water Quality

Lake Union is part of Water Resources Inventory Area (WRIA) 8[24] and is designated by Ecology as "lake class," which says that water quality must support multiple beneficial uses, including salmonid summer habitat, swimming and boating, water supply (i.e., domestic[25], industrial, agricultural, and stock watering), wildlife habitat, fishing, commerce, and navigation[26]. Historically, these beneficial uses have been adversely affected by nutrient, bacterial, and toxicant loadings; high temperatures and duration; periods of low dissolved oxygen (DO); and saltwater intrusion due to operation of the Ballard Locks. In 2016, Lake

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[21] Twenty soil samples were collected from each of six neighborhoods: West Seattle, Georgetown, South Park, Capitol Hill, Ravenna, and Ballard.

[22] A toxic equivalent concentration is a sum of individual cPAHs that have been weighted relative to the toxicity of benzo(a)pyrene.

[23] WAC 173-340-900

[24] WRIA 8 comprises Lake Washington, Lake Sammamish/River, and Cedar River watersheds.

[25] As part of the 1999 Consent Decree, Ecology did not consider Lake Union a drinking water source; however, Ecology currently believes that Lake Union should be protected for potential future use as potable water. However, use of Lake Union as a water supply is currently closed because Ecology has determined that additional water withdrawal would adversely affect beneficial uses (Section 173-508) related to fish, wildlife, aesthetics, navigation, and water quality.

[26] WAC 173-201A-602

Union was listed as impaired under the Clean Water Act Section 303(d)[27] for bacteria and temperature. Exceedances of sediment bioassay maximum allowable thresholds in AOI sediment (see Table 5-6, which is discussed in Section 5) also contributed to the 2016 impaired waterbody listing of Lake Union.

Quarterly water quality monitoring by King County (King County Major Lakes Monitoring Program)[28] has established that Lake Union surface waters exhibit seasonal changes. Over the course of a year, water temperature ranges from about 40°F to 75°F. Warmer temperatures (>70°F) generally occur from late June to through September and cause thermal stratification of the water column. Winter water temperatures are more homogeneous and stratification dissipates, thus allowing mixing to occur. Seasonal data collected by RETEC Group, Inc. (RETEC) between November 2002 and February 2005 documented trends in conventional parameters (pH, DO, salinity, conductivity [a surrogate for salinity], and turbidity) throughout the water column at four locations: two in the AOI, one west of the AOI, and one in the center of Lake Union (Figure 3-1). The observed water column stratification during late summer as well as the seasonal profiles agreed with King County and USACE data. Water column profiles that illustrate trends in these parameters are provided in Appendix 3A.

Thermal stratification results in very warm water at the lake's surface and cooler temperatures at the bottom, thus trapping low oxygen/high nutrient water in the bottom layer.

Because of the Ballard Locks, salt water from Puget Sound has intruded into Lake Union. During the summer, with increased boat traffic through the Ballard Locks and low flushing in the lake, salt water can still be detected in the western part of Lake Union in the bottom-most layer of the water column.

Contribution of organic material from Lake Union and the larger watershed has created an organically enriched surface sediment layer in Lake Union, with a significant biological oxygen demand that can depress DO levels, particularly near the lake bottom. During periods of water column stratification and saltwater intrusion, DO in the dense bottom layer of the lake water column can approach 0 milligrams per liter (mg/L), particularly in the deeper, southern portion of the lake.

Limited contaminant data are available to establish Lake Union water quality. A long-term lake monitoring program conducted by King County measured metals at a sampling location in the Montlake Cut where surface water from Lake Washington enters Lake Union. Data available from 2007 and 2008 monitoring events, as reported in Ecology's Environmental Information Management (EIM) system, were compiled and the 90th percentile upper tolerance limits[29] for arsenic, chromium, and lead were calculated as follows:

- Arsenic = 0.9 μg/L
- Chromium = 0.2 μg/L
- Lead = 0.1 μg/L

3.1.2.4. Sediment

Numerous studies of Lake Union sediment quality have been conducted since the 1970s. The sediment portion of the AOI, defined in the 2005 Agreed Order, was designed to encompass sediment impacted by former MGP-related sources and to distinguish such sediment from sediment outside of the AOI impacted

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[27] EPA approved the 303(d) list of impaired waters of the state on July 22, 2016. https://fortress.wa.gov/ecy/approvedwqa/ApprovedSearch.aspx accessed June 5, 2018.

[28] King County monitoring data provided at green2.kingcounty.gov/lakes/LakeUnion.aspx

[29] An upper tolerance limit describes the value below which a stated proportion of the population lies (in this case 90 percent of the population).

due to the urban-industrial nature of the land surrounding the lake and the lake itself. That area of the lake outside of the AOI impacted by multiple point and non-point sources is referred to as the ambient Lake Union (ALU) area and is defined as Lake Union between Ship Canal (I-5) Bridge and the Fremont Bridge, not including areas within 300 feet of the shoreline that may be influenced by point sources along the lake shore (Figure 3-2). In addition to showing the ALU area, Figure 3-2 shows the sediment portion of the AOI. Surface sediment concentrations representing general ALU conditions are presented in Table 3-1.

The iterative evaluation of sediment benzo(a)pyrene, TPAH, and high molecular weight PAH (HPAH) data inside and outside of the AOI presented in Appendix 4C was used to show that the AOI boundary is an estimate of the location where sediment concentrations within the AOI, on average, have declined to ALU conditions.

The iterative evaluation includes comparing surface sediment data sets from samples collected within the AOI to surface sediment data sets from samples collected outside of the AOI (that is, samples that represent ALU conditions). The first iteration used all the surface sediment data inside the AOI. The second iteration assumed that a narrow band of sediment along the shoreline within the AOI was remediated. In subsequent iterations the band was expanded or extended further into the AOI. The AOI surface sediment data sets used in the statistical comparisons only include surface sediment data from samples collected outside the area assumed to be remediated. As shown in Section 5 figures, the highest surface sediment concentrations are in a narrow band along the shoreline. Each iteration assumes that more of these highest surface sediment concentrations are remediated. The results show that after remediating the highest surface sediment concentrations along the shoreline, the surface sediment concentrations in the remaining portion of the AOI are not statistically different than ALU surface sediment concentrations.

3.1.3. Regional Geologic Setting

Seattle lies between the Cascade Mountain range and the Olympic Mountains, in a lowland called the Puget Sound trough or Puget Sound basin. Four of the most prevalent types of geologic materials present in the Puget Sound Basin are listed below:

- Igneous (volcanic) and sedimentary rocks -- includes recent volcanic deposits from the Cascade volcanoes as well as older deposits of lava and sediment originating from ancient landscapes.
- Glacial deposits -- deposited beneath or adjacent to glacial ice and consisting of varying amounts of gravel, sand, silt, and/or clay that are either glacially consolidated (till) or less consolidated (outwash).
- Recent sediment -- includes sediment deposited since the most recent Ice Age by any means, including moving water such as rivers and streams (alluvium), lakes (lacustrine), wind (aeolian), and gravity (colluvium).
- Fill -- materials placed by human activities such as during construction earthwork.

Surface topography within the basin was created by scouring (erosion) and deposition related to the repeated advance and retreat of large continental glaciers.

A **drumlin** is an elongated hill shaped by the erosion of soil and rock beneath glacial ice.

Lake Union was formed more than 17,000 years ago when a large tongue of continental glacial ice moved southward from British Columbia and Vancouver Island, partly filled the Puget Sound basin, and scoured much of the area now occupied by Lake Union. The geologic deposits present at ground surface in most of the uplands and hills in Seattle consist of glacial till or advance outwash deposits. The MGP occupied what was historically known as Brown's Point, a prominent natural point formed where south-sloping Wallingford Hill enters Lake Union. Wallingford Hill, as with many of Seattle hills, is a geologic feature called a drumlin, which was shaped by the flow of one or more of the Pleistocene-era glaciers. Drumlins in Seattle are typically composed of glacial till. Glacial outwash materials deposited by receding glacial ice at the end of the Ice Age, known as recessional outwash deposits and classified locally as Qvr, are typically present in valleys, drainages, or along the margins of drumlins or other upland features. This pattern of localized deposition and erosion created the complex geology in the Lake Union area with thin and laterally discontinuous geologic horizons (GWSA Technical Team 2011 a, b). The Y-shaped arms of Lake Union resulted from preferential erosion that has recurred over time.

3.1.4. Regional Seismic Setting

The GWPS is located within the central portion of the Puget Lowland near the western margin of the North American tectonic plate. The Cascadia Subduction Zone is the plate boundary along which the subduction of the oceanic plates beneath the North American plate occurs. Along western Washington, the oceanic plate is being thrust beneath the North American plate obliquely relative to the plate margin. Convergence rates along the plate boundary range up to 45 millimeters per year at the northern end offshore of Washington and Vancouver Island (McCrory et al. 2012). Global positioning system (GPS) modeling of the Pacific Northwest (McCaffrey et al. 2007, 2013; Mazzotti et al. 2011; Brocher et al. 2017) indicates clockwise rotation of the North American plate, with a resulting horizontal compression of the Puget Lowland region of about 4 millimeters per year (this is in addition to of the compression resulting from subduction of the oceanic plates).

Earthquakes in the Pacific Northwest originate from four different types of sources: (1) interplate earthquakes on the Cascadia Subduction Zone associated with eastward movement of the Juan de Fuca tectonic plate beneath the North American plate, (2) intraplate earthquakes within the subducting Juan de Fuca plate as it sinks and breaks up below the North American plate, (3) shallow crustal earthquakes on faults and background seismicity within the North American plate, and (4) volcanic earthquakes such as those associated with the eruption of Mount St. Helens. In addition to the Cascadia Subduction Zone interplate and intraplate earthquakes, shallow crustal faults in the Puget Lowland have the potential to generate large earthquakes in the Seattle region. The largest and closest fault to the GWPS is the Seattle fault, which extends from the Hood Canal area on the west across the southern margin of downtown Seattle, then along the Interstate 90 corridor to the Snoqualmie River Valley on the east (Pratt et al. 2015).

Along the Lake Union shoreline, areas of fill could be subject to reduced strength and liquefaction during seismic events, where saturated. This liquefaction of saturated, loose to medium dense fill material could result in slope instability and lateral spreading toward Lake Union, with movement of the slope expected to be greater at the shoreline. Lake Union bottom soft sediment might be subject to seismic liquefaction, but the flat lake bottom surface significantly reduces the potential for lateral movement of sediment.

3.1.5. Regional Hydrogeology and Groundwater Occurrence

Hydrogeology is the field of geology that studies the movement and distribution of water that occurs underground (i.e., groundwater) within void spaces in the earth's soil, sediment, and rocks. Groundwater in the Seattle area primarily occurs within alluvium and glacial geologic materials. Groundwater could occur within pore spaces or voids in both consolidated and unconsolidated deposits.

An **aquitard** is a low-permeability geologic deposit that slows groundwater movement between geologic layers and may control groundwater flow directions.

Geologic deposits that yield sufficient quantities of groundwater are called an aquifer. The type of geologic materials that comprise an aquifer controls the movement of groundwater. For example, groundwater may readily move through permeable sand and gravel outwash deposits, while fine-grained and denser glacial till deposits may slow groundwater flow (Vaccaro et al. 1998). Multiple aquifers may be separated by low-permeability deposits (sometimes called an aquitard) that can act as a vertical barrier to groundwater flow between geologic layers. Bedrock in the Seattle area does not exhibit significant control on shallow groundwater flow because it is typically buried under several hundred feet of glacial deposits.

Shallow aquifers in the Seattle area are typically recharged by precipitation infiltrating permeable ground surfaces such as grass, landscaped areas, or ditches; aquifers might also be recharged through inflow from surface water such as rivers or lakes or from adjacent aquifers. In Seattle, the most significant recharge occurs in uplands areas, where precipitation infiltrates through porous glacial outwash sands and gravels.

Recharge is the deep percolation of precipitation and surface water to groundwater, the primary method through which water enters an aquifer.

Recharge in upland areas where glacial till is exposed is generally limited due to the relatively low permeability of the till unit. Recharge in upland areas where outwash is exposed at the surface occurs more readily. Groundwater movement from upland areas is primarily toward lower-lying discharge areas, including major surface water bodies such as Portage Bay, Lake Union, Lake Washington, and Puget Sound.

3.1.6. Lake Hydrology

Lake hydrology is an important factor in understanding how contaminants (both released from the GWPS as well as other sources) might move around or collect in certain areas. In addition, hydrology also contributes to the potential for natural recovery of the lake bottom, when cleaner sediment is brought into Lake Union by currents carrying suspended sediment. Hydrology will also play a role in how the sediment cleanup remedy will be designed and implemented.

Lake Union is part of the Ship Canal. Historically, the relatively shallow 580-acre freshwater lake was isolated from surrounding water bodies, receiving most of its inflow from springs, small streams, runoff, and groundwater infiltration from the surrounding hills. The only discharge from the lake was via a small low-gradient stream in the northwest corner (where the Fremont Cut is today) that led to Salmon Bay. During the summer, the lake was often stagnant. Lake levels averaged about 21 feet USACE[30], with a 0.5-foot seasonal variation.

In the 1800s, Lake Washington was about 9 feet higher than Lake Union and discharged to Puget Sound via the Black and Duwamish rivers. Completion of the Ship Canal system in 1917 lowered Lake Washington and changed its outflow to Puget Sound via Lake Union.

Although present-day lake water elevations are similar to those before the Ship Canal was built (Chrzastowski 1981), levels in Lake Union are now controlled by the Ballard Locks in Salmon Bay at the

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[30] Elevations presented in this RI are referenced to the USACE Government Locks/Lake Vertical Datum. The following are other commonly used datum systems in the Seattle area and their conversions to USACE datum.

- NGVD29 – National Geodetic Vertical Datum of 1929, previously called "Sea Level Datum of 1929." USACE = NGVD29 + 6.82 feet
- NAVD88 – North American Vertical Datum of 1988. USACE = NAVD88 + 3.25 feet
- City of Seattle (COS) Datum. USACE = COS + 12.95 feet

west end of the Ship Canal. Lake Union water level elevations vary between 20 and 22 feet USACE, with higher water levels in the summer and lower water levels in the winter.

The connection to Lake Washington increased the size of the watershed by orders of magnitude[31] and increased the inflows to Lake Union. Circulation in Lake Union is complex with current patterns being influenced by seasonal precipitation and runoff, the amount of water released through the Ballard Locks, frequency and duration of lock openings, wind patterns (direction, strength and duration), and occasional seiches[32] in Lake Washington (Seckel and Rattray 1953). The main inflow to the lake is from Lake Washington via the Montlake Cut; the main outlet is the Ballard Locks via the Fremont Cut. In general, the strongest currents flow from east to west through the northern portion of the lake, with occasional flow reversals depending on tidal conditions in Puget Sound when the Ballard Locks are opened frequently in the summer. Although connected to Lake Washington, Lake Union might not completely flush during some parts of the year, particularly in the southern portion of the lake. Complete flushing only occurs in late winter and early spring during periods of high rainfall or snowmelt, taking about a week to exchange the total volume of water. Under seasonal high flow conditions, currents flow more strongly and entrain water from the southern and deeper parts of the lake resulting in increased flushing (CH2M Hill 1975). Under low flow conditions, the water column tends to stratify, particularly as temperatures warm, which contributes to incomplete flushing and stagnation of deeper water.

3.2. Site-specific Setting

The following sections describe physical characteristics within the AOI that potentially affect cleanup planning and implementation, including topography/bathymetry, offshore debris distribution, substrate conditions, geology, hydrology, hydrogeology, natural resources, land use, structures, infrastructure, and historic and cultural resources.

3.2.1. Topography/Bathymetry

The general topography and bathymetry of the AOI reflects the glacial history discussed above in Section 3.1.3, Regional Geologic Setting. Existing topography[33] (Figure 3-3) reflects the expansion of the upland through historical in-water filling, as well as significant upland filling in the 1960s and 1970s, demolition of the former MGP, and regrading during the development of the park in the 1970s. The northern part of Gas Works Park is relatively flat (elevation 40 to 45 feet USACE) and is separated from the rest of the park by an old railroad grade that is currently a foot and bike path. Kite Hill (elevation 65 feet USACE) is the most prominent topographic feature of the upland, constructed of fill and rising about 35 feet above the surrounding land surface. The southeast area of the upland slopes gently toward Lake Union (elevation 21 feet USACE). The top of the shoreline bank has an approximate elevation of 23 to 30 feet. The bank slope ranges from near vertical in some areas, such as Kite Hill and the Prow, to moderately flat in other areas like the southeastern shoreline.

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[31] Lake Union is now part of the Lake Washington watershed, which includes the Cedar River and its tributaries, Lake Washington, and several small creeks. The Sammamish watershed— consisting of Lake Sammamish, numerous small creeks, and several surface water bodies—contributes inflow to the Lake Washington Watershed through the Sammamish River.

[32] A seiche is a tidal-like change in water elevation created by wind or atmospheric pressure variations on large bodies of water.

[33] Surface topography data used in this RI report for the upland and surrounding areas were based on an AECOM base map, supplemented with elevation contours from the City that reflect the 2005 grading changes to the northwest corner area. Surface topography in the Kite Hill area was professionally surveyed in 2014 as part of Kite Hill capping efforts.

The sediment portion of the AOI extends from the shoreline 200 to 1,100 feet into Lake Union. Bottom elevations within the sediment area range from about 22 to -25 feet USACE (Figure 3-3)[34]. The maximum depth of Lake Union is 50 feet[35]. The sediment portion of the AOI has a relatively shallow nearshore zone (lakeshore), with a low to moderately sloping bottom leading to a steep slope (lake slope) that flattens out onto a slightly sloping bottom (lake bottom) that extends towards the center of the lake. The location of the lakeshore, lake slope, and lake bottom are depicted in Figures 3-3 and 3-4. The lake bottom is the most dominant feature of the sediment area and is characterized by slopes of less than 10 degrees and water depths deeper than approximately -20 feet USACE. The lake slope falls between bottom elevations of approximately 5 feet and -20 feet USACE, with steep 20- to 50-degree slopes. The most steeply sloped bottoms are closest to the shoreline (within about 50 feet) in the western and eastern sediment portions of the AOI. Accordingly, the shallow (greater than 5 feet USACE), relatively flat lakeshore zone is very narrow in these locations, except for the shallow, broader bottom within Waterway 19.

In the central portion of the sediment area, there is a shallow bench offshore of the Prow; the southeast portion of this bench is an extension of the drumlin that is evident in the upland. Portions of the bench were likely formed by historical filling and dredging; the footprint of the past dredging can still be seen in the bathymetry adjacent to the western side of the Prow[36]. The lake slope zone in front of the Prow begins about 100 feet or more offshore and extends over 300 feet into the lake.

3.2.2. Offshore Debris Distribution

Technologies used in bathymetric surveys (i.e., multi-beam and side-scan sonar), video surveys, and diver observations compiled as part of other investigations listed in Appendix 2C have documented the presence of debris and other subsurface features in lake sediment within the AOI (Figure 3-5). Debris observed offshore within the AOI includes sunken vessels, dock remnants, milled lumber, pieces of large wood (e.g., pilings, sunken wooden structures, logs, and beams), metal drums or containers, tires, trash (e.g., chains, rope, aluminum cans, bottles, brick fragments, and orange traffic cones), agglomerate, and boulders. Wood debris has commonly been found in the upper 2 feet of soft sediment roughly 100 to 300 feet offshore. Logs have been observed from approximately 100 to 500 feet offshore and are likely the result of historical log-rafting near the former MGP. As shown in Figure 3-5, the majority of mapped debris within the AOI has been encountered offshore of the Prow, Kite Hill, and the current Harbor Patrol property. However, smaller debris is prevalent in the fill. A significant amount of debris (cable, steel tanks, sunken boats, bathtubs, lawn furniture, and bicycles) is also located at the Gas Works Park Marina.

3.2.3. Sediment Substrate

Sediment substrate has been characterized through visual inspection of sediment samples, laboratory testing, and surveys including, but not limited to, underwater towed video, soft sediment diver probing (Appendix 3H), and shoreline inventories between 1999 and 2005.

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[34] The elevations of the sediment bed within the GWPS were obtained from several bathymetric studies conducted in 1999, 2002, 2005, and 2006 using lead line, side-scan sonar, diver surveys, and single- or multi-beam technologies.

[35] Lake depth from http://green.kingcounty.gov/lakes/LakeUnion.aspx.

[36] Limited dredging has occurred at the GWPS: dredging near the west end of the Prow to maintain a barge docking area was permitted in 1943 and 1953; the latter date is the last known dredging event. Dredging removed approximately 4,300 cubic yards in 1953.

Results of these investigations indicate that several substrate types are present throughout the sediment area. The variations in substrate type are generally delineated by the hydrodynamic conditions associated with changes in bathymetric elevation. There are two main sediment substrate types:

- Hard substrates – characterized by human-generated debris, cobbles, riprap, concrete, and glacial till. Hard substrates are present in shoreline banks and nearshore slopes. Fill is an example of a human-generated hard substrate that is prevalent along the shoreline and in lakeshore and upper lake slope zones. Glacial till crops out or is near the mudline offshore, southeast of uplands, and forms an area of hard substrate[37].
- Soft sediment – characterized by areas of organic silts and fine sand underlain by glacial deposits. Organic silts dominate the lake bottom region, where they are characterized as very soft sediment to fluid mud.

3.2.4. Geology

Extensive evaluations of AOI geology have been conducted. Information necessary to understand the site-specific conditions are summarized below; supplemental information including detailed maps and description of geologic units are provided in Appendix 3B.

More than 250 soil borings and test pits and more than 150 sediment (lake) cores were completed within the AOI between 1971 and 2017. Six major geologic units have been identified at the GWPS; Figures 3-6A and 3-6B describe these units in generalized geologic stratigraphic sections for the AOI upland and offshore areas. These geologic units are described in more detail in Section 3.2.4.1 below. Figure 3-7 presents the surficial geology, which shows the geologic unit closest to or at ground surface or mudline across the AOI. Figure 3-8 shows the alignment of four generalized cross sections (Figures 3-9 through 3-12 that depict the vertical and lateral extent of the six geologic units in cross-sectional view).

Additional detailed geologic cross sections for select areas of the AOI are provided as part of the evaluation of NAPL distributions in Appendix 5F. Logs for borings and sediment cores are included in Appendix 3C. Geotechnical test[38] results, which provide information on the physical characteristics of the subsurface layers, are included in Appendix 3D, along with a table and figure of geotechnical sampling locations. Maps showing geologic unit thickness (isopach map) and/or surface topography contours (structure contour map) are presented in Appendix 3B (Figures 3B-1 through 3B-5).

3.2.4.1. Geologic Units

General characteristics and occurrence of each geologic unit are described below; the units are presented from generally the youngest to oldest. The site geology plays a main role in groundwater and contaminant transport within the AOI, as discussed in Section 6, Contaminant Fate and Transport. The geologic units and hydrostratigraphic units (see Section 3.2.5.1) are categorized in the following table[39].

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[37] The glacial till outcrop southeast of the upland is locally covered by a thin veneer of fill.

[38] Geotechnical results include but are not limited to cone penetrometer tests, standard penetration tests, vane shear, bearing plate, moisture content, dry density, grain size, Atterberg limits, consolidation, specific gravity, and triaxial tests. Physical properties of the AOI geologic units, such as sediment strength, are discussed in more detail in the FS.

[39] The localized recent beach and shallow shelf deposits unit (Qb) is not listed—see Appendix 3B for more information.

Geologic Unit	Hydrostratigraphic Unit
Fill (Af)	Fill
Recent Lacustrine Deposits (Ql)	Lake Sediment
Vashon Recessional Glaciolacustrine Deposits (Qvrl)	
Vashon Recessional Outwash (Qvr)	Glacial Outwash
Vashon Advance Outwash (Qva)	
Pre-Fraser Till (Qpgt)	Glacial Till

Fill (Af) – During development of the upland area, upland and shoreline areas were filled to level the ground and extend land into the lake. Fill now composes most of the upland surface to an average thickness of about 10 feet. Thicker fill is present at Kite Hill and near the shorelines. In most of the upland, fill lies directly on top of the till.

Lake Deposits (Ql, Qvrl) – The upper portion of the recent lake deposits contain elevated amounts of wood and organic matter from historical logging, land clearing, and sawmill operations around Lake Union and soot, as well as plant material and detritus from the algae, phytoplankton, zooplankton, and diatoms that live in the lake.

In Lake Union, silty and clayey recessional glaciolacustrine deposits (Qvrl) are locally present above outwash. These deposits date from late in the Vashon glaciation and early Holocene epoch, when there was still abundant glacial sediment entering the lake. These deposits are generally composed of fine-grained mineral sediment, in contrast with the subsequent recent (Ql) lake sediment that contains a high proportion of fine organic matter.

Glacial Outwash (Qvr, Qva) – Vashon advance outwash (Qva) and Vashon recessional outwash (Qvr) deposits are present beneath the fill across a large part of the western and southwestern portion of the upland and a smaller area in the eastern portion of the upland. The outwash deposits are not present in the central, north, and southeast portions of the upland; fill directly overlies till in these areas.

Glacial Till (Qpgt) – The pre-Fraser glacial till unit (Qpgt, also referred to as the till throughout this RI) is the most extensive and oldest unit encountered within the AOI. Till is the most laterally extensive geologic unit (and deepest) and forms the core of the upland and nearshore portions of the AOI (Figure 3B-5 of Appendix 3B). None of the more than 400 deep explorations have fully penetrated the till. The deepest boring completed (MW-31) indicates that the till is at least 70 feet thick underneath the park. In much of the upland, the till is encountered near the ground surface and is overlain by less than 10 to 15 feet of fill and/or glacial outwash deposits.

3.2.4.2. Key Upland Geologic Characteristics

In the upland, the two most prevalent geologic units are human-derived fill underlain by till. Vashon recessional and Vashon advance outwash deposits are "draped" on the flanks of the northwest/southeast-trending drumlin, sandwiched between the fill and till. Upland geology characteristics with significant influence on the transport of both groundwater and contaminants are described below.

Fill History – Fill is generally continuous across the upland portion of the AOI and extends an average of approximately 80 feet offshore (Figure 3B-1 of Appendix 3B). The fill history is complex but can be understood by reviewing historical documentation, historical aerial photographs, and topographic maps. Three "eras" of fill have been identified (Table 3B-1 of Appendix 3B). The oldest fill was placed between the early 1900s and the 1960s during industrial use of the upland, and this deeper fill includes debris, products, and byproducts from the MGP as well as municipal landfill waste. The second era of fill placement was during park development in the 1970s and includes the substantial quantity of fill soil placed at Kite Hill. The last era of fill placement occurred between approximately 2001 and 2014, where thin layers of fill (i.e., up to 4 feet thick) were placed in select areas of the park to provide a clean soil cap. Additional details regarding the placement of fill during these three eras is presented in the Appendix 3B.

Orientation of Till and Overlying Outwash or Fill Deposits – Variations in the topography of the top of the till unit and the orientation of outwash or fill deposits overlying the till have controlled the movement of groundwater and the migration of contaminants within the AOI. Dense NAPL (DNAPL) has migrated downward through more permeable fill and outwash units to the top of the till. Due to the dense and fine-grained nature of the till, vertical movement of contaminants through the till is limited. In areas where DNAPL has penetrated down to the till, DNAPL follows the till surface downslope or has collected in depressions in the till surface. Additional information related to geologic controls on contaminant migration is presented in Section 6, Contaminant Fate and Transport, and Appendix 3B.

Glacial Till Ridge and Trough Feature – One feature controlling contaminant transport is a southeast-trending till ridge, or drumlin, in the southeastern quadrant of the upland, east of the Cracking Towers, which slopes offshore to the southeast (Figure 3B-5 of Appendix 3B). The western and eastern flanks of the drumlin slope down to the southwest and east, respectively. North of the till ridge, a depression in the till forms an east-trending “trough” that is up to 200 feet wide and approximately 15 feet deep. This depression is most noticeable in the east-central area of the upland, south of the Play Barn. The depression is a natural feature, as evidenced by the fact that the deposits overlying the till in this area are native outwash deposits.

Shoreline Changes – Prior to industrial development of North Lake Union, the property and shoreline in 1899 were known as Brown’s Point. The present-day shoreline is the result of fill placed primarily between 1907 and 1929 to expand the peninsula for industrial use (Sanborn Fire Insurance 1919; Washington State Board 1907; Seattle Gas Company 1949). Since then, the shoreline was slightly cut back by excavation and regrading during park development and eroded by subsequent wave action and storm events. Shoreline changes over time within the AOI are shown in Figure 3-13. Lake levels have stayed somewhat constant since about 1916, following completion of the Ballard Locks and breaching of a temporary dam at Montlake (Chrzastowski 1981).

Historical shoreline changes are important to consider for understanding the GWPS, such as the timing of historical operations, location of docks and outfalls as compared to the historical shorelines (e.g., outfalls along historical shorelines might now be within the upland in areas that were filled), and the potential for erosion to expose previously buried material. Erosion has potentially contributed to exposure of tar near the eastern shoreline.

3.2.4.3. Key Geologic Characteristics of the Sediment Area

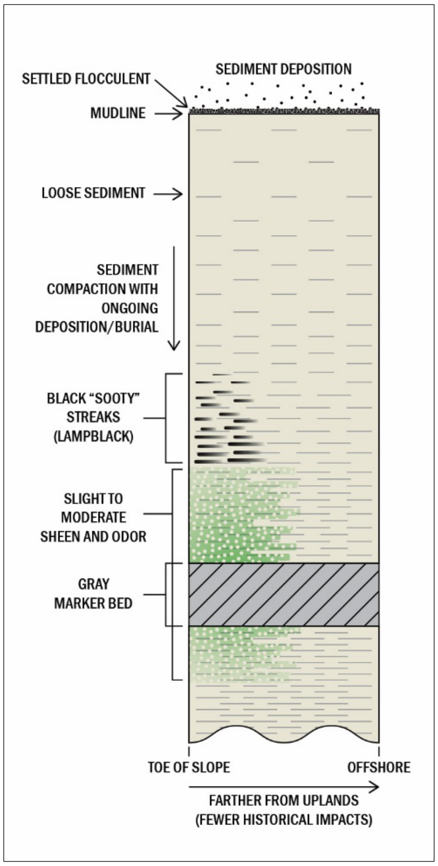
A stratigraphic column depicting the geology of the offshore portion of the AOI is presented as Figure 3-6B. The offshore geologic sequence varies by location, as shown on cross sections A-A’ through D-D’ (Figures 3-9 through 3-12). Geological characteristics of the sediment area that explain the distribution or influence the fate and transport of contaminants are described below:

Extent of Offshore Fill – Fill extends offshore an average of approximately 80 feet (Figure 3-7). Farther offshore, there are pockets of fill at the mudline surface or just below the mudline, presumably due to past vessel dumping. The fill has a relatively high black carbon content east and south of Gas Works Park, as described in Appendix 3B.

Drumlin – The drumlin or till ridge described above extends offshore to the southeast of the park. The till is highest and closest to the mudline just east of the Prow. The drumlin separates areas of thicker lakeshore and lake slope fill and recent lake deposits to the north and west. The drumlin also appears to be subject to greater hydrodynamic forces because its substrate is much different from that of areas to the west and north, where organic silt deposits are present closer to shore.

Sedimentation Rates and Deposition – Much of Lake Union acts as a depositional basin for the Ship Canal system, in part due to the underwater rise created by the shallowing of the Fremont Cut (relative to lake depths). Suspended sediment from the Lake Washington watershed enters Lake Union, along with soil eroded from unprotected banks in Lake Union or washed into the lake via stormwater. This deposition contributes to the soft sediment that dominates the bottom substrates in much of the lake.

Sedimentation varies both geographically (e.g., center of the lake versus nearer to shore) and with depth. Within the AOI, a gray clay "marker bed" observed in many sediment cores likely dates from the construction of the Ship Canal system (see *Representative Sediment Column in the Lake Bottom Zone* inset). Sediment above this marker bed contains material from human activity and is generally darker in color. Sediment below this marker bed was mostly deposited prior to industrialization and has less material from human activity[40]. Further evaluation of lake sedimentation is provided in Section 6.6. Additional detail on deposition rates can be found in Appendix 2D-3.3.



Representative Sediment Column in the Lake Bottom Zone

Character of Sediment Carbon – Organic carbon measured in sediment from the AOI and broader areas of Lake Union (Figure 3-14) indicates that organic carbon is elevated in most Lake Union sediment (around 9 percent by mass). Much of the carbon is from degrading plants and plankton, which according to a petrology study performed by Stanford University (Appendix 2D-7) makes up a significant portion of the sediment. Soot and other types of carbon are also found within lake sediment (see Representative Sediment Column at Lake Bottom figure above). Within the AOI, black carbon from lampblack and other MGP activities contribute to the organic carbon in the sediment. The presence of carbon in the sediment plays a significant role in the fate and transport of many contaminants and affects their behavior in the environment. Carbon tends to bind organic contaminants, thus lessening their bioavailability.

3.2.5. Hydrogeology

Scientists have drawn on their understanding of the site-specific hydrogeology to evaluate the groundwater-to-sediment pathway. Groundwater data have been collected and hydrogeologic evaluations have been performed since 1986 to understand hydrogeology in the AOI. Well logs are presented in Appendix 3C.

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[40] In some areas, the gray clay appears to demarcate pre- and post-industrial lake deposits. In other areas, post-industrial deposits underlie the gray clay (diver cores collected south of the Prow show a thin layer of sediment with anthropogenic impacts beneath the clay layer).

Table 3J-1 in Appendix 3J includes a comprehensive presentation of available well construction information.

Groundwater levels in upland wells have been measured periodically since 1986 through an evolving network of monitoring wells. Groundwater elevations for monitoring wells are presented in Appendix 3J.

Hydrogeologic testing refers to methods to test the flow and storage properties of an aquifer. Hydrogeologic testing typically involves displacing or pumping groundwater from a well and monitoring the change in water level over time.

Hydrogeologic testing and groundwater modeling also have been conducted to evaluate how groundwater moves through the geologic units that are present within the AOI. Hydrogeologic testing has included slug tests and pumping tests. Numerous slug tests have been performed to evaluate hydraulic conductivity. In addition to single-well tests such as slug tests, pumping tests have been performed on three occasions. The most recent testing consisted of one full-scale pumping test and two short-duration pumping tests. Details regarding the results of hydrogeologic testing are discussed in Appendix 3E. Hydraulic conductivity values for AOI hydrostratigraphic units are presented in Table 3E-2 of Appendix 3E.

Groundwater flow models have been developed for the AOI to predict where and how much groundwater discharges into the lake. Groundwater modeling incorporates site hydrogeologic data (e.g., water levels and pumping/recharge rates) to facilitate the understanding of 3D groundwater flow and provide better predictions of groundwater discharges to Lake Union. In addition to developing a better understanding of site hydrogeology, the groundwater flow model was used to evaluate fate and transport as described in Section 6, Contaminant Fate and Transport, and select remedial technologies in the FS. The results of the most recent numerical groundwater flow model are presented in Appendix 3F.

3.2.5.1. Hydrostratigraphic Units

Four major hydrostratigraphic units are present within the AOI (see inset table in Section 3.2.4.1): fill, lake sediment, glacial outwash, and glacial till. Each hydrostratigraphic unit consists of one or more adjacent geologic units with similar hydraulic properties as determined during hydrogeologic investigations. The hydrostratigraphic units are complimentary to the geologic units and form the basis for understanding groundwater flow within the AOI. The hydrostratigraphic units are described below, from youngest to oldest.

Fill – Fill is generally thin and unsaturated in the northern portion of the upland and generally becomes thicker and water-bearing in the shoreline areas. The uppermost groundwater (i.e., water table) typically occurs in the fill, which extends from the upland across the shoreline to the Lake Union lakeshore and lake slope. Most shallow groundwater discharges into Lake Union from the fill. The fill has the highest measured hydraulic conductivity of the four hydrostratigraphic units, with a geometric mean of 0.019 centimeter per second (cm/sec) (57 feet/day) based on field testing.

Lake Sediment – The lake sediment hydrostratigraphic unit is present beginning 100 to 300 feet from the shoreline in the offshore portion of the AOI. A small component of deep groundwater discharges through lake sediment into Lake Union. The estimated vertical hydraulic conductivity (groundwater predominantly flows vertically through lake sediment) of the lake sediment hydrostratigraphic unit is 0.000039 cm/sec (0.11 feet/day).

Glacial Outwash – The two glacial outwash geologic units (Vashon recessional outwash [Qvr] and Vashon advance outwash [Qva]) compose the glacial outwash hydrostratigraphic unit due to their similar properties and stratigraphic position (i.e., between the fill and till)[41]. Glacial outwash deposits generally make up a large portion of the upper water-bearing zone (i.e., above the till) in the western, southwestern, and eastern portions of the upland. Glacial outwash deposits are absent in the northern and the southeast portion of the upland (beneath and east of the Cracking Towers), where fill lies directly on glacial till or glacial till is present at the ground surface. Most of the deep shoreline monitoring wells are screened in glacial outwash. The glacial outwash is not in direct contact with Lake Union except possibly in small localized areas along the till ridge (see Figure 3B-5 in Appendix 3B for location of till ridge). The geometric mean hydraulic conductivity for glacial outwash is 0.0020 cm/sec (5.8 feet/day).

Till – The till hydrostratigraphic unit consists of pre-Fraser glacial till unit (Qpgt). These deposits underlie the entire AOI, forming the lowest and most widespread unit in the site-specific stratigraphic sequence. Where the fill unit is absent or unsaturated in portions of the northern upland area, the till is the primary unit transmitting groundwater to other units in the upland. The till has the lowest hydraulic conductivity for all units, with a geometric mean hydraulic conductivity value of 0.00024 cm/sec (0.69 feet/day).

3.2.5.2. Key Hydrogeology Characteristics

Key site hydrogeology characteristics of the AOI that exhibit significant influence on the movement of groundwater and the transport of contaminants are described below and depicted in Figure 3-15, which presents the hydrogeologic CSM.

Till is the Dominant Hydrostratigraphic Unit – Till is the dominant hydrostratigraphic unit controlling the amount and direction of groundwater flow within the AOI. Because of its low hydraulic conductivity, till limits recharge to the water-bearing zone from upslope and the total amount of groundwater flowing across the upland. Groundwater flow within the till is limited due to its low hydraulic conductivity. The till ridge controls the horizontal groundwater flow direction and radial flow pattern (see Figures 3-16 and 3-17).

Low Groundwater Flow and Yield – On-site recharge from precipitation is the primary source of groundwater, accounting for up to 98 percent of the groundwater flowing through the upland (Figure 3-18). The through-flow (i.e., groundwater flowing through the till from areas upslope of the park) accounts for only approximately 2 percent of the total groundwater flow from the upland to the lake, based on the site-specific groundwater flow model completed in 2018 (Appendix 3F). Low through-flow limits the amount of groundwater flowing through the upland. Low pumping rates (0.1 to 0.48 gallon per minute [gpm] during recent pumping tests) indicate that hydrostratigraphic units would not be considered aquifers due to the low yield. Because of low yields, groundwater is not considered to be a drinking water source according to the definition of potable water in WAC 173-340-720(2)(b)(i).

Low Groundwater Flow Rates/Velocities – Groundwater flows radially outward from the AOI upland toward Lake Union, with low hydraulic gradients near the shoreline. Figures 3-16 and 3-17 present groundwater elevation contours for April 2016 and September 2017, respectively. Moderate hydraulic conductivities for the fill and outwash combined with low groundwater gradients near the shoreline result in low groundwater flow rates. Near the shoreline, horizontal groundwater velocity in the till ranges from approximately 0.001 to 0.0001 foot per day, whereas groundwater velocities in the fill and outwash are higher—but still less than

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[41] The recent beach and shallow shelf deposits (Qb) is also included in the glacial outwash hydrostratigraphic unit where present. See Appendix 3E for more information.

0.1 foot per day. Groundwater travel time from upland to sediment in most areas is long, on the order of 2.5 years (see Appendix 6A, Table 6A-4).

Groundwater Flow Occurs Primarily Within the Fill and Outwash – Groundwater flow through the upland occurs primarily within the fill and outwash hydrostratigraphic units. For example, over three quarters of total groundwater flow in the model domain (see Appendix 3F, Figure 3F-9) flows through the fill and outwash at the AOI shoreline.

Groundwater Discharge to Lake Union – The upland groundwater-to-surface water pathway is predominantly through the fill and outwash and mostly discharges to Lake Union through the fill, with a lower amount discharging through lake sediment. The majority of groundwater discharges to Lake Union relatively close to the shoreline. Figure 3-18 depicts the numerical model results for estimated groundwater discharge at the lake mudline. As shown in Figure 3-18, predicted groundwater discharge at the mudline varies across the sediment portion of the AOI, but generally discharges from 0.02 to greater than 0.05 feet/day at the OHWM and less than 0.0001 to 0.0050 foot per day 100 or more feet offshore. A groundwater flow model developed for the AOI (Appendix 3F) estimated total discharge to AOI in Lake Union in April 2013 as 2,120 cubic feet per day. Additional details regarding water balance are discussed Appendix 3E.

Water Balance is an accounting of the inputs and outputs of water within a system (e.g., watershed) or groundwater flow model.

Groundwater Discharge Zone – Ninety-two percent of groundwater discharges nearshore in the area where mudline discharge is greater than 0.001 feet/day (see Figure 3-18). This area, defined as the “groundwater discharge zone”, encompasses the area where groundwater flowing through the fill and the outwash at the shoreline discharges (Figure 3-15).

3.2.6. Localized Hydrology

A hydrodynamic evaluation of the sediment portion of the AOI was performed in 2005, details of which are provided in Appendix 3G. In summary, current meters (acoustic Doppler and vector-averaging) were deployed at four locations in the central and eastern portions of the AOI sediment area (Figure 3-1) in 2005 to evaluate the speed, duration, and direction of currents offshore of Gas Works Park. In addition, hydrodynamic forces associated with wind- or vessel-generated waves within the AOI were modeled.

Findings suggest that strong (125 to 140 cm/sec) currents can be generated by wind or wakes in shallow water (≤3 feet deep; above 17 feet USACE in elevation) along the shoreline. Spikes measured in nearshore currents were generally associated with vessel wakes rather than weather (although storm events were not monitored). Wave forces were predicted to attenuate with depth, moderating to an estimated 20 cm/sec in 10 feet of water or bottom elevation of 10 feet USACE.

In general, near-bottom currents measured in deeper water were slow (average of 3 cm/sec); observed current spikes at depth were due to vessel propellers. Site-specific current data are summarized and provided in Appendix 3G.

3.2.7. Natural Resources

The AOI consists of both upland and aquatic habitats, with their associated plant and animal assemblages. Upland habitats are highly modified and typical of an urban environment (e.g., deliberate landscaping; invasive plants in unmaintained areas; and soil altered through amendments, irrigation, compaction and paving). Species using upland habitats include resident, migratory, or introduced birds; mammals; insects; and plants.

As a large freshwater lake within an urban environment and part of the much larger Lake Washington watershed, Lake Union provides habitat for resident and migratory aquatic or water-dependent birds, fish, mammals, invertebrates, and plants.

3.2.7.1. Habitats

The AOI includes upland, riparian (shoreline) zone, lake bottom, and water habitats (i.e., in-water structures and the water column itself). The upland area of the AOI occupies approximately 21 acres, mostly as Gas Works Park. Available habitat is limited to maintained turf grass fields; small stands of ornamental or evergreen trees; and invasive or volunteer blackberries, shrubs, and small trees. Vegetation is irrigated and periodically fertilized. The remainder of the upland area consists of historical MGP structures, other buildings, extensive paving, and compacted gravel paths.

Riparian habitat, which provides a transition from upland to aquatic habitats, has been affected by the extensive shoreline modification. Shorelines in the western and central portion of the upland (i.e., the South Yard, Harbor Patrol, and the Prow) are dominated by riprap or bulkheads; the areas with over-water structures are unvegetated. The remaining shoreline is a steep vegetated bank (primarily with invasive species) of low to moderate height. The shoreline bank materials are typically sand, gravel, or cobble with some armoring. Where bank erosion has occurred or tar has been exposed, Seattle Parks and Recreation has placed a layer of gravel along the shoreline. Results of a 2006 nearshore habitat survey of the western portion of the GWPS are included as Appendix 3I, which also includes notes from a November 2006 habitat objectives meeting involving key GWPS stakeholders.

Flocculents are clumps of suspended particulates that settle to the bottom from the water column.

Bottom substrates within the 56-acre sediment portion of the AOI are highly variable and depend, in part, on localized hydrology and human activities. In areas subject to currents, wind-driven waves, or boat traffic (typically shallow nearshore slopes), bottom substrates consist of gravel, cobble, or exposed beds of till or clay. In more quiescent areas (e.g., Gas Works Park Marina, deeper offshore areas), bottom substrates contain highly organic flocculents, fine sands, and silts (Figure 3-19). Industrial debris has modified bottom substrates, particularly in the shallow nearshore areas.

The water column habitat in Lake Union ranges from vegetated shallows to deep, seasonally stratified water depths. Lake Union provides rearing and foraging habitat for various life stages of freshwater fishes and invertebrates. Construction of the Ship Canal, which altered Lake Washington's connection to Puget Sound, resulted in the Ship Canal becoming a migratory corridor for salmonids.

A **mesotrophic lake** is one with a moderate amount of plants and available nutrients.

Originally separated from Lake Washington, Lake Union was a poorly flushed system, discharging to Salmon Bay via a small stream. Historical water quality in Lake Union was likely similar to other mesotrophic lakes with moderate nutrient inputs and productivity and seasonal stratification of the water column. Construction of the Ship Canal significantly altered the hydrodynamics and created a greater flow through the lake; however, development along the shoreline degraded the water quality. Water quality impairments continue due to the following:

- Urban stormwater runoff
- Industrial discharges

- Natural seasonal stratification following warming temperatures in the late spring, summer, and early fall resulting in low DO in water near the deep lake bottom
- Saltwater intrusion from Puget Sound via the Ballard Locks during frequent summertime Lock openings

3.2.7.2. Biological Assemblages Within the AOI

Species that have been observed at the GWPS or are reported to use Lake Union[42] and surrounding habitats are listed in Table 3-2. Most of these species are well adapted to urban environments. Resident birds include Canada goose, American robin, European starling, northern flicker, and American crow; resident mammals are typified by mice, voles, rats, squirrels, rabbits, and raccoon. The primary soil macroinvertebrates noted in a September 2010 field survey (Hart Crowser 2012a) were earthworms; European crane fly larvae are also known to be seasonally abundant but were not observed at the time of the survey.

A **biological assemblage** in a group of species that live in the same habitat or environment.

The AOI upland vegetation is dominated by ryegrass but includes small plantings of native and non-native shrubs and trees that were planted as part of the park landscaping. The invasive Himalayan blackberry and Scotch broom occupies much of the shoreline riparian area (Figure 3-20), with landscaped plantings of native shrubs such as red osier dogwood and *Spirea* spp. along the northeast shoreline. Other riparian vegetation along the eastern and southeastern shoreline includes willows, butterfly bush, and alder. A narrow fringe of wetland plants is present along the northeastern, eastern, and southeastern shorelines, where a shallow beach occurs seasonally. Wetland species vary by location but generally include rushes, sedges, and iris. Two invasive aquatic species—purple loosestrife and reed canarygrass—are also found along the eastern shoreline.

Aquatic or water-dependent species that may be present, whether resident or migratory, include ducks, geese, gulls, cormorants, loons, grebes, muskrat, beaver, and river otter. The types of fish in Lake Union include perch, bass, sculpin, and a number of other warm water[43] species (Landolt Busch and Associates 1991). Four species of salmonids are seasonally present and use Lake Union as a migratory corridor between Puget Sound and the cool waters in the Lake Washington watershed.

Few quantitative studies of the benthic community assemblages have been conducted in Lake Union; however, very small clams (*Pisidium* spp.), annelid worms (primarily tubificid and naidid oligochaete worms), and crayfish have been noted where samples have been collected (Yake et al. 1986). The benthic species that are present tend to be indicative of stressed habitats, and the assemblage is dominated by only a few species, which further indicates stressed conditions. Water column invertebrates from samples collected in the vicinity of the AOI consist of zooplankton species, including cladocerans, copepods, mysids, and rotifers.

Aquatic vegetation occurs only in the photic zone of the water column (i.e., where light is sufficient to support photosynthesis) and in areas with minimal disturbance. In Lake Union, the vegetated stratum occurs at depths between 9 and 17 feet; waves and vessel wakes limit aquatic vegetation in shallower depths. Where present, aquatic plant assemblages are dominated by American waterweed and invasive

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[42] http://www.atlakeunionpark.org/about-lake/common-creatures.

[43] Warm water fish species are those tolerant of seasonally warm water temperatures.

species such as milfoil. Diatoms and algal mats cover the sediment surface in the photic zone. Phytoplankton species occupy the photic zone of the water column throughout the lake.

3.2.7.3. Sensitive Species or Habitats

Riparian and wetland habitats are considered priority habitats by the Washington Department of Fish and Wildlife (WDFW). Although present, these habitats have limited distribution and functionality within the AOI. Limited to a thin band along the shoreline, they provide little of their expected ecological function (e.g., nutrient cycling, organic material export, shoreline stabilization, water storage). The City has identified protection and restoration of riparian and littoral (shallow nearshore) habitats as a key focus for aquatic habitat management. Restoration of the shallow-water habitats of Gas Works Park is viewed as a potential project to help the City meet its aquatic habitat management goals (City of Seattle 2003).

3.2.7.4. Endangered Species or Critical Habitats

Three aquatic species that might use Lake Union habitats have been listed as threatened under the Endangered Species Act:

- Chinook salmon (Puget Sound Evolutionary Significant Unit)
- Steelhead (Puget Sound Distinct Population Segment)
- Bull trout (Puget Sound Management Unit, Coastal Puget Sound Distinct Population Segment)

Critical habitats, which must be specified for each species listed under the Endangered Species Act as endangered or threatened, are specific locations within the species’ range that contain physical or biological attributes essential to its conservation and recovery. Critical habitats have been identified for Chinook, steelhead and bull trout. Of the many areas that constitute critical habitat for Chinook, the only one present in Lake Union is the freshwater migratory corridor required by adults to access spawning grounds in the Lake Washington watershed or by juveniles during outmigration to Puget Sound. Although bull trout have not been recorded in Lake Union, the lake is identified as foraging, migration, and overwintering habitat for this threatened species. The Lake Washington watershed has been excluded from the critical habitat designation for Puget Sound steelhead (NOAA 2016). Additional habitat criteria for salmon is presented in Attachment 3I-3 in Appendix 3I.

Both the National Oceanic and Atmospheric Administration (NOAA) and the WDFW consider the nearshore area of the AOI to be an important part of the migratory corridor for salmonids. A migratory corridor to support species recovery has three main attributes:

- No obstructions or excessive predation
- Water quantity and quality sufficient to support mobility and survival by both juveniles and adults
- Presence of natural features providing refuge (e.g., overhanging riparian or in-water vegetation, side channels, undercut banks)

The nearshore environment of the AOI has no obstructions to salmonid migration; however, few other attributes of this type of critical habitat are currently in place. Acoustic tagging studies of juvenile salmonids suggests that juveniles use the upper water column in deeper parts of the lake (greater than 8 to 10 meters [26 to 32 feet]) in the vicinity of Gas Works Park (USFWS 2008).

3.2.8. Current and Planned Future Local Land Use

Properties surrounding the AOI upland have been developed to support industrial, commercial, and residential uses. Land use planning designations support this variety of uses, as shown on Figure 3-21 (Seattle Department of Planning and Development [DPD] 2012).

Gas Works Park is located within an Industrial Buffer (IB) zone, the intent of which is to provide transition between industrial areas and other uses—specifically, adjacent residential zones and commercial zones that have a residential orientation or pedestrian character (Seattle DPD 2012). The park will remain in its current land use as a public park for the foreseeable future (Hart Crowser 2012a). Its open space character also contributes to the 6-mile loop known as the Cheshiahud Lake Union Loop (City of Seattle 2013a), which circumnavigates Lake Union and follows the Burke-Gilman Trail and North Northlake Way near the GWPS (City of Seattle 2013b).

Properties north and adjacent to the AOI upland lie within the Wallingford neighborhood. Property uses within this commercial-zoned (C1) area include warehouses, office buildings, light industry, apartments, and condominiums (mixed-use). The C1 zone is generally defined as an automobile-oriented, primarily retail and service commercial area that serves surrounding neighborhoods as well as a citywide or regional clientele (Seattle DPD 2012). There are no known proposals to modify land use in this area.

The lake shoreline within the AOI supports a variety of public and private commercial land uses. Shoreline properties to the east of Gas Works Park, including Gas Works Park Marina and Waterway 19, also are also zoned IB. Gas Works Park Marina provides moorage for residential houseboats.

Nearby shoreline properties to the west, including Harbor Patrol, the King County parcel that is currently leased to the Center for Wooden Boats (previously leased to the Northwest Schooner Society), and the Northlake Shipyard, are zoned Industrial Commercial (IC) (Figure 3-21) (Seattle DPD 2012). The intent of the IC zone is to promote development of businesses that incorporate a mix of industrial and commercial activities, including light manufacturing and research and development, while accommodating a wide range of other employment activities (Seattle DPD 2012).

Lake Union and its shoreline are regulated under Seattle's Shoreline Master Program and are subject to shoreline overlay designations (King County 2011), three of which exist within the AOI (Figure 3-21):

- Conservancy Management (CM) – its purpose is to conserve and manage areas for public purposes, recreational activities, and fish migration routes; it need not be maintained in a pure state.
- Conservancy Waterway (CW) – its purpose is to preserve waterways for navigation and commerce, including public access to and from the water. All waterways are designated CW to provide navigational access to adjacent properties and for the loading, unloading, and temporary moorage of watercraft.
- Urban Maritime (UM) – its purpose is to preserve areas for water-dependent and water-related uses while still providing some views of the water.

The City's Shoreline Master Program (Seattle Municipal Code [SMC] 23.60A) governs activities near and overwater, including restoration activities. Proposed projects in the vicinity of Gas Works Park, identified as "Subreach 10b" in Exhibit C of the Master Program (Anchor QEA 2012), include "bank softening at Gasworks Park," South Wallingford Drainage improvements, and removal of North Lake Union in-water structures. This area is considered impaired habitat and is identified for priority actions.

3.2.8.1. Residential

Near the GWPS, the north end of Lake Union is occupied by houseboats on the eastern (e.g., Gas Works Park Marina) and western shorelines. Upland property north of the AOI is zoned commercial and includes condominiums and apartments (Seattle DPD 2012; King County 2013).

3.2.8.2. Commercial

Shoreline properties west of Gas Works Park are zoned IC. Operations in this area include the Seattle Police Department Harbor Patrol, Center for Wooden Boats, and Northlake Shipyard.

A small commercial crayfish fishery operating out of Union Bay has harvested crayfish from Lake Union in the past (Houck 2004); current operations are unknown. Catch volume for this operation was not well documented because WDFW does not require a license for crayfish fishing (Floyd|Snider 2007).

Muckleshoot Tribal Treaty fishing occurs within the area. Tribal fishing occurs in almost all of North Lake Union, including along the shoreline within the AOI. Fishing activities are based on specific fishing schedules established annually by the Tribe and the resource agencies (St. Amant 2007).

3.2.8.3. Industrial

Industrial properties on Lake Union are located along the Ship Canal to the west, east, and southeast. Land use and zoning consist of an IB designation throughout the park and nearby shoreline properties to the east, and an IC designation for the adjacent shoreline properties west of the park.

The Center for Wooden Boats is the current tenant of the Metro Lake Union South Yard. Northlake Shipyard, Inc., an operational shipyard and marine cargo operation, is east of Waterway 21. The shipyard operates as a ship repair facility (self-service and shipyard-conducted) and as an overflow yard for other shipyards in the area (Kelly 1996).

3.2.8.4. Recreational

Gas Works Park is a 19-acre public park that provides opportunities for viewing, picnicking, kite-flying, and play. Highly popular, the park is also the site of numerous city-wide events and celebrations. The park is also accessed by the heavily used Burke-Gilman Trail, a multi-use trail. Many events use the park as a venue, especially during the summer, when a city-wide celebration of Independence Day takes place there.

Access to Lake Union is restricted at the park. Entering the water and launching boats are prohibited, as are swimming, fishing, and wading (in accordance with the SMC 18.12.070) (Hart Crowser 2012c), not because of water quality but rather due to concern regarding contact with potentially contaminated sediment. However, all of the prohibited activities have been observed along the park shoreline. Wading, swimming, and fishing are popular activities during the summer.

Swimming is prohibited throughout Lake Union beyond 50 feet from shore (unless the swimmer is accompanied by a boat), except in designated swimming areas. Without a diving permit issued by the Chief of Police, skin and scuba diving are prohibited within the waters of the Ship Canal system, including Lake Union (Floyd|Snider 2007).

Waterway 20 includes a boat ramp within a fenced area with a locked gate. Boat launching is currently not allowed on the portion of Waterway 19 within Gas Works Park because accessing Lake Union from Gas Works Park is currently prohibited (in accordance with SMC.18.12.070). Signage prohibiting access is one of the Institutional Controls (Graves 2014). To a limited degree, boat-based recreational fishing occurs in Lake Union, primarily for smallmouth bass and sculpins. WDFW permits chumming east of the Fremont

Bridge and promulgates special size limitations for trout and steelhead in addition to statewide fishing rules (Floyd|Snider 2007).

3.2.8.5. Navigation

The 13th District of the United States Coast Guard (USCG) has determined that, for the purposes of exercising USCG authority and jurisdiction, the Ship Canal is navigable between Lake Washington and Puget Sound. Although vessels passing through the Ship Canal must traverse North Lake Union, there is no defined navigation channel. Lake Union does not appear to be subject to maintenance dredging (Floyd|Snider 2007). A single buoy is present about 350 feet south of the Prow and 50 feet east of the east end of the Prow. Commercial vessels stay outside of this buoy. Recreational power boaters, which make heavy use of the lake, frequently pass inside the buoy.

Lake Union is designated a State Harbor Area by WDNR. The historical outer harbor line, as provided by WDNR and based on 1907 survey information, is shown on Figure 3-21. Current waterfront activities are governed by the Seattle construction limit line (Figure 3-21), which is defined below in Section 3.2.9. Lake Union is heavily used by seaplanes (Floyd|Snider 2007), with two commercial seaplane terminals operating in the southern and eastern portions of the lake.

To maintain optimal navigational depths, USACE periodically dredges the canal portions of the Ship Canal system (Fremont and Montlake Cuts) (Cubbage 1992).

3.2.9. Overwater/Shoreline Structures

Existing over-water structures in the AOI are associated with the Shipyard, Metro South Yard, Harbor Patrol, and Gas Works Park Marina. Each over-water structure, including its current use, is described in Table 3-3. The City has established a construction limit line in Lake Union, beyond which it is unlawful to “erect, construct, or maintain any building or structure outward from the shores of Lake Union” (City of Seattle 2015, SMC Chapter 23.60A) (Figure 3-21).

3.2.10. Subgrade Utilities and Permitted Discharges

Various forms of infrastructure are present at and nearby the upland portion of the AOI. Permitted discharges and various subgrade utilities (e.g., sewer, water, and gas) are discussed here as well as rights-of-way and parcels adjacent to the AOI upland, which share utilities with the park and Harbor Patrol. Subject parcels include Gas Works Park, Harbor Patrol, and Waterways 19 and 20.

3.2.10.1. Permitted Discharges

Stormwater discharges at and immediately adjacent to Gas Works Park are permitted through Ecology’s National Pollutant Discharge Elimination System (NPDES) Phase 1 Municipal Stormwater (municipal separate storm sewer [MS4]) Permit, which was established and required by the Federal Water Pollution Control Act (more commonly, the Clean Water Act). Phase 1 MS4 permits are applicable to municipalities with populations greater than 100,000 people in areas of the city not served by a combined sewer. Gas Works Park is partially served by separated storm and sanitary systems and partially served by a combined storm and sanitary system. Only the portions of the system that are dedicated to stormwater fall within the Phase 1 MS4 permit; the combined storm and sanitary system is outside of Phase 1 MS4 permit coverage.

The Phase 1 MS4 permit requires the City to develop and implement a stormwater management program that outlines the programs and projects that the City must implement to reduce contamination of stormwater runoff and prohibit illicit discharges. The City manages and regulates the stormwater management program through the SMC Title 22 – Building and Construction Codes, Subtitle VIII – Stormwater Code, Chapter 22.800. The Phase 1 MS4 permit was last issued to the City on July 1, 2019, with an effective date of August 1, 2019 and will expire on July 31, 2024.

The City and King County are constructing a tunnel between Wallingford and Ballard to store excess runoff during storm events. This tunnel will reduce the number of combined sewer overflows that occur in the Ship Canal. The tunnel project will be operational by 2026 and reduce both the solid and dissolved phase pollutant loadings to Lake Union and the Ship Canal[44].

3.2.10.2. Gas Works Park

Existing subsurface utilities are described in the sections below. Information on the status of the GWPS-related stormwater systems is derived from a series of source control reports prepared for Seattle Public Utilities (SPU) and Ecology (Floyd|Snider 2007; 2009; 2010a, b; 2011; 2012a, b).

3.2.10.2.1 Gas Works Park Water, Sanitary Sewer, and Gas Lines

An 8-inch-diameter fire water main loops around Gas Works Park; at least two domestic water lines tee off the fire main and there are two points of connection for the irrigation system. The 8-inch-diameter fire main has entry points to Gas Works Park near the intersection of Meridian Avenue North and North Northlake Way on the east and near the intersection of Densmore Avenue North and North Northlake Way on the west. One of the domestic water lines teed-off the fire main serves the restroom facility on the east side of the park, while the other domestic water line teed-off the fire main serves the Harbor Patrol facility on the west side of the AOI upland. There are two points of connection from the fire main for the irrigation system: one on the east side of the park near the restroom and another at the northern toe of Kite Hill, which was replaced during the 2014 Kite Hill maintenance project.

A sanitary sewer line serving the park starts at the restroom and continues south through the Play Area and then west, continuing past the Harbor Patrol property. This line, which serves the restroom and the Harbor Patrol facility, connects with the City's public sanitary sewer main at the intersection of North Northlake Place and North Northlake Way.

A 1.5-inch-diameter gas line that served the former AS/SVE system runs north from the former Cracking Towers to connect with the gas main line at North Northlake Way. This gas line has been capped but is still considered an active gas line (Graves 2014).

3.2.10.2.2 Gas Works Park Stormwater Drainage System

Eight existing outfalls are in place to convey stormwater from within the park to Lake Union (additional outfalls associated with shared utilities are discussed below). Stormwater from the park is also discharged through outfalls at Waterways 19 and 20. The park outfalls are noted as Outfalls A through F, Prow Outfall, and Kite Hill Outfall; however, inspections of the storm drain system indicate that Outfall F and the Kite Hill Outfall are damaged and non-functional and the Prow Outfall has not been observed to discharge during a heavy rain event. The locations of all outfalls are described in detail in Appendix 6B and shown in Figure 3-22. The majority of the storm system for Gas Works Park was constructed in the 1970s, with follow-up improvements constructed in the early 2000s. The City evaluated the current condition of the storm drain system through a series of inspections conducted in 2008, 2010, and 2011. The results of this evaluation are provided in Appendix 6B

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[44] http://www.seattle.gov/util/EnvironmentConservation/Projects/ShipCanalWaterQuality/index.htm

3.2.10.3. Waterway 19

Waterway 19 is located between the northeastern shoreline of Gas Works Park and Gas Works Park Marina and is partially contained within the AOI. The Waterway 19 outfall captures stormwater runoff from a portion of Meridian Avenue North, North Northlake Way, the Burke-Gilman Trail, a landscaped area, and a portion of the roof from an adjacent building that includes both private and commercial facilities. Storm drainage conditions are provided in Appendix 6B and storm drain layout is shown in Figure 3-22.

3.2.10.4. Waterway 20

Waterway 20 is located west of Gas Works Park between the Harbor Patrol and the Metro Lake Union South Yard. The storm drainage system associated with Waterway 20, which is shown in Figure 3-22, was built in the early 1900s. The Waterway 20 outfall discharges into Lake Union through an 8-inch-diameter stormwater pipe. This outfall captures and conveys stormwater runoff from a portion of North Northlake Place, North Northlake Way, Densmore Avenue North, the northwest portion of Gas Works Park, a condominium building at the intersection of Densmore Avenue North, and the majority of the former Metro Lake Union North Yard (now the NorthEdge Building)[45]. Storm drains associated with Waterway 20 were video-inspected in 2008 and 2009. Results are discussed in Appendix 6B.

3.2.10.5. Seattle Police Department Harbor Patrol

Harbor Patrol is located between Gas Works Park and the Northlake Shipyard. The storm system and associated outfall for the Harbor Patrol property are shown on Figure 3-22. Storm drains and the oil-water separator associated with the Harbor Patrol Outfall were video-inspected in June 2010 (Floyd|Snider 2010a); results of this inspection are provided in Appendix 6B.

3.2.11. Historic or Cultural Resources

Gas Works Park is a City of Seattle Designated Landmark, a form of control designated by the Landmarks Preservation Board and administered by the Historic Preservation Program in the Department of Neighborhoods.

Gas Works Park was added to the National Register of Historic Places on January 2, 2013 (Washington State Department of Archaeology and Historic Preservation [WDAHP] 2013). The park was categorized as a Historic District, defined as geographical areas consisting of contributing and non-contributing properties. The boundaries of the Gas Works Park Historic District conform to the park boundaries.

On the basis of information included in the Historic Register Report (WDAHP 2013):

> *The park is considered historically significant for its direct association with serving the broad recreational needs of the citizens of Seattle and for its radical reformation of what was considered a park. The design conserved a part of Seattle's industrial heritage along with introducing a groundbreaking experiment in bioremediation into urban life.*

The National Register of Historic Places registration form lists 20 contributing resources within the property (Rusa Fels and Edstrom 2012).

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[45] King County sold the Metro Lake Union North Yard property in 2009. The property was redeveloped and is now occupied by the NorthEdge Building. The Waterway 20 Outfall still captures and conveys stormwater runoff from most of the property.

Most of the AOI upland is within an archaeological buffer area and within the original U.S. Government Meander Line of Lake Union that constitutes the historical jurisdictional boundary of the upland (Figure 3-21). The location of the U.S. Government Meander Line does not limit the area of the cleanup actions considered for the shoreline banks. The GWPS is located within the former traditional hunting, fishing and gathering areas for three indigenous communities (the Duwamish, Hachooabsh, and Shilsholes) who lived in the Seattle area. The indigenous people lived in villages along the southern and southwestern shores of Lake Union, but there were other villages and seasonal camps between Lake Washington and Salmon Bay. The shores of Portage Bay, Lake Union, and Lake Washington served as travel routes between settlements or camps and Puget Sound, key hunting or fishing areas, and sacred sites. There was a documented trail between Lake Union and Lake Washington along the northern bank of the present-day Ship Canal that the current Burke-Gilman trail follows (Graves 2020).

4.0 SCREENING LEVELS AND IDENTIFICATION OF COCS

This section summarizes the selection of screening levels and identification of contaminants of concern (COCs) for soil, groundwater, and sediment. The COCs are identified for each medium according to MTCA or SMS. In Section 5, screening levels are used to evaluate the nature and extent of COCs within the AOI.

For the purposes of this RI, groundwater is differentiated as either upland groundwater or offshore groundwater. Upland groundwater is defined as groundwater beneath the upland portion of the AOI (that is, groundwater landward of the OHWM). Offshore groundwater is defined as groundwater waterward of the OHWM and extending to the base of the biologically active zone (BAZ; top 10 centimeters [cm] of sediment). In accordance with Ecology guidance, groundwater becomes porewater at the base of, and within, the BAZ[46].

4.1. Screening Levels

This section provides an overview of exposure pathways and receptors, and for each potential receptor, discusses screening levels applicable to the AOI (see Figure 4-1).

As described below in Section 4.2, COCs for soil and upland groundwater were established in the 1999 Consent Decree. Consent Decree cleanup levels for soil and upland groundwater are retained as screening levels (see Sections 4.1.1 and 4.1.2). As a result of the previous cleanup actions described in Section 2, Summary of Investigations and Cleanup Actions, exposures (ingestion and direct contact) to contaminated soil and upland groundwater have been eliminated or reduced within the upland portion of the AOI[47].

The development of screening levels for offshore groundwater and sediment are presented in Sections 4.1.3 and 4.1.4, respectively.

4.1.1. Soil Screening Levels

The 1999 Consent Decree established soil cleanup levels to protect people from incidental ingestion and direct contact with contaminated soil. These cleanup levels are retained as screening levels. In addition, to comply with changes in regulatory benchmarks since the 1999 Consent Decree, other potential exposure pathways, receptors, and screening levels were evaluated and are discussed below.

4.1.1.1. Human Health (Incidental Ingestion and Direct Contact)

The 1999 Consent Decree defined cleanup levels (MTCA Method B unrestricted land use exposure scenario) for the following COCs: arsenic, fluoranthene, naphthalene, pyrene, and individual cPAHs. These cleanup levels are retained as screening levels and are presented in Table 4-1.

4.1.1.2. Human Health (Inhalation of Indoor and Outdoor Air)

A risk evaluation was performed to assess potential risks associated with the inhalation of indoor and outdoor air pathways (see Appendix 4D, Section 3.2). The evaluation concluded that risks associated with

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[46] Ecology has defined porewater as water within the BAZ near the sediment-lake interface (Ecology 2017a). In Lake Union, the top 10 cm of sediment represents the BAZ (and therefore, the porewater zone).

[47] Direct contact with soil is eliminated in areas with soil caps (referred to as “covers” in the 1999 CD). Upland groundwater is not considered a drinking water source due to low yield, eliminating groundwater exposure via ingestion. Previous cleanup actions have addressed upland plumes, reducing groundwater contaminant transport. Restrictive covenants (Section 2.2.2) prohibit cap disturbance and withdrawal of groundwater without prior approval from Ecology.

the inhalation pathway complied with MTCA requirements. Therefore, no screening levels were developed for this pathway.

4.1.1.3. Ecological Health (Incidental Ingestion and Direct Contact)

A simplified terrestrial ecological evaluation (TEE) as defined by MTCA was conducted to assess the potential for significant adverse effects to terrestrial ecological receptors posed by soil in the upland portion of the AOI (see Appendix 4D, Section 4). The simplified TEE process was used for this evaluation because the park is not managed to maintain native or semi-native vegetation and is not inhabited by endangered or threatened animals or plants or state species of concern (Attachment 4D-3). The simplified TEE consisted of an exposure analysis, which found that land use at the site and surrounding area makes substantial wildlife exposure unlikely (Attachment 4D-5). The simplified TEE concluded that there is not a potential for significant adverse effects. As a result, there are no applicable screening levels.

4.1.1.4. Protection of Sediment (Erosion)

Erosion of upland soil is a complete pathway because cleanup actions conducted as part of the 1999 Consent Decree intentionally did not include bank soil, which could erode into the lake. The 1999 Consent Decree deferred addressing the bank soil erosion-to-sediment pathway to the future sediment remedy.

As discussed in Section 12.1, as part of each cleanup action alternative, bank soil within the park will be excavated as necessary to transition from the existing upland ground surface to the in-water sediment remedy and may include additional excavation for mass removal. Following excavation, the bank will be capped with a vegetated soil cap to prevent direct exposure to park users and to prevent erosion into Lake Union. As a result, no soil screening levels are necessary because, following implementation of the sediment cleanup, there will be no complete soil to sediment migration pathway (potential erosion will have been addressed).

4.1.2. Upland Groundwater Screening Levels

The 1999 Consent Decree established upland groundwater cleanup levels designed to protect surface water (MTCA Method B formula values based on people consuming fish). These cleanup levels are retained as screening levels (see Table 4-1). In addition, to comply with changes in regulatory benchmarks that have occurred since the 1999 Consent Decree, other potential exposure pathways, receptors, and screening levels were evaluated and are discussed below.

4.1.2.1. Human Health (Ingestion)

In accordance with MTCA, the 1999 Consent Decree determined that upland groundwater was not usable as a source of drinking water and required administrative mechanisms to prohibit such use. As a result, restrictive covenants are currently in place to prohibit use of groundwater as drinking water. Therefore, this is an incomplete exposure pathway, and no screening levels were developed.

4.1.2.2. Protection of Surface Water

The 1999 Consent Decree established upland groundwater cleanup levels protective of surface water (based on people consuming fish) for the following COCs: benzene, toluene, ethylbenzene, naphthalene, and cPAHs. These cleanup levels are retained as screening levels (Table 4-1). The 1999 Consent Decree did not consider Lake Union a drinking water source. However, Ecology currently considers Lake Union a potential future drinking water source and therefore, offshore groundwater screening levels were developed that are protective of Lake Union as a drinking water source (see Section 4.1.3 below).

4.1.2.3. Protection of Sediment

To evaluate the potential contribution of upland groundwater to sediment contamination, offshore groundwater screening levels were developed and are discussed in Section 4.1.3 below.

4.1.3. Offshore Groundwater

Offshore groundwater screening levels were derived to comply with changes in regulatory benchmarks since the 1999 Consent Decree (e.g., consideration of all beneficial uses of Lake Union, including potential use as drinking water and protection of sediment quality). Offshore groundwater, not porewater, is considered a compliance medium. However, porewater data are used in Section 6, Contaminant Fate and Transport, to assist in the evaluation of the groundwater-to-surface water and sediment pathway.

Values considered when developing screening levels for offshore groundwater are presented in Table 4-2. The source of each screening level is highlighted in Table 4-2 and represents the lowest value, except as modified by the practical quantitation limit (PQL) or background in accordance with MTCA. The offshore groundwater screening levels presented in Table 4-2 are used to identify offshore groundwater COCs (see Section 4.2.2, Offshore Groundwater COCs) listed in Table 4-1.

4.1.3.1. Human Health (Ingestion) and Protection of Surface Water

Numerical criteria for protection of freshwater are based on MTCA Method B surface water (freshwater) cleanup levels protective of aquatic organisms and human health[48] and by reference, the standard for potable groundwater[49]. MTCA Method B cleanup levels for surface water (protective of people who drink surface water and eat fish) and groundwater (protective of people who drink groundwater) are included, when available, in Table 4-2.

As noted in WAC 173-340-720(4)(b) and 173-340-730(3)(b), MTCA Method B groundwater and surface water cleanup levels are set at concentrations established under applicable state and federal laws, if available. The state and federal criteria are adjusted downward, if necessary, so that they are considered by Ecology to be "sufficiently protective." Ecology considers a criterion sufficiently protective if the excess cancer risk is not greater than 1×10^{-5} or the hazard quotient is not greater than 1 (Ecology 2005b). Because the lowest available state and federal criteria are considered sufficiently protective, no adjustments were necessary.

MTCA Method B standard formula groundwater and surface water cleanup levels are also presented in Table 4-2. These values were used to evaluate the protectiveness of the state and federal criteria. The MTCA Method B standard formula surface water cleanup levels were calculated using modified exposure assumptions—a fish consumption rate of 97.5 grams per day and a fish diet fraction of 1[50].

4.1.3.2. Protection of Sediment

Groundwater criteria that are protective of freshwater sediment were calculated using the sediment cleanup objectives presented in Table 4-3. The calculations for the groundwater screening level protective of sediment are presented in Appendix 4F, Table 4F-1.

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[48] WAC 173-340-730[3][b]

[49] WAC 173-340-720[4][b]

[50] The default surface water exposure assumptions include a fish consumption rate of 54 grams per day and a fish diet fraction of 0.5.

4.1.3.3. *Modifying Criteria*

MTCA[51] specifies that the screening level for a given contaminant shall not be set at a level below the natural background concentration or analytical PQL, whichever is higher. Groundwater screening levels were initially selected based on the lowest of the risk-based criteria and then adjusted, as necessary, based on background concentrations (arsenic only) and PQLs. The background value for arsenic in groundwater is the natural background concentration for the Puget Sound Basin (Ecology 2022). The PQLs listed in Table 4-2 were obtained from Analytical Resources, Inc. (ARI), a Washington-certified laboratory.

4.1.4. Sediment Screening Levels

SMS has a two-tier framework for establishing sediment cleanup levels. For a COC, the sediment cleanup level is initially established at the sediment cleanup objective (SCO)—the lower end of the cleanup level range. Subject to specific criteria, the SMS allows the cleanup level to be adjusted upwards but not exceed the cleanup screening level (CSL).

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

- The lowest risk-based level protective of benthic invertebrate communities (direct contact), human health (direct contact and bioaccumulation), higher trophic level ecological receptors (bioaccumulation), or existing regulatory criteria;
- Background (natural or regional); or
- PQL.

This section derives SCOs and CSLs for use as screening levels (see Tables 4-3 and 4-4).

At EPA’s request, the City and PSE conducted ecological and human health risk evaluations based on exposure to sediment. Risk evaluation results are presented in Appendix 4C. Information from the risk evaluations was used in this RI to support the identification of sediment COCs (see Section 4.2.3, Sediment COCs).

4.1.4.1. *Protection of Benthic Organisms*

Regulatory criteria for freshwater sediment are provided under the SMS, which includes an SCO and a CSL for both chemical and biological endpoints. The SCO criteria correspond to sediment concentrations or biological responses below which adverse effects (acute or chronic) to benthic invertebrates are unlikely. The CSL criteria correspond to concentrations or effects thresholds above which adverse effects are anticipated and represent the maximum allowed concentrations and biological effects for use in establishing cleanup levels. Concentrations or biological effects falling between the SCO and CSL represent potential minor adverse effects.

Biological tests measuring effects on survival and growth in several species were also used to determine whether sediment might be toxic to benthic organisms (see Section 5.2.3.1). Biological effects are considered definitive with respect to compliance with SMS criteria and override chemical exceedances that predict a biological effect.

The SCO and CSL values protective of benthic invertebrates are applicable to sediment in the BAZ, which is the upper 10 cm of sediment, applied on a point basis throughout the sediment portion of the AOI.

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[51] WAC 173-340-705[6]

The benthic SCO criteria presented in Table 4-3 were used as screening levels to identify benthic sediment COCs (see Section 4.2.3.1, Benthic COCs).

4.1.4.2. Human Health – Incidental Ingestion and Dermal Contact

Sediment screening levels were developed to protect people encountering contaminated sediment during beach play, wading, or net fishing. The SCOs, CSLs, and calculations used to develop the SCO and CSL sediment screening levels protective of ingestion and dermal contact are presented in Tables 4F-2 and 4F-3 in Appendix 4F. SCO and CSL sediment screening levels were only developed for contaminants identified as human health direct contact COCs (see Section 4.2.3.2, Human Health Direct Contact COCs).

The beach play and wading screening levels are applicable to the upper 45 cm of sediment within a portion of the lakeshore area (see Figure 3-3) that extends from the OHWM to a lake bottom elevation of 15 feet. This lake bottom elevation corresponds to a maximum water depth of 5 to 7 feet, depending on the time of the year. The net fishing screening levels are applicable to the upper 10 cm of sediment within the AOI. Both sets of screening levels are applied as surface-area-weighted average concentrations (SWACs) within their respective exposure areas.

4.1.4.3. Human and Ecological Health – Fish Consumption (Potential for Bioaccumulation)

For bioaccumulative contaminants, sediment screening levels were also developed to protect people and wildlife (birds, mammals, and other fish) who eat finfish and crayfish from the lake. Sediment screening levels based on bioaccumulation were developed for those contaminants in Tables 4-3 and 4-4 identified as bioaccumulative COCs (see Section 4.2.3.3 for identification of bioaccumulative COCs).

Ecology's *Sediment Cleanup User's Manual* (SCUM) guidance includes two options for developing sediment screening levels for bioaccumulative contaminants. In Option 1, the SCO and CSL are set at background (natural or regional, respectively) or PQLs, whichever is higher. Option 2 requires the use of site-specific biota-sediment accumulation factors (BSAFs) to back-calculate risk-based sediment concentrations from risk-based tissue concentrations. Option 1 was selected because (1) risk-based concentrations, if calculated, are likely to be lower than background concentrations and (2) site-specific BSAFs have not been developed for the GWPS and based on work conducted for the Lower Duwamish Waterway Superfund Site, may be difficult to develop for arsenic and cPAHs[52].

Natural background values for arsenic and cPAHs, and a Lake Washington watershed regional background value for cPAHs, are included in Ecology's SCUM guidance. However, Ecology has not yet established a Lake Washington watershed regional background value for arsenic. As a result, a preliminary site-specific value was calculated for use at the GWPS; the derivation of this value is presented in Appendix 4A. Natural or regional background values are not available for the remaining bioaccumulation COCs.

The SCO and CSL values protective of human and ecological health for fish consumption are applicable to the upper 10 cm of sediment, applied as a SWAC concentration over the entire sediment portion of the AOI.

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[52] According to the Lower Duwamish Waterway Record of Decision (EPA 2014a), data collected during the RI/FS showed little relationship between sediment and tissue concentrations for arsenic and cPAHs; therefore, site-specific BSAFs were not developed for these two analytes.

4.2. Identification of COCs

COCs were selected for each media according to MTCA or SMS. COCs are contaminants identified as posing a potential risk to human health (people) or the environment. The following sections detail the identification of COCs for soil, upland groundwater, offshore groundwater, and sediment.

COCs for each media are listed in Table 4-5.

4.2.1. Soil and Upland Groundwater COCs

COCs for soil and upland groundwater were established in the 1999 Consent Decree (see Table 4-5).

4.2.2. Offshore Groundwater COCs

Offshore groundwater COCs were identified by comparing the offshore groundwater concentrations for contaminants of potential concern (COPCs) to the offshore groundwater screening levels. Offshore groundwater COPCs include contaminants that were tested for in offshore groundwater samples and were identified as soil, upland groundwater, or sediment COCs. An offshore groundwater COPC was identified as a COC if the maximum detected concentration is greater than the offshore groundwater screening levels (see Table 4-6). Over half of the offshore groundwater COPCs (19 out of 34) exceeded their respective criterion in at least one sample and were, therefore, identified as offshore groundwater COCs.

4.2.3. Sediment COCs

Consistent with SMS, sediment COCs were identified based on protection of benthic organisms (benthic COCs), people contacting sediment during beach play, wading, or net fishing (direct contact COCs), and people and wildlife (birds, mammals, and other fish) who eat finfish and crayfish from the AOI (bioaccumulative COCs).

The overall process for identifying sediment COCs is shown on Figure 4-2. The first step is identifying sediment COPCs, as shown in Figure 4-3. Sediment COPCs are contaminants that are detected in sediment and, if available, at concentrations greater natural background levels. As indicated in Figure 4-2, a sediment COPC is identified as a sediment COC if it is identified as a benthic, direct contact, or bioaccumulative COC (see Figures 4-4 through 4-6).

Table 4-7 presents the sediment COCs for the AOI by pathway. The individual pathways are discussed below.

4.2.3.1. Benthic COCs

Benthic COCs were identified by comparing sediment COPC concentrations in surface sediment to SMS benthic SCO criteria, as shown in Figure 4-4. An SCO exceedance in any sample resulted in that contaminant being included as a benthic COC (see Table 4-8). Two-thirds of the contaminants with promulgated criteria (21 out of 31) exceeded their respective criterion in at least one sample and were, therefore, identified as benthic COCs.

4.2.3.2. Human Health Direct Contact COCs

The process for identifying human health direct contact COCs is shown in Figure 4-5 and discussed in detail in Appendix 4E. The direct contact COCs are based on people encountering contaminated sediment during beach play, wading, or net fishing.

Direct contact COCs are identified using MTCA Method B soil cleanup levels, EPA Regional Screening Levels (RSLs), and information from the human health risk evaluation presented in Appendix 4C.

In general, the process to identify the direct contact COCs is as follows:

Start with sediment COPCs (discussed above).

Retain contaminants with maximum detected sediment concentrations greater than the direct contact screening levels (MTCA Method B and EPA RSLs).

Identify contaminants as direct contact COCs if the estimated risks for beach play, wading, or net fishing are greater than 1 x 10^{-6} or a hazard quotient (HQ) of 1.

4.2.3.3. Bioaccumulative COCs

The process for identifying bioaccumulative COCs is shown in Figure 4-6 and discussed in detail in Appendix 4E. The bioaccumulative COCs are based on people and wildlife (birds, mammals, and other fish) who eat finfish and crayfish from the AOI.

Bioaccumulative COCs are identified using regulatory lists of potentially bioaccumulative contaminants[53] and information from the human health and ecological risk evaluation presented in Appendix 4D. In general, the process to identify the bioaccumulation COCs is as follows:

Start with sediment COPCs (discussed above).

Retain contaminants that are considered potentially bioaccumulative.

Retain contaminants with maximum detected tissue concentrations greater than the tissue screening levels.

Identify contaminants as bioaccumulative COCs under the following conditions:

Contaminants that were not tested for in crayfish tissue samples[54],

The estimated risks for crayfish consumption are greater than 1 x 10^{-6} or an HQ of 1.

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[53] 173-333-310 WAC and the *Dredged Material Evaluation and Disposal Procedures User Manual* (DMMP) (ACOE et al. 2016).

[54] These contaminants were not included in the risk evaluation for the bioaccumulative pathway, and, therefore, could not be eliminated as bioaccumulative COCs.

5.0 NATURE AND EXTENT OF CONTAMINATION

This section describes the nature and extent of COCs (identified in Section 4) in soil, groundwater, and sediment at the GWPS. The occurrence and characteristics of NAPL, tar, and black carbon also are presented because of their association with and influence on the distribution of specific COCs.

While this section includes a description of the nature and extent of upland contamination, previous soil and groundwater cleanup actions have significantly reduced the potential for exposure to contaminants in the upland (see Section 2, Summary of Investigations and Cleanup Actions). The effects of prior cleanups are addressed in Section 5.1.

A large amount of data regarding the nature and extent of contamination and site conditions has been collected over the last four decades. Types of data used in this RI include chemical, geotechnical, petrophysical, physical, observational, and biological.

This vast data set was evaluated, and decisions made regarding development of two data sets, the RI Chemical Data Set and the RI Current Conditions Data Set. The data compilation process and management rules for developing these data sets are summarized in Appendix 5A. The two data sets are presented in Appendix 5B.[55] Data were drawn from more than 80 investigations conducted by PSE or the City, Ecology's project files, King County files, EPA reports, and Ecology's inventory of freshwater sediment quality studies maintained in the agency's searchable online database (Tables 2-1 and 2-2 list the previous upland and sediment investigations, respectively).

This section is organized as follows:

- Section 5.1 describes the effect of previous cleanup actions on current site conditions.
- Section 5.2 presents the distribution and concentration of contaminants in soil, groundwater, and sediment.
- Section 5.3 describes the occurrence and characteristics of NAPL, tar, and black carbon that influence the distribution of contaminants in media within the AOI.

5.1. Effect of Previous Cleanup Actions on Current Site Conditions

Both recent and historical data were used to evaluate the nature and extent of contamination in environmental media within the AOI. However, historical data do not reflect present-day conditions in many portions of the AOI because of the effects of the previous upland cleanup actions described in Section 2 (e.g., groundwater treatment, monitored natural attenuation of groundwater, soil capping, and tar removal) and sediment natural recovery (e.g., deposition of cleaner sediment in lower-energy environments) since the data were collected. The implications of previous cleanup actions and sediment recovery on the nature and extent of contamination in the upland and sediment portions of the AOI are discussed in the following paragraphs.

A significant portion of the upland has been remediated with a clean soil layer (i.e., soil cap) to prevent people from being exposed to contaminated soil. The contaminated subsurface soil and the clean soil layer

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[55] The RI chemical data set is the larger data set and includes data from 1984 through 2020. The RI current-conditions data set was developed by removing older data not representative of current conditions and highly uncertain data from the RI chemical data set.

are separated by geotextile fabric, which serves as an indicator to alert park maintenance workers of the possible presence of contaminated soil below. Figure 2-7 in Section 2 shows the locations of the soil caps. Historical shallow surface soil data are not representative of current surface soil concentrations in areas where a clean soil layer was placed. These previous surface soil data are evaluated as subsurface soil. Historical surface soil data from areas that were not capped were retained as representative of the nature and extent of contamination in surface soil.

Light NAPL (LNAPL) conditions have also changed in the upland portion of the AOI due to previous cleanup actions. LNAPL recovery performed in 1998 and 1999 reduced the LNAPL mass in the southeast corner of the park. This mass was further reduced or eliminated by the 6-year operation of the AS/SVE system.

The following upland cleanup actions have reduced upland groundwater concentrations:

- Operation of the AS/SVE system reduced concentrations of benzene (and other contaminants) in groundwater (and soil) in the southeast portion of the upland. The benzene concentrations have been reduced to below the groundwater cleanup level of 43 µg/L in OBS-1 (the compliance monitoring point) downgradient of the AS/SVE system.
- Natural attenuation has reduced naphthalene and benzene concentrations in groundwater. Evaluations of temporal trends in groundwater for naphthalene and benzene are provided in Sections 5.2.2.1.2 and 5.2.2.1.3, respectively and show stable or shrinking plumes.
- The Play Area groundwater treatment interim action utilized in-situ chemical fixation to reduce dissolved arsenic concentrations in groundwater beneath the Play Area. Treatment was able to achieve between 35 percent and 99 percent reduction in dissolved arsenic concentrations in the fill layer and more than 97 percent reduction of dissolved arsenic concentrations in the underlying outwash layer in the target treatment areas (GeoEngineers 2021).

Sediment conditions are represented by data collected over several decades. Long-term transport of sediment from the Lake Washington watershed and other parts of Lake Union to AOI sediment have contributed to burial and attenuation of contaminants in the surface (0 to 10 cm) sediment in depositional areas (sediment is naturally recovering in some areas of the lake bottom). A temporal evaluation of sediment concentrations is included in Section 6.6, Natural Recovery, to assess the trends in changing sediment concentrations over time, along with other lines of evidence indicating natural recovery is occurring.

5.2. COC Distribution and Magnitude in Site Media

COCs for soil and upland groundwater within the AOI are identified in the 1999 Consent Decree. COCs for offshore groundwater and sediment are identified in Sections 4.2.2 and 4.2.3, respectively. The COCs are summarized in Table 4-5 and vary by medium; however, to evaluate cross-media (e.g., upland groundwater to sediment) relationships, some constituents that were identified as COCs for only certain media are discussed below for all media.

The analytical data for environmental media are summarized in Tables 5-1 through 5-5. As discussed in Appendix 5A, some soil samples were excluded from the evaluation because the sampled media were removed by excavation, displaced during regrading, or located in the southeast upland area and remediated by AS/SVE. For samples from areas that have been capped or partially excavated, depths presented in Appendix 5B, Tables 5B-1.1 and 5B-2.1 represent current depths bgs rather than depths at the time of exploration and chemistry reflects pre-capping or pre-excavation conditions (as opposed to capping material that currently forms the surface soil). Given the extent of upland capping, surface soil concentrations summarized in Table 5-1 are not representative of the clean material currently at the ground surface within the AOI. The analytical data summary tables include frequency of detection (FOD), concentration (minimum, maximum, median, and average), screening level (as described in Section 4), frequency of exceedance (i.e., the frequency at which a contaminant exceeded its respective screening level), and exceedance factor (i.e., sample concentration divided by its respective screening level; factors greater than 1 mean the screening level is exceeded).

COC data are displayed in Section 5 figures using concentration contours that were developed using geographic information system (GIS) and Earth Volumetric Studio (EVS) interpolation techniques of concentrations in soil and sediment (combined) and upland groundwater. The GIS two-dimensional (2D) interpolations are based on a common inverse-distance weighted method that displays contoured concentrations in surface soil and surface sediment, whereas the Earth Volumetric Studio 3D model is used to depict groundwater concentrations and soil/sediment concentrations from a 3D interpolation (i.e., using data from all sampling points and depths).

The 3D model contours are based on the maximum concentrations across sample depths when in plan view. The 3D model extrapolates to the limit of the modeling domain. In areas where there are no surface data, the model estimates soil and sediment surface concentrations using subsurface data; therefore, figures depicting only surface concentrations provide a better estimate of ground surface and mudline conditions.

Contour intervals vary by analyte, depending on the screening level and the range of concentrations encountered for each COC and medium. Areas where impervious surfaces or caps have been installed are shown on the soil nature and extent figures; chemistry depicted in these areas reflects pre-capping conditions. Simple plan-view figures are used where there are few data points to display. Model parameters are described in more detail in Appendix 5A.

5.2.1. Soil

Soil contamination in the upland was evaluated prior to the cleanup actions described in Section 2, Summary of Investigations and Cleanup Actions. Samples were collected at over 240 locations, with over 300 soil samples collected at depths ranging from ground surface to approximately 90 feet bgs. A summary of soil analytical results is presented in Table 5-1. Data are provided in Appendix 5B.

As identified in the 1999 Consent Decree and in Section 4, COCs in soil are cPAHs [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-c,d)pyrene and dibenzo(a,h)anthracene], other non-carcinogenic PAHs (fluoranthene, naphthalene and pyrene), and arsenic. The following COCs were selected for further evaluation to represent the most mobile or the most toxic of these contaminants:

- cPAH TEQ (to represent all cPAH constituents)
- Benzo(a)pyrene (the most toxic cPAH)
- Chrysene (the most mobile cPAH)
- Naphthalene (the most mobile of all carcinogenic or non-carcinogenic PAHs)

- Fluoranthene (the most toxic non-carcinogenic PAH)
- Arsenic

The distribution of TPAH (a sum of carcinogenic and non-carcinogenic PAHs), which is a COC for sediment but not soil, is evaluated further in Section 5.2.3, Sediment.

The following sections discuss the extent of these COCs in soil in the upland portion of the AOI. Analytical concentrations of cPAH TEQ, naphthalene and arsenic in soil are presented in Figures 5-1A through 5-3B.

5.2.1.1. Carcinogenic PAHs

For all but one individual cPAH, the frequency of detection (FOD) in soil was greater than 75 percent; the FOD for dibenzo(a,h)anthracene, the one exception, was 64 percent (Table 5-1). Of individual cPAHs detected, frequency of exceedances were greater than 60 percent, again except for dibenzo(a,h)anthracene, which was 52 percent.

5.2.1.1.1 Carcinogenic PAH TEQ

Individual cPAHs were COCs in the 1999 Consent Decree. In this section, cPAH TEQ is used as a surrogate for these individual COCs. In soil, cPAH TEQ was reported at a maximum concentration of 1,000 mg/kg and had an average exceedance factor of 290 (exceedance factor is based on soil samples collected at all depths across the upland portion of the AOI and does not account for the clean soil caps); 81 percent of the 297 soil samples across all depths had cPAH TEQ concentrations greater than the screening level (Table 5-1). These exceedances in soil occurred at 192 upland exploration locations, almost all of which are now below clean soil caps (Figures 5-1A and 5-1B).

cPAH TEQ Profile in Soil

Current Depth Interval (feet bgs)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)	Average Detected Exceedance Factor
Screening Level	0.137[a]	0.137[a]	
0-1 (uncapped areas [b])	4.5	16	120
1-15	6.7	48	350
>15	1.2	25	180
All Depths	5.5	40	290

Notes:

[a] Screening level is not a median or an average value.

[b] Existing areas not capped as part of the cleanup actions described in Section 2. These areas comprise 3.3 acres of the 21-acre upland portion of the AOI (see Figure 2-8).h

Concentrations of cPAH TEQ in shallow soil were several orders of magnitude above the screening level in uncapped areas near the Cracking Towers and in the northeastern portion of the upland (Figure 5-1A).

Subsurface soil concentrations followed a similar pattern, with the highest concentrations occurring near the Cracking Towers and in the eastern portion at the upland (Figure 5-1B). The average concentration of cPAH TEQ was highest in the 1- to 15-foot bgs depth interval and decreased with increasing depth, as shown in the inset table above. The distribution of cPAHs did not appear to be directly linked to areas of NAPL-impacted soil; rather, the distribution of cPAHs likely reflected the more widespread occurrence of black carbon (e.g., lampblack) found in the fill layer.

5.2.1.1.2 Benzo(a)pyrene and Chrysene

Benzo(a)pyrene is the most toxic of the individual cPAHs and contributes the highest fraction to the TEQ; all other individual cPAHs are expressed as a fraction of benzo(a)pyrene based on relative toxicity. Consequently, concentration distributions in surface and subsurface soil for benzo(a)pyrene are like those for cPAH TEQ (Figures 5-1A and 5-1B).

The average concentration of benzo(a)pyrene was highest in the 1- to 15-foot bgs depth interval and decreased with increasing depth, as shown in the inset table below. As discussed for cPAHs, average shallow and all depths soil concentrations do not account for the presence of clean soil caps (see Figures 5-1A and 5-1B).

Benzo(a)pyrene Profile in Soil

Current Depth Interval (feet bgs)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)	Average Detected Exceedance Factor
Screening Level	0.137[a]	0.137[a]	--
0-1 (uncapped areas [b])	2.9	12	88
1-15	7.2	40	290
>15	1.6	24	180
All Depths	5.4	34	250

Notes:

[a] Screening level is not a median or an average value.

[b] Existing areas not capped as part of the cleanup actions described in Section 2. These areas comprise 3.3 acres of the 21-acre upland portion of the AOI (see Figure 2-8).

Chrysene is considered one of the most mobile cPAHs, although overall mobility in environmental media is low for all individual cPAHs. The frequency of exceedance and exceedance factor were generally similar to or less than those for benzo(a)pyrene and cPAH TEQ. The footprint for chrysene fell within that of cPAHs in all but two cases (two deep subsurface samples—one located in the central meadow and one located in the northeast corner); thus, chrysene was not mapped separately.

Because other individual cPAHs are not as toxic as benzo(a)pyrene or as mobile as chrysene, they are not mapped or discussed individually. Other individual cPAHs are co-located with (fall within the footprint of) cPAH TEQ, which is mapped in Figures 5-1A and 5-1B.

5.2.1.2. Non-carcinogenic PAH COCs

Non-carcinogenic PAH COCs (i.e., fluoranthene, naphthalene, and pyrene) were detected greater than 80 percent of the time in soil. Non-carcinogenic PAHs rarely exceeded screening levels (<4 percent frequency of exceedance). Because pyrene (a COC in soil) is not as toxic as naphthalene or as mobile as fluoranthene, it is not mapped or discussed individually.

5.2.1.2.1 Naphthalene

Naphthalene was detected in 81 percent of soil samples tested for this analyte; however, only 3 percent of the 305 soil samples had naphthalene concentrations greater than the screening level of 3,200 mg/kg (Table 5-1). Naphthalene was detected in soil at a maximum concentration of 110,000 mg/kg (exceedance factor = 34). The exceedances in soil occurred at seven upland exploration locations in deeper soil (Figure 5-2B). There were no exceedances in surface soil (Figure 5-2A). The average concentration of naphthalene in soil was lowest in the shallowest depth interval (0- to 1-foot bgs) and highest in the 1- to 15-foot depth interval, and decreased below the 15-foot depth, as shown in the inset table below. Naphthalene concentrations were higher in the subsurface (i.e., 1- to 15-foot depth) because it is associated with residual NAPL.

Naphthalene Profile in Soil

Current Depth Interval (feet bgs)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)	Average Detected Exceedance Factor
Screening Level	3,200[a]	3,200[a]	--
0-1 (uncapped areas[b])	1.4	6.0	<1
1-15	2.2	1,500	<1
>15	14	350	<1
All Depths	2.3	1,100	<1

Notes:

[a] Screening level is not a median or an average value.

[b] Existing areas not capped as part of the cleanup actions described in Section 2. These areas comprise 3.3 acres of the 21-acre upland portion of the AOI (see Figure 2-8).

Naphthalene was detected at concentrations greater than the screening level beneath the northeastern meadow (currently capped), at several locations along the eastern shoreline (one northeast of the Play Area and another adjacent to and east of the Play Area), and in two locations near the Harbor Patrol yard (currently beneath asphalt paving or within a secured, fenced area). All of these exceedances were in subsurface soil. The highest naphthalene concentrations (94,000 mg/kg and 110,000 mg/kg) were found at 10-feet to 15-feet bgs southeast of the Play Barn (Figure 5-2B).

5.2.1.2.2 Fluoranthene

Fluoranthene is the most toxic of the non-carcinogenic PAHs and is a soil COC. The frequency of exceedance for fluoranthene was less than the frequency of exceedance for naphthalene. When averaged by depth interval, exceedance factors for fluoranthene were also less than those for naphthalene. The naphthalene or cPAH footprint encompassed the fluoranthene footprint; thus, the latter is not mapped.

5.2.1.3. Arsenic

Arsenic was detected in 86 percent of 168 soil samples tested for this COC. About 26 percent of the detected concentrations exceeded the screening level of 20 mg/kg (Table 5-1). Arsenic was detected at a maximum concentration of 20,000 mg/kg (exceedance factor = 1,000) in a deep (11.5 feet bgs) soil sample. Exceedances occurred at 44 upland exploration locations (Figures 5-3A and B), most of which were in subsurface soil (>1 foot bgs). The average concentration of arsenic in soil was lowest in the shallowest depth interval (0 to 1 foot bgs) and highest in the 1- to 15-foot depth interval, and decreased with increasing depth, as shown in the inset table below.

Arsenic Profile in Soil			
Current Depth Interval (feet bgs)	**Median Detected Concentration (mg/kg)**	**Average Detected Concentration (mg/kg)**	**Average Detected Exceedance Factor**
Screening Level	20[a]	20[a]	–
0-1 (uncapped areas[b])	10	12	<1
1-15	7.9	340	17
>15	13	220	11
All Depths	8.6	291	15

Notes:

[a] Screening level is not a median or an average value.

[b] Existing areas not capped as part of the cleanup actions described in Section 2. These areas comprise 3.3 acres of the 21-acre upland portion of the AOI (see Figure 2-8).

The broadest footprint of screening level exceedances occurred in the 1- to 15-foot depth interval in the east-central shoreline area of the upland (Figures 5-3A and B), an area associated with the former Thylox process area, a known arsenic source. The arsenic was highest in the well-delineated area (both vertically and laterally) south of the Play Barn. Much of this is below the newly renovated Play Area[56], which serves as a cap over the arsenic-impacted soil and prevents infiltration.

Arsenic exceeded the screening level in surface soil in the bank area along the northeast shoreline.

5.2.1.4. Human Health Risk Evaluation

A human health risk evaluation was conducted for areas of the upland (including banks) that remain uncapped using exposure parameter values consistent with MTCA (see Appendix 4D, Section 3.1). The total cancer risk for exposures to arsenic and cPAHs in the uncapped areas under current conditions is 2 x $10^{\ 6}$, primarily due to cPAHs in the northeast corner near the Play Barn. The total cancer risk is less than the MTCA acceptable risk level for exposure to multiple COCs of 1 x 10^{-5}. However, the cancer risk for cPAHs of 2 x 10^{-6}, under current conditions, is greater than the MTCA acceptable risk level for individual COCs of 1 x 10^{-6}.

As shown in Appendix 4D, addressing uncapped bank (shoreline) soil[57] as part of the sediment remedy (as anticipated by the 1999 Consent Decree) will reduce the human health risk for cPAHs under post-cleanup conditions to 1 x 10^{-6}, which is an acceptable risk level for individual COCs under MTCA.

5.2.1.5. Soil Key Findings

Key observations related to the nature and extent of COCs in soil in the AOI are as follows:

- cPAHs (surface soil) – The distribution of cPAHs that exceed screening levels in surface soil was limited to uncapped areas that were not addressed as part of previous cleanup actions (see Figure 2-8).
- cPAHs (subsurface soil) – cPAHs were widespread in subsurface soil and encompassed the distribution of individual PAHs (i.e., individual PAHs were co-located with cPAHs).

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[56] Play Area soil is beneath a layer of concrete and brick pavers or poured in place rubber playground surface, sand, and an impermeable liner. The liner and stormwater collection system prevents infiltration of stormwater to the underlying soil.

[57] The human health risk evaluation assumed that shoreline/bank soil is accessible; however, most of the shoreline/bank is not accessible due to overgrowth by Himalayan blackberries.

- Non-carcinogenic PAHs (surface soil) – Non-carcinogenic PAHs were not detected in surface soil at concentrations greater than screening levels.
- Non-carcinogenic PAHs (subsurface soil) – The distribution of non-carcinogenic PAHs in subsurface soil that exceeded screening levels was limited. Naphthalene exceeded the screening level at discrete locations in the northeast corner, to the west within the Harbor Patrol property, and near the Play Barn.
- Arsenic (surface soil) – Arsenic exceedance of the screening level in surface soil is limited to the uncapped bank area along the northeast shoreline. These exceedances were co-located with the cPAH exceedances in surface soil noted above.
- Arsenic (subsurface soil) – The highest concentrations of arsenic were found at considerable depth bgs in the eastern portion of the upland near the former Thylox process area.
- Human health risk – cPAH soil concentrations above screening levels in uncapped areas currently pose an unacceptable human health risk. However, addressing the uncapped shoreline/bank areas shown on Figure 2-8 as part of the sediment remedy (as anticipated by the 1999 Consent Decree) will reduce the human health risk to acceptable levels.

5.2.2. Groundwater

This section compares upland and offshore groundwater data to the screening levels described in Section 4.1, Screening Levels, to evaluate the extent of contamination in AOI groundwater.

For upland groundwater, the 1999 Consent Decree established a groundwater conditional point of compliance in surface water, as close as technically possible to the point where it flows into surface water (e.g., the mudline). Therefore, while this section uses upland groundwater screening levels to evaluate upland groundwater, in particular groundwater located at the shoreline, these screening levels apply at the mudline (offshore) not at the shoreline[58]. The comparison of upland groundwater data to upland groundwater screening levels was conducted to illustrate and describe the location of screening level exceedances.

5.2.2.1. Upland Groundwater

Analytical results for all upland groundwater sampling events are included in Appendix 5B, Table 5B-3.2[59]. A discussion of naphthalene and benzene concentration trends over time is incorporated below; naphthalene is used as a surrogate for other PAHs due to its mobility. Overall, upland groundwater has been collected from over 100 locations in the upland, including monitoring wells, multi-level sampler (MLS) wells, and temporary wells. Over 400 groundwater samples were collected between 1986 and 2018. Table 5A-3 provides a groundwater testing summary for all sampling events.

Upland groundwater current conditions have been interpreted using recent (since April 2013; see bullets describing data sets below) data from over 60 monitoring wells, 6 MLS wells with at least three levels each, and 9 temporary wells. The temporary well data are from 2014 and 2016 sampling events and are in areas where there are no permanent monitoring wells. The temporary well data are mainly used to bound the arsenic extent around the Play Area. Monitoring wells are categorized as shallow wells (i.e., screened at or near the water table) and deep wells. The deep monitoring wells have screens positioned below the water

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[58] The mudline is where groundwater discharges to surface water and is defined by the upper sediment surface. The mudline is shown schematically on Figure 3-18.

[59] As noted in Appendix 5A, groundwater collected from temporary wells as grab samples are not included in Table 5B-3.2, except for several grab samples in the Play Area.

table and are generally co-located with shallower wells. Most of the shallow/deep well pairs are located near the shoreline.

The extent of upland groundwater contamination in the AOI has been interpreted using the data described below:

- The data set for COCs other than arsenic was derived from groundwater sampling events in April 2013 and December 2014[60]. As described below, results confirmed that plumes were stable or shrinking and provided sufficient data to evaluate the upland to sediment pathway so no additional sampling was warranted. The additional data for non-arsenic COCs was collected in December 2014 as part of the supplemental investigation of arsenic at the Play Area. Data statistics are presented in Table 5-2. Data are provided in Appendix 5B, Table 5B-1.2; this data set is used for groundwater Figures 5-4 through 5-8.
- The arsenic data set was derived from groundwater sampling events in October 2013, December 2014, September and October 2016, and December 2020[61]. Data statistics are presented in Table 5-2, and the arsenic groundwater data are provided in Appendix 5B, Table 5B-1.2. The arsenic groundwater data set is used for Figure 5-9, which shows the distribution of arsenic in shoreline wells. Figure 5-9 also shows the shoreline arsenic-contaminated groundwater area, which is identified in the Play Area Interim Action Monitoring Report (GeoEngineers 2021), and represents the area of elevated dissolved arsenic within and downgradient of the Play Area that is expected to be amenable to treatment by the same method used for the interim action. The 2014, 2016, and 2020 sampling events focused on defining the arsenic extent within and around the Play Area and evaluating the efficacy of the Play Area interim action (see Section 5.2.2.1.4). The arsenic analysis for 2020 was by method SW6010C on lab-filtered and non-preserved samples; previous arsenic analyses were by method SW6010C on field-filtered samples preserved with nitric acid.

As identified in the 1999 Consent Decree and in Section 4, COCs in upland groundwater include:

- Individual cPAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-c,d)pyrene, and dibenzo(a,h)anthracene)
- Naphthalene
- Volatile organic compounds (VOCs; benzene, ethylbenzene, and toluene)

In the April 2013 and December 2014 groundwater sampling events, PAHs were analyzed in both filtered and unfiltered samples to evaluate dissolved and TPAH concentrations, respectively. In general, PAH concentrations were lower in filtered samples than in unfiltered samples. This finding suggests that unfiltered PAH concentrations might have been affected by suspended solids, a condition that would preclude accurate assessment of PAHs dissolved in the groundwater. To be conservative, unfiltered PAH sample results were used to map PAHs in groundwater (and when discussing current groundwater conditions).

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[60] Compliance monitoring for non-arsenic COCs was completed in 2010 and the purpose of the 2013 sampling was to confirm trends and evaluate potential upland to sediment groundwater pathways

[61] Arsenic data for Play Area temporary wells PAI-10, -11, -22D, -25D, -27S, -27D, -30S, and -30D precede the Play Area Interim Action treatment rounds and do not represent post-remediation concentrations. Groundwater samples from these temporary wells were collected in 2014 or 2016. Arsenic data from December 2020 represent post-treatment conditions collected at the end of the Play Area Interim Action.

The following contaminants were selected for the nature and extent discussion for upland groundwater:

- cPAH TEQ (not a COC, but representative of individual cPAHs that are COCs)
- Benzo(a)pyrene
- Naphthalene
- VOCs

In addition, dissolved arsenic (not an upland groundwater COC) was mapped to better evaluate cross-media relationships. Arsenic results are further evaluated in Section 6.5.3 for the groundwater-to-sediment and surface water pathway.

The analytical results for benzo(a)pyrene, naphthalene, benzene, and arsenic in upland groundwater are displayed in Figures 5-4 through 5-9[62]. The following sections discuss the extent of these contaminants in upland groundwater in the AOI in order to evaluate the upland groundwater to sediment pathway.

Offshore groundwater samples collected in conjunction with porewater samples in 2004 and 2005 are discussed in Section 5.2.2.2.

5.2.2.1.1 Carcinogenic PAHs

cPAH TEQ

In upland groundwater, cPAH TEQ was detected in 36 percent of the unfiltered shallow well samples and 29 percent of the unfiltered deep well samples. The maximum concentration detected was 1.4 µg/L (Table 5-2) in an unfiltered sample (1 µg/L was the highest concentration in a filtered sample). The highest concentrations were associated with the Harbor Patrol property and the area east of the Play Barn, and with known NAPL distributions. The distribution of cPAHs is not mapped because it is essentially the same as that depicted for benzo(a)pyrene (see Figure 5-4), the major constituent of the cPAH TEQ. The average concentrations in groundwater in April 2013 and December 2014 for deep-screened wells and shallow-screened wells are shown in the inset table below along with screening level exceedance factors. The exceedance factors indicate the upland groundwater concentrations relative to the screening level; however, the conditional point of compliance for upland groundwater, as established in the 1999 Consent Decree, is at the mudline, as close as technically possible to the point where groundwater flows into surface water.

cPAH TEQ (Total[a]) Profile in Upland Groundwater

Relative Depth of Groundwater	Median Detected Concentration (µg/L)	Average Detected Concentration (µg/L)	Average Detected Exceedance Factor
Screening Level	0.0296[b]	0.0296[b]	--
Shallow/Water Table Wells	0.088	0.30	10
Deep Wells	0.10	0.30	10
All Wells	0.088	0.30	10

Notes:

[a] Data represent unfiltered (total) concentrations instead of dissolved concentrations and are likely biased high.

[b] Upland groundwater screening level is not a median or an average value.

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[62] For COCs other than arsenic, the April 2013 groundwater results were chosen for mapping instead of the October 2013 groundwater results. The rationale is threefold: (1) the suite of wells included all wells on the GWPS, (2) reporting limits tended to be more elevated in October, and (3) concentrations of COCs in groundwater were generally higher in April than in October.

Carcinogenic PAH TEQ concentrations were similar for shallow and deep groundwater, with similar frequencies of detection in shallow-screened wells (36 percent) and deep-screened wells (29 percent) (Table 5-2). Individual cPAHs with the highest detection frequencies in groundwater were chrysene and benzo(a)pyrene. Carcinogenic PAH TEQ exceedance factors in shoreline wells ranged from <1 to 35 µg/L in shallow/water table wells and <1 to 21 µg/L in deep wells.

Benzo(a)pyrene and Chrysene

The most toxic cPAH is benzo(a)pyrene, which has a screening level of 0.0296 µg/L and a maximum detected concentration of 1.1 µg/L (exceedance factor = 37). In the 70 samples analyzed for benzo(a)pyrene (reported as a total concentration) in April 2013 and December 2014, the compound was detected in 31 percent of the shallow well samples and 27 percent in deep well samples.

Based on mapping of benzo(a)pyrene groundwater results (Figure 5-4), apparent screening level exceedances were widespread across the AOI upland, with the areas of highest concentrations focused near the eastern shoreline southeast of the Play Barn and the eastern half of the Harbor Patrol property. These areas correspond to known areas of DNAPL (Figure 5-26B). For mapping purposes, samples in which constituents were not detected were assumed to be present at a concentration equal to one-half the laboratory reporting limit. Because of elevated laboratory reporting limits for benzo(a)pyrene[63], the one-half reporting limit value for many wells exceeded the screening level for benzo(a)pyrene (see the blue dots on Figure 5-4). Therefore, the extent of benzo(a)pyrene mapped as exceeding the screening level for groundwater is likely overestimated, particularly in the central portion of the shoreline (from TSW-3 to OBS-1/OBS-2).

It should be noted that several of the elevated benzo(a)pyrene reporting limits discussed above and shown on Figure 5-4 are greater than the site-specific solubility of 0.1 µg/L, as measured by Purdue University (Attachment 2C-1 of Appendix 2C) (see Section 6, Contaminant Fate and Transport, for more detail), and therefore do not appear to be representative of dissolved concentrations.

The average concentrations of total benzo(a)pyrene in groundwater in April 2013 and December 2014 for deep-screened wells and shallow-screened wells are shown in the inset table below along with screening level exceedance factors. The exceedance factors indicate the upland groundwater concentrations relative to the screening level; however, the conditional point of compliance for upland groundwater, as established in the 1999 Consent Decree, is at the mudline, as close as technically possible to the point where groundwater flows into surface water.

Benzo(a)pyrene (Total[a]) Profile in Upland Groundwater

Relative Depth of Groundwater	Median Detected Concentration (µg/L)	Average Detected Concentration (µg/L)	Average Detected Exceedance Factor
Screening Level	0.0296[b]	0.0296[b]	--
Shallow/Water Table Wells	0.12	0.30	10
Deep Wells	0.090	0.20	7
All Wells	0.10	0.30	10

Notes:

[a] Data represent unfiltered (total) concentrations instead of dissolved concentrations and are likely biased high.

[b] Upland groundwater screening level is not a median or an average value.

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[63] Some groundwater samples collected during the 2013 Supplement Investigation required laboratory dilution to quantify other target analytes. The reporting limits for benzo(a) pyrene are elevated because of these laboratory dilutions (see Appendix 2A, Sub-Attachment 2A-9.1)

The occurrence of benzo(a)pyrene by depth was similar between shallow-screened wells (31 percent frequency of detection) and deep-screened wells (27 percent frequency of detection) (Table 5-2). The average benzo(a)pyrene concentration was similar in deep wells and in shallow wells. These averages mostly reflected reporting limits, so the similarity is expected. The distribution of benzo(a)pyrene along the shoreline is depicted in the cross section in Figure 5-4. Benzo(a)pyrene exceedance factors in shoreline wells ranged from <1 to 25 µg/L in shallow/water table wells and <1 to 17 µg/L in deep wells.

Chrysene is considered the most mobile cPAH. The average concentration, frequency of exceedance, and maximum exceedance factor for chrysene was similar to benzo(a)pyrene in groundwater (Table 5-2). In addition, the footprint for benzo(a)pyrene exceedances encompassed that for chrysene; therefore, the latter is not mapped. Chrysene exceedance factors in shoreline wells ranged from <1 to 24 µg/L in shallow/water table wells and <1 to 16 µg/L in deep wells.

Because other individual cPAHs are not as toxic as benzo(a)pyrene or as mobile as chrysene, they are not mapped or discussed individually.

Comparison of Dissolved and Total cPAH Upland Groundwater Results

Samples were filtered in the April and October 2013, and December 2014 events; the October 2013 event has the greatest well network coverage for dissolved cPAHs[64]. For comparison of dissolved and total cPAHs, the following inset table presents statistics for all wells (shallow and deep) for the October 2013 event.

Analyte	Dissolved Median Detected Concentration (µg/L)	Total Median Detected Concentration (µg/L)	Dissolved Average Detected Concentration (µg/L)	Total Average Detected Concentration (µg/L)
Benzo(a)pyrene	Not detected	0.019	Not detected	0.021
Chrysene	0.007	0.024	0.007	0.035
cPAH TEQ	0.008	0.018	0.008	0.029

The total cPAH median and average TEQ concentrations were higher than the dissolved concentrations. Dissolved chrysene was detected in 1 out of 26 October 2013 groundwater samples; the other dissolved cPAHs were not detected. Total benzo(a)pyrene, chrysene and cPAH were detected in 7 to 10 out of 26 samples.

5.2.2.1.2 Non-carcinogenic PAHs

Naphthalene is a COC for groundwater in the AOI upland, with a screening level of 9,880 µg/L and a maximum detected concentration of 13,000 µg/L[65] (wells MLS-5-3 and MLS-5-4 in April 2013). Screening level exceedances for naphthalene in groundwater occurred at the Harbor Patrol property owned by the City

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[64] Upland groundwater samples were filtered either in the field with a 45-micrometer (µm) filter, or by the analytical lab with a glass filter. Filtered groundwater is representative of primarily the dissolved fraction, although colloids may be present following the filtering. It should be noted that field filtration of groundwater samples submitted for PAH analysis might inadvertently introduce a low bias to dissolved concentrations because of potential adherence of PAHs to the filtration medium. However, the presence of suspended solids that bias PAH results high in unfiltered samples is a bigger concern for the accurate assessment of dissolved PAHs in groundwater. PAHs were analyzed in both filtered and unfiltered groundwater samples in October 2013; however, the unfiltered PAH groundwater results were used when mapping PAHs in groundwater and when discussing current groundwater conditions. Therefore, the discussion in this RI and data presentation is overly conservative because the results used are likely biased high for PAHs.

[65] Although PAHs were sampled using filtered and non-filtered techniques in the April and October 2013 groundwater sampling events, PAH mapping conservatively shows results for non-filtered samples.

(not the upland portion of Waterway 20 that is owned by the State and used by Harbor Patrol (Figure 5-5), a NAPL-impacted area (see discussion of NAPL distribution in Section 5.3.2).

The average concentration of naphthalene in groundwater in April 2013 and December 2014 was higher in deep-screened wells than in shallow-screened or water table wells, as shown in the inset table below along with screening level exceedance factors. The exceedance factors indicate the upland groundwater concentrations relative to the screening level; however, the conditional point of compliance for upland groundwater, as established in the 1999 Consent Decree, is at the mudline, as close as technically possible to the point where groundwater flows into surface water.

Naphthalene Profile in Upland Groundwater

Relative Depth of Groundwater	Median Detected Concentration (µg/L)	Average Detected Concentration (µg/L)	Average Detected Exceedance Factor
Screening Level	9,880[a]	9,880[a]	–
Shallow/Water Table Wells	3.4	840	<1
Deep Wells	54	4,000	<1
All Wells	15	2,500	<1

Notes:

[a] Upland groundwater screening level is not a median or an average value.

Naphthalene concentrations in groundwater have been monitored in the southwest area of the AOI since 1988; concentrations over time for three wells (MLS-6-1, MW-17 and MW-19) located in this area show a marked decline in concentrations since 1998 (see Figure 5-6). There have been minor fluctuations in concentrations since 2005, but naphthalene concentrations in these three wells remained below the screening level through the last sampling event in 2013. Differences in shallow versus deep groundwater naphthalene concentrations are depicted in the shoreline cross section in Figure 5-5. Naphthalene exceedance factors in shoreline wells ranged from <1 to 1.0 µg/L (maximum detected concentration is 10,000 µg/L and the naphthalene screening level is 9,880 µg/L) in shallow/water table wells and <1 to 1.2 µg/L in deep wells.

5.2.2.1.3 VOCs

Benzene is a COC for groundwater in the AOI upland, with a screening level of 43 µg/L. A maximum detected concentration of 9,100 µg/L was observed in April 2013 at well MW-36D along the eastern shoreline (the December 2014 result is plotted in Figure 5-7). Shallow shoreline benzene concentrations were below the screening level of 43 µg/L except for southeast of the Play Barn and at the Harbor Patrol property. Deep shoreline benzene concentrations exceeded the screening level in the southern part of the Harbor Patrol property and adjacent area southwest of Kite Hill, west of the Prow, and southeast of the Play Barn (Figure 5-7). Areas where benzene exceeded screening levels correspond with known areas of LNAPL and DNAPL (see Sections 5.3.2 and 5.3.3), as depicted on Figure 5-26B.

In many wells along the shoreline, benzene was not detected, including certain wells located downgradient of NAPL areas, such as in the northeast corner (MW-38S, MW-39S/D, and MW-40S) and in the central and southwestern shoreline (MW-13, TSW-3, MW-25, and MW-33) (Figure 5-7).

The average concentration of benzene in groundwater in April 2013 and December 2014 was higher in deep-screened wells than in shallow-screened wells, as shown in the inset table below along with screening level exceedance factors. The exceedance factors indicate the upland groundwater concentrations relative to the screening level; however, the conditional point of compliance for upland groundwater, as established in the 1999 Consent Decree, is at the mudline, as close as technically possible to the point where groundwater flows into surface water.

Benzene Profile in Upland Groundwater			
Relative Depth of Groundwater	**Median Detected Concentration (µg/L)**	**Average Detected Concentration (µg/L)**	**Average Detected Exceedance Factor**
Screening Level	43[a]	43[a]	--
Shallow/Water Table Wells	20	480	11
Deep Wells	470	2,000	47
All Wells	160	1,300	30

Notes:

[a] Upland groundwater screening level is not a median or an average value.

In April 2013 and December 2014, benzene was detected in 86 percent of deep wells sampled and 68 percent of shallow wells sampled. This relationship between shallow and deep groundwater is generally depicted in the shoreline cross-sectional view on Figure 5-7. Benzene exceedance factors in shoreline wells ranged from <1 to 15 µg/L in shallow/water table wells and <1 to 210 µg/L in deep wells.

Benzene concentration trends in groundwater are shown on Figure 5-8 for seven wells. Benzene concentrations have been decreasing in six of the wells and achieved concentrations below the screening level in three of these six wells (benzene was not detected in the seventh well, MW-13). Three of the wells, which are in the southeast corner at the AOI (OBS-1, OBS-2, and OBS-3), lie within the area where the highest benzene concentrations were measured in the 1990s near the eastern shoreline and within the former sparging area. The AS/SVE system was shut down in 2006 and, as shown on Figure 5-8, benzene concentrations continued to decline in the area through April 2013. Concentrations of benzene measure at OBS-3 (the most inland well) declined from 10,000 µg/L to 2,000 µg/L between 2009 and 2013. OBS-2 (downgradient of OBS-3) benzene concentrations have declined from 330 µg/L in 2009 to 150 µg/L. Benzene concentrations in OBS-1 (the shoreline well) declined from 280 µg/L to 22 µg/L (below the screening level) in that same period.

Toluene and ethylbenzene were detected in the majority of 2013 and 2014 groundwater samples, but at concentrations that did not exceed their respective screening levels.

5.2.2.1.4 Dissolved Arsenic

Arsenic is not a COC for upland groundwater. Arsenic was not retained in the FFS as a COC for the upland cleanup because it was known to be a natural constituent of groundwater in the area as confirmed by the presence of arsenic in upgradient well MW-3D (Parametrix and Key 1998). However, elevated groundwater concentrations were discovered at MW-36D, east of the Play Area, during the April 2013 sampling event that incorporated new locations and sample depths. Arsenic was then added as an analyte to the October 2013 groundwater sampling event to further evaluate extent and potential pathways.

Groundwater concentrations in other upland areas of the AOI were less than or slightly higher than the natural background screening level of 8.0 µg/L (Ecology 2022) (Figure 5-9). The average detected arsenic concentration in shoreline wells outside of the Play area is 7.4 µg/L. Differences in shallow versus deep groundwater arsenic concentrations are depicted in the table below along with screening level exceedance factors. The exceedance factors indicate the upland groundwater concentrations relative to the screening level; however, as discussed in Section 9.3.2, the preliminary conditional point of compliance for groundwater is proposed to be set at 10 cm below the sediment mudline, at the base of the BAZ.

Arsenic Profile in Upland Groundwater[66]

Relative Depth of Groundwater	Median Detected Concentration (µg/L)	Average Detected Concentration (µg/L)	Average Detected Exceedance Factor
Screening Level	8[a]	8[a]	--
Preserved Samples (samples collected between 2014 and 2016)			
Shallow/Water Table Wells	3.4	19	2.4
Deep Wells	9.9	5,100	640
All Wells	6.0	2,400	300
Unpreserved Samples (samples collected in 2020; Play Area only)			
Shallow/Water Table Wells	300	3,800	480
Deep Wells	14,000	82,000	10,000
All Wells	1,200	38,000	4,800

Notes:

[a] Upland groundwater screening level is not a median or an average value.

The shoreline cross section in Figure 5-9 shows that arsenic screening level exceedances are focused in the Play Area (cluster of wells on the right side of the cross section) with higher concentrations in deeper groundwater.

Minimum and maximum arsenic exceedance factors in shoreline monitoring wells outside of the Play Area[67] are as follows:

- Shallow/Water Table Wells: <1 to 5.9 µg/L
- Deep wells: <1 to 2.3 µg/L

Following the 2013 results, a 2014 investigation characterized the nature and extent of arsenic in the Play Area. The 2014 investigation included a geochemical evaluation of conditions in soil and groundwater, which is included as Attachment 2B-2 and discussed in Sections 6.5.1.3 and 6.5.2.2. Arsenic speciation analyses performed for the geochemical evaluation indicated that dissolved arsenic in groundwater likely contains thioarsenate species of arsenic, which is the original form of arsenic used in the former Thylox process that operated within the Play Area footprint. This finding suggests that dissolved arsenic in groundwater is not primarily associated with releases from soil, as previously thought, but rather is primarily associated with thioarsenates representing preserved Thylox solution. Prior to the Play Area interim action, thioarsenates had remained generally stable and in dissolved form due to alkaline conditions associated with the Thylox solution. The geochemistry of the thioarsenates in Play Area groundwater is presented in more detail in Attachment 2B-2.

In 2017, an interim action injection system was installed in the Play Area under an amendment to the 2005 Agreed Order (Ecology 2017a) to reduce dissolved arsenic concentrations and the source of arsenic to the eastern shoreline. Operation and monitoring of the treatment system was completed under a separate 2005 Agreed Order amendment (Ecology 2017b). The monitoring network included seven interim action performance monitoring wells located within the expected area of reagent influence of the in-situ treatment

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[66] Preserved and unpreserved arsenic sample analyses are discussed in Section 5.2.2.1.

[67] Monitoring wells outside of the Play Area include PZ-1 through OBS-1 and MW-37S through MW-40S.

plus two upgradient and eight downgradient wells. The 17 interim action performance monitoring wells are shown in Figure 5-9. The construction and operation of the interim action is documented in the Play Area Interim Action Construction Completion Report (GeoEngineers 2022).

The first round of injection was completed in October 2017. The unique arsenic geochemistry required a change in sample preparation as the standard approach reduced dissolved concentrations.[68] The new sample preparation approach was implemented in November 2017. Additional rounds of injection were performed in June/December 2018 and October 2019. Post-injection performance monitoring continued and based on favorable results; confirmation monitoring was completed in December 2020. Arsenic concentrations in the Play Area have been substantially reduced due to the interim action. A comparison of pre-treatment arsenic concentrations at the performance monitoring wells to concentrations one year after completion of interim action injection is provided in the inset table below.

Dissolved Arsenic Results (µg/L) for Interim Action Performance Monitoring Wells[a]

Well ID	Pre-injection September 2017	Post-injection December 2020	% Reduction
MW-41S[b]	10,600	1,830	83
MW-42S	18,700	303	98
MW-43S	8,230	5,340	35
MW-44S	7,990	80.1	99
MW-45S	48,300[c]	24,700	49
MW-45D	2,770	32.6	99
MW-48D	3,900[c]	Not Detected	97[d]
		Average % Reduction	80

Notes:

[a] Performance monitoring well MW-47S is not included as it is outside of the treatment area.

[b] Upgradient monitoring well MW-41S is included as data show that it is in the treatment area.

[c] Results are from November 2017—after the first round of injection.

[d] Arsenic was not detected in MW-48D in December 2020. The reporting limit of 100 µg/L was used to calculate percent reduction.

After three rounds of injection, there was significant arsenic reduction in monitoring wells within the treatment area and one immediately upgradient well (MW-41S); the average percent arsenic reduction for these wells was 80 percent. The percent reduction is likely underestimated because pre-injection samples collected during the baseline event were preserved and filtered which likely reduced dissolved arsenic concentrations in these samples. To partially account for reduced concentrations associated with the baseline event, the pre-treatment data for MW-45S and MW-48D are based on samples collected after the first round of injection, using modified sampling methods without filtering and preserving the samples in the field[69]. A detailed evaluation of the interim action treatment performance is provided in the Play Area Interim Action Monitoring Report (GeoEngineers 2021).

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[68] The GWPS sampling and analysis plan (SAP) specified field filtering followed by preservation with nitric acid. Preservation reduced the pH, as designed, but resulted in precipitation of arsenic in the sample jars which subsequently reduced dissolved arsenic concentrations prior to analysis. This effect was primarily observed in samples that initially had high pH. The SAP was modified in November 2017. Samples are no longer filtered or preserved in the field. Unpreserved samples are filtered in the lab prior to analysis.

[69] See explanation in previous (#70) footnote.

The Play Area Interim Action Monitoring Report (GeoEngineers 2021) identifies areas of elevated arsenic concentrations in fill and outwash groundwater within and downgradient of the Play Area that are expected to be amenable to treatment by the method used for the interim action. In fill unit groundwater, this includes an area of high concentration dissolved arsenic near the Kelly Filter and in deeper fill unit groundwater downgradient from the Play Area. Outwash groundwater along the shoreline also has elevated dissolved arsenic and is expected to be treatable using the in-situ treatment method used in the interim action. The combination of these fill and outwash areas results are shown in the shoreline arsenic-contaminated groundwater area that is highlighted on Figure 5-9.

Minimum and maximum arsenic exceedance factors in shoreline monitoring wells in the Play Area[70], post interim action, are as follows:

- Shallow/Water Table Wells: 2.0 to 8.8 µg/L
- Deep Wells: 15 to 39,000 µg/L

5.2.2.1.5 Upland Groundwater Key Findings

Screening of upland groundwater was performed to evaluate (1) the status of contamination in upland groundwater following upland cleanup and (2) potential migration of upland groundwater contamination to surface water at the mudline in the lake (the upland groundwater conditional point of compliance established under the 1999 Consent Decree). The status of contamination in upland groundwater can be summarized as follows:

- Previous upland cleanup actions have reduced upland groundwater concentrations. Concentrations of upland groundwater COCs meet upland groundwater screening levels in most shoreline wells.
- Remaining exceedances of upland groundwater screening levels in deep shoreline wells are not likely to cause screening level exceedances at the mudline due to natural attenuation (see Section 6.6.2, Physical Characteristics Supporting Natural Recovery Processes, for further discussion).
- cPAHs – The extent of dissolved[71] cPAH upland groundwater screening level exceedances appear to be limited to deep groundwater at the Harbor Patrol property.
- Non-carcinogenic PAHs – Naphthalene concentrations are decreasing or stable in the upland. Upland groundwater screening level exceedances for naphthalene in groundwater occurred at the Harbor Patrol property within an area impacted by DNAPL.
- Benzene concentrations in groundwater are decreasing in most areas of the upland. Benzene exceeded the upland groundwater screening level in two localized areas along the shoreline where NAPL is known to be present (Harbor Patrol and Play Barn), with lesser exceedances at the western end of the Prow. Benzene concentrations are higher in deep wells than in shallow wells.
- Ethylbenzene and toluene do not exceed upland groundwater screening levels.
- Arsenic – Concentrations of arsenic are significantly elevated in the Play Area and downgradient of the Play Area. The Play Area interim action has reduced concentrations in the Play Area. Concentrations in other upland areas of the AOI are less than or slightly higher than natural background.

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[70] Shoreline monitoring wells in Play Area include MW-49D through MW-52DDe.

[71] Comparison of filtered and unfiltered cPAH results and comparison to site-specific solubility suggest that filtered results are representative of dissolved concentrations. All but one dissolved (filtered) benzo(a)pyrene screening level exceedance is driven by elevated reporting limits. Unfiltered groundwater samples from most wells exceeded the screening level; however, several exceedances are higher than the site-specific solubility.

5.2.2.2. Offshore Groundwater

Offshore groundwater has been collected at six stations within the sediment portion of the AOI (Figure 5-10). However, the data collected are not sufficient to establish the nature and extent of contamination in offshore groundwater[72]. These limited results were used to assess what is currently known about offshore groundwater.

As identified in Section 4, COCs in offshore groundwater include the following:

- cPAHs (cPAH TEQ, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-c,d)pyrene, and dibenzo(a,h)anthracene)
- PAHs (fluoranthene, naphthalene, and pyrene)
- VOCs (benzene and ethylbenzene)
- Semivolatile organic compounds (SVOCs; bis(2-ethylhexyl)phthalate and dibenzofuran)
- Metals (arsenic, cadmium, copper, lead, and mercury)

Offshore groundwater COCs and screening levels are used in the following sections to discuss offshore groundwater data. The 1999 Consent Decree established a groundwater conditional point of compliance in surface water, as close as technically possible to the point where it flows into surface water (e.g., the mudline). Therefore, while this section uses offshore groundwater screening levels to evaluate offshore groundwater, these screening levels apply only at the mudline, not at the depths where the offshore groundwater samples were collected[73]. The comparison of offshore groundwater data to offshore groundwater screening levels was conducted describe the relative extent of offshore groundwater contamination.

5.2.2.2.1 Offshore Groundwater Sampling and Results

Seven offshore groundwater samples were collected at six locations within the sediment portion of the AOI in 2004 and 2005 at depths ranging from 0.5 foot to approximately 3.4 feet below mudline (bml). Figure 5-10 shows the offshore groundwater sample locations. Sediment cores were collected in the field and then centrifuged in the lab to collect offshore groundwater[74]. The volume of water recovered was sufficient to analyze for PAHs, SVOCs, selected metals, and VOCs, as summarized in Table 5-3. Carcinogenic PAHs and arsenic were elevated relative to screening levels (0.02 µg/L and 8 µg/L, respectively) in offshore groundwater[75]; however, as shown in Figures 5-18 and 5-20, cPAHs and arsenic are elevated in sediment relative to ambient conditions throughout much of Lake Union due to the historical and, to some extent,

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[72] Offshore groundwater COCs are different then upland groundwater COCs because upland groundwater COCs are based on the 1999 CD/CAP and regulatory benchmarks have changed since then (e.g., consideration of all beneficial uses of Lake Union, including potential use as drinking water and protection of sediment quality). As a result, some contaminants detected in upland groundwater below 1999 CD/CAP cleanup levels (and not identified as upland groundwater COCs) were detected in offshore groundwater at concentrations greater than offshore groundwater screening levels established under current regulations and are identified as offshore groundwater COCs.

[73] The mudline is where groundwater discharges to surface water and is defined by the upper sediment surface. The mudline is shown schematically on Figure 3-18.

[74] This sampling and processing approach eliminates overlying surface water from offshore groundwater samples.

[75] The source of contaminated offshore groundwater is contaminated sediment rather than contaminated upland groundwater. Figures 5-1B and 5-3B show the occurrence of cPAHs and arsenic contaminated subsurface sediment, respectively, where cPAHs and arsenic in offshore groundwater are elevated above screening levels. Most of the offshore contaminated groundwater was collected outside of the groundwater discharge zone for upland contaminated groundwater. As described in Section 6.5, cPAHs and arsenic in upland groundwater attenuates prior to reaching the locations where offshore groundwater was sampled.

current inputs and discharges to the lake. As shown in Table 5-3, other upland groundwater COCs that were detected in offshore groundwater at concentrations greater than screening levels include benzo(a)pyrene, chrysene, benzene, ethylbenzene, and naphthalene.

Too few data are available to discern trends or distribution of offshore groundwater exceedances in the AOI. Available offshore groundwater data, along with porewater data, is discussed further in Section 6, Contaminant Fate and Transport.

Additional offshore groundwater and porewater data will be collected as part of remedial design to inform a remedy that meets groundwater compliance requirements. The area of greatest groundwater discharge to the lake (aka, the "groundwater discharge zone" discussed in Section 6) is within the contaminant exposure areas to be addressed in the FS (see Section 8).

5.2.3. Sediment

Twenty-seven contaminants were identified in Section 4.2.3 and presented in Table 4-7 as sediment COCs. This section compares sediment data to the screening levels for these COCs to evaluate the extent of COCs within the sediment portion of the AOI.

The description of the extent of COCs within the sediment portion of the AOI is based on analytical results of over 390 samples (both surface grabs and subsurface cores) at over 180 locations. The samples were collected during investigations conducted between 1999 and 2005 (see Table 2-2). Surface sediment samples represent the BAZ of the lake and were collected from the interval extending from the sediment surface or mudline to 10 cm (0.33 feet) bml[76]. Subsurface sediment samples were collected from various intervals extending from the mudline to 23 feet bml; cores that incorporated the surface interval but extended below 0.33 feet bml were interpreted to represent subsurface conditions. Individual subsurface core samples were typically 3 feet or less in length and represented depth ranges of 0.5 foot to 15 feet; most of the subsurface core samples represented depth ranges of 2 feet to 5 feet (see Appendix tables 5B-1.5 and 5B-3.5 for sample interval details).

Samples were analyzed for the following:

- Conventional parameters (e.g., grain size, total organic carbon [TOC])
- Inorganic and organic constituents currently regulated under SMS
- Constituents without promulgated sediment criteria but nonetheless related to upland historical releases (e.g., VOCs)

The extent of COCs in sediment was determined by evaluating three exposure pathways in accordance with the SMS and Ecology's SCUM guidance: (1) benthic invertebrate community exposure to sediment (i.e., benthic toxicity); (2) park users and Tribal net fishers exposure to sediment during beach play, wading, and net fishing (i.e., direct contact); and (3) people and higher-order ecological receptors consuming contaminated fish, shellfish, or prey that have been exposed to sediment (i.e., bioaccumulation). The general extent of contamination based on a pathway-specific screening is provided below in Sections 5.2.3.1 through 5.2.3.3.

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[76] Although the upper 10 cm of cores was typically considered to represent surface sediment, it may represent deeper sediment due to the difficulty of collecting soft, shallow sediment in cores. Accordingly, two samples that occurred in surface core intervals were reclassified as subsurface sediment. Specifically, samples NLU-117 0810 and NLU-119 0608 are classified as subsurface sediment samples based on multiple lines of evidence.

Section 5.2.3.4 then evaluates COC concentrations in the sediment portion of the AOI and the rest of Lake Union to identify COCs attributable to historical MGP and other industrial operations in the upland and co-located COCs attributable to other point or non-point sources to the lake. Finally, Section 5.2.3.5 provides a detailed evaluation of the extent of COCs associated with historical industrial operations at the GWPS and a general evaluation of co-located COCs attributable to lake-wide or other point sources.

5.2.3.1. Extent of Benthic Toxicity in Surface Sediment

The extent of benthic toxicity in surface sediment was first identified by comparing contaminant concentrations in surface sediment (top 10 cm) within the AOI to SMS numeric benthic chemical criteria (see Table 5B-2.1). The results of this comparison are illustrated in Figure 5-11.

To confirm the potential toxicity indicated by the chemistry results, select surface sediment samples were submitted for biological testing (bioassays). Appendix 5D details the biological evaluation work, which ultimately defines the extent of benthic toxicity in surface sediment. The following paragraphs provide a summary of the bioassays.

Bioassays were conducted on surface sediment collected from 31 sampling locations within the AOI and 11 locations near the AOI boundary (see Appendix 4C and 5C for data summaries). Consistent with current SMS requirements, the bioassays evaluated survival of juvenile amphipods (*Hyalella azteca*) as well as survival and growth of larval midges (*Chironomus tentans*). Test durations varied and included 10-day exposures for the amphipod test[77] and 10- and 20-day exposures for the midge tests. Although the Microtox® test (evaluating luminescence in the marine bacterium *Aliivibrio [=Vibrio] fischeri*) was conducted, it is not recommended for use in freshwater under current SMS guidance and was, therefore, not included. Biological testing results are presented in Table 5-6.

The bioassay results were compared to SMS biological criteria, which include both a numeric and statistical threshold. Of the samples tested, results from 30 of the 42 locations did not exceed biological criteria, thus indicating that adverse effects to the benthic community are unlikely at those locations. Surface sediment samples from eight locations within the AOI exceeded criteria for one or more bioassays; four locations outside of the AOI (near the shipyard in the west and east of the Gas Works Park Marina) also exceeded criteria. Locations of biological benthic criteria exceedances are shown in Figure 5-12, and the SMS status is summarized in Table 5-7. As indicated by the extent of chemical benthic criteria exceedances (Figure 5-11) relative to limited extent of biological benthic criteria exceedances (Figure 5-12), the exceedances of SMS chemical criteria do not appear to be a good predictor of benthic toxicity. The high levels of anthropogenic (human-derived) and natural carbon reduce the bioavailability of many of the compounds that are present in the sediment and thus reduce toxicity.

The surface sediment samples submitted for bioassays represent the influence of different sources, ranges of concentrations, and spatial distribution within and near the AOI. Therefore, the response data generated from the tested samples were used to interpolate areas of biological criteria exceedances. This approach and methods used are described in Appendix 5D. The interpolated areas for amphipod survival, midge survival, and midge growth were combined to create a composite area of benthic toxicity (Figure 5-13) that also shows the individual locations exceeding biological criteria.

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[77] One investigation (out of three) evaluated amphipod survival and growth following a 28-day exposure. This data set was not included; however, test results for the 10-day exposure results at these same locations were included. The only sample that failed a biological criterion (28-day amphipod survival) was collected from LU-2; however, this location is uncertain. See Appendix 5D for additional discussion of data selection.

Areas of benthic toxicity were identified in the lake bottom near the western boundary of the AOI, in an area extending from the shoreline near Kite Hill southwest to the lake bottom, and in the lakeshore area adjacent to the Prow and Play Barn. The extent of the area that is toxic to benthic organisms southwest of Kite Hill is uncertain because the location of sediment sample LU-1 is uncertain. This location (as well as sediment sample location LU-2) was moved in the field during Ecology's sampling event and revised coordinates were not provided (see Appendix 5E for additional discussion of this uncertainty). It is very likely that these locations were closer to shore. The remaining portions of the AOI were not predicted to be toxic to the benthic community.

Bioassays indicate the type and magnitude of effect, but not the cause. Correlation and stepwise regression analyses were conducted in Appendix 4B to identify the most likely source of toxicity. PAHs (as a group) and metals (arsenic, copper, chromium, mercury, and zinc) appeared to explain most of the variability in the biological responses within the AOI, which suggests a possible relationship between observed toxicity and these contaminants. In addition, spatial clustering of bioassay responses identified a group of sampling locations near the western boundary, where the responses were primarily due to elevated metals in the sediment (referred to as the shipyard cluster). Two locations just southwest of the AOI boundary (NLU13[2002] and NLU13[2005]) were part of the shipyard cluster. Concentrations of metals were elevated at these two locations relative to other AOI surface sediment, and TPAHs were present at concentrations lower than statistically determined toxicity levels[78]. Because toxicity was likely due to metals from the adjacent shipyard rather than GWPS sources, these two samples were not included in the area of benthic toxicity.

One sampling location outside of the eastern boundary of the AOI and east of the Gas Works Park Marina (NLU01) exceeded biological criteria but is separated from exceedances within the AOI by several locations that do not have exceedances and therefore, was not included in the area of benthic toxicity.

Within the AOI, bioassay failures (SCO and CSL exceedances) occurred in areas where the TPAH concentration was about an order of magnitude higher[79] than the TPAH SCO (17 mg/kg). These areas are associated with the lakeshore and lake slope zones of the AOI, with the exception of the westernmost portion of the AOI where the lake bottom sediment is also characterized by concentrations of PAHs greater than 10 times the SCO, along with metals elevated above their respective SCO and CSL criteria.

5.2.3.2. Extent of Direct Contact Screening Level Exceedances in Surface Sediment

The direct contact pathway was evaluated by comparing concentrations of cPAHs, arsenic, and hexachlorobenzene in surface sediment to SCO and CSL criteria derived for the direct contact pathway (that is, people exposed to contaminated sediment through incidental ingestion or dermal contact). The results are reported in Appendix 5B, Attachment 5B-2, Tables 5B-2.2 and 5B-2.3. Comparisons were made for two areas (the entire AOI where net fishing could take place and near the shoreline where beach play and wading might occur). Criteria (either the SCO or the CSL) were exceeded at all locations where surface sediment samples were tested for direct contact COCs. Results are displayed in Figures 5-14 and 5-15 for the net fishing and beach play/wading areas, respectively.

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[78] A no-adverse effect level (170 mg/kg) and a minor adverse effect level (290 mg/kg) were developed for TPAH based on bioassay responses measured in site sediment in Appendix 4B.

[79] Statistical analyses provided in Appendix 4B identified a no adverse effect TPAH value of 170 mg/kg.

5.2.3.3. Extent of Bioaccumulation Screening Level Exceedances in Surface Sediment

Concentrations of bioaccumulative COCs in surface sediment (top 10 cm) were compared to SCO and CSL criteria for the bioaccumulation pathway (that is, people and wildlife [birds, mammals, and other fish] eating finfish and crayfish from the AOI). The results are provided in Appendix 5B, Attachment 5B-2, Table 5B-2.4 and presented in Figure 5-16. All samples tested for bioaccumulative contaminants exceeded criteria for one or more COCs. The cPAH CSL (based on regional background) was exceeded at all locations, and the arsenic CSL (based on preliminary regional background) was frequently exceeded. The other bioaccumulative COCs were either not detected or had lower frequency of exceedances.

5.2.3.4. Identification of GWPS and ALU COCs in AOI Surface Sediment

Given the urban/industrial setting of Lake Union, the sediment COCs identified in Section 4.2.3 were evaluated further to identify which of them are site-related COCs, referred to as GWPS COCs, associated with historical MGP, tar refinery, and other upland industrial activities and which of them are widespread co-located COCs primarily associated with other non-point or point sources (e.g., CSOs, storm drains, marinas, houseboats, fueling docks, recreational and commercial boat traffic, etc.) affecting sediment quality throughout the lake (referred to as ALU COCs).

Both GWPS and ALU COCs were identified using surface sediment data from samples collected within the sediment portion of the AOI. The difference between the two sets of COCs is that the GWPS COCs are site-related and the ALU COCs are not.

While the process discussed in this section identifies sediment COCs that are site-related and those that are associated with other sources, the cleanup alternatives evaluated in the FS are required to address both sets of COCs within the sediment portion of the AOI.

The process to identify GWPS and ALU COCs is detailed in Appendix 5E.

Generally, the process to identify GWPS COCs and ALU COCs in surface sediment involved three steps:

1. The average concentrations of each COC in the sediment portion of the AOI and ALU area were compared Figure 5-17 shows the boundaries of the areas used in the comparison. A statistical pair-wise comparison was made to determine if the average surface sediment concentrations for a given COC in each area were statistically different. If the average concentration in the sediment portion of the AOI was statistically significantly[80] higher than the ALU area average, that COC was classified as a GWPS COC. If the average concentration in the ALU area was statistically significantly higher than the average in the sediment portion of the AOI, that COC was classified as an ALU COC. All other outcomes (i.e., the averages were indistinguishable or there are too few data to evaluate) were carried forward to the next step.
2. Lake-wide maps were then prepared for the remaining COCs. Where no difference could be identified by the statistical pair-wise testing in Step 1, individual COC concentrations were mapped to evaluate the distribution of elevated COC concentrations and to identify concentration gradients. Map contours were based on the SCO and CSL for each contaminant. If there were too few data for statistical evaluation, there was also insufficient detected data for interpolation. For these COCs, data were posted on maps, but concentrations were not interpolated. If COC concentrations are higher in the AOI lakeshore and decrease with distance away from the shoreline (i.e., an offshore gradient is clearly present), the COC was categorized as a GWPS COC. If concentrations in the AOI near the shore are lower relative to the rest of the lake or increase with distance away from the shoreline (i.e., an onshore

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[80] See Section 1.2 of Appendix 5E for a description of the approach used to determine statistical significance.

gradient was clearly present), the COC was categorized as an ALU COC. If there was no clear gradient due to limited data or gradients were not definitive, the COC was evaluated on a case-by-case basis as described below.

3. For those COCs where concentration gradients and distribution were insufficient to classify the COC, a third step was employed. In this final step, literature was reviewed to identify potential sources of contaminants. If the contaminant is not known to be associated with MGP sources, it was assumed to be an ALU COC.

This process relied upon the current conditions data set used in this RI for the AOI; the ALU area data were represented by a broader data set that spanned from 1981 to 2008. Sampling locations in the ALU area within 300 feet of the shoreline were not included in the statistical comparison; however, sampling locations near the shore were mapped in order to help discern concentration gradients.

5.2.3.4.1 Results of Step 1, Statistical Evaluation

Table 5-8 presents a summary of the pair-wise testing statistical outcomes for COCs in the ALU area compared to the sediment portion of the AOI. ProUCL statistical outputs are provided in Attachment 5E-1 to Appendix 5E. A summary of the statistical testing outcomes is provided below and in Table 5E-1.

GWPS COCs

The average concentrations for three sediment COCs are statistically significantly higher in the AOI compared to the ALU area (AOI > ALU column in Table 5-8) and they are classified as GWPS COCs.

- cPAH (expressed as the TEQ)
- TPAH
- Dibenzofuran

TPAH and cPAHs are considered two of three primary GWPS COCs; arsenic is the third (see discussion below under *Remaining Sediment COCs*). Dibenzofuran co-occurs with PAHs within the sediment portion of the AOI.

ALU COCs

Those sediment COCs with average concentrations statistically significantly higher in the ALU area compared to the AOI are:

- Bis(2-ethylhexyl)phthalate
- Di-n-butylphthalate
- Phenol
- 4,4’-DDE
- Total polychlorinated biphenyls (PCBs)
- Lead
- Mercury

These sediment COCs are classified as ALU COCs (ALU > AOI column in Table 5-8).

Remaining Sediment COCs

The remaining sediment COCs had average concentrations that are similar to each other (i.e., ALU ≈ AOI) or there were too few detected concentrations in either the ALU area and/or the AOI for statistical comparison. Those sediment COCs where no significant difference could be detected between the AOI and ALU area are listed in the No Detectable Difference column in Table 5-8 and included:

- Sulfide
- 4-Methylphenol
- Benzoic acid
- Carbazole
- Pentachlorophenol
- Tributyltin
- Arsenic
- Cadmium
- Chromium
- Copper
- Nickel
- Silver

The average arsenic concentration in the AOI was not significantly different than ALU, even when outliers were removed from both data sets during the comparison. However, arsenic is retained as a primary GWPS COC because of elevated arsenic concentrations in upland soil and groundwater associated with the former Thylox process area and in sediment near the shore east of this upland area.

Five sediment COCs could not be statistically tested because there were too few detected concentrations in either the ALU area and/or the AOI:

- Diesel-range hydrocarbons
- Di-n-octyl phthalate
- Hexachlorobenzene
- Chlordane
- Methyl mercury

These latter two lists were carried forward to the mapping step.

5.2.3.4.2 Results of Step 2, Mapping

The results of Step 2 are discussed in Appendix 5E along with Figures 5E-1 to 5E-17 that display concentrations in Lake Union for those contaminants where a difference between the sediment portion of the AOI and the ALU area could not be detected statistically or where there were too few detected concentrations in either area for statistical comparison. The distribution of arsenic is not evaluated in this section because it is classified as a GWPS COC; the nature and extent of arsenic is evaluated in

Section 5.2.3.5.6. Mercury, which is an ALU COC, is mapped as a surrogate for the potential distribution of methylmercury because this latter COC was only measured once and can only form where mercury is present.

Table 5-9 summarizes where concentration gradients or the mapped distribution of contaminants were used to classify COCs. Carbazole was classified as a GWPS COC based on its distribution. With the exception of hexachlorobenzene and nickel, maps for the remaining COCs evaluated in Step 2 indicate that these contaminants are ALU area COCs. Hexachlorobenzene and nickel were evaluated further in Step 3.

5.2.3.4.3 Results of Step 3, Source Considerations

Two contaminants could not be categorized as GWPS or ALU COCs through statistical analysis or mapping: nickel and hexachlorobenzene. Neither of these contaminants are upland COCs. There are many potential sources of nickel. Primary sources are related to transportation and fabrication or use of metal alloys (Ecology 1992, CHRIS database 1988, Technical Resources, Inc. 1989); nickel is also found in lubricants and marine diesel oil. Nickel is not a primary MGP-related contaminant but was classified as a GWPS COC because this metal is a minor component of coal and petroleum. Hexachlorobenzene does not have a known association with MGPs, rather, its biggest known historical source is pesticides. This COC is classified as an ALU COC.

5.2.3.4.4 Summary of Evaluation

In summary, the statistical, mapping concentration gradients and distribution, and source evaluations described above identified GWPS and ALU COCs in surface sediment.

The following are the GWPS COCs:

GWPS Contaminants of Concern	
PAHs	TPAH
	cPAHs
Organic Compounds	Carbazole
	Dibenzofuran
Metals	Arsenic
	Nickel

TPAH, cPAH and arsenic are considered primary GWPS COCs because of their broad distribution and magnitude within the AOI; Figures 5-18, 5-19A, and 5-20 map the lake-wide distribution of these three COCs and show the relationship between AOI and ALU concentrations. All other GWPS COCs occur within the footprint of these primary COCs within the AOI.

TPAH, cPAH, dibenzofuran, and carbazole are known byproducts of the combustion and pyrolysis of coal and petroleum fuels. Arsenic and nickel appear to have multiple sources. The highest arsenic concentrations occur in two areas within the sediment portion of the AOI, one of which is associated with likely discharges from the Thylox process area (where thioarsenate was used to remove impurities from the manufactured gas) in the east and another appears to be associated with the shipyard and/or other sources in the west. Arsenic is also present throughout Lake Union above its preliminary regional background concentration from multiple regional non-point sources (Figure 5-20). The source of nickel is unclear, but it was included as a GWPS COC because of elevated concentrations along the eastern and southeastern shorelines.

The following are the ALU COCs:

Ambient Lake Union Contaminants of Concern	
Phthalates	Bis(2-ethylhexyl)phthalate
	Di-n-butylphthalate
	Di-n-octylphthalate
Phenolic Compounds	4-Methylphenol
	Pentachlorophenol
	Phenol
Pesticides	Chlordane
	4,4'-DDE
Other Organic Compounds	Benzoic acid
	Diesel
	Hexachlorobenzene
	PCBs
Metals/Organometals	Cadmium
	Chromium
	Copper
	Lead
	Mercury
	Methyl mercury
	Silver
	Tributyltin
Other Compounds	Sulfide

ALU COCs are those contaminants that have had significant historical use in the region or have on-going urban sources. These COCs co-occur with GWPS COCs but tend to have widespread distribution in Lake Union. There are numerous historical and current sources of these contaminants such that source identification for all ALU COCs is not possible.

5.2.3.5. Nature and Extent of GWPS COCs

The evaluation of the nature and extent of contamination in the sediment portion of the AOI focuses on GWPS COCs (cPAH, TPAH, dibenzofuran, carbazole, arsenic, and nickel). Although benzene is not a COC in sediment, it is a COC for upland groundwater and offshore groundwater, and its distribution in sediment is used to evaluate the potential pathway from the upland to surface water for the purpose of developing remedial alternatives. Similarly, fluoranthene, naphthalene, and pyrene are discussed; all three are COCs for soil and offshore groundwater; naphthalene is also a COC for upland groundwater. Tables 5-4 and 5-5 include sediment data for GWPS COCs plus benzene, ethylbenzene, toluene, fluoranthene, naphthalene, and pyrene.

For presenting the extent of contamination, the distribution of GWPS COCs is mapped relative to the respective SCO and CSL sediment screening levels.

The most frequently detected COCs in surface sediment were cPAHs (expressed as TEQ), TPAH[81], and nickel. These three COCs were detected in all surface samples. Arsenic was detected in 61 percent of surface samples. Dibenzofuran and carbazole were detected about half the time (51 percent). The other PAHs naphthalene, fluoranthene, and pyrene (not sediment COCs) were detected in more than 90 percent of surface samples. Benzene, ethylbenzene, and toluene (also not sediment COCs) were detected in about 10 percent of the samples.

Detection frequencies for sediment COCs and other COCs of interest (as defined above) were generally higher in surface sediment than in subsurface sediment. Benzene, ethylbenzene, and toluene were exceptions to this trend, having been more frequently detected in subsurface sediment (29 to 38 percent) than in surface sediment (8.9 to 13 percent).

The frequency of exceedance of SCO and CSL screening levels varied by analyte and depth (surface versus subsurface). Where cPAH was measured in surface sediment, the CSL screening level was exceeded. Other COCs less frequently exceeded their respective screening levels in both surface and subsurface sediment, as summarized in the inset table below.

Frequency of Exceedance

GWPS COC	Screening Level (mg/kg)	Surface Sediment (percent)	Subsurface Sediment (percent)
TPAH	17 (SCO)	78	53
	30 (CSL)	71	49
cPAH TEQ	0.021 (SCO)	100	65
	0.21 (CSL)	100	59
Dibenzofuran	0.20 (SCO)	40	44
	0.68 (CSL)	25	34
Carbazole	0.90 (SCO)	15	25
	1.1 (CSL)	15	24
Arsenic	11 (SCO)	59	30
	24 (CSL)	52	18
Nickel	50 (SCO)	67	24
	110 (CSL)	9	<1

Despite lower frequencies of detection and exceedances in subsurface sediment, subsurface COC

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[81] TPAH is reported as detected if at least one constituent included in the sum is detected; otherwise the group sum is represented by the highest reporting limit and flagged as not detected.

concentrations tended to be higher than surface concentrations for organic COCs, as shown by average concentrations (Table 5-5) and the maximum exceedance factors noted in the following inset table:

Magnitude of GWPS COCs in Sediment

GWPS COC	Screening Level (mg/kg)	Surface Sediment		Subsurface Sediment	
		Maximum Exceedance Factor	Location of Maximum Concentration	Maximum Exceedance Factor	Location of Maximum Concentration
TPAH	17 (SCO)	660	NLU65	4,100	CR-10[a]
	30 (CSL)	370		2,300	
cPAH TEQ	0.021 (SCO)	67,000	NLU 65	140,000	CR-10[a]
	0.21 (CSL)	6,700		14,000	
Dibenzofuran	0.20 (SCO)	70	NLU122	4,200	CR-10[a]
	0.68 (CSL)	21		1,200	
Carbazole	0.90 (SCO)	6.8	NLU68	170	NLU52
	1.1 (CSL)	5.5		140	
Arsenic	11 (SCO)	220	NLU62	110	NLU73
	24 (CSL)	100		51	
Nickel	50 (SCO)	5.4	NLU53	3.3	NLU58
	110 (CSL)	2.4		1.5	

Notes:

[a] CR-10 sediment contained a significant amount of tar.

A summary of COC detection frequencies, screening-level exceedance frequencies, and maximum exceedance factors for sediment is presented in Tables 5-4 and 5-5.

The following sections discuss the nature and extent of the GWPS COCs in the sediment portion of the AOI.

5.2.3.5.1 Total PAH

TPAH was calculated for 111 surface sediment samples and 282 subsurface samples; typically, one PAH constituent was missing from the sum[82]. Detected concentrations in surface sediment ranged from 3.4 to 11,000 mg/kg dry weight (dw) (average = 470 mg/kg). TPAH exceedance factors for surface sediment samples ranged from <1 to 660, with an average exceedance factor of 28. The SCO screening level for TPAH was exceeded in 78 percent of the locations where surface samples were collected.

Concentrations reported in subsurface sediment samples ranged from 0.015 to 69,000 mg/kg dw (average = 1,500 mg/kg) and were higher than those detected in the surface samples. Exceedance factors ranged from <1 to 4,000, with an average of 88. The screening level for TPAH was exceeded in 53 percent of the subsurface samples. Most exceedances occurred from near the mudline to about 6 feet bml; however, concentrations greater than the SCO extended to more than 9 feet bml in some areas. For example, 36 percent for samples collected deeper than 9 feet bml exceeded the SCO.

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[82] 1-methylnaphthalene was typically not analyzed for in sediment and was not included as a component of TPAH in freshwater sediment criteria until the 2013 version of the SMS.

A summary of TPAH concentrations by depth category and screening level is provided in the inset table below:

TPAH Profile in Sediment

Depth Interval (feet bml)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)	Average Detected SCO Exceedance Factor	Average Detected CSL Exceedance Factor
Screening Level	--	—	17[a]	30[a]
Surface (0–0.5)	76	470	28	16
Subsurface (>0.5)	110	1,500	88	50
0.5 to 3	490	2,900	170	97
3 to 6	130	1,100	65	37
6 to 9	4.9	280	16	9.3
>9	34	920	54	31
All Depths	88	1,200	71	40

Notes:

[a] Screening levels are SCO and CSL concentrations in mg/kg, not exceedance factors.

The distributions of surface and subsurface TPAH concentrations are depicted in Figures 5-19B and 5-19C.

Exceedances of the TPAH screening levels in surface sediment were associated with the lakeshore and adjacent lake slope zone (generally in a band within 300 feet of the OHWM). The highest surface TPAH concentrations coincided with the area impacted by black carbon to the east and south of the Prow (see Figure 5-27 for black carbon distribution). Surface sediment farther offshore had lower concentrations, likely due to lesser historical impacts and to deposition of cleaner material that has supported the natural recovery of this region. One area of the lake bottom where concentrations did not decrease substantially from nearshore to offshore was the western portion of the AOI (adjacent to the shipyard); in this area, TPAHs tended to be elevated in surface sediment over a broader area that extends farther offshore.

Subsurface sediment follows a similar spatial pattern, although the TPAH concentrations tended to be higher in subsurface sediment than in surface sediment, except for the far western area of the AOI adjacent to the Shipyard. The highest subsurface TPAH concentrations generally coincided with NAPL impacts. Cross sections showing subsurface TPAH concentrations based on distance from shore were developed; locations of the cross-sections are shown in Figure 5-19C.

Cross sections (see Figures 5-19D and 5-19E) display TPAH vertical concentration contours (over depth) and suggest that TPAH concentrations exceed screening levels down to the glacial till in the lakeshore and lake slope zones bordering the upland (see 50-foot, 100-foot, and 200-foot cross sections). The EVS model predicted that TPAH-contaminated sediment extended over 35 feet bml in some areas. Subsurface data are limited in the lake bottom zone, but available core data suggest that higher concentrations were primarily in shallow sediment (see 500-foot cross section)[83]. In lakeshore and lake slope areas, TPAH concentrations were commonly higher at depth than in shallow sediment; where this occurs, it tended to be where subsurface NAPL was present. The thickest layer of TPAH-contaminated sediment is shown in an

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[83] Data input for the EVS model and resulting model output are not sufficiently precise to show natural recover in near-surface sediment.

area of deep DNAPL southwest of Kite Hill. The other organic COCs (cPAH, dibenzofuran, and carbazole) in sediment co-occur with TPAH and their distribution is similar (cPAH) or less widespread.

5.2.3.5.2 Carcinogenic PAHs

Carcinogenic PAHs are the major constituents of high molecular weight PAH (HPAH) (7 of the 10 typical HPAH constituents are considered carcinogenic); however, cPAH concentrations are expressed based on their toxicity relative to that of benzo(a)pyrene (i.e., as cPAH TEQ). Calculated cPAH TEQs ranged from 0.47 to 1,400 mg/kg (average = 54 mg/kg) in surface sediment; exceedance factors ranged from 22 to 67,000 for the SCO and 2.2 to 6,700 for the CSL. The highest concentrations were measured in surface sediment samples in a band within 300 feet of the OHWM; the broadest areas of the highest cPAH TEQ concentrations (greater than 20 mg/kg) was south of the Prow—the area impacted by black carbon—and in the western portion of the AOI—a part at the AOI that is more heavily influenced by other sources[84]. Figure 5-1A includes the cPAH distribution in sediment based on the RI data set. More recent data suggest concentrations are declining as discussed in Section 6.6.

Subsurface sediment cPAH TEQ concentrations ranged from 0.015 to 2,900 mg/kg (average = 73 mg/kg). The exceedance factors (ranging from <1 to 140,000 for the SCO and <1 to 14,000 for the CSL) were higher than that for surface sediment, although average exceedance factors were relatively similar (see the inset table below). The maximum cPAH TEQ concentrations were calculated for samples collected in the same core intervals as where maximum TPAH concentrations occurred. Figure 5-1B depicts subsurface sediment concentrations of cPAH.

The cPAH TEQ profiles based on the SCO and CSL are summarized in the inset table below:

cPAH TEQ Profile in Sediment

Depth Interval (feet bml)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)	Average Detected SCO Exceedance Factor	Average Detected CSL Exceedance Factor
Screening Level	--	--	0.021[a]	0.21[a]
Surface (0–0.5)	11	54	2,600	260
Subsurface (>0.5)	11	79	3,800	380
0.5 to 3	31	150	6,700	670
3 to 6	12	53	2,500	250
6 to 9	1.1	13	620	62
>9	2.4	32	1,500	150
All Depths	11	69	3,300	330

Notes:

[a] Screening levels are SCO and CSL concentrations in mg/kg, not exceedance factors.

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[84] The influence of other sources in the western region of the AOI is based on a preponderance of evidence including the locations of the MGP versus other industries, areas of likely groundwater transport, the distribution of PAHs in surface sediment and subsurface DNAPL, and the distribution of metals. These lines of evidence are discussed in the nature and extent chapter (e.g., Sections 5.2.3.4.4 and 5.3.3) and in the fate and transport section (e.g., Section 6.3).

5.2.3.5.3 Non-carcinogenic PAHs

Sediment contamination was evaluated for three non-carcinogenic PAH constituents (fluoranthene, naphthalene, and pyrene) that are not considered to be COCs for sediment but are COCs for soil, groundwater, or both. Surface sediment concentration ranges for each constituent are as follows:

- Fluoranthene ranged from 0.63 to 1,900 mg/kg dw (average = 82 mg/kg)
- Naphthalene from 0.042 to 120 mg/kg dw (average = 7.2 mg/kg)
- Pyrene from 0.62 to 2,200 mg/kg dw (average = 97 mg/kg)

Screening levels were not established for fluoranthene, naphthalene, and pyrene because they are not sediment COCs, and exceedance factors were not calculated. However, these three non-carcinogenic PAHs were not detected in surface sediment at concentrations greater than their soil screening levels, which are protective of sediment exposures during beach play and net fishing (freshwater benthic criteria are not available for these PAHs). Their occurrence is accounted for in the TPAH evaluation.

Fluoranthene and pyrene concentrations were similar across sediment depths, while naphthalene concentrations were considerably higher in subsurface sediment (average = 430 mg/kg) than surface sediment (average = 7.2 mg/kg). Subsurface naphthalene concentrations are depicted in Figure 5-2B. The highest naphthalene concentration was east of the Play Area at Tar Area 3 (see Section 5.3.4).

Non-carcinogenic PAH profiles are summarized in the following inset table:

Non-carcinogenic PAH Profiles in Sediment

Depth Interval (feet bml)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)
Fluoranthene		
Surface (0–0.5)	12	82
Subsurface (>0.5)	15	150
0.5 to 3	61	280
3 to 6	15	100
6 to 9	0.5	22
>9	3.0	79
All Depths	14	120
Naphthalene		
Surface (0–0.5)	1.4	7.2
Subsurface (>0.5)	7.7	430
0.5 to 3	12	680
3 to 6	7.3	340
6 to 9	1.6	92
>9	14	400
All Depths	3.4	290

Non-carcinogenic PAH Profiles in Sediment		
Depth Interval (feet bml)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)
Pyrene		
Surface (0-0.5)	14	97
Subsurface (>0.5)	14	160
0.5 to 3	70	320
3 to 6	18	100
6 to 9	0.60	25
>9	2.8	82
All Depths	14	140

5.2.3.5.4 Dibenzofuran

Dibenzofuran concentrations detected in surface sediment ranged from 0.033 to 14 mg/kg (average = 1.8 mg/kg); exceedance factors ranged from <1 to 70 for the SCO and <1 to 21 for the CSL. The highest concentrations measured in surface sediment samples were in a band within 300 feet of the OHWM; the highest dibenzofuran concentration (14 mg/kg) was near the northwestern corner of the AOI. Figure 5-21 depicts surface sediment concentrations of dibenzofuran.

Dibenzofuran co-occurred with PAHs, but exceedances of SCO and CSL were less extensive and exceedance factors were lower than TPAH and cPAH. As such, the sediment distribution of dibenzofuran fell within the footprint of cPAH and TPAH (Figure 5-23). Detected concentrations of dibenzofuran in subsurface sediment ranged from 0.012 to 830 mg/kg (average = 30 mg/kg). The exceedance factor (ranging from <1 to 4,200 for the SCO and <1 to 1,200 for the CSL) and maximum detected concentrations were greater than those for surface sediment.

The dibenzofuran profiles based on the SCO and CSL are summarized in the inset table below:

Dibenzofuran Profile in Sediment				
Depth Interval (feet bml)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)	Average Detected SCO Exceedance Factor	Average Detected CSL Exceedance Factor
Screening Level	--	--	0.20[a]	0.68[a]
Surface (0–0.5)	0.65	1.8	9.0	2.6
Subsurface (>0.5)	2.5	30	150	44
0.5 to 3	6.0	49	250	72
3 to 6	1.2	20	100	29
6 to 9	1.5	9.9	50	15
>9	1.5	25	130	37
All Depths	1.6	22	110	32

Notes:

[a] Screening levels are SCO and CSL concentrations in mg/kg, not exceedance factors.

5.2.3.5.5. Carbazole

Carbazole concentrations detected in surface sediment ranged from 0.034 to 6.1 mg/kg (average = 1.2 mg/kg); exceedance factors ranged from <1 to 6.8 for the SCO and <1 to 5.5 for the CSL. The highest concentrations measured in surface sediment samples were in a band within 200 feet of the OHWM east and south of the AOI upland; the broadest area of the highest carbazole concentrations (greater than 1.1 mg/kg) is south of the Prow and east of the upland—areas impacted by black carbon. Unlike cPAH, TPAH, and dibenzofuran, there were no SCO exceedances to the west. Figure 5-22 depicts surface sediment concentrations of carbazole.

Carbazole co-occurred with PAHs, but exceedances of SCO and CSL were much less extensive and exceedance factors much lower than for TPAH and cPAH. As such, the sediment distribution of carbazole fell within the footprint of cPAH and TPAH plus dibenzofuran (Figure 5-23). Detected concentrations of carbazole in subsurface sediment ranged from 0.024 to 150 mg/kg (average = 13 mg/kg). The exceedance factor ranges (<1 to 170 for the SCO and <1 to 140 for the CSL) and maximum detected concentrations were greater than those for surface sediment.

The carbazole profiles based on the SCO and CSL are summarized in the inset table below:

Carbazole Profile in Sediment

Depth Interval (feet bml)	Median Detected Concentration (mg/kg)	Average Detected Concentration (mg/kg)	Average Detected SCO Exceedance Factor	Average Detected CSL Exceedance Factor
Screening Level	--	--	0.90[a]	1.1[a]
Surface (0–0.5)	0.54	1.2	1.3	1.1
Subsurface (>0.5)	1.3	13	14	12
0.5 to 3	1.7	7.3	8.1	6.6
3 to 6	1.1	17	19	15
6 to 9	0.75	3.4	3.8	3.1
>9	1.0	20	22	18
All Depths	0.81	9.6	11	8.7

Notes:

[a] Screening levels are SCO and CSL concentrations in mg/kg, not exceedance factors.

5.2.3.5.6 Arsenic

Arsenic concentrations detected in surface sediment ranged from 6.0 to 2,400 mg/kg (average = 110 mg/kg); exceedance factors range from <1 to 220 for the SCO and <1 to 100 for the CSL. Arsenic exceeds its natural background (SCO) screening level in 59 percent of the locations where it was detected. When compared to average ambient Lake Union conditions (54 mg/kg), 31 percent of the samples were higher than ambient levels. The highest concentration was measured in the surface sample from NLU62 immediately east of the Play Barn; higher concentrations also occurred offshore of the shipyard in the west. In contrast to other COCs, the lowest concentrations occurred near the shore (e.g., south of the Prow, see Figure 5-3A).

Subsurface arsenic concentrations were lower than surface concentrations and ranged from 3 to 1,200 mg/kg (average = 70 mg/kg); associated exceedance factors ranged from <1 to 110 for the SCO and <1 to 50 for the CSL. The highest concentrations were measured in subsurface intervals east of the Play Barn (Figure 5-3B).

The arsenic profiles for the SCO and CSL are summarized in the inset table below:

Arsenic Profile in Sediment				
Depth Interval (feet bml)	**Median Detected Concentration (mg/kg)**	**Average Detected Concentration (mg/kg)**	**Average Detected SCO Exceedance Factor**	**Average Detected CSL Exceedance Factor**
Screening Level	--	--	11[a]	24[a]
Surface (0-0.5)	58	110	10	4.6
Subsurface (>0.5)	20	70	6.4	2.9
0 to 3	33	100	9.1	4.2
3 to 6	20	48	4.4	2.0
6 to 9	9.5	11	1.0	<1
>9	9.0	91	8.3	3.8
All Depths	30	85	7.7	3.5

Notes:

[a] Screening levels are SCO and CSL concentrations in mg/kg, not exceedance factors.

5.2.3.5.7 Nickel

Nickel concentrations detected in surface sediment ranged from 10 to 270 mg/kg (average = 64 mg/kg); exceedance factors ranged from <1 to 5.4 for the SCO and <1 to 2.4 for the CSL. Nickel exceeded its natural background (SCO) screening level in 67 percent of the locations where it was detected. When compared to average ambient Lake Union conditions (85 mg/kg), 16 percent of the samples were higher than ambient levels. The highest concentrations measured in surface sediment were in the lake slope area between the Prow and the head of Waterway 19; the highest concentration (268 mg/kg) was reported in the sample from location NLU53 southeast of the upland. Nickel also was reported in a surface sediment sample collected in the westernmost portion of the AOI at a concentration exceeding the CSL of 110 mg/kg (Figure 5-24).

Nickel concentrations detected in subsurface sediment were lower than concentrations detected in surface sediment and ranged from 18 to 160 mg/kg (average = 46 mg/kg); associated exceedance factors ranged from <1 to 3.2 for the SCO and <1 to 1.5 for the CSL.

The nickel profiles based on the SCO and CSL are summarized in the inset table below:

Nickel Profile in Sediment				
Depth Interval (feet bml)	**Median Detected Concentration (mg/kg)**	**Average Detected Concentration (mg/kg)**	**Average Detected SCO Exceedance Factor**	**Average Detected CSL Exceedance Factor**
Screening Level	--	--	50[a]	110[a]
Surface (0–0.5)	55	64	1.3	<1
Subsurface (>0.5)	42	46	<1	<1
0.5 to 3	60	66	1.3	<1
3 to 6	39	44	<1	<1
6 to 9	39	38	<1	<1
>9	43	43	<1	<1
All Depths	44	51	1.0	<1

Notes:

[a] Screening levels are SCO and CSL concentrations in mg/kg, not exceedance factors.

5.2.3.5.8 Benzene

Benzene is not a COC for sediment but is presented here because it is a COC in upland and offshore groundwater that may be discharging to surface water. Benzene was detected in only 8.9 percent of surface sediment samples; however, detection limits were elevated in several samples. Surface sediment concentrations ranged from 0.0030 to 34 mg/kg dw (average = 7.4 mg/kg). The highest concentration was in a sample collected southeast of the upland coinciding with an area where DNAPL (NAPL Area 14) is close to or at the surface.

Benzene was more frequently detected in subsurface sediment (38 percent FOD) and at higher concentrations (0.0010 to 3,500 mg/kg dw, with an average of 97 mg/kg) relative to surface sediment. Maximum concentrations were associated with subsurface samples from the area east of the Play Area and Play Barn near NAPL Area 15.

A sediment screening level was not established for benzene because it is not a sediment COC, and exceedance factors were not calculated. The benzene profile is summarized in the following inset table:

Benzene Profile in Sediment		
Depth Interval (feet bml)	**Median Detected Concentration (mg/kg)**	**Average Detected Concentration (mg/kg)**
Surface (0-0.5)	1.2	7.4
Subsurface (>0.5)	3.6	97
0 to 3	3.1	67
3 to 6	1.5	81
6 to 9	0.051	240
>9	6.6	22
All Depths	3.1	91

5.2.3.6. Nature and Extent of ALU COCs

ALU COCs are co-located with GWPS COCs within the sediment portion of the AOI. ALU COCs, along with GWPS COCs, were identified using surface sediment data from samples collected within the sediment portion of the AOI. The difference between the two sets of COCs is that the GWPS COCs are site-related and the ALU COCs are not.

Lake-wide maps showing the distribution of ALU COCs in surface sediment are provided in Appendix 5E.

5.2.3.7. Sediment Key Findings

The extent of site-related sediment contamination is summarized as follows:

- cPAH – This GWPS COC was widespread in surface and subsurface sediment at TEQ concentrations greater than screening levels, with typically higher concentrations in subsurface sediment. Surface sediment concentrations were highest in the lakeshore and adjacent lake slope area, and diminished to ALU concentrations (which are also above screening levels) within about 100 to 400 feet of the shoreline east and south of the upland (within the lake bottom zone). The cPAH footprint encompassed the distribution of all other PAHs.

- TPAH – Exceedances of screening levels for this GWPS COC in surface sediment were in the lakeshore and adjacent lake slope area; surface sediment concentrations farther offshore (lake bottom) were often below the screening level, likely due to natural sedimentation of cleaner material. The main exception was the deeper lake bottom in the western portion of the AOI (adjacent to the Shipyard), where TPAH concentrations tended to be elevated in surface sediment farther offshore. Subsurface sediment followed a similar spatial pattern, although TPAH concentrations generally tended to be higher in subsurface sediment than surface sediment at any given location.
- PAHs – The highest cPAH concentrations in surface sediment coincided with the black carbon area south and east of the upland (see Figure 5-27 for black carbon distribution in surface sediment). The highest subsurface cPAH and TPAH concentrations coincided with the black carbon areas to the south and east of the upland and DNAPL to the east, southeast, and southwest of the upland (see Figure 5-26B for DNAPL distribution in subsurface sediment).
- Dibenzofuran and carbazole – These GWPS COCs co-occurred with PAHs, but their exceedances of screening levels were less extensive and exceedance factors were lower. The spatial distribution of these COCs fell within the footprint of cPAH and TPAH.
- Benzene and naphthalene – Benzene surface sediment detections and naphthalene surface sediment screening level exceedances were limited to small areas and few samples. Benzene and naphthalene concentrations were higher in subsurface sediment.
- Arsenic – This GWPS COC was widespread in surface and subsurface sediment at concentrations greater than the screening levels (except along some areas of the lakeshore and lake slope), but the distribution differed from the other GWPS COCs. Concentrations in surface sediment tended to be higher than in subsurface sediment and the lowest arsenic concentrations were near the shore. Arsenic concentrations in surface sediment were less than ambient Lake Union concentrations except for east of the Play Barn and offshore of the Shipyard.
- Nickel – The highest concentrations of this GWPS COC measured in surface sediment were in the lake slope area southeast and east of the upland and near the shipyard. As with arsenic, nickel concentrations in surface sediment tended to be higher than in subsurface sediment.
- ALU COCs tend to be distributed throughout Lake Union and are co-located with GWPS COCs within the sediment portion of the AOI.

5.3. NAPL, Tar, and Black Carbon

The nature and distribution of NAPL, tar, and black carbon influence the distribution, fate, and transport of and, ultimately, the cleanup approach for key COCs. This section first reviews the general occurrence, chemical composition, and physical properties of NAPL and tar within the AOI. A description of the general occurrence, properties, and distribution of black carbon follows. A more detailed discussion of NAPL and tar is included in Appendix 5F. NAPL and tar stability is discussed in Section 6.2, Mobile NAPL and Tar Transport.

5.3.1. NAPL and Tar Characteristics and General Occurrence

NAPL, tar, and indicators of petroleum impacts have been identified within the AOI. Multiple lines of evidence were used to define the types and distribution of NAPL or tar, including:

- Depth of occurrence in soil relative to the water table
- Field observations in soil and sediment cores

- Ultraviolet core photography
- Petrophysical testing
- TarGOST®[85]
- Chemical data
- Physical data

NAPL and tar types are described below within the overall LNAPL, DNAPL, and tar families. NAPL pictures, definitions, and an explanation of NAPL terminology used in this report are presented in Table 5-10.

NAPL is an immiscible fluid that co-occurs with water and/or soil gas within the pore spaces between soil or sediment grains. NAPL more easily migrates through coarser soil and sediment layers where pore spaces are larger and less easily through fine-grained material where pore spaces are much smaller. NAPL will preferentially travel through fractures, cracks, and voids that might be present in any substrate type.

Because LNAPL is less dense than water, it tends to accumulate near the water table. Under unconfined conditions, changes in groundwater levels will create a smear zone of LNAPL in the soil as the water level rises and falls. LNAPL has been observed only in localized areas of soil and shallow groundwater in the upland portion of the AOI and not in sediment.

DNAPL is denser than water and, if enough volume has been released, can migrate below the water table. Because migration is driven by gravity, DNAPL tends to move downslope and accumulate above geologic layers of lower permeability. DNAPL that is highly viscous (semisolid, very tacky, and pliable) is considered tar for purposes of this RI and is generally not mobile.

Compared to LNAPL, DNAPL distribution is more complex within the AOI. DNAPL migrates both vertically and laterally, and migration patterns tend to change with depth and geologic unit. Near historical source areas, DNAPL formed thicker impact zones. At these source areas, DNAPL might have penetrated deeper or migrated laterally along preferential pathways and downslope away from the source area. DNAPL is more dispersed with increasing distance from the source areas and occurs in the form of “fingers” or thin lenses within soil and sediment.

As referenced in this report, tar is a semi-solid to solid material that might be synonymous with “pitch,” which is the term used for similar material in the petrographic analyses (Attachment 2D-8). This physical description of tar differs from usage in previous reports and does not imply specific products and byproducts (e.g., coal tar). Material defined as tar in this report is dark in color and dominated by heavier PAHs with very low aqueous solubilities; tar analytical results are included in Appendix 5F. Tar typically occurs as small discrete masses, layers, or deposits within the fill unit and upper portion of the recent lacustrine unit and, to a lesser extent, in underlying glacial deposits. Small tar masses are interspersed sporadically within the fill unit, and tar particles are locally disseminated in the fill unit; some larger tar deposits have also been identified (see the further discussion of tar distribution in Section 5.3.4).

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[85] TarGOST® specializes in delineating coal tar and creosotes. The TarGOST® probe is deployed via direct push and features a sapphire window that allows direct laser-induced fluorescence (LIF) measurements as the probe is advanced into the soil. This is further discussed in Appendix 5F.

The samples where NAPLs and tar were identified have been mapped (Figure 5-25); areas impacted by NAPL or tar are delineated in Figure 5-26A (shallow) and 5-26B (all depths).

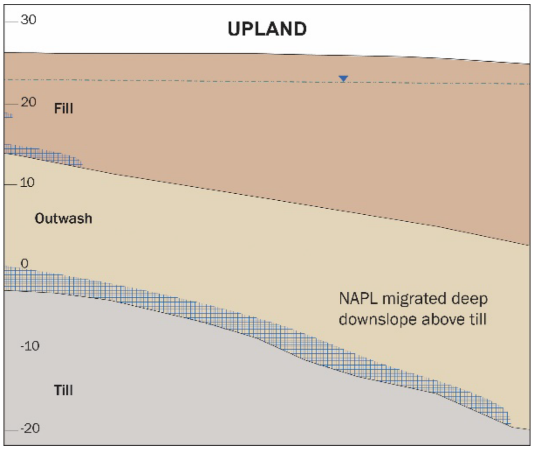
The interpreted extent of NAPL and tar within the AOI is based on detailed field-screening of over 700 soil and sediment explorations, evaluation of 48 TarGOST® explorations, and observations of NAPL presence in monitoring wells. Figure 5-25 depicts the relative degree of NAPL and tar occurrence where NAPL field observations were made or a TarGOST® boring was performed. The presence and degree of NAPL impact and the presence of tar at each sample location is categorized according to the following NAPL and tar occurrence categories and used in NAPL/tar mapping:

- Tar
- Heavy sheen with NAPL
- Heavy sheen and/or trace NAPL
- Slight to moderate sheen
- Staining or odor
- No impacts

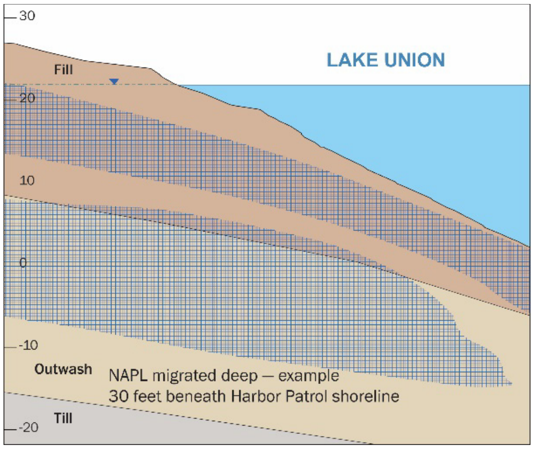
The first category has been used to define tar areas (i.e., areas with tar observed in more than one contiguous exploration), and the second and third categories have been used to define NAPL areas (i.e., areas with the greatest degree of NAPL impact or highest NAPL saturations, as interpreted from TarGOST® fluorescence measurements, observed in more than one contiguous exploration). The conceptual extent of areas with continuous NAPL and tar impacts are presented in Figures 5-26A and 5-26B. Appendix 5F provides a detailed discussion of NAPL and tar terminology; a description of NAPL occurrence categories; NAPL and tar area characteristics and delineation methodology; a NAPL stability evaluation; detailed NAPL cross sections and NAPL depth and elevation maps; and a NAPL CSM. The following information/cross sections are from Appendix 5F.

With few exceptions (NAPL Areas 5A and 15), NAPL areas in sediment are not contiguous with NAPL in the upland. Offshore NAPL impacts extend from shallow subsurface lake sediment or in-water fill into the outwash layer in most NAPL areas. NAPL extends down to the till layer in several areas. When NAPL reached the till, it migrated downslope to greater depths (see *Section F-F'* inset below) and/or became trapped in depressions in the till layer. NAPL-impacted sediment has complex characteristics because it is not present as a single, discrete layer or body. NAPL can occur in sediment as thin lenses or fingers, interbedded with cleaner sediment that does not contain NAPL (see *Section L-L'* inset below). It can also extend deep (see *Section G-G'* inset No. 1 below); in the offshore it can be found beneath a thick layer of NAPL-free sediment (see *Section G-G'* inset No. 2 below) or can be more isolated within the sediment column or by water depth or distance offshore (see *Section J-J'* inset below).

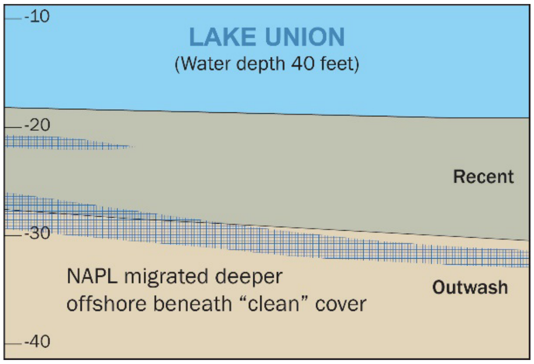
The lateral and vertical extent of NAPL and, to a lesser extent tar, influence the distribution and concentrations of contaminants in groundwater within the AOI, and control (in many areas) the distribution and concentrations of contaminants in soil and sediment.



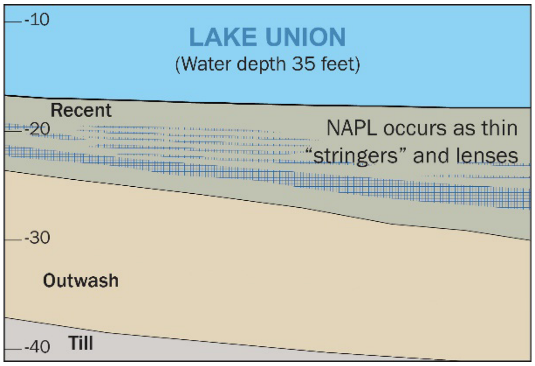
Section F-F' Inset (from Figure 5F-14)



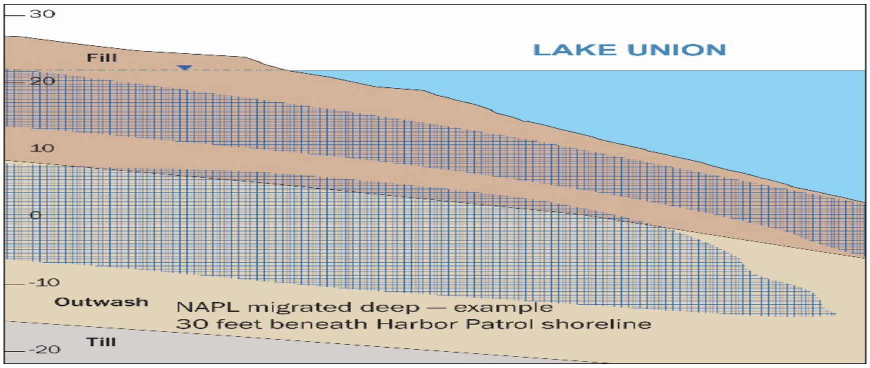
Section G-G' Inset No. 1 (from Figure 5F-15)



Section G-G' Inset No. 2 (from Figure 5F-15)



Section L-L' Inset (from Figure 5F-20)



Section J-J' Inset (from Figure 5F-18)

5.3.2. LNAPL Distribution

LNAPL within the AOI is only found in the upland and generally occurs in the fill near the water table; however, it has also been encountered in the Vashon recessional outwash unit in one upland area between the Cracking Towers and Kite Hill (location of the gully) (see NAPL Area 6 in Figure 5-26B). Four contiguous areas of LNAPL-impacted soil are present in the upland, occurring at depths ranging from 1 foot to 15 feet bgs (these areas are under a soil cap, except for the shoreline northeast and east of the Play Area).

Measurable LNAPL (i.e., at least 0.01 foot) was present during the last RI groundwater monitoring event (December 2020) in three wells near the Play Area (MW-09, MW-44S, and MW-45S) and in one western well (MW-18[86]) out of the approximately 40 monitoring wells screened near the water table[87] in the AOI upland; see Appendix 3J, Table 3J-2 for NAPL thickness in wells.

Petroleum-based LNAPL (including hydrocarbons in the light- to heavy-oil range) was found in samples from the gully immediately west of the Cracking Towers, in well MW-09, west of the Play Area, and in the northeast corner (Figure 5-26B) of the upland. The presence of LNAPL was determined from chemical analytical data, TarGOST®, UV screening, and physical properties. Benzene, toluene, ethylbenzene, xylenes- (BTEX-) rich LNAPL (up to 84 percent by weight BTEX) was historically observed in only the southeast corner of the AOI upland near the location of the former light-oil plant. LNAPL is this area was remediated through use of an AS/SVE system that operated from 2001 to 2006. The historical extent of BTEX-rich LNAPL is mapped as NAPL Area 12 in Figure 5-26B. NAPL in the northeast corner is described as a mixture of LNAPL and DNAPL because it has characteristics of both. LNAPL appears to be comingled with DNAPL in the gully near the Cracking Towers (Figure 5-26B).

5.3.3. DNAPL Distribution

DNAPL impacts within the AOI have been observed in both upland soil and offshore sediment in at least 11 areas and are generally more widespread than LNAPL impacts (Figure 5-26A and 5-26B). DNAPL within the AOI occurs in all geologic units but has rarely been encountered in the till unit. DNAPL impacts have been observed at depths ranging to 40 feet bgs in the upland and to at least 25 feet bml offshore.

Although DNAPL has been observed in soil in several areas shown on Figure 5-26B, measurable DNAPL (i.e., >0.01 foot) has been observed in monitoring wells in only two of these areas: near the Play Barn and wells in the Harbor Patrol vicinity. Appendix 3J, Table 3J-2 presents NAPL thickness with all the incidents of measurable DNAPL and LNAPL in wells.

For purposes of identifying distinct DNAPL areas within the AOI, three types of DNAPL have been defined:

- Naphthalene-rich DNAPL (also referred to as “light oil,”[88] “middle oil,” or “medium oil” by various authors) – This DNAPL has been observed to have a distinct yellow sheen in some areas, and based on field observations, appears to have a relatively low viscosity as compared to other DNAPLs encountered within the AOI. This type of DNAPL has been encountered in sediment in the western offshore area.
- PAH-rich DNAPL, [also referred to as coal tar, creosote[89], or tar by various authors (Attachment 2C-1 of Appendix 2C)] – This DNAPL may be derived from various MGP processes. PAH-rich DNAPL was also a raw material, byproduct, or product of the tar refinery, in the form of coal tar (the feedstock) or as various grades of creosote. PAH-rich DNAPL was also used for other industrial purposes such as at the

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[86] MW-18 contained 0.01 foot of LNAPL. The presence of a small amount of LNAPL in this well does not represent LNAPL in soil but rather phase separation from subsurface DNAPL screened by the well.

[87] The screen interval of most of these wells span the water table where LNAPL is expected to accumulate in soil. Deep monitoring wells, screened well below the water table, would not be expected to detect LNAPL.

[88] There is inconsistent usage of “light oil” in literature regarding manufactured gas plants. Light oil has been used to describe both BTEX-rich and naphthalene-rich products.

[89] Creosote is a coal tar-based product that might also contain petroleum.

adjacent shipyard. The wide range of DNAPL viscosity within the AOI is an indication of the variety of DNAPL products and byproducts, the various degrees of weathering, or both. However, DNAPL viscosities are sufficiently high to limit mobility of this material.

- Lower-PAH DNAPL with petroleum – This DNAPL has relatively low PAH concentrations. It is described as "oily," with chemical evidence of petroleum, and an unresolved complex mixture (UCM) signature in chromatograms. The presence of this type of DNAPL in sediment in the western offshore area suggests an additional or other source of DNAPL. Multiple potential sources existed, including top-down overwater releases from the various industrial activities located along the lake. Where present near the mudline, oily sediment might not be DNAPL but rather weathered LNAPL that might may have sunk to the lake bottom as oil particulate aggregates (oil droplets coated with sediment particles and mixed in with sediment).

5.3.4. Tar Distribution

Where tar has been observed within the AOI, it has been found predominantly in the fill unit, although it was also found in the outwash unit offshore to the east. In five areas, tar has been observed in borings adjacent to each other at similar depth intervals; these areas are identified in Figure 5-26B. The depth of tar-impacted soil or sediment ranges from ground surface to 14 feet bgs in the upland, and from mudline to 5 feet bml in the offshore area (but not as continuously impacted intervals). Only one tar area is currently exposed at the ground surface along the eastern shoreline (Tar Area 5, see Figures 5-26A and 5-26B)[90].

Isolated occurrences of tar (i.e., not contiguous with adjacent borings) have also been observed in the fill unit. Tar, as identified by various surface observations and subsurface explorations, has two modes of occurrence: (1) tar-impacted soil or sediment and (2) discrete tar bodies or layers. Tar-impacted media might reflect weathered DNAPL. Tar bodies or layers are thought to represent an original deposit or perhaps a historical DNAPL seep that has subsequently weathered or hardened.

The thickest[91] interval of tar-impacted soil or sediment encountered within the AOI (12.5 feet) was observed near the southeastern shoreline (Figure 5-26B). The thickest tar layer encountered was 3 feet in the center of the upland (Tar Area 1), and the thickest interval offshore is 1.5 feet (east of the Play Barn; Tar Area 3). Most of the tar-impacted intervals are less than 3 feet thick.

Although not observed for a number of years (since installation of soil caps), tar in the upland portion at the AOI has occasionally "upwelled" or seeped to the ground surface during or following a period of hot weather. In addition, wave action has eroded the bank in some locations, exposing tar in the fill unit (e.g., along the eastern and southeastern shoreline). Periodically, cleanup actions have removed tar from accessible areas of the AOI; Appendix 5F, Figure 5F-2 shows tar removal areas. Tar stability is discussed further in Section 6, Contaminant Fate and Transport.

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[90] The northeastern tar occurrence, called the "tar mound" in Appendix 5F, is fenced to prevent public access to the area.

[91] Tar thickness does not necessarily mean 100 percent tar with no soil. Tar thickness here is defined as tar-impacted media.

5.3.5. Black Carbon Distribution

Carbon originating from industrial activities in the AOI upland contributed to TOC concentrations in surface sediment (see Figure 5-27) and elevated PAHs in both soil and sediment. Most black carbon is formed by the incomplete combustion of coal and other fuels.

Black carbon[92] is present throughout a large portion of the AOI and occurs mostly as carbon black (soot-like particles), pitch, coke, and coal. These black carbon materials are scattered throughout the older portion of the fill unit (also known as the Gas Works deposit) in both the upland and offshore areas to the east and south, as described in Table 3B-1. In addition, small black carbon particles have historically been distributed over a large portion of near-surface sediment within the AOI by wave action, erosion, spills, stormwater runoff, and over-water releases. In addition to MGP operations, there were many other sources of black carbon, including the tar refining, other industrial operations, fires, and combustion of coal and petroleum for transportation and heating.

Of all the black carbon forms, carbon black (a colloidal carbon material consisting of nanometer-sized spheres and their fused aggregates) appears to be the most abundant and most widespread. The conversion to oil gasification in 1937 resulted in the increased production of lampblack (a form of carbon black). Lampblack was generated, stored, and processed in structures in the south-central portion of the upland (see Figure 1-5). Lampblack was also incorporated into the older fill and redistributed during regrading.

Sediment samples from the eastern and southern sediment areas within the AOI were analyzed in 2005 by researchers from Stanford University and R&D Carbon Petrography to evaluate the types of carbon present, both natural (e.g., organic plant matter) and anthropogenic (e.g., carbon black, coal, coke) (Appendix 2D). Figure 5-27 shows the distribution of black carbon in surface sediment for the sampled area. The highest concentrations are evident offshore just west of the Prow, offshore just east of the Prow, and offshore northeast of the Play Barn. Although the number of data points is limited, the distribution of black carbon can be inferred from TOC analyses and from descriptions of soil and sediment. In soil, black carbon content is expected to be higher in older fill mostly to the east and in the south-central area. In sediment, black carbon content is highest in sediment to the south and northeast, coincident with some of the highest TOC concentrations in AOI sediment (Figure 3-14); this latter finding indicates that black carbon potentially accounts for most of the elevated TOC in sediment in lakeshore and upper lake slope areas in the AOI.

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[92] Black carbon is another term for anthropogenic solid carbon. Carbon black is a type of black carbon. Lampblack is type of carbon black.

6.0 CONTAMINANT FATE AND TRANSPORT

Risks associated with environmental contaminants are best understood when their distribution, transport mechanisms, and pathways through soil, groundwater, sediment, and porewater as well as their ultimate fate are known. Fate and transport processes govern the movement or migration (transport) of contaminants from the point of release, through the media through which the contaminants migrate, where they end up, and the physical and chemical processes that affect contaminant concentrations during and after transport.

This section focuses on potentially active transport mechanisms: mobile NAPL and tar transport, partitioning and groundwater transport to sediment and surface water, erosion and surface water transport, and other factors affecting sediment stability. Deposition and burial are described because they comprise an important mechanism for attenuation (natural recovery) of contamination in surface sediment. This section also includes a preliminary evaluation of the likelihood of the on-site stormwater system to transport contaminants and potentially recontaminate sediment; a more detailed evaluation is included in Appendix 12A.

The information presented in this section provides part of the framework used to develop and evaluate potential remedies in the FS. Further discussion and technical details related to contaminant fate and transport are presented in Appendices 5F and 6A.

6.1. Fate and Transport Overview

When released, contaminants can migrate through soil, groundwater, sediment, and porewater by various physical and chemical processes or transport mechanisms. The processes below have historically occurred within the AOI:

Entrainment refers to the transport particles by the flow of a fluid.

- **Erosion, Entrainment, and Deposition** – The physical processes by which contaminated soil or sediment particles or other immobile matrices (e.g., tar in sediment) are disturbed and suspended (eroded) and then entrained and transported by water currents to a new location.
- **Advection** – The physical movement of contaminants, typically by a fluid, through soil or sediment. Advection is primarily controlled by the properties of soil or sediment, gravity, and the properties of an aquifer and the gradient of groundwater. The ability of a given contaminant to dissolve into an aqueous phase also affects advection.
- **Diffusion** – A very slow chemical process in which contaminants in environmental media migrate from areas of high contaminant concentration to areas of low contaminant concentration (i.e., random molecular activity in response to a gradient).

Contaminants that have been released to the environment can be transferred or transformed by various processes, including the following:

- **Partitioning** – The transfer of contaminants between different environmental media by volatilizing to air, dissolving in water or other solvents, and/or sorbing (i.e., attaching) to solids or being taken up into biological tissues (e.g., bioaccumulation).

- **Attenuation** – The reduction of contaminant concentrations by the following means:
    - Chemical (e.g., chemical precipitation, hydrolysis, photolysis)
    - Biological (e.g., biodegradation, biotransformation)
    - Physical (e.g., dispersion, mixing, dilution, burial)

Conditions have changed within the AOI since industrial operations ceased. Releases of contaminants from MGP operations are no longer occurring. Contaminants have migrated or have been moved from their initial point of release, thus resulting in conditions described in Section 5. Contaminants in upland soil have been treated, removed, or capped. As a result, some of the transport mechanisms and pathways described above are no longer active or now play only a minor role in potential human or ecological exposures.

For example, airborne releases of contaminants through volatilization and combustion are no longer a pathway of concern, although they were likely significant historically. Historical industrial and land-filling activities near the MGP that released contaminants to Lake Union no longer occur. NAPL flow within the AOI has stopped because releases no longer occur; upland sources of NAPL have been removed through excavation; and NAPL in the subsurface has reached equilibrium with the gravitational forces that were originally responsible for its flow. Upwelling of tar historically observed in the upland no longer occurs. Groundwater in portions of the AOI has been remediated, and upland groundwater plumes are stable or shrinking because of upland cleanup actions and/or natural attenuation. Examples provided in this paragraph are supported by data and analyses provided in preceding sections and associated appendices[93].

The processes driving contaminant transport within the AOI are dominated by the following:

- Water-borne transport of contaminants partitioning (dissolving) from tar and residual NAPL
- Periodic erosion of soil and sediment in uncapped shoreline areas
- Erosion, resuspension, and surface water transport of sediment in shallow nearshore areas

Stormwater outfalls conveying stormwater from the AOI upland are not a significant source of contaminants to the AOI sediment based on multiple lines of evidence (see Section 6.7 for further discussion).

Residual NAPL and tar in soil and sediment contribute to groundwater contamination through partitioning between NAPL and aqueous media (groundwater and porewater). Groundwater transport of COCs is limited by various attenuation mechanisms in soil and sediment, with the high TOC content of lake sediment and presence of black carbon in upland soil and nearshore sediment providing important controls (e.g., via adsorption) on the fate of organic compounds. Under current conditions, transport of contaminated soil to sediment is possible through erosion of unstable bank areas and runoff from exposed, uncapped bank areas. Sediment erosion from wind-generated wave action and propeller wash, subsequent resuspension in the water column, and water-borne transport occurs in the lake, primarily in the lakeshore and lake slope areas.

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[93] Historical activities and remedial actions are described in Section 2.2; upwelling tar is discussed in Section 2.2 and Appendix 5F; NAPL migration is based on the data and analysis provided in Appendix 5F; evidence for stable or shrinking plumes is discussed in Section 5.2.2.1.

The fate and transport mechanisms with the greatest potential to affect current conditions in the AOI are discussed in more detail in the following sections. For key COCs, physical and chemical parameters that affect these processes are listed in Table 6-1.

6.2. Mobile NAPL and Tar Transport

The majority of NAPL-impacted soil and sediment as well as tar are confined to the subsurface and do not pose a risk to human and ecological receptors as these receptors are not expected to contact (be exposed to) subsurface soil and sediment (see Appendices 4C and 4D for discussion of exposure pathways). Those areas where NAPL and tar are at or near the surface represent a complete pathway that is addressed in the FS. This section examines the current potential for subsurface NAPL and tar to migrate to the ground surface or mudline, where human or ecological exposure could occur.

The historical migration and distribution of these source materials within the AOI were influenced by the following:

- Location of historical sources
- Quantities released
- Mechanism of release
- Age of release
- Viscosity and density of the NAPL or tar
- Depth of the water table and characteristics of the geologic strata underlying the AOI

The general characteristics of NAPL-impacted soil and sediment and tar as well as a site-specific evaluation of the potential for NAPL migration are discussed below. Additional information on the characteristics of NAPL and tar and associated definitions and terminology is presented in Table 5-10.

6.2.1. Potential for NAPL Migration

NAPL is a mixture of chemicals and its composition varies based on the original source, the amount of time since the release, and environmental conditions where it occurs. When NAPL (both DNAPL and LNAPL) is released to the environment, it migrates through substrate pore spaces, replacing air and water (in soil) or water (in sediment or saturated soil). NAPL is relatively insoluble in water and moves separately from water. In the saturated zone in soil or in sediment (i.e., where water would typically fill the pore spaces), water tends to preferentially “coat” the soil or sediment grains (i.e., water is the “wetting” fluid), while NAPL occupies the center of larger pore spaces (i.e., NAPL is the “nonwetting” fluid[94]) (see migrating/mobile NAPL inset below).

Following release, DNAPL and LNAPL behave differently. DNAPL is denser than water and can sink below the water table and penetrate saturated porous soil and sediment. DNAPL might sink until encountering a capillary barrier, typically a low-permeability material such as silt or clay, at which point it might flow horizontally or pool in depressions above geologic strata it cannot penetrate. DNAPL migration is driven by the head (overlying thickness of NAPL) in source areas and is controlled primarily by gravity (density differential with water), its viscosity, and the size and distribution of soil or sediment pores. LNAPL is less

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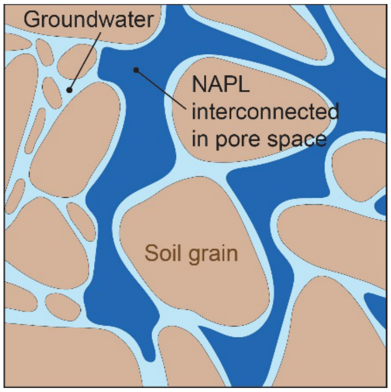
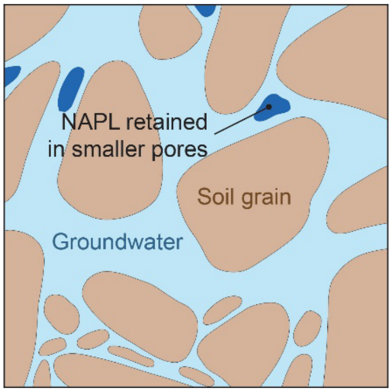
[94] NAPL can become the wetting fluid as it weathers.

dense than water. Given a sufficiently large release within soil, LNAPL will migrate downward and accumulate near the water table—in most conditions, LNAPL does not penetrate far below the water table. Upon reaching the water table, LNAPL spreads laterally, the LNAPL body flattens ("pancakes"), the gradient driving NAPL migration diminishes, and LNAPL stops migrating. Most LNAPL migration occurs shortly after a release.

NAPL mobility is a function of the physical characteristics of the soil, sediment, and NAPL; the groundwater conditions; and the timing, rate, and volume of a release. NAPL mobility decreases with time after a release ceases. The main factors controlling migration are NAPL saturation (the amount of the soil or sediment pores occupied by NAPL) and gradient. While migrating, NAPL occupies larger interconnected pore spaces and NAPL saturations are higher (see *Migrating/Mobile NAPL* inset). NAPL saturations decrease as it spreads through an increasing volume of soil or sediment. Gradients decrease as LNAPL bodies flatten and DNAPL drains away from the source area.



Migrating/Mobile NAPL



Residual NAPL

After migration, some of the NAPL remains trapped in the smaller pore spaces between the soil or sediment particles, which results in residual NAPL where saturations are lower (see *Residual NAPL* inset). Some of it remains mobile (exceeds residual saturation and is hydraulically connected in the pore space) but becomes trapped (stops migrating and is stable) due to geological conditions. In some cases, NAPL can migrate upward with gas bubbles through a process called ebullition.

Ebullition refers to the transport of subsurface contamination by bubbling up of sediment gasses.

NAPL migration is not expected within the AOI, considering the time that has passed since releases occurred 60 to 100 years ago. Multiple lines of evidence were used to assess potential migration. The following site-specific data and observations support conclusions related to NAPL stability.

- Petrophysical testing of soil containing NAPL demonstrates that NAPL saturations are low and that NAPL is not significantly mobilized even when subjected to pressures equal to 1,000 times the force of gravity[95] (Table 6A-1). These data indicate that most NAPL is in a residual state that is not mobile.

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[95] Of the 20 samples tested, only two had NAPL saturations greater than 20 percent—a typical threshold for mobile NAPL. NAPL mobility is measured by the change in saturation during petrophysical testing. The saturation did not change in the two samples with >20 percent saturation. The average change in saturation for all 20 samples was 0.6 percent of the pore volume.

- Most monitoring wells screened within NAPL-impacted areas do not have measurable thicknesses of NAPL, indicating NAPL is not mobile in most areas (see Appendix 5F for further details).
- Viscosity and density test results for DNAPL (Appendix 5F) indicate that AOI DNAPL tends to have high viscosity, a characteristic that limits mobility.
- TarGOST® testing indicates that deeper DNAPL has weathered[96] and become more tar-like and less mobile.
- Divers inspecting nearshore sediment did not observe NAPL seeps.

Most of the NAPL within the AOI is residual (i.e., occurs as small droplets or "stringers" left behind in the soil or sediment) and, with one minor exception where ebullition might be occurring[97], is no longer migrating. Further analysis of NAPL areas was conducted to evaluate whether NAPL could become exposed. The comprehensive analysis of NAPL migration is provided in Appendix 5F. Figures 5F-19 through 5F-23 in Appendix 5F show the elevation of the upper surface of NAPL impacts and the depth of NAPL to depict areas where NAPL is close to the ground or sediment surface and could potentially be exposed by erosion or other disturbance (e.g., anchor drag).

LNAPL migration is not a threat to sediment. The main shoreline occurrence of LNAPL (Area 12, see Appendix 5F, Figure 5F-23) was remediated by AS/SVE between 2000 and 2006. Recent well installation indicates very little mobile LNAPL remains in LNAPL Area 13, which is adjacent to the remediated area near the shoreline. LNAPL is currently present in quantities greater than 0.01 foot in in only one well (MW-09), which is located west of the Play Area and delineated in the upland (i.e., does not extend offshore to sediment).[98]

Most of the DNAPL released in the upland is now in a residual state. Small pockets of mobile DNAPL have been observed perched above geologic contacts, such as in depressions in the surface of the low permeability till unit, and are stable (i.e., no longer migrating). There are two areas where upland DNAPL historically migrated to sediment (Area 5 and Area 15, see Appendix 5F, Figures 5F-9 and 5F-14, respectively); DNAPL in these areas is no longer mobile based on petrophysical testing.

Where DNAPL was historically released over water, it sank to the sediment surface and spread laterally and vertically into sediment. In some offshore areas, the distribution and occurrence of DNAPL along vertical planes, or "veins," suggests vertical migration through recent lacustrine deposit sediment or other preferential pathways. Once in sediment, DNAPL migrated deeper offshore, where it is overlain by up to 20 feet of cleaner sediment not impacted by NAPL (see Appendix 5F maps and cross sections depicting NAPL depths). The only evidence of migration since the beginning of sediment investigations are rare observances of ebullition in the lake bottom in the western portion of the AOI.

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[96] NAPL weathering involves the loss of volatile and soluble constituents present in the NAPL, resulting in reduced viscosity (and thus mobility) and a lower potential for partitioning.

[97] Rare instances of ebullition have been observed offshore in the western sediment portion of the AOI where NAPL is close to the surface. The last report of a sheen to Ecology in this area was in 2015. The source of the sheen was unknown.

[98] In December 2020, a thin accumulation of LNAPL (not greater than 0.01 foot) was also measured in wells MW-18, MW-44S, and MW-45S. These wells are near the Play Area or Harbor Patrol and are also isolated from sediment (that is, there are wells without LNAPL between these three wells and the sediment portion of the AOI).

6.2.2. Potential for Tar Migration

Tar is generally considered to have a low potential for mobility because of the semi-solid and solid states in which it typically occurs. Unlike DNAPL, tar does not migrate through the pore spaces of granular soil but rather moves as a plastic solid, which displaces or incorporates soil particles into a tar matrix. Tar is considered to have a low potential for migration within the AOI. Areas where tar seeps were historically observed during hot weather have been addressed through soil capping. No seeps have been observed in capped areas nor have new seeps been observed in uncapped shoreline areas over the past 10 years.

6.3. Erosion and Entrainment

Transport of contaminated soil or sediment through the processes of erosion and entrainment is one mechanism responsible for the current distribution of chemicals in contaminated media within the AOI. For example, much of the eastern shoreline has receded since 1973, when demolition of the former MGP and development of Gas Works Park began. Filling; earthwork; and erosion of soil or sediment containing raw material, products, and byproducts likely led to the transport and deposition of impacted soil offshore and shallow nearshore sediment downslope and farther offshore. Although erosion, entrainment, and transport was likely a dominant transport mechanism in the upland, it decreased after completion of the park and stabilization of most upland soil by capping. Today erosion and entrainment are no longer occurring at the upland areas of the AOI stabilized by capping and are limited to uncapped areas along the shoreline.

Stormwater runoff, shoreline sloughing, and erosion continue to be potential concerns. Surface water moves suspended material in the direction of currents and moves unconsolidated material downslope from the lakeshore toward the lake bottom (i.e., bedload transport). This transport process is likely responsible for the presence of impacted sediment at the toe of the slope in many shoreline areas of the AOI. The shoreline bank has sloughed and contributed sediment to the lakeshore zone. The lakeshore zone is also strongly influenced by wind- and vessel-induced waves that intermittently create conditions that result in erosion, except, for example, in protected coves or waterways. Processes affecting physical transport of particles is shown in Figure 6-1.

The upper lake slope adjacent to the lakeshore zone does not have substantial amounts of fine-grained sediment, which indicates this zone is non-depositional and possibly erosive. In addition to limiting natural recovery and exposing impacted sediment, erosion of surface sediment in the lake slope zone and, in particular, the fill deposit, could expose tar where it occurs near the mudline (only thinly covered by sediment).

Most erosion processes take place along the shoreline and in the lakeshore zone, where the lake bottom is shallow enough that wind-generated waves impinge on the sediment surface. Vessels also generate waves that can impact shoreline stability. Propeller forces can impact the lake bottom in deeper areas when vessels are maneuvering, as indicated by evidence of scouring observed in bathymetric surveys. Anchor use in the soft sediment of the lower lake slope and lake bottom zones would also affect sediment stability on a localized, short-term basis. The low current velocity in deeper portions of Lake Union would generally limit the potential for lateral transport of contaminated sediment disturbed by prop wash or anchor drag prior to resettling on the lake bottom. The results of site-specific studies evaluating erosive forces, including storm waves, currents, and propeller wash, are discussed in Section 3.2.6 and Appendix 3G.

Key physical transport mechanisms for contaminated soil and sediment are illustrated in the conceptual block diagram depicted in Figure 6-2. The locations where these physical transport mechanisms occur are shown in Figure 6-3. These areas are a focus of the FS.

6.4. Other Factors Affecting Soil and Sediment Stability

In addition to the erosion processes described in Section 6.3 above that have resulted in significant transport of shoreline soil and lakeshore and upper lake slope sediment, other factors might affect the stability of soil and/or sediment within the AOI to a lesser degree or on an infrequent basis. Natural processes that might affect the stability of the lake bottom include bioturbation, where animals such as crayfish disturb the sediment surface while feeding or seeking shelter. Similar activities by smaller benthic organisms can serve to make the sediment more cohesive (e.g., tube building) or less stable by increasing the sediment water content (e.g., burrowing). Bioturbation processes are expected to be limited in the lake bottom, with minimal effect on the stability of soft lake bottom sediment, due to the anoxic conditions that limit colonization and survival of burrowing invertebrates. If active, bioturbation is not likely to affect the stability of the AOI lake bottom sediment that is already highly fluid and subject to disturbance. The depth of sediment impacted by these activities is estimated to be within the top 10 cm of the lake sediment.

Other natural, but rare, events that could influence sediment stability are seismic events. Using building code-based seismic design criteria, geotechnical analysis of soil and sediment stability has concluded that some existing slopes and soil conditions at Gas Works Park are not stable under seismic loading conditions. Saturated portions of the fill and recessional outwash units as well as lacustrine deposits in Lake Union are subject to reduced strength and liquefaction during seismic events. Saturated loose to medium dense fill material are particularly susceptible to liquefaction. Liquefaction could result in ground settlement in the upland, lateral spreading toward Lake Union, slope deformation, and/or sand boils. The areas of the AOI subject to movement as a result of seismic activity would be limited to areas of steeper slopes, such as the southern slope of Kite Hill including adjacent lakeshore and lake slope zones and, to a lesser extent, slopes offshore of the Play Area. Seismic events strong enough to generate liquefaction and lateral movement of soil or sediment can contribute to transport of contaminants by destabilizing the sediment, which could be subject to subsequent erosion, resuspension, and transport (e.g., downslope migration of sediment, as shown on Figures 6-1 and 6-2). Lake bottom soft sediment might be subject to seismic liquefaction, but the flat lake bottom surface significantly reduces the potential for significant lateral movement of sediment.

The effect of seismic conditions within the AOI have generally been investigated to support analysis of cleanup action technologies and are preliminary. Further analysis of the seismic stability of upland soil, lake sediment, and cap materials will be conducted during future remedial design activities.

6.5. Partitioning and Groundwater Transport

Transport of dissolved contaminants is a pathway of concern both for the upland groundwater-to-sediment pathway and sediment-to-porewater pathway. Dissolved transport includes both chemical and physical mechanisms that generate or impede transport in groundwater and porewater. A thorough understanding of the fate and transport of dissolved-phase contamination includes an understanding of the distribution of contaminants in source materials (e.g., tar and NAPL) and environmental media (soil, sediment, and groundwater) and how dissolved concentrations change over time and distance from the contaminant source. For aqueous-phase transport, the controlling factors are contaminant partitioning and other characteristics or conditions that attenuate dissolved concentrations with time and distance from source areas. Additional discussion of aqueous phase transport is provided in Appendix 6A.

Contaminant partitioning is dictated largely by the chemical and physical properties of the contaminants. In general, chemical constituents with similar physical and chemical characteristics show similar patterns of transformation, transport, or attenuation in the environment. A summary of key physical and chemical parameters that are likely to affect partitioning and fate of contaminants within the AOI is found in Table 6-1 and summarized below:

- Benzene (as a surrogate for ethylbenzene and toluene), and to a lesser extent naphthalene and dibenzofuran, are the only COCs that are considered volatile as measured by vapor pressure and Henry's Law Constant.
- COCs have a broad range of solubilities (ability to dissolve in water). Chrysene and benzo(a)pyrene (HPAHs) have the lowest solubility of all organic COCs (0.0016 mg/L); benzene solubility is considerably higher (1,790 mg/L). Other key organic contaminants found in the AOI fall within this range.
- Arsenic can be highly soluble but is the most persistent because it can be transformed into a different chemical state but not destroyed (i.e., half-lives are not an applicable concept); similarly, nickel is considered persistent. Benzene and dibenzofuran are the least persistent as measured by attenuation half-lives and are capable of degrading.
- The affinity to bind (partition) to organic material contained in soil and sediment varies considerably, from benzene with a low to moderate affinity, to benzo(a)pyrene and benzo(b)fluoranthene that have high affinities for binding to organic material in soil and sediment.

The following sections describe the general processes governing partitioning to the aqueous phase in source areas and mechanisms that reduce dissolved-phase transport. Benzene, PAHs, and arsenic provide the focus for these discussions because their properties encompass the behavior of other GWPS COCs. Nickel is not discussed further because it is most likely to be in an insoluble form in sediment (nickel forms nickel sulfide under anaerobic conditions in the presence of sulfur). Additional details and site-specific interpretations related to chemical-specific partitioning and contaminant fate and transport are presented in Appendix 6A.

6.5.1. Partitioning to the Aqueous Phase

Contaminant partitioning from soil or sediment, NAPL, or tar is the main mechanism contributing to groundwater contamination within the AOI. Dissolved concentrations increase where groundwater flows through contaminated soil or sediment within the AOI. In these source zones (typically NAPL or tar-impacted soil or sediment), COCs such as benzene and PAHs slowly transfer from soil or sediment (i.e., partition) into groundwater or porewater. Physico-chemical properties indicate that the heavier (on a molecular-weight basis) PAHs are less likely to be present in an aqueous phase because of their low solubility and high affinity for binding to organic material. Benzene and naphthalene are more likely to be present in an aqueous phase because of their higher solubility and lower affinity for binding to organic material.

The following sections describe site-specific conditions that influence partitioning to the aqueous phase.

6.5.1.1. NAPL and Tar Partitioning

NAPL and, to a lesser degree, tar are the main sources of dissolved benzene and PAHs in AOI groundwater and porewater. As described in Section 5, groundwater monitoring results show that dissolved-phase concentrations are higher in NAPL-impacted source areas, with concentrations staying stable or slowly decreasing with time.

The effect of NAPL on dissolved-phase concentrations was studied in detail during the EPRI study (Attachment 2C-1 of Appendix 2C), which included sampling at multiple levels throughout and downgradient of NAPL and leaching tests on NAPL and tar-impacted soil. Another study conducted by Stanford University (Hong and Luthy 2005) developed site-specific partitioning coefficients for NAPL and tar-impacted sediment. Combined, these studies provide site-specific insight into partitioning in source areas.

NAPL- and tar-impacted soil and sediment are diminishing sources of benzene and naphthalene because the propensity for NAPL or tar to partition to an aqueous phase depends on its chemical composition. The DNAPL-tar continuum illustrates this point:

- The leachate from DNAPL and tar differs because of the relative ratios of the chemicals in DNAPL versus tar and their individual solubility limits, with tar having lower concentrations of more soluble compounds such as benzene and naphthalene.
- PAH-rich DNAPL weathers to tar through volatilization and partitioning of lighter (lower molecular weight) components to water.

As DNAPL weathers to tar, more soluble chemicals are removed, and the remaining composition has higher proportions of lower-solubility chemicals. Through this process, weathering reduces partitioning of more soluble chemicals and NAPL and tar diminish as sources of benzene and naphthalene. A discussion of NAPL and tar leachability to groundwater and sediment porewater is discussed in Appendix 6A, Section 6.2.3.

6.5.1.2. Black Carbon Partitioning

Another site-specific influence on partitioning is the presence of black carbon in soil and sediment within the AOI. The most predominant form is lampblack; coke, coal, and soot are other forms of black carbon present. Black carbon is present in soil (fill unit) and sediment (fill and upper portion of recent lake deposits). Black carbon is a solid and is not mobile in groundwater. The known distribution of black carbon in sediment is shown in Figure 5-27.

Black carbon plays an important role in chemical partitioning in AOI media and can act as a source of aqueous-phase COCs or a sink into which contaminants are incorporated (sorption site), thus limiting the mobility of organic compounds through the process of sequestration. In this way, black carbon affects partitioning both from the solid-to-aqueous phase and from the aqueous-to-solid phase, depending on the nature of the black carbon (i.e., high PAH or low PAH) and aqueous concentrations.

Partitioning coefficients (K) predict the distribution of a chemical between two phases. The coefficients are calculated as a ratio between octanol (an organic solvent) and water in the case of the K_{ow}, between organic material and water in the case of K_{oc}, or between a solid (soil or sediment) and water in the case of the K_d. A K_{oc} is the same solid/water distribution ratio as K_d normalized to organic carbon. Chemicals with low values tend to be more soluble and partition readily to water; high values are less soluble and more likely to be associated with organic material or a solid phase.

Hong and Luthy (see Attachment 2D-7 in Appendix 2D) conducted aqueous equilibrium tests and calculated site-specific PAH partitioning coefficients (i.e., K_d values) that are higher than would be indicated by standard theory (i.e., calculating K_d from K_{ow} and fraction of organic carbon), meaning that PAHs in soil and sediment within the AOI have a stronger affinity to bind with soil and sediment than would be expected. Soil and sediment with black carbon have lower aqueous solubilities and less partitioning to water than expected. The results of Hong and Luthy's studies suggest that PAHs are at least partially sequestered in AOI sediments with high black carbon and are less toxic compared to sediments with similar PAH concentrations and less black carbon. In addition to lowering partitioning from soil or sediment to water, the presence of black carbon influences plume migration and attenuation, as described below in Section 6.5.2, Attenuation of COCs.

6.5.1.3. Arsenic Partitioning

Arsenic is present at elevated concentrations in soil and groundwater beneath the Play Area, groundwater downgradient of the Play Area near the shoreline and in near-surface sediment off the eastern shoreline. Partitioning of arsenic between solid and aqueous phases is controlled by site-specific geochemistry. Geochemical conditions favor the partitioning of dissolved arsenic to soil in the source area by adsorption and precipitation mechanisms, as indicated by the following lines of evidence:

- Geochemical evaluation of arsenic conditions in soil and groundwater indicate that dissolved arsenic in groundwater still contains high fractions of arsenic as thioarsenate, which is the original form of arsenic assumed to have been released from the Thylox process area. This finding suggests that arsenic in groundwater is not primarily associated with releases from soil but remains in the dissolved or aqueous form in which it was originally released.
- Sequential arsenic extraction analysis of soil samples determined that the majority of arsenic mass in soil is present in highly stable arsenic sulfide precipitates. Arsenic sulfides are stable under the reducing conditions present within the AOI upland.
- Geochemical modeling discussed in Appendix 2B, Attachment 2B-2 supports the relative insolubility of arsenic solid phases and limited partitioning of arsenic from solid to dissolved phases.

The fate and transport of dissolved arsenic is discussed below in Section 6.5.2.2.

6.5.2. Attenuation of COCs

Natural processes can decrease the mass, toxicity, mobility, volume, or concentrations of contaminants in groundwater at contaminated sites (Krupka and Martin 2001). Such natural attenuation processes include biodegradation; dispersion; dilution; sorption; volatilization; and chemical or biological stabilization, transformation, or destruction of contaminants (EPA 1999).

Attenuation of organic compounds might occur via a nondestructive mechanism (e.g., sorption, dilution) or a destructive mechanism (e.g., biodegradation). For some organic contaminants (e.g., benzene), natural biodegradation by bacteria and fungi is the dominant process by which the contaminant is transformed to less toxic or nontoxic compounds. Although the specifics and efficiencies of these processes vary widely, the net result is typically a nonreversible chemical change that reduces a contaminant's concentration in the environment.

Conversely, inorganic contaminant concentrations are typically attenuated by nondestructive natural processes that do not cause a chemical transformation. Inorganic contaminants thus generally persist and are not removed from the environment. These nondestructive reactions (collectively referred to as sorption) include precipitation, adsorption on the surfaces of soil or sediment minerals, absorption into the matrix of soil or sediment, and partitioning into organic matter.

Site-specific evidence of attenuation is discussed in the following sections.

6.5.2.1. PAHs and Benzene

The primary line of evidence used to evaluate natural attenuation is COC concentration data. As demonstrated by investigation data, PAHs and benzene concentration decrease downgradient of source areas. Natural attenuation was demonstrated in the upland by the EPRI study (Attachment 2C-1 of Appendix 2C) and groundwater monitoring data. Offshore groundwater and porewater sampling shows that dissolved concentrations are decreasing between deeper subsurface sediment sources towards the mudline as well (see Section 6.5.3, Upland Groundwater-to-Sediment and Surface Water Pathway, below for further discussion).

In addition to aqueous-phase concentration data, consideration of chemical properties and site-specific conditions indicate that COCs are attenuating downgradient from source areas. COCs with low solubilities and high affinity for organic carbon in soil and sediment do not travel far from source areas. HPAHs (e.g., benzo(a)pyrene and chrysene) have very low solubility limits and tend to partition to soil and sediment. The high organic carbon content of fill material and sediment in Lake Union binds dissolved PAHs. As a result, there is limited migration of most PAHs from source areas. Elevated concentrations of HPAHs in subsurface and surface sediment are a result of over-water releases of NAPL and other source materials and transport of eroded fill, rather than groundwater transport.

Another consideration is a comparison between travel times of upland groundwater and dissolved COCs to Lake Union and attenuation half-lives. Travel times for the movement of representative PAHs and benzene and attenuation half-lives are presented in Table 6A-4 in Appendix 6A to help illustrate the potential for attenuation of site-specific contaminants in groundwater flowing from the upland through sediment and, ultimately, to surface water. Solubility, attenuation half-life, and order-of-magnitude travel times are provided for both typical upland soil and subsurface sediment. A comparison of the estimated total contaminant travel time to the average contaminant attenuation half-life demonstrates there is enough time for natural attenuation processes to occur, which results in groundwater concentrations less than offshore groundwater screening levels (see Section 4.2, Identification of COCs) before groundwater reaches the mudline (i.e., groundwater conditional point of compliance, as established in the 1999 Consent Decree).

Naphthalene is the most soluble of all the PAHs. In addition to partitioning to organic carbon in soil and sediment, naphthalene is subject to dispersion and biodegradation, which reduces the concentrations with distance from source areas. The following lines of evidence indicate dissolved naphthalene is unlikely to impact surface sediment and surface water.

- Groundwater naturally attenuates downgradient of upland source areas, as shown by decreasing naphthalene concentrations (Figure 5-6).
- Concentration profiles in sediment show significant attenuation of naphthalene between subsurface sediment to surface sediment (concentrations are generally higher in subsurface sediment and lower in surface sediment).
- Fate and transport modeling predicts attenuation for the areas of highest shoreline groundwater naphthalene concentrations (attenuation factors range from 420 to greater than 700,000 for shoreline to mudline transport).
- Measured porewater concentrations do not exceed the offshore groundwater screening level (see Table 6-2).
- Comparison of offshore groundwater to porewater data show attenuation of naphthalene from groundwater in subsurface sediment to porewater (in the BAZ).

Benzene has a higher solubility than PAHs but tends not to persist due to dispersion, volatilization, and biodegradation. The main upland source of benzene in groundwater was remediated by AS/SVE in the southeast corner of Gas Works Park. Data collected since cleanup show significant attenuation in groundwater concentrations over time. Similar to naphthalene, upland groundwater is attenuating (Figure 5-8), sediment profiles show significant attenuation; fate and transport modeling predicts attenuation (attenuation factors range from 290 to 120,000); and offshore groundwater and porewater data show attenuation from subsurface sediment to the BAZ. Benzene concentrations are only detected in sediment where significant NAPL exists near the mudline, thus indicating that the sediment itself is the benzene source, rather than upland groundwater.

Given the length of time since source release, dissolved contaminant PAH and benzene plumes are either (1) in equilibrium (stable and not expanding) and mass flux from source areas is balanced by natural attenuation processes (e.g., biodegradation, sorption) or (2) receding where attenuation processes exceed mass flux from diminishing sources. Additional discussion related to the potential for PAH and benzene attenuation is presented in Appendix 6A.

6.5.2.2. Arsenic

Investigations of the Play Area portion of the park show that dissolved arsenic attenuates by either precipitation or binding (adsorption) to the soil matrix under geochemical conditions typically found in other areas of the park. Therefore, where dissolved arsenic has migrated outside of the Play Area it is expected to attenuate by similar mechanisms (i.e., precipitation or adsorption). The interim action initiated in 2017 has confirmed reduction of dissolved arsenic when geochemical conditions are modified (see Section 5.2.2.1.4. for discussion of the interim action).

Dissolved arsenic beneath the eastern shoreline is present primarily as thioarsenate and arsenite because of localized geochemical conditions in groundwater (e.g., alkaline pH) (Appendix 2B-2 discusses geochemical conditions controlling arsenic distribution). The pH of the upland groundwater is generally mildly acidic; the localized alkaline conditions that have preserved thioarsenates are unlikely to persist outside of the eastern shoreline. To impact a receptor in surface sediment or surface water, dissolved arsenic would need to move from the outwash deposit into the overlying fill unit and/or recent lacustrine deposits prior to discharging to surface water. Conditions in soil and sediment outside of the outwash deposit are more conducive to partitioning of arsenic from dissolved to solid phase. Lower pH in the fill unit and recent deposits, combined with reducing conditions and abundant sulfide and iron, strongly favor attenuation processes (i.e., surface adsorption of arsenic, absorption of arsenic within iron oxides and oxyhydroxides, and precipitation of highly immobile solid arsenic minerals such as arsenic sulfides) that reduce dissolved arsenic concentrations. In areas where conditions are less favorable for arsenic sulfide precipitation (i.e., lower arsenic or sulfide concentrations) or arsenic absorption in iron oxyhydroxide phases, attenuation is controlled by arsenic adsorption to carbon material that is abundant in recent lacustrine deposits.

Attachment 2B-2 presents a geochemical evaluation of the arsenic conditions and attenuation processes in the former Thylox process area. Additional discussion related to the potential for arsenic attenuation within the AOI is presented in Appendix 6A.

6.5.3. Upland Groundwater-to-Sediment and Surface Water Pathway

The evaluation of the groundwater-to-sediment and surface water pathway within the AOI encompasses all components or matrices (soil, upland groundwater, offshore groundwater, sediment, and porewater) where contaminants could be transported or come to reside, but focuses on the shoreline area because that is where the groundwater monitoring network has been installed and monitored. Although not the point of compliance, shoreline groundwater concentrations are compared to upland groundwater screening levels to evaluate areas of potential upland-to-surface water transport.

At the shoreline, areas of COC groundwater concentrations that exceed upland groundwater screening levels are limited to the eastern shoreline near the Play Area and the southwestern shoreline near the Harbor Patrol property and the western end of the Prow (see Figures 5-4, 5-5, 5-7, and 5-9). Benzene and naphthalene exceed upland groundwater screening levels along the southwestern shoreline, but concentrations have remained stable. Other upland groundwater plumes (for example, benzene downgradient of the AS/SVE) are stable or shrinking and do not exceed upland groundwater screening levels at the shoreline.

Because of natural attenuation processes, these remaining exceedances of upland groundwater screening levels in shoreline wells are not expected to result in exceedance of surface water criteria at the mudline; rather, subsurface sediment contamination is a more likely source of any exceedances at the mudline. There is strong evidence that groundwater plumes originating in the upland attenuate as they approach the shoreline (see Figures 5-6 and 5-8), and again between the upland and mudline (see previous section), and in sediment (see below). Consequently, contaminant concentrations are expected to decline to below offshore groundwater screening levels before reaching surface sediment and porewater. However, the presence of subsurface sediment contamination prevents a direct demonstration of offshore groundwater attenuation downgradient of the shoreline. Dissolved concentrations in offshore groundwater are elevated in subsurface sediment due to partitioning from contaminated sediment rather than upland groundwater. For example, DNAPL is present in subsurface sediment offshore of both the southwestern and eastern upland groundwater plumes (NAPL Areas 5B and 15—see Figure 5-26B), which means groundwater flowing from the upland is being recontaminated as it flows through DNAPL-impacted sediment. Similarly, arsenic-impacted shallow sediment (Figure 5-3A) off the eastern shoreline recontaminates groundwater flowing from the upland.

A comparison of shallow and deep groundwater monitoring data shows that deep groundwater has higher contaminant concentrations than shallow groundwater (another indication of attenuation). Deep groundwater has a longer pathway to sediment, discharges to the lake farther from shore, and is likely to flow through NAPL-impacted sediment.

Evidence of attenuation in groundwater was demonstrated in the offshore groundwater/porewater data. Seven offshore groundwater and six porewater samples were collected at six locations within the AOI in 2004 and 2005 at depths ranging from the mudline to approximately 3.4 feet bml.[99] Offshore groundwater and porewater results are summarized in Tables 5-3 and Table 6-2, respectively. Figure 5-10 shows the offshore groundwater and porewater sample locations. Results for PAHs, benzene, and arsenic are summarized in the table below. Average concentrations are provided for porewater (0 to 0.5 feet) and offshore groundwater (>0.5 to 3.4 feet). As shown below, porewater concentrations were 3 to about almost 1,000 times lower than offshore groundwater—this is a substantial attenuation factor over a short distance (i.e., several feet).

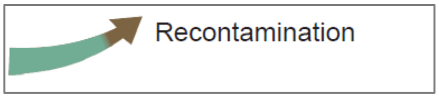
Analyte	**Average Concentration (µg/L) Offshore Groundwater (>0.5 ft bml)**	**Average Concentration (µg/L) Porewater (0 to 0.5 ft bml)**	**Attenuation Factor**
TPAH	1,600	5.9	270
HPAH	52	2.3	20
cPAH TEQ	8.3	Not detected	12 to 24[a]
Naphthalene	1,300	3.4	400
Benzene	130	Not detected	640 to 1,300[a]
Arsenic	200	70	3

Notes:

[a] Range of attenuation factors based on use of half and full detection limits.

Figure 6-4 shows a conceptual cross section of chemical transport mechanisms, including attenuation and partitioning from sediment sources, along the upland-to-surface water pathway. Figure 6-5 shows where these chemical transport mechanisms occur. Attenuation and recontamination from sediment sources along groundwater flow paths are shown in the images below and described as follows:

- Multiple lines of evidence show that dissolved contaminant concentrations attenuate downgradient of source areas. The dark brown part of the arrow represents higher (source area) concentrations. Attenuation is shown by the gradation to lighter shades of brown and ultimately blue.



- Recontamination occurs where attenuating groundwater from the upland flows through contaminated sediment (blue changes to brown). Where sediment contamination is present near the mudline (e.g., shallow NAPL or surficial arsenic), porewater is contaminated.

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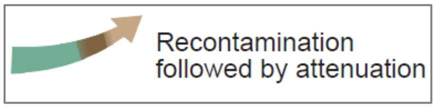
[99] Sampling and processing are described in Section 5.2.2.2.1.



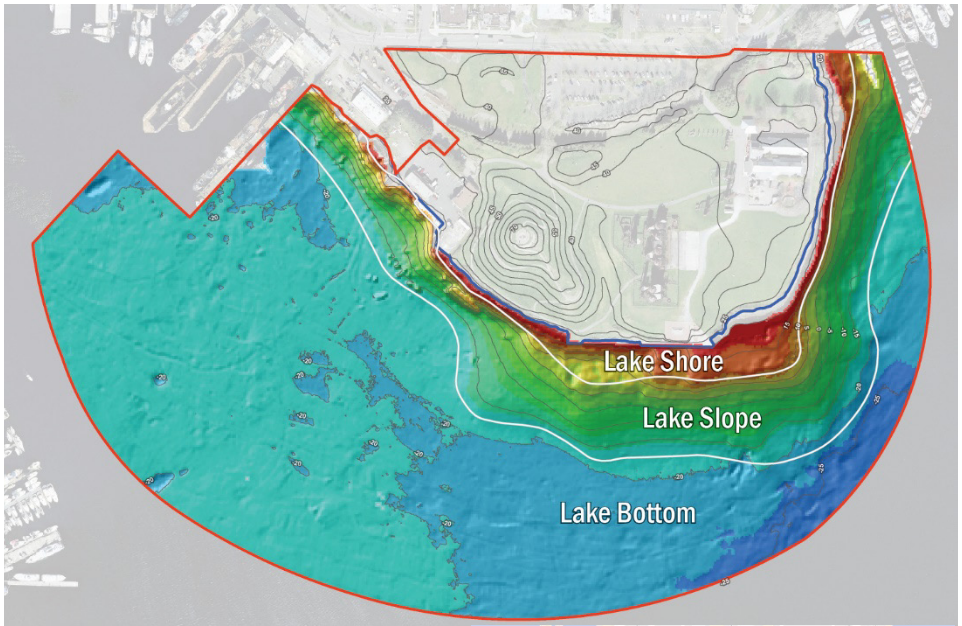
- Groundwater that is contaminated due to partitioning from sediment attenuates above the sediment source as shown by the lighter shade of brown.

Based on the information presented above, upland groundwater plumes are likely attenuating prior to reaching Lake Union. However, groundwater can become recontaminated or cannot attenuate where it flows through subsurface sediment contamination. Therefore, in some areas of the AOI, dissolved contaminant concentrations in groundwater sufficiently attenuate, while in other areas sediment contamination is near the mudline and porewater is contaminated.

6.6. Natural Recovery

Natural recovery of sediment refers to physical, chemical, and biological processes that reduce contaminant concentrations in surface sediment over time. Processes that contribute to natural recovery include burial by deposition of sediment transported from elsewhere within the watershed, dilution from mixing caused by bioturbation (organisms reworking the top layer of sediment) or other physical processes, dispersion (e.g., partitioning to other media, diffusion, hydraulic transport of resuspended material), and chemical and biological degradation. In most systems, burial by and/or mixing with cleaner sediment is the dominant natural recovery process in surface sediment.

Evidence that natural recovery in sediment is occurring is primarily established by documenting changes in contaminant concentrations or spatial distribution over time. Data that provide this evidence include differences in the vertical and lateral extent of contaminants in surface and subsurface sediment and reductions in concentrations over time. Characteristics of the physical environment (e.g., hydrology, energy regime, and sediment inputs) are also used to demonstrate whether natural recovery is occurring.



AOI Lake Zones

The lines of evidence that demonstrate natural recovery is occurring within the sediment portion of the AOI are discussed in the following sections based on cPAHs and TPAHs, the two primary site-related surface sediment COCs. The physical characteristics that make it favorable for natural recovery are also discussed.

Natural Recovery Area

To present the lines of evidence, the sediment portion of the AOI is divided into three zones that have different physical characteristics, hydrology, and proximity to historical contaminant sources. Lake zones are depicted below (see *AOI Lake Zones* inset) and described in Section 3.2.1; this section focuses on the lake bottom zone, where the lines of evidence indicate that natural recovery is taking place in a portion of this zone (aka the natural recovery area; see *Natural Recovery Area* inset).

6.6.1. Contaminant Distribution and Magnitude

Concentrations within the sediment portion of the AOI show patterns and trends over time, by depth and in spatial distribution.

6.6.1.1. Temporal Trends in the Distribution and Magnitude of Contaminants of Concern

Changes in the distribution and concentrations of TPAHs in surface sediment were evaluated for the central and eastern portion of the sediment AOI that has been repeatedly sampled over time. An areal, rather than point-by-point, approach was used to look at temporal changes because historical sample locations were not accurately documented nor are the exact same locations sampled over time. This area was repeatedly sampled by EPA and/or PSE and the City between 1984 and 2005.

Changes in chemical concentrations are represented as SWACs using GIS interpolation and averaging methods[100].

Changes in the distribution and magnitude of TPAH are shown in the three-panel series on Figure 6-6, which shows TPAH concentrations from 1984, 1995, and 2005. In 1984, TPAH concentrations were elevated throughout much of the sediment AOI. Over time, concentrations in the lake bottom decreased such that by 2005, the highest concentrations were limited to the lakeshore and lake slope areas. The highest concentrations of TPAHs have persisted close to shore since 1984, but the lake bottom TPAH concentrations in the natural recovery area have decreased over time where sediment deposition occurs. Changes in TPAH concentrations over time are included as a line of evidence to show that natural recovery processes are occurring in the SCU. The evaluation is not specific to the natural recovery area.

In a similar analysis, the temporal trends in cPAH TEQ concentrations were evaluated within the natural recovery area. Carcinogenic PAH TEQ data from samples obtained primarily in 1984, 1995, 1999, 2002, and 2004/2005 were used to calculate cPAH TEQ SWACs for each sampling period to estimate the percent reduction in cPAH TEQ concentrations in surface sediment in the natural recovery area. Figure 6-7 shows the location of samples associated with each time period; data are presented in the table below. The GIS interpolation of cPAH TEQ surface sediment concentrations in the natural recovery area for these five periods is shown on Figure 6-8.

Period	cPAH TEQ SWAC (mg/kg)	Percent Reduction Since Previous Period	Average Annual Reduction %
1984/1985	156[a]		
1995–	29	81	14
1999	23	21	6
2002	10	57	24
2004/2005	3.3	67	31
Overall reduction between 1984 and 2005		98	17

Notes:

[a] Based on limited data points.

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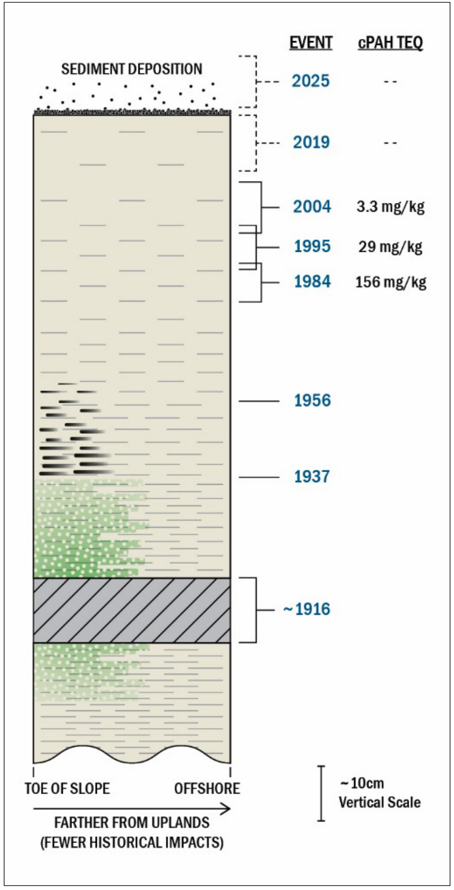
[100] GIS interpolation and the calculation of SWACs is discussed in Appendix 5A.

Although the rate of decline varied from period to period, the overall trend of cPAH concentrations in the natural recovery area is downward, with significant reductions over the 20 years evaluated.



Representative Sediment Column Showing Natural Recovery in Lake Bottom

6.6.1.2. Patterns in Spatial Distribution of Contaminants of Concern under Current Conditions

Concentrations of cPAHs and TPAHs tend to be highest in the shoreline and lakeshore zones that were near points of historical contaminant releases and ongoing erosion of contaminated fill and lowest in the southern and eastern portions of the lake bottom zone. This attenuation with distance from the shoreline is not evident in the western portion of the AOI.

The natural recovery area of the lake bottom zone sediment contains the lowest concentrations of contaminants within the AOI and has concentrations of PAHs that are similar to ALU concentrations[101]. Figure 6-9 shows the distribution of cPAHs based on 2002 to 2005 data. The average concentration of cPAHs within the ALU area was 5.4 mg/kg (Table 3-1) based on data collected from the mid-1980s to about 2005 (the ALU area is shown on Figure 3-2). The average concentration of cPAHs within the natural recovery area was 3.3 mg/kg based on 2004/2005 data. TPAHs showed a similar pattern—the ALU area average concentration was 47 mg/kg, and the natural recovery area average concentration was 22 mg/kg.

6.6.1.3. Trends in Vertical Distribution of Contaminants of Concern

A general model of occurrence and type of contamination below the mudline and improving sediment conditions near the surface is depicted on page 6-17 in the *Representative Sediment Column Showing Natural Recovery in the Lake Bottom* inset graphic[102]. The type and levels of contamination in the natural recovery area change with depth below mudline and reflect the history of industrial activities and timing of releases.

Deeper sediment reflects discharges, accidental spills, and releases during the operation of the MGP. The gray marker bed created during the initial flush of sediment from Lake Washington when the Ship Canal was completed helps date sediment impacted by industrial activities after about 1916. In the lake bottom zone near the toe of the slope, the source(s) of slight to moderate sheens and odor in subsurface sediment likely date back to early years of MGP operation (1907 to about 1937). Sooty layers observed in overlying sediment likely represent lampblack releases including stormwater transport from storage areas during later years of MGP operations (post-1937) and episodic erosion of fill material along the shoreline.

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[101] The area used to calculate average ALU conditions outside of the AOI (Figure 5-17), did not include potential lakeshore source areas (specifically, samples within 300 feet of the shoreline were not included in the average).

[102] Inset shows cPAH TEQ SWACs over time in the natural recovery area . Sample depths are conceptual, accounting for deposition and consolidation of surface sediment.

Sediment quality improves in sediment closer to the mudline. Results of each successive surface sediment sampling event had lower concentrations of cPAHs. Based on sediment core and grab samples, sediment petrology, and sediment transport and deposition patterns, specific contaminant layers are less distinguishable farther offshore in the lake bottom zone (see Figure 7-1D). The primary source of sediment in the lake bottom zone is suspended solids from shoreline/lakeshore erosion; stormwater runoff and transport from Lake Washington, Portage, and Union Bays; and plankton and plant material deposited from the water column. This deposited material has buried the evidence of historical releases over time.

The concentration of cPAHs in surface and subsurface sediment was evaluated for vertical trends based on cores collected in the lake bottom zone (Figure 6-10). The relative percent difference between the top 10 cm and the first interval of a co-located core (typically within the first 3 feet below the mudline) was calculated. These two intervals occur within the soft sediment that has been deposited on the lake bottom. On average, the surface interval was 11 percent of the concentration of the shallow subsurface sediment (that is, the surface sediment cPAH TEQ concentrations are, on average, 89 percent lower than subsurface concentrations). The change in concentration demonstrates that the more recent sediments being deposited are cleaner. These improvements are a result of the cessation of the MGP operations, cleanup of the upland portion of the AOI, and source control activities throughout the lake. Sample locations used in the comparison of surface and subsurface concentrations are shown on Figure 6-10, and the associated sediment results are shown in the following table.

	cPAH Carcinogenic PAH (TEQ) (mg/kg)		
Location	**Subsurface (~0-3 feet below mudline)**	**Surface (0 - 0.33 feet below mudline)**	**% Reduction**
NLU04	22	4.2	81
NLU12	65	6.8	90
NLU41	9.8	1.8	82
NLU43	17	0.8	95
NLU48	22	2.4	89
NLU49	31	1.2	96
NLU70	24	1.0	96
NLU-121	136	23	83
		Average	**89**

6.6.2. Physical Characteristics

The data describing contaminant distribution and magnitude are the primary lines of evidence that natural recovery is occurring in the lake bottom zone, including the natural recovery area. There are also physical processes affecting natural recovery in the lake bottom, including the source of material that settles out on the bottom, current speeds near the bottom, and frequency and magnitude of waves or vessel propeller wash.

The lake bottom of Lake Union is largely depositional and non-erosive. The lake bottom zone starts at elevations of about -15 to -18 feet USACE and gently slopes toward the center of the lake and channels leading from Portage Bay to the east and toward Fremont in the west. Surface sediment in the lake bottom is very fine-grained, which is indicative of a low energy environment where suspended sediment settles. Soft sediment forms a thick layer on the bottom; geological investigations suggests this layer may be as thick as 50 feet.

Rates of deposition were established in historical studies and range from about 0.1 to 1.7 cm per year (cm/year), depending on location:

- In 1974, researchers from the University of Washington (Barnes et al. 1978) measured the net sedimentation rate in Lake Union using Pb^{210} radioisotopes. Estimates range from 0.12 cm/year in the middle of the lake to 0.8 cm/year in the western portion of the lake near the Ship Canal.
- In a similar study for Metro, the University of Washington evaluated sedimentation at four locations in Lake Union (Tomlinson et al. 1977). Historical records of atmospheric deposition of metals from the Asarco smelter near Tacoma, Washington (which began smelting in 1890), Pb^{210} radioisotopes, and in one case dredging records were used to evaluate deposition rates. Net sedimentation rates were found to be lowest in the center of the lake (0.16 cm/year), with a range of 0.8 to 1.0 cm/year in the northern part of the lake.
- Site-specific radioisotope sediment profile analyses based on both Pb^{210} and Cs^{137} (RETEC 2004) were conducted to estimate sedimentation rates at four locations within the AOI. The rate of sedimentation based on the one interpretable core (most radioisotopes were not detected) from the eastern portion of the AOI was estimated to be between 0.92 and 1.7 cm/year.
- Battelle calculated sedimentation rates ranging from 0.2 to 0.9 cm/year at five offshore locations within the AOI (NLU109, NLU-110, NLU117, NLU-119, and NLU-125) (Attachment 2D-3 of Appendix 2D).

A gray clay marker bed observed in many AOI sediment cores dates from the construction of the Ship Canal system (1916). The average deposition rate for sediment above the marker bed was derived using the depth of the marker bed. Dividing the depth below the mudline by the number of years of accumulation since 1916, on average, 0.8 cm/year have been deposited in the AOI.

Sediment in the lake bottom zone has both a mineral and biogenic component. Mineral particles are sourced from suspended solids transported from Lake Washington, Portage Bay, and Union Bay; discharges from storm drains and combined-sewer overflows; erosion of the shorelines surrounding Lake Union; and resuspended sediment from the lakeshore and lake slope zones. Dead plankton, including diatoms with silica frustules, and decomposing aquatic and terrestrial plant material compose the biogenic component. A study of the sediment petrology conducted by Stanford (Appendix 2D) quantified the relative proportions of mineral, diatomaceous, and plant fractions of sediment from cores collected within the sediment AOI. For those cores collected in the lake bottom zone, approximately 35 percent of the sediment was biogenic in origin and about 65 percent was mineral in origin. Diatoms and decaying plant material contribute to the characteristics of the soft sediment and provide a relatively clean source of sediment for continued natural recovery. Figure 6-11 shows ongoing deposition and burial and the relative effect of ongoing sources on natural recovery in the western portion of the sediment AOI compared to the central and east portions.

Currents in Lake Union are also relatively slow and contribute to the depositional nature of the lake bottom. Currents in North Lake Union tend to flow from Lake Washington to Puget Sound via the Ballard Locks. The rate of discharge is controlled by the Locks; circulation is further restricted by the configuration of the lake basin, bottom features, and seawater intrusion. A sill (a shallow rise in bathymetry) near the beginning of the Fremont Canal inhibits the circulation of deeper lake water and enhances sedimentation. Repeated openings of the Locks for recreational and commercial boat traffic in the summer allows intrusion of saltwater, which also affects lake circulation over the longer term and contributes to flocculation and sedimentation within the lake basin.

6.7. Potential for Contaminant Transport by Stormwater

Stormwater runoff from the AOI uplands to the AOI sediment is primarily managed by a series of pipes and catch basins that discharge to the lake (there is limited overland runoff). The layout of the stormwater infrastructure that exists today is shown in Figure 3-22. The City conducted a series of investigations between September 2008 and June 2010 (Floyd|Snider 2009, 2010a, b) and again at the beginning of 2015 and in January and December of 2017 to evaluate the condition of each storm drain line and chemical characteristics of particles trapped in individual catch basins in different areas of the upland portion of the AOI and upslope properties. The first three investigations are referred to as Phase 1, 2, and 3 investigations; the latter three investigations were conducted as part of Seattle Public Utilities' (SPU) ongoing Business Inspection Program. A description of these investigations is provided in Appendix 6B.

The chemical characteristics of solids collected from catch basins in the AOI upland are provided as part of this RI to provide preliminary information about the potential for sediment recontamination by stormwater-transported solids. Catch basin solids data are summarized in Table 6-3, and sample results for cPAHs, TPAH and arsenic are shown on Figure 6-12. The current conditions catch basin data set is included in Appendix 5B (Table 5B-1.5).

The chemical characteristics of catch basin solids collected in the AOI upland provide information that can be evaluated regarding the potential for sediment recontamination by stormwater-transported solids from the AOI. There are no regulatory standards for catch basin solids; however, SPU uses the SMS CSL to prioritize drainage basins that need more investigations in its city-wide stormwater management program. The comparisons made in this section, including in Figure 6-12, only provide a general indication of catch basin solids quality. The City inspects catch basins and storm drains annually and uses physical conditions observed (i.e., depth of accumulated solids) to trigger cleanout of catch basins and uses chemical data, when available, for accumulated material, to guide maintenance decisions. The inspection, cleanout, and maintenance of catch basins and storm drains further reduces stormwater-transported solids as a mechanism for contaminant transport from the AOI upland.

Use of the SMS criteria as screening levels for storm drain solids may be conservative because the criteria actually apply to the top 10 cm of sediment in Lake Union on a point basis for non-bioaccumlative contaminants and on a surface-weighted average basis for bioaccumulative contaminants. Concentrations of COCs in catch basin solids greater than screening levels do not necessarily mean that the sediment offshore of the outfall will exceed screening levels because the amount of storm drain solids discharged from a storm drain might be insufficient and storm drain solids disperse in the receiving environment and mix with sediment from other sources before and after deposition.

Most catch basin solids sampled contained cPAH exceeding screening levels. Catch basin solids sampled contained TPAH, but only four catch basins associated with active storm drains (Outfall A in the northeast corner of Gas Works Park) exceeded the CSL[103]. Arsenic concentrations exceeding screening levels were

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[103] Storm drain lines associated with other catch basins previously exceeding the TPAH screening level have been plugged or replaced.

associated with lateral connections for Outfall A (northeast corner of the park) and Outfall C (in the vicinity of the Play Area)[104].

GWPS COC statistics for catch basin solid samples are presented in Table 6-3 and summarized below:

COCs in Catch Basin Solids				
COC	**SCO (mg/kg)**	**CSL (mg/kg)**	**Median Detected Concentration (mg/kg)**	**Average Detected Concentration (mg/kg)**
TPAH	17	30	9.1	18
cPAH TEQ	0.021	0.21	0.92	1.9
Carbazole	0.90	1.1	0.27	0.30
Dibenzofuran	0.20	0.68	0.19	0.20
Arsenic	11	24	19	22
Nickel	50	110	Not analyzed	

The park and Harbor Patrol outfalls are not a significant source of contaminants transported from the AOI upland to sediment based on the following lines of evidence and observations:

- Catch basin solid concentrations of GWPS COCs are much lower than sediment concentrations near outfalls.
- Two outfalls are non-functioning (Outfall F and Kite Hill Outfall), one outfall was determined to not discharge during a heavy rain event (Prow Outfall), and sections of perforated piping for three other storm drains have been plugged (Outfalls A and B) or capped, lined, and replaced (Outfall C).
- With the exception of Outfall A, discharge has been reduced and is rarely observed in the remaining active shoreline outfalls within the park. Outfall A drains the park parking lot, and discharges during rain events.

In addition to outfalls within the park and Harbor Patrol, the City is evaluating source control for storm drains and a drainage swale located predominantly outside of the park that discharge within the AOI (Waterway 20 outfall) and at the boundary of the AOI (Waterway 19 outfall) as described in Appendix 6B.

Six soil samples (WW19-01 through WW19-06) were collected from the drainage swale leading to Waterway 19 in 2010. The locations of the samples are shown on Figure 5-1A and data from these samples are summarized below:

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[104] The storm drain piping to Outfall C was lined during Play Area renovation in 2018. Sampling data predates storm drain modification.

COCs in Waterway 19 Drainage Swale				
COC	**SCO (mg/kg)**	**CSL (mg/kg)**	**Median Detected Concentration (mg/kg)**	**Average Detected Concentration (mg/kg)**
TPAH	17	30	11	29
cPAH TEQ	0.021	0.21	1.4	3.8
Carbazole	0.90	1.1	0.13	0.15
Dibenzofuran	0.20	0.68	0.08	0.11
Arsenic	11	24	10	10
Nickel	50	110	Not analyzed	

The soil in the Waterway 19 drainage swale is not a significant source of contaminants transported to the sediment AOI because the soil concentrations of GWPS COCs are much lower than sediment concentrations near the Waterway 19 outfall.

Options being considered by the City to address potential recontamination after the cleanup construction include remediating the surface soils in this area by extension of the vegetated soil cover already in place over much of Gas Works Park or extending the storm drain pipe all the way to the Waterway 19 outfall, thereby, eliminating the potential for contaminated soil entrainment.

Similarly, the Waterway 20 storm drain mainline also represents a potential pathway for contaminant transport from the upland based on observations of cracks in the pipes, pipe segment offsets, and other defects in the storm drain system. Options under consideration for this drain include spot repairs of impacted portions of the pipe, in-place pipe lining, or pipe replacement.

The FS presents a storm drain source control evaluation which includes these options for addressing the drainage basins leading to Waterways 19 and 20.

7.0 CONCEPTUAL SITE MODEL

A CSM summarizes where contaminants came from, where they ended up, how contaminants might continue to move, and who or what might be exposed to potentially harmful levels of contaminants. The CSM provides the basis for developing remedial options that reduce or eliminate the potential risks to people and environmental receptors by controlling remaining exposure pathways. Guidance on how to develop a CSM is provided in Ecology's SCUM guidance (Ecology 2021).

According to MTCA (Section 173-340-200), a CSM is a "conceptual understanding of a site that identifies potential or suspected sources of hazardous substances, types and concentrations of hazardous substances, potentially contaminated media, and actual and potential exposure pathways and receptors."

Facilities or activities that released hazardous substances to the environment during the operation of the MGP and nearby industries are referred to as primary or historical sources. There are no remaining primary sources in the AOI, although nearby off-site sources are still active (e.g., shipyards, marinas, and outfalls). MGP products and byproducts (e.g., NAPL, tar, or black carbon) that have persisted in the environment following historical releases and environmental media (i.e., soil, sediment, porewater, and groundwater) contaminated by these materials are referred to as secondary or remaining sources in this CSM.

Contaminants have reached Lake Union by different mechanisms and pathways that have varied over time. To reflect these temporal differences, graphics (Figures 7-1A, B, C, and D) were developed to represent four different periods: pre-industrial conditions, during MGP operations, post-industrial operations and present day. The discussion of CSM elements is organized as follows:

- Historical sources, release mechanisms, and transport mechanisms and pathways by time period (Section 7.1)
- Current potential sources (Section 7.2)
- Active transport mechanisms (Section 7.3)
- Location of currently active transport mechanisms and pathways (Section 7.4)
- Current exposure pathways and potentially affected receptors (Section 7.5)

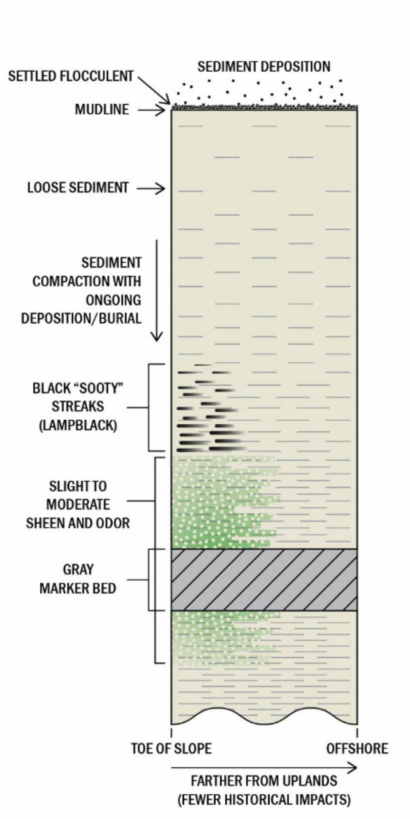
7.1. Historical Sources, Release Mechanisms, and Transport Mechanisms and Pathways

As a "working" lake, Lake Union has long supported industrial and marine commerce typified by the storage and transport of coal, timber, and petroleum; shipbuilding; metal fabrication; product manufacturing and assembly; and lumber milling. Over the years, contaminants ultimately entered the lake sediment through direct discharge, spills, leaks, runoff, erosion, and disposal. A unique gray clay/silt layer ("marker bed") deposited during construction of the Ship Canal (completed in 1917) demarcates native sediment and early industrial impacts (below the marker bed) from later industrial era impacts (above the marker bed) (see *Timing of Industrial Impacts* inset) on page 7-2.

Most industrial operations along the Lake Union shoreline have ceased and related historical sources of contamination have been eliminated; ongoing sources are generally limited to permitted discharges from CSOs, releases from existing industries such as marinas and shipyards, and low-level contributions of urban contaminants from non-point sources. Ambient conditions in Lake Union reflect these remaining sources.

Historical and on-going discharges and releases of contaminants have adversely affected water and sediment quality in the lake. Water quality is further degraded by occasional[105] saltwater intrusion along the lake bottom, and warm summer/fall temperatures that contribute to seasonal stratification. Slow flushing rates of the lake tend to retain both contaminants and sediment in Lake Union, which magnifies the effect of discharges and releases to the lake. These factors continue to influence sediment quality in the lake.

Where contamination occurs within the AOI, it can be understood by reviewing historical and remaining sources, release mechanisms, and transport mechanisms and pathways over time.



Timing of Industrial Impacts

7.1.1. Pre-Industrial Setting (circa 1900)

Prior to construction of the MGP, the area around historical Brown's Point was a growing community of farms, homes, and small businesses, with little industry. Figure 7-1A depicts the predevelopment condition at what is now known as Gas Works Park. The site geology was characterized by native soil and lake sediment, underlain by glacial outwash and till. The lakeshore was farther inland than it is today.

7.1.2. MGP Operational Period (1907 to 1956)

The MGP and a tar refinery were the two main industries operating in the AOI upland for much of its history. Generalized sources, release mechanisms, and transport mechanisms and pathways for the MGP and tar refinery operational period are depicted in Figures 7-1B and 7-3A. A more detailed presentation of industrial operations by area is available in Appendix 1C.

The MGP was constructed in 1907 on the eastern side of Brown's Point and expanded over time to the south. West of the MGP, a tar refinery that later became ATCO operated during the same period (1907 to the mid-1960s) and was one of the historical sources of contamination found in the western portion of the AOI.

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[105] Saltwater intrusion tends to be seasonal and is a function of the frequency of lock openings at the Ballard Locks, including how often the large lock is used. The main impact occurs in the northwestern portion of the lake, Fremont Canal, and Salmon Bay, but low salinity water occasionally reaches the Montlake Cut (Ecology 2000).

Four different processes were used to manufacture gas from coal or petroleum. Gas manufacturing created products and byproducts such as tar, coke, lampblack, and light oil that were reused in other manufacturing steps, burned as fuel, or sold as commercial materials.

ATCO purchased tar from the MGP and other manufactured gas plants in the Pacific Northwest. Using steam distillation, ATCO produced various grades of tar and tar derivatives. Tar and tar products were transported to/from this facility both by rail and potentially by boat.

During operations of both the MGP and tar refinery, raw materials, wastes, and commercial products and byproducts leaked or overflowed from tanks, pipelines, and process areas or were spilled to the ground or overwater during shipping and handling. MGP bulk fuels (e.g., coal) and commercial byproducts (e.g., lampblack) were stored in open areas near points of use or loading/offloading in the southern portion of the upland.

Although most waste products with no commercial value were landfilled off-site, some ended up in fill as the MGP expanded during its early operational period. Where the fill was used to expand the upland area into the lake, waves associated with storms or ship traffic may have eroded materials in the fill into the lake surface sediment. Figure 7-2 depicts the location of historical industrial sources within the AOI upland and nearshore area, structures, subgrade structures (e.g., sections of oil and tar pipelines, gas purification facilities), and areas of historical shoreline filling.

Coal and byproducts such as lampblack were transferred to/from the MGP via barges and stored near the shoreline. The materials could be lost to the lake during transfer, slough off storage piles, or be periodically carried by stormwater into the lake. Once in the lake, materials could be reworked by currents, mix with sediment, and migrate downslope toward the lake bottom, where they came to rest.

Oil released to the ground was typically denser than water (i.e., it was a DNAPL) and tended to sink down through fill materials and the spaces between underlying soil grains until fine-grained or dense deposits left behind by glaciers (outwash or glacial till) were encountered. Some DNAPL continued to flow along interfaces between geologic layers that slope toward the lake. Offshore DNAPL migration occurred near/beneath the present-day Harbor Patrol property, downslope from the former ATCO refinery, and along the eastern shoreline (downslope from upland MGP facilities).

LNAPLs that were less dense than water would migrate vertically through soil when leaked or spilled near or at ground surface until they reached the water table, where they would migrate laterally. LNAPL migration primarily occurred from releases in the eastern and central (MGP) portion of the AOI upland.

LNAPLs and, to a lesser extent, DNAPLs would tend to quickly stabilize, and their constituents would slowly dissolve into the water. These dissolved constituents could be moved by groundwater toward the lake.

Fuel, oil, tar, coal, and other bulk products were transferred to/from barges and ships along much of the shoreline (pier and wharfs at and between the present-day Harbor Patrol property and the Prow and docks along the eastern shoreline). DNAPL and tar spilled over water would have likely sunk to the lake bottom because their densities are greater than water. Depending on the nature of the spill and lake bottom conditions, DNAPL and tar would have accumulated at the lake bottom and/or penetrated the mudline and migrated through sediment before stabilizing. The fate of oil that spilled over the water during transfer or discharged via outfalls depended on the type and volume of oil and conditions at the time of the spill or discharge. In some cases, oil might have sunk to the lake bottom as oil particulate aggregates (oil droplets coated with sediment particles and mixed in with sediment); otherwise these materials would spread along the water's surface and volatilize to air or dissolve in the water column and degrade via chemical, physical, and biological processes.

Thylox solution that contained arsenic was used in gas purification at the MGP and tended to sink downward through soil and groundwater because it was denser than water. The Thylox process area was located near the present-day Play Area. Thylox solution, when spilled or leaked, would migrate through soil, with local geology and geochemistry controlling how and where it would move (Figure 7-3A). Arsenic in the Thylox solution could dissolve in groundwater and migrate through fill and outwash layers toward the lake. Some discharges of Thylox solution might have occurred from outfalls along the eastern shoreline, as evidenced by the higher concentrations of arsenic in surface versus deeper sediment layers.

The production of manufactured gas and tar refining were not the only industrial operations. Other operations included boatbuilding and repair, municipal waste incineration, municipal waste landfilling, light oil refining, chemical manufacturing, briquetting operations, fuel storage and sales, shingle milling, coal and gravel storage, and barge and tug operations. Many of these were water-dependent industries, handling and shipping raw materials, fuels, and finished products along the waterfront or over piers and wharves. Releases of fuels, chemicals, and other contaminated materials from some of these operations might have contributed to contamination in Lake Union sediment within the AOI, primarily in the western portion. ATCO was noted as a frequent source of oil to the lake in historical regulatory documents, discharging via the Waterway 20 outfall. ATCO's second facility (Nortar) also discharged to the Waterway 20 outfall. The former Standard Oil (later Chevron bulk storage facility) was noted as having had one release to the lake in 1970.

7.1.3. Post-Industrial Setting (circa 1973)

A representation of the sources and transport pathways associated with the park development period is shown in Figure 7-1C and discussed below.

The MGP ceased operation in 1956, with the City receiving the title to the Gas Works property in 1962. Most of the historical MGP structures, including pipelines, below-grade structures, and buildings, along with contaminated soil and stored byproducts were removed as part of park development. Heavily contaminated soil was removed and disposed off-site. ATCO relocated across Northlake Way in the mid-1960s and became Nortar, where it continued to operate until the late 1980s. ATCO facilities on the Gas Works property were demolished in the late 1960s. The former owners of the Northlake Shipyard, located west of the GWPS, were subject to civil complaints and ultimately were cited as violating the Clean Water Act in the 1980s because of extensive releases of sandblast grit and other waste materials that ended up in the sediments.

Thylox facilities were removed in the Play Area prior to park development. The historical migration of Thylox solution through soil layers left behind arsenic bound to soil or as a mineral precipitate (primarily in the fill layer) or dissolved in groundwater (depending on soil and groundwater chemistry). Some Thylox solution might have reached the deep groundwater in the outwash above the till interface by this time (see Figure 7-3B).

Contamination consisted of remaining source materials, such as subsurface DNAPL, LNAPL, tar, and Thylox solution and byproducts (e.g., lampblack) incorporated into fill, and soil, groundwater, and sediment contaminated by historical releases. Without additional leaks and spills, subsurface DNAPL and LNAPL migration slowed until these materials no longer readily moved through soil pore spaces. Within the soil, NAPLs dispersed and were partially degraded. Droplets of DNAPL became trapped in the smallest pore spaces (i.e., present as residual DNAPL) or accumulated in low spots in the till surface (see the *Residual* and *Trapped DNAPL* insets in Figure 7-1C). DNAPL in lake sediment might have continued to migrate downslope through lake sediment or along interfaces between geologic layers deep below the lake bottom or might have stabilized by this time.

When in contact with groundwater, chemical constituents of NAPL dissolved into groundwater, but the magnitude was reduced with time as more soluble constituents were depleted. Transport towards the lake continued, with groundwater discharging to the lake through sediment closest to the shoreline. Depending on the location of the original release or source, dissolved upland contaminant concentrations might have been either higher or lower than sediment dissolved concentrations. Groundwater concentrations of NAPL constituents might have attenuated by dispersion and dilution or chemical/biological degradation prior to reaching the lake. Conversely, attenuated groundwater concentrations might have increased by encountering additional source materials in contaminated soil or sediment and become recontaminated.

Contamination released overwater mixed in with the sediment and, in areas not subject to erosion, became buried by deposition of locally resuspended material or sediment carried in from other parts of both Lake Washington and Lake Union. Burial was particularly active in the deeper portions of the AOI.

7.1.4. Current Conditions

CSMs for current conditions are presented in Figures 7-1D and 7-3B; additional details regarding retained structures, by area, are provided in Appendix 1C.

Current conditions represent the effect of upland soil and groundwater cleanup actions (as described in Section 2.2) and more than 40 years of subsequent fate and transport processes that have further reduced the distribution and magnitude of contamination. Upland sources of contamination were excavated and disposed, demolished, and removed, or cleaned and reused as part of Gas Works Park. Clean soil, paving, or structures cover the park surface, except for small areas around the park, as shown in Figure 2-7. Ongoing inspection and maintenance addresses occasional, minor upwelling of tar to the soil surface in uncapped areas. It has been at least 10 years since any tar appeared in the uplands. Small, solid tar bodies have been exposed by erosion of the fill in the lakeshore zone. Most large tar bodies near the shoreline have been removed. One larger area of hardened, exposed tar remains within a fenced area along the northeastern shoreline (see Figure 5-26A). Shoreline and seasonal beach areas have been covered with gravel to minimize further erosion.

Contaminated surface sediment remains throughout the AOI. As shown in Figure 7-1D and 7-3B, exposed fill in the shoreline and shallow nearshore area continues to erode and be redistributed down the lake slope to the toe of the slope. Cleaner organic and mineral materials, carried in from Lake Washington and other parts of Lake Union, are slowly burying surface sediment contamination, particularly in the deeper lake bottom portion of the AOI. These depositional processes contribute to the natural recovery of sediment over time, although the rate of recovery is slowed by ongoing urban contaminants (such as street grit, vehicle exhaust particles, petroleum leaks, and eroded soil, etc.) that also enter the lake and are deposited on the lake bottom. See Section 6.6, Natural Recovery, for detailed information on the natural recovery processes occurring within the sediment portion of the AOI.

Subsurface DNAPL, which is present primarily as residual material, no longer migrates through soil or sediment. As shown in Figure 7-1D, residual DNAPL constituents continue to dissolve in groundwater or porewater, with more soluble DNAPL constituents undergoing the greatest reduction in contaminant concentrations[106], which significantly lessens the transfer of DNAPL constituents to groundwater. LNAPLs present in the upland have undergone significant degradation and weathering by loss of more volatile and soluble constituents. Additional detail about the behavior of DNAPL and LNAPL constituents is in Section 6, Contaminant Fate and Transport.

Associated dissolved contaminants (e.g., benzene and naphthalene) are still present in groundwater, although partitioning to groundwater has lessened due to weathering. In addition, groundwater plumes have stabilized or are shrinking. Groundwater contaminant concentrations at the shoreline have attenuated to concentrations less than upland groundwater screening levels except for two shoreline areas:

- Along the southwest shoreline and downgradient of the former ATCO facility at the Harbor Patrol property (primarily benzene and naphthalene)
- East and downgradient of the former Thylox process area (arsenic, benzene, and naphthalene)

While contaminant concentrations in shoreline wells remain elevated above upland groundwater screening levels (or in the case of arsenic, offshore groundwater screening levels) in these areas, multiple lines of evidence suggest that the groundwater plumes attenuate and concentrations would decline to below offshore groundwater screening levels before reaching the mudline if not for intervening contaminated sediment.

Groundwater associated with the former light-oil plant in the southeastern portion of the present-day park was remediated using AS/SVE technologies between 2000 and 2006 (Figure 2-7 shows the air sparging area), which significantly lowered benzene concentrations (Figure 5-8) and met the 1999 Consent Decree upland groundwater cleanup level that was selected to be protective of surface water.

The highest concentrations of arsenic in groundwater are associated with deep upland groundwater at the shoreline east of the Play Area in the outwash and weathered till in the vicinity of the original source area (Figure 7-3B). Groundwater monitoring data and geochemical conditions in upland soil and sediment (e.g., high iron concentrations) and groundwater (e.g., slightly acidic pH) support attenuation of dissolved arsenic by precipitation or adsorption as dissolved arsenic migrates away from the thioarsenate source area.

The surface sediment arsenic impacts in the nearshore area of the lake do not appear to be from groundwater transport, but from a direct point discharge to the lake. Analysis of upland groundwater flow paths and fate and transport modeling does not support a complete pathway for arsenic from upland groundwater to surface sediment. In sediment adjacent to the Play Area, arsenic concentrations tend to be the highest in shallow sediment and decline with increasing depth below the mudline (Figures 5-3A and 5-3B). This indicates that arsenic in sediment is associated with historical top-down sediment

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[106] Reduction occurs due to depletion and relatively rapid degradation of the more soluble constituents of the original source material.

contamination from offshore arsenic releases rather than the precipitation of dissolved arsenic being transported by groundwater flowing through sediment.

In addition, the area where surface sediment has the highest arsenic concentrations is located outside (down slope or farther offshore) of the primary area of groundwater discharge and offset to the north of the upland arsenic plume. Appendix 6A provides additional background regarding past and current fate and transport processes affecting current contaminant conditions in groundwater and sediment.

Groundwater treatment provided as part of an interim action has reduced dissolved arsenic concentrations within the footprint of the Play Area (Figure 2-7 shows the interim action area). Interim action treatment and monitoring has been completed (GeoEngineers 2022) and the need for additional arsenic source control measures downgradient of the Play Area is evaluated in the FS.

7.2. Current Potential Sources

Contaminants in uncapped soil along the shoreline, upland groundwater, offshore groundwater, and sediment exceed screening levels in the AOI and may act as ongoing sources where concentrations are greater than lake-wide conditions. In addition, MGP products and byproducts (NAPL, tar, and black carbon[107]) are mixed in with soil and sediment and are sources of GWPS COCs. Collectively, these remaining sources have an ongoing potential for releases to Lake Union. Figure 7-4 shows remaining areas of contamination and the remaining sources in the shoreline (including the shoreline arsenic area) and sediment where the primary GWPS COCs (TPAHs, cPAHs, and arsenic) are present at concentrations greater than ALU concentrations.

Other potential ongoing sources of contamination to the sediment portion of the AOI include Northlake Shipyard to the west and Gas Works Park Marina to the east (see Figure 1-3). Northlake Shipyard underwent an interim action to remove sand blast grit and shipyard debris via dredging in 2013 and 2014. Environmental dredging resuspends sediment that has the potential to be transported away from the area being remediated; however, no post-dredging data outside of the dredge footprint were collected to assess the extent, if any, of dredging impacts to the surrounding area. The construction completion report (Hart Crowser 2014) noted releases during dredging and that not all sediment contamination within the shipyard was removed as part of dredging.

Spills and releases of oils, fuels, and ballast water from boats in Lake Union and the Ship Canal occur on an ongoing basis[108]. Given the heavy boat traffic in Lake Union and the history of marina practices, petroleum releases (and associated PAHs) are likely to persist as a source of contamination to the sediment.

No industrial outfalls currently discharge from the AOI upland; however, on-site stormwater is collected within a conveyance system that discharges via outfalls along the park shoreline and at the Harbor Patrol property (see Figure 3-22) . Storm drain underground piping might also transport subsurface soil particles that infiltrate the system at damaged portions of the piping. Stormwater from the surrounding neighborhood also discharges through outfalls in Waterways 19 and 20. A regional City/County project will be constructed

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[107] Lampblack or other black carbon sources.

[108] Ecology maintains a database reporting responses to spill incidents. Current link to data base is https://ecology.wa.gov/Spills-Cleanup/Spills/Spill-preparedness-response/Responding-to-spill-incidents/Spill-incidents

by 2025 to store combined stormwater and sewage from the Wallingford and Fremont neighborhoods during high rainfall events to reduce CSO discharges in the Ship Canal.

7.3. Active Transport Mechanisms

Movement or transfer of contaminants or contaminated media within the AOI are affected primarily by physical transport mechanisms that are, in turn, affected by chemical transport mechanisms.

Physical transport mechanisms of contaminants associated with particulates (i.e., solid phase) include erosion, sediment resuspension, downslope (gravitational) migration, and stormwater runoff. Dissolved-phase contaminants are transported by groundwater movement. Ebullition (vertical migration associated with gas bubbles) can transport DNAPL, but this is a minor and localized mechanism.[109] Key physical transport mechanisms for contaminated soil and sediment are illustrated in the conceptual block diagram depicted on Figure 6-2.

Chemical transport mechanisms are responsible for transferring contamination between solid and aqueous phases, which affects contaminant mobility. Chemical-specific properties determine how much of a chemical occurs in a dissolved form or is bound to a solid (e.g., carbon or sediment particle). Dissolved contaminants can be transported from a secondary source to downgradient, lower concentration areas, where they tend to repartition to solid phases (e.g., soil or sediment), particularly where organic material is present. This affinity for sediment carbon reduces the mobility of the contaminant. Diffusion (molecular motion across a concentration gradient) can also transport contaminants, but this is a very minor mechanism.

Under current conditions and given the large mass of carbon in soil and sediment, groundwater transport (i.e., advection) of contaminants from the upland is unlikely to contribute to sediment contamination. However, in some locations, groundwater passing through contaminated sediment might be a significant transport mechanism of contaminants to the lake because of recontamination. This is particularly relevant in the nearshore area where the highest sediment concentrations occur and groundwater flow to the lake is greatest (i.e., the groundwater discharge zone; see Figure 6-3).

Dispersion and biochemical degradation can also reduce dissolved concentrations of contaminants and limit migration, thus resulting in stable or shrinking plumes. Various scenarios (plumes getting cleaner as they migrate through less contaminated soil versus recontaminating as they move through more contaminated sediment) are described in Section 6.5.3, Upland Groundwater-to-Sediment and Surface Water Pathway and illustrated in Figure 6-4 (see arrows and coloration).

Physical transport processes have the greatest impact on the distribution of contaminants in sediment within the AOI under current conditions and are much more significant than chemical transport.

7.4. Location of Active Transport Mechanisms and Pathways

Transport pathways link a contaminant source via a transport mechanism to a location or medium where a receptor can be exposed. A contaminant might pass through different media and might change between solid and dissolved forms along the pathway. Identification of where active transport pathways occur is needed to

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[109] The last report of a sheen to Ecology in this area was in 2015. The source of the sheen was unknown.

select effective cleanup actions that will protect ecological and human receptors. With the original historical sources removed, the main transport pathways of concern in the AOI are the movement of GWPS COCs from the remaining sources. Contaminant distribution is mapped in Section 5, Nature and Extent of Contamination. Active transport pathways are discussed in detail in Section 6, Contaminant Fate and Transport, and are summarized here:

- Erosion and water-borne transport of contaminated soil/fill in the shoreline banks to surface sediment
- Stormwater discharge of entrained soil particles from the upland to lake sediment
- Resuspension and downslope transport of nearshore contaminated sediment to the offshore lake bottom
- Aqueous transport of dissolved contaminants to sediment and surface water
- Deposition of sediment from the Lake Washington/Lake Union watersheds on the sediment surface within the AOI

The locations of active transport pathways are depicted in Figures 6-3 (physical) and 6-5 (chemical). Sediment deposition occurs throughout Lake Union, but sediment only accumulates under the more quiescent conditions associated with the lake bottom.

7.5. Current Exposure Pathways and Potentially Affected Receptors

Exposure pathways represent the ways people or ecological receptors are exposed to contaminants, either directly or indirectly. Exposure requires that contaminants partition from a contaminated medium across a biological membrane of a receptor following contact. Contact may involve touching or accidently ingesting contaminated soil or sediment or eating contaminated food. The receptors for the GWPS are park visitors, park workers, recreational fishers, Tribal fishers, the benthic invertebrate community, and fish and aquatic-dependent wildlife (e.g., otters, heron, ducks, etc.), as depicted in Figure 7-5. These receptors may be exposed to contaminated media by several key pathways. The following exposure pathways represent a current risk of exposure to contaminants for receptors at the GWPS, as illustrated in Figure 7-6:

- Human contact with or incidental ingestion of:
    - Uncapped surface soil during park visit
    - Seasonal beach surface sediment during play
    - Offshore surface sediment while net fishing
- Human ingestion of contaminated fish and shellfish
- Benthic invertebrate contact with or ingestion of contaminated surface sediment
- Fish consumption of contaminated prey[110]
- Aquatic-dependent wildlife consumption of contaminated prey

Previous cleanup actions, including upland soil capping, installation and operation of the AS/SVE groundwater treatment system in the southeast area, ongoing removal of tar, groundwater treatment for arsenic near the Play Area, and fencing of the Cracking Towers, have significantly reduced risks from exposure of receptors to contaminated media. The risk evaluation presented in Section 5.2.1.4 concludes

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[110] Risks from ingestion of contaminated prey by fish and aquatic-dependent wildlife are driven by non-GWPS contaminants (i.e., tributyltin).

that there will be no unacceptable risks from exposure to cPAH-contaminated surface soil when existing uncapped, unstable shoreline bank soil (Figure 7-4) is addressed as part of the sediment remedy. Groundwater contaminant concentrations have continued to naturally decline.

Exposure can still occur in the following areas (Figure 7-5):

- Tar- and cPAH-contaminated surface soil and sediment along the shoreline where people might play and wade in the water
- In the lakeshore, lake slope, and lake bottom zones, where Tribal net fishers, crayfish, and finfish might contact surface sediment contaminated with cPAHs and arsenic
- In the lakeshore, lake slope, and lake bottom zones, where crayfish and finfish might be caught and ingested by wildlife and people
- PAH-contaminated surface sediment in the lakeshore and lake slope zones, where the benthic invertebrate community might be present[111]

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[111] Habitat in lake bottom does not support benthic macroinvertebrate assemblages due to its high water content.

8.0 RI CONCLUSIONS

This RI is one of the key documents in cleanup planning for the GWPS. Extensive analysis of physical, chemical, and biological data and models demonstrate where there are remaining risks to human health and the environment and what site characteristics require consideration when developing remedial alternatives in the FS. The following summaries of remaining risks and site characteristics identified by the RI form the basis of the FS.

8.1. Risk Areas to be Addressed in the FS

The remaining areas of risk are pathway-dependent and are based on benthic toxicity, bioaccumulation and direct contact pathways (Figure 8-1). Risk areas are discussed in Sections 5.2.3.1 through 5.2.3.3. Areas of benthic toxicity were identified in the lake bottom near the western boundary, in an area extending from the shoreline near Kite Hill southwest to the lake bottom and in the nearshore area adjacent to the Prow and Play Barn. The areas of bioaccumulation risk and direct contact risk from net fishing include the entire sediment portion of the AOI. The area of direct contact risk from beach play and wading only includes the lakeshore sediment where beach play and wading might occur.

The upland human health risk evaluation (Section 5.2.1.4) concludes that addressing contaminated surface soil in eroding shoreline bank soils along the eastern and southwestern shorelines will reduce the human health risk to acceptable levels in the upland portion of the AOI.

8.2. Characteristics to Consider in the FS

Chemical and physical characteristics of the GWPS COCs and the environmental conditions in which they occur affect what types of cleanup actions will be effective in minimizing the risks to human health and the environment. Those characteristics that will be key considerations in developing effective remedial alternatives in the FS include:

- Areas within the AOI where sediment concentrations of primary GWPS COCs are greater than ALU concentrations (Figures 8-2A and 8-2B).
- Areas of active physical transport, natural recovery, or remaining sources (Figures 8-3A and 8-3B).

8.2.1. Areas Exceeding Ambient Lake Union Concentrations for Primary GWPS COCs

Figure 8-2A shows the areas within the AOI where cPAH, TPAH, and arsenic concentrations are highest and exceed ALU concentrations, and the combined area where these primary GWPS COCs exceed ALU concentrations.[112] The area with concentrations of primary COCs greater than ALU conditions includes the areas that are toxic to benthic organisms and where direct contact from wading and beach play might take place.

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[112] The areas exceeding ambient conditions were mapped using surface sediment data collected and analyzed in 2002 and later. This data set represents the most recent data that provide sufficient coverage for mapping.

Figure 8-2B shows a simplified version of the combined area exceeding ALU concentrations for cPAH, TPAH, and arsenic.[113] This generalized version follows the toe of the slope to the east and south, just past the Prow, and encompasses the entire AOI (including the lake bottom zone) to the west. This area was a key consideration in developing remedial alternatives in the FS.

8.2.2. Physical Transport, Natural Recovery, and Source Areas

The areas of physical transport and remaining sources (e.g., shallow NAPL), are also key considerations in developing remedial alternatives in the FS.

Figure 8-3A shows areas of physical transport and remaining sources. The main physical transport mechanisms include soil transport from unstable banks, downslope sediment transport from the lakeshore and lake slope, and groundwater transport in the groundwater discharge zone. The other significant transport mechanism is deposition depicted as “depositional” and “depositional-recovering” (that is, deposition is contributing to natural recovery) in the upper left of Figure 8-3A. Remaining sources include arsenic-contaminated groundwater along the eastern shoreline and shallow NAPL and tar, due to their potential to contribute to aqueous transport of dissolved contaminants through sediment. These areas are shown both individually and combined in Figure 8-3A.

Figure 8-3B is a simplified version of the lower right quadrant of Figure 8-3A. This figure merges the soil (unstable bank) transport, sediment transport, groundwater discharge zone, and most areas of shallow NAPL and tar into a single area. The remaining shallow NAPL is included in the generalized “depositional source area.”

The areas shown on Figure 8-3B, other than the “depositional-recovering” area, fall within the sediment portion of the AOI where primary GWPS COC concentrations are greater than ALU concentrations (Figure 8-5).

8.3. Summary

The risk areas (Figure 8-4) and site characteristics (Figure 8-5) described above form the basis of the FS. The FS will develop, and evaluate, remedial alternatives that address the risk areas in consideration of these site characteristics.

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[113] The delineation of the simplified area exceeding ambient concentrations (Figure 8-2B) is an approximation and balances some areas that are greater than ambient concentrations outside of the line (as shown on Figure 8-2A), with areas that are less than ambient concentrations shoreward of the line.

9.0 CLEANUP REQUIREMENTS

This section describes the cleanup action requirements for the GWPS that form the basis for developing and evaluating cleanup action alternatives in this FS, as well as for implementing the cleanup action ultimately selected for the GWPS by Ecology. The purpose and regulatory framework for conducting this FS is addressed in Section 9.1. Section 9.2 describes the potentially applicable laws that govern cleanup actions under the conditions at the GWPS. The preliminary cleanup standards that must be met by the cleanup action are presented in Section 9.3.

9.1. Purpose of the FS and Regulatory Framework

This FS is being conducted in accordance with the 2005 Agreed Order, which calls for evaluating the nature and extent of contamination in the SCU and evaluating cleanup action alternatives to address this contamination. The 2005 Agreed Order was modified in 2013 to combine the upland area remediated under the 1999 Consent Decree with the sediment area to create a single AOI, which is the focus of this RI/FS. The sediment portion of the AOI (the SCU) was developed to encompass areas of elevated contamination associated with the historical MGP, tar refining or other upland activities. The SCU cleanup actions are being managed in accordance with the SMS.

The overall objectives of the FS are to develop and evaluate a range of cleanup action alternatives to remediate sediment in accordance with MTCA and SMS and to identify a preferred alternative. The FS builds on the understanding of existing conditions and contaminant characteristics defined in the RI portion of this RI/FS report (Sections 1 through 8). This FS follows the Ecology procedures outlined in MTCA (WAC 173-340-350[8]) and SMS (WAC 173-204-550[7]).

9.2. Potentially Applicable Laws

Cleanup actions conducted under MTCA and SMS must comply with the local, state and federal laws (WAC 173-340-710) that have jurisdiction over the cleanup or that Ecology otherwise determines may apply to the cleanup. The potentially applicable laws identified for cleanup of the SCU are listed in Table 9-1. The procedures, standards and other requirements specified in MTCA and SMS are the primary laws governing cleanup actions for the SCU. Additional laws regulate specific components of the cleanup, such as waste disposal, management of stormwater during construction, and worker safety during implementation.

Most of the requirements associated with the additional laws are specified as regulatory permit conditions; however, cleanup actions conducted under an Agreed Order or Consent Decree are exempt from the procedural requirements of most state and local permits. Cleanup actions are exempt from the procedural requirements of the Washington State Clean Air Act, Solid and Hazardous Waste Management Act, Hydraulic Code Rules, Water Pollution Control Act, Shoreline Management Act, and local regulations. However, permits associated with two federal regulations administered by the State of Washington—the CWA NPDES and treatment, storage, or disposal of hazardous waste under the Resource, Conservation and Recovery Act (RCRA)—are not exempt. 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 state agencies and local governments for the exempted permits to ensure cleanup actions comply with the substantive requirements.

A number of the laws governing cleanup of sediment will be addressed through the Joint Aquatic Resource Permit Application (JARPA). The JARPA coordinates information applicable to the USACE-issued

CWA Section 10 and Section 404 permits (Nationwide 38 or individual 404 permit), Ecology-issued CWA Section 401 Water Quality Certifications, and WDNR Use Authorizations for State-Owned Aquatic Lands, among others. A state-issued NPDES permit may be required for any on-site water treatment or discharge of stormwater during implementation of the cleanup action. Table 9-1 includes regulatory requirements that may impact project permitting and implementation.

Construction projects are subject to environmental impact review under State Environmental Policy Act (SEPA), National Environmental Policy Act (NEPA), or both. For most projects in Washington, this review consists of a SEPA checklist, although an environmental impact statement is sometimes required. Ecology will conduct the SEPA review for the GWPS cleanup action as part of finalizing the draft CAP for public review; the SEPA review will indicate whether additional environmental impact analysis is necessary. The SEPA review will be completed at the time of project permitting by USACE.

Shoreline Master Plan requirements apply to projects located within 200 feet of the shoreline. In addition to any local compliance review, Ecology conducts site-specific review of cleanup actions conducted under MTCA, to evaluate whether those actions are consistent with the substantive requirements of the Shoreline Master Program. As part of CAP development and/or future remedial design activities, the City and WDFW will be asked for a written description of their substantive permit requirements.

Federal permitting for in-water construction can be implemented under a 404 Individual or a Nationwide 38 permit; the latter is anticipated for cleanup of the SCU. The federal permitting process includes review of issues relating to wetlands, Tribal treaty rights, threatened and endangered species, habitat impacts and other factors. As part of the federal permitting process, the USACE will consult with the following:

- Tribes regarding tribal treaty rights,
- Natural resource trustees regarding potential project impacts on species and habitats protected under the ESA and related requirements,
- State Department of Archaeology and Historic Preservation to determine the effects of the cleanup action under Section 106 of the National Historic Preservation Act (Gas Works Park was listed in the National Register of Historic Places in 2013).

Many of the permits likely to be associated with any remaining upland cleanup actions are either exempt from the corresponding procedural requirements per MTCA (although substantive requirements must be met) or will be coordinated as part of City land use permit requirements. Other permits that may be required include a King County Wastewater Discharge Authorization permit, City building and grading permits, and a City Parks Revocable Use permit.

Ecology will be responsible for final approval of the cleanup action, following consultation with other federal, state and local regulators. The USACE will separately be responsible for approval of the project under Nationwide Permit 38 or Section 404 permit, following ESA consultation with the federal natural resource trustees, and incorporating Ecology’s 401 Water Quality Certification.

9.3. Preliminary Cleanup Standards

The following sections describe the preliminary cleanup standards that must be achieved by the cleanup action. Under SMS and MTCA cleanup standards consist of:

- Cleanup levels – chemical concentrations (or levels) in environmental media or biological effect thresholds that are protective of human health and the environment
- Points of compliance – locations where the cleanup levels must be met. Typically established on either a point or area basis and have a depth component

The 1999 Consent Decree (Ecology 1999) includes soil and groundwater cleanup standards. The groundwater addressed by cleanup actions required in the 1999 Consent Decree is equivalent to the "upland groundwater" discussed in the RI. The remaining pathways to sediment and surface water that were not addressed in the 1999 Consent Decree are erosion of unstable shoreline bank soil and potential transport of COCs in groundwater to surface water and sediment.

As described in Section 4.1.1.4, the 1999 Consent Decree deferred addressing the bank soil erosion-to-sediment pathway to the future sediment cleanup. Therefore, this FS addresses the areas of bank soil with the potential for erosion to sediment as an element of the sediment cleanup and a cleanup level for the erosion pathway is not proposed. As discussed in Section 12.1, as part of each cleanup action alternative, bank soil within the park will be excavated as necessary, to transition from the existing upland ground surface to the in-water sediment remedy and may include additional excavation for mass removal. Following excavation, the bank will be capped with a vegetated soil cap to prevent direct exposure to park users and to prevent erosion into Lake Union. As a result, no soil cleanup levels are necessary because, following implementation of the sediment cleanup, there will be no complete soil to sediment migration pathway (the potential for erosion will have been addressed).

The RI included two sets of groundwater SLs for upland and offshore groundwater. Transport of COCs in upland groundwater is not expected to result in exceedances of sediment and surface water criteria at the respective points of compliance (see fate and transport discussion in Section 6.5.3 and Section 7.0 Conceptual Site Model). Rather, the concern is transport of COCs in sediment via offshore groundwater. Therefore, this FS uses a preliminary groundwater cleanup standard, applicable only to offshore groundwater as defined in the RI, based on protection of surface water and sediment.

9.3.1. Preliminary Sediment Cleanup Standards

This section presents preliminary sediment cleanup standards for analytes identified as GWPS COCs in Section 5.2.3.4. GWPS COCs are associated with historical MGP, tar refinery, and other upland industrial activities. ALU COCs[114] tend to be distributed throughout Lake Union and are primarily associated with other non-point and point sources. ALU COCs are co-located with GWPS COCs within the SCU and the cleanup action will reduce concentrations of these ALU COCs to meet regulatory goals. Because the ALU COCs are not associated with historical MGP, tar refinery, and other upland industrial activities, preliminary sediment cleanup standards are not developed for these COCs.

Preliminary sediment cleanup levels and points of compliance address multiple exposure pathways and receptors. The preliminary sediment cleanup levels for GWPS COCs are based on protection of benthic organisms (direct contact and ingestion), protection of people that may contact sediment during beach play/wading (i.e., direct contact comprising incidental ingestion and dermal contact), and protection of people and ecological receptors that may consume fish and shellfish foraged from the SCU (bioaccumulation). The exposure pathways and receptors considered in developing the sediment cleanup

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[114] ALU COCs, along with GWPS COCs, were identified using surface sediment data from samples collected within the sediment portion of the AOI. The difference between the two sets of COCs is that the GWPS COCs are site-related and the ALU COCs are not.

levels for GWPS COCs are consistent with those used to develop the RI sediment screening levels discussed in Section 4.0.

In general, the preliminary sediment cleanup levels are set as the highest of the following levels:

- The lowest risk-based concentration protective of benthic organisms (multiple pathways), human health (direct contact and bioaccumulation) or ecological receptors (bioaccumulation)
- Background (natural or regional) levels
- PQLs

Preliminary sediment cleanup standards for GWPS COCs are presented in Table 9-2. Sediment screening levels applicable to ALU COCs are presented in Table 9-3.

Preliminary Sediment Cleanup Level – According to SMS, the SCO is the sediment quality goal. Sediment cleanup levels are initially established at the SCO and may be adjusted up to, but not higher than, the CSL based on an evaluation of technical possibility and net adverse environmental impact (WAC 173-204-560[2][a][ii]). The Sediment Cleanup User's Manual (Chapter 7 Section 7.2.3.2; Ecology 2021) details how to determine whether it is technically possible to attain the SCO based on site-specific factors, including, but not limited to, the ability to:

- Achieve the SCO using available cleanup technologies, and
- Maintain the SCO after cleanup construction.

The preliminary sediment cleanup levels for carbazole and dibenzofuran are set at the SCO, based on the protection of benthic organisms. The preliminary sediment cleanup level for nickel is set at the SCO based on Puget Sound natural background.

For cPAH TEQ, TPAH, and arsenic the technical possibility to attain SCO was evaluated against the site-specific factors above; while the SCO can be achieved using available cleanup technologies, it cannot be maintained after cleanup construction due to numerous ongoing diffuse regional sources that are not under the authority or responsibility of the potentially liable parties (PLPs).

Lake-wide maps for these COCs (Figures 5-18, 5-19A, and 5-20) show widespread exceedances of SCO and CSL throughout Lake Union, the Lake Washington Ship Canal upstream of Lake Union, and the Seattle urban environment as a result of numerous historical and ongoing diffuse regional sources. Also, mean ALU concentrations (Table 5E-1) outside of the SCU are well above the CSL.

Ongoing diffuse regional sources would be transported to and recontaminate the cleanup action, and these sources are not under the authority or responsibility of the PLPs. Therefore, the preliminary sediment cleanup levels for cPAH TEQ, TPAH, and arsenic are adjusted upward from the SCO to the CSL. The TPAH CSL is based on the protection of benthic organisms. The cPAH TEQ and arsenic CSLs are based on regional and preliminary regional background values, respectively.

Preliminary Point of Compliance – Different points of compliance are applied to sediment based on the exposure pathways and receptors associated with each cleanup level. TPAH, carbazole, dibenzofuran, arsenic, and nickel are benthic COCs. cPAHs and arsenic are direct contact and bioaccumulative COCs.

- **Benthic** – TPAH, carbazole, dibenzofuran, arsenic, and nickel: The point of compliance depth for protection of benthic invertebrates is the biologically active zone, which is considered the upper 10 cm of sediment (i.e., surface to 0.33 feet below mudline). This point of compliance depth addresses direct toxicity to benthic organisms caused by ingestion of or contact with contaminated sediment and associated porewater. Appendix 5D developed areas of benthic toxicity (see Figure 5D-8). The associated point of compliance area is identified as the "Benthic Toxicity Area" on Figure 9-1. Compliance will be evaluated on a point-by-point basis because of the relatively small home range of most benthic organisms.
- **Direct contact** – cPAHs and arsenic: The direct contact exposure areas extend from the OHWM to a lake bottom elevation of 15 feet. This corresponds to a range of maximum water depth between 5 and 7 feet, depending on the time of year and lake level. The point of compliance depth for nearshore sediment that is seasonally exposed by USACE-managed lake levels is the upper 45 cm (i.e., 0 to 1.5 feet below mudline) based on beach play exposure potential. The point of compliance depth for sediment that is always covered by water is the upper 10 cm based on wading exposure. The associated point of compliance areas are identified as the "Direct Contact Beach Play and Wading Exposure Area" and the "Direct Contact Wading Exposure Area" on Figure 9-1. Compliance will be evaluated on the basis of SWACs.
- **Bioaccumulation** – cPAHs and arsenic: The exposure area for bioaccumulative compounds is the SCU. The point of compliance depth is the upper 10 cm; this point of compliance is intended to protect exposure during netfishing and the bioaccumulation exposure pathway for both people and ecological receptors consuming fish and shellfish. The associated point of compliance area is identified as the "Bioaccumulation Exposure Area" on Figure 9-1. Compliance will be evaluated on the basis of SWACs.

9.3.2. Preliminary Groundwater Cleanup Standard

Preliminary groundwater cleanup standards, applicable to offshore groundwater as defined in the RI, are based on protection of surface water and sediment and presented in Table 9-4 along with the basis for each value.

Preliminary Groundwater Cleanup Level – The preliminary groundwater cleanup level for each COC is the same as the offshore groundwater screening levels presented in Section 4 (Table 4-1) of the RI. The preliminary arsenic groundwater cleanup level is 8 µg/L, which is the natural background concentration for the Puget Sound Basin (Ecology 2022. This value may not be achievable due to background conditions within the SCU and throughout Lake Union. Offshore arsenic groundwater concentrations estimated using ALU concentrations and the site-specific arsenic Kd indicate that offshore groundwater area background concentrations are greater than the preliminary groundwater cleanup level.[115] This is supported by offshore groundwater concentrations away from GWPS sources ranging from <50 to 150 µg/L.[116] Therefore, because the offshore groundwater background concentrations are higher than the preliminary arsenic groundwater cleanup level, an alternative site-specific arsenic groundwater background concentration may need to be developed during the future design phase of the cleanup process.

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[115] Using the ALU arsenic concentration of 53 mg/kg (Table 3-1) and the arsenic Kd for recent lacustrine deposits of 1,654 L/kg (Table 6A-3 of Appendix 6A), the estimated arsenic groundwater concentration is 32 µg/L.

[116] See Appendix 5B, Table 5B-1.3 for arsenic offshore groundwater data. Offshore groundwater locations away from GWPS sources include NLU58, NLU64, NLU70, and NLU72.

Preliminary Point of Compliance – As noted in Section 9.3, the 1999 Consent Decree established a conditional point of compliance (CPOC) as close as technically possible to the location where groundwater flows into Lake Union for the selected upland groundwater COCs: benzene, ethylbenzene, toluene, naphthalene, and cPAHs.[117] Arsenic and 11 other offshore groundwater COCs[118] were not identified as groundwater COCs in the 1999 Consent Decree, and as a result, a CPOC has not been established for these contaminants.

The standard point of compliance for groundwater under MTCA is throughout the site. MTCA allows use of a CPOC, 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]). For properties abutting surface water, where groundwater cleanup levels are based on the protection of surface water beneficial uses, MTCA allows Ecology to approve use of a CPOC located as close as technically possible to the point where groundwater flows into surface water (WAC 173-340-720[8][d][i]). Use of a CPOC is subject to several conditions, which are outlined in WAC 173-340-720[8][d][i], that must be met in order for Ecology to approve a CPOC beyond the upland. Those conditions and their applicability to the SCU are described below. This evaluation applies to arsenic, which is associated with former MGP activities in the Play Area.

- *Contaminated groundwater enters the surface water and will continue to enter the surface water even after implementation of the selected cleanup action.*

This condition is met as regardless of cleanup actions in the upland, contaminated groundwater would continue to enter surface water due to the presence of sediment contamination.

- *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 met as it is not practicable to meet the groundwater cleanup level solely by upland remediation technologies due to the presence of sediment contamination.

- *A mixing zone is not used to demonstrate compliance with surface water cleanup levels*.

This condition is met as 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 water*.

This condition is met for arsenic in upland groundwater, an evaluation of all known available and reasonable methods of treatment (AKART) and the selected technologies are presented in Section 11.

- *Groundwater discharges do not result in exceedances of sediment quality values in Chapter 173-204 WAC*.

This condition will be met as the groundwater cleanup levels are protective of freshwater sediment.

- *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 cause bioaccumulative effects*.

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[117] Though not specifically identified in the 1999 Consent Decree, the CPOC also applies to cPAH TEQ, which is derived from the individual cPAHs.

[118] Bis(2-ethylhexyl)phthalate, cadmium, carbazole, copper, dibenzofuran, fluoranthene, lead, mercury, nickel, pyrene, and silver.

This condition will be met as compliance monitoring to evaluate cleanup action performance will be conducted following implementation; the monitoring details will be specified in the future CAP.

- *Notice of proposed conditional points of compliance is made to natural resource trustees, WDNR and USACE*.

This condition will be met as the required notice and request for comment will be made by Ecology concurrent with issuance of the future draft CAP for review.

Because the above conditions have been or will be met, the preliminary groundwater cleanup standard for arsenic is proposed to include the use of a CPOC set as close as technically possible to the location where groundwater flows into Lake Union, consistent with that established in the 1999 Consent Decree. The arsenic CPOC may eventually be set farther upgradient, closer to the source if the collection of offshore groundwater data and development of a site-specific arsenic groundwater background concentration during the pre-remedial design investigation phase shows that a CPOC farther upgradient is appropriate.

The above conditions only apply to groundwater at properties abutting surface water. Because the other 11 offshore groundwater COCs are associated with sediment, rather than upland groundwater, the conditions for establishing a CPOC do not apply. However, to maintain consistency, a point of compliance set as close as technically possible to the location where groundwater flows into Lake Union is also proposed for these other 11 offshore groundwater COCs.

For this FS, the CPOC is proposed to be set at 10 cm below the sediment mudline, at the base of the biologically active zone within the Groundwater Discharge Zone. Section 3 identified the “Groundwater Discharge Zone” (see Figure 3-18) as the area of highest groundwater discharge within the SCU. Approximately 92 percent of the cumulative groundwater discharge and all the groundwater discharge from the contaminated upland aquifers (i.e., fill and outwash) occurs within this zone[119]. The groundwater discharge zone includes groundwater with a flow rate of greater than 0.001 feet per day. Outside of the groundwater discharge zone, groundwater flow and resulting advective transport of contaminants is insignificant and groundwater exceedances are associated with collocated sediment contamination (i.e., sediment and groundwater are in equilibrium). Therefore, preliminary groundwater cleanup levels only apply to the groundwater discharge zone (see Figure 9-2).

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[119] The calibrated groundwater flow model was used to calculate discharge along the shoreline (Figure 3F-16, Appendix 3F) and to Lake Union (Figure 3F-17, Appendix 3F) within the SCU. Discharge through the fill and outwash at the shoreline within the SCU was 1,660 cubic feet per day compared to 1,940 cubic feet per day (92% of the total discharge of 2,118 cubic feet per day [Figure 3F-14, Appendix 3F]) discharging to lake Union within the Groundwater Discharge Zone.

10.0 CLEANUP UNITS AND MANAGEMENT AREAS

To assist in the development and evaluation of cleanup action alternatives, the GWPS has been divided into management areas based on environmental conditions and other factors that affect the applicability of specific remediation technologies and the feasibility of their implementation.

Ecology's SCUM guidance outlines the process to divide sediment sites into management areas and served as the model for subdividing the GWPS. The SCUM guidance defines "sediment cleanup units" (SCUs) and "sediment management areas" (SMAs) as the two classifications for splitting a large site into manageable parts. The SCUM guidance approach is used for the GWPS and, due to Site conditions, includes management areas for shoreline sources in addition to SMAs.

10.1. GWPS Cleanup Units

Two cleanup units have been defined within the AOI: the upland cleanup unit and the SCU. The upland cleanup unit has largely been remediated consistent with the 1999 Consent Decree (Ecology 1999). This FS focuses on the SCU and includes upland shoreline source control elements. The boundary between the upland and sediment cleanup units is defined in the Consent Decree as the OHWM, which is near or below the top of the shoreline bank.

The SCUM guidance states that upland conditions at a site that have a direct influence on sediment or surface water conditions should be included with sediment alternatives for the purposes of source control. As the upland-to-sediment pathway was not addressed in the previous upland remediation work, the shoreline is an area for prospective implementation of source control actions to protect sediment within the AOI. Therefore, in accordance with SCUM, upland shoreline source control elements for sediment are included in the sediment alternatives presented in Section 12.

The outermost extent of the SCU is defined by the AOI boundary, which was established in the 2005 Agreed Order. Bathymetric and chemical data collected between 1995 and 2002 formed the basis of the delineation. PAH patterns and concentration gradients along with Site physical characteristics were used to identify the AOI boundary. The AOI encompasses the PAH signature that is indicative of MGP sources at concentrations that are statistically significantly higher than the ambient concentrations of Lake Union. Conservatively, the AOI incorporates an area of mixed MGP and ambient Lake Union chemical signatures. Further, the AOI incorporates the steeply sloped areas where downslope erosion and transport from nearshore, high concentration areas may occur. The AOI also addresses the distribution of arsenic from the GWPS while distinguishing it from the distribution of shipyard metals associated with the adjacent property to the west.

The western portion of the SCU includes an area that is significantly impacted by sources other than GWPS sources. Metals associated with the adjacent shipyard activities are elevated and appear to be the main driver of benthic toxicity. PAHs are also elevated in this area and appear to be associated with the adjacent shipyard's activities in addition to GWPS sources (see Appendix 5E and Section 5.2.3.5 of the RI).

10.2. Factors Used to Delineate Management Areas

According to SCUM guidance, larger complex sediment sites may be divided into discrete management areas, which represent the smallest area for which individual cleanup decisions are made. In this FS, these sub-areas are termed groundwater management areas (GWMAs) and SMAs. As shown on Figure 10-1, areas of the upland unit that have a direct influence on sediment or surface water are divided into three management areas (GWMA-1, SMA-1, and SMA-2) and the SCU is divided into multiple management areas (SMA-3 to SMA-14). The management areas were delineated using the following Site-specific conditions that affect remedy implementation and performance:

- COC distribution and magnitude of concentrations;
- Physical attributes of the sediment, sediment bed, and the area in which the sediments are located;
- Chemical migration or transport pathways; and
- Property ownership and associated land use.

Section 8 of this RI/FS report describes areas requiring remediation and depicts them on Figure 8-4. The areal limits for remediation considered in this FS are based on those shown on Figure 8-4. The limits of remediation along with the GWMAs and SMAs form the basis for technology screening and alternative development in subsequent sections of this FS.

10.2.1. Contaminant Distribution and Magnitude and Exposure Areas

Factors related to the distribution of the various Site contaminants and their interactions with applicable remedial technologies include contaminant properties, concentrations, exposure areas and sources. Specifically, the following areas were considered when delineating GWMAs and SMAs:

- Surface sediment where preliminary cleanup levels (developed in Section 9 of this FS) were exceeded primarily or only by cPAHs and/or arsenic.
- Sediment impacted by shallow subsurface NAPL.
- PAH concentrations in sediment greater than preliminary cleanup levels to prevent direct contact exposure in the beach play and wading areas.
- Arsenic-impacted sediment and upland groundwater in the eastern portion of the GWPS near the Play Area.
- Uncapped bank soil containing tar and cPAHs at concentrations greater than preliminary cleanup levels to prevent direct contact exposure to park users.
- Benzene- and naphthalene-impacted upland groundwater.

10.2.2. Physical Factors

Physical conditions at the GWPS that affect the applicability of remediation technologies are the presence of structures, the slope of the lake sediment surface, sediment density or strength and groundwater discharge from the upland to the lake. These conditions are described below.

10.2.2.1.Structures

The presence of structures impacts the access of remediation equipment and work platforms (e.g., barges) to the sediment. Possible effects on the stability and integrity of fixed structures affect dredging depths and thickness of caps. If temporary removal and replacement of structures is necessary, construction may need to be phased to allow continued operation of facilities such as the Harbor Patrol. The following upland and in-water structures, ordered from east to west, affect potential cleanup action alternatives:

- Gas Works Marina – The eastern limit of the GWPS overlaps with a portion of the Gas Works Park Marina, where floating homes and large boats are moored along a pile-supported dock (Figure 1-3). The dock is reinforced with anchors and cable cross-bracing. Utilities under the dock serve the floating homes. The dock's supporting piles and cables prevent the use of removal technologies that may damage the structure.
- Gas Works Park Seawall/Prow – The seawall at the Prow is a concrete remnant of the original gas plant. Construction methods, design specifications and depth of the seawall base are unknown. Given the age of this structure and the unknown below-grade condition dredging of sediment in front of the seawall may significantly compromise its structural integrity.
- Harbor Patrol – The City of Seattle Harbor Patrol facility falls within the GWPS, including upland and inwater elements (Figure 1-3). Several structures at Harbor Patrol are expected to affect the cleanup action:
    - A log boom along the eastern edge of the shoreline extending approximately 125 feet into the lake.
    - A timber-supported pier west of the log boom extending approximately 150 feet into the lake.
    - A concrete wharf northwest of the timber pier that is 100 feet long and supported by concrete piling.
    - Two floating docks.
    - A sheet pile bulkhead driven 35 to 40 feet below grade, into the Advance Outwash Unit.

  There is also a known sunken boat that rests on the lake bottom in the vicinity of the Harbor Patrol.
- Metro Lake Union – King County Metro's South Yard facility is located at the northwest corner of the AOI (Figure 1-3). The Metro facility includes two pile-supported docks within the County-owned portion of Lake Union that falls within the AOI.
- Northlake Shipyard – The Northlake Shipyard facility includes Shipyard-owned upland and in-water property, as well as an adjacent area that is leased from WDNR. The Northlake Shipyard is mostly outside the footprint of the AOI (Figure 1-3), however, the leased area, including a portion of one of the shipyard docks and an area commonly used for vessel storage, does extend into the AOI.

10.2.2.2.Slopes

The slope of the bottom of Lake Union varies substantially within the GWPS. As described in Section 3.2.1 of the RI report, the in-water portion of the GWPS is divided into three zones: lakeshore, lake slope and lake bottom. Slopes within the lakeshore and lake slope zones typically range from 10V:1H (vertical:horizontal) to 3V:1H. The toe of the lake slope transitions to the flat lake bottom zone. Within the lakeshore zone, a primary concern is the need to both address contamination and preserve aquatic habitat. In addition, the slope affects sediment stability, which in turn affects cap design (e.g., armoring, benching), placement and maintenance.

10.2.2.3.Sediment Density

Soft sediment, which is located primarily in the deeper portions of the lake slope zone and across the lake bottom zone, occurs at thicknesses approaching 50 feet (western portion of the SCU). By contrast, the occurrence of soft sediment in the lakeshore zone is limited by the zone's steeper, higher-energy environment. The presence of soft sediment affects the applicability and effectiveness of remediation technologies, including capping and removal. In particular, removal of soft sediment poses significant implementability issues, as discussed in Section 11.

10.2.2.4. Groundwater Discharge

Groundwater discharges from the upland through sediment to the surface waters of the lake. The greatest flux occurs immediately adjacent to the shoreline; groundwater flux reduces significantly with distance from the shoreline (as discussed in Appendix 3F of the RI). Figure 9-2 shows the groundwater compliance area, which represents the area where groundwater discharge may affect cap design.

10.2.3. Chemical Migration or Transport

Facilitated by erosion of shoreline soil or fill materials and by bedload transport of sediment, historical contamination continues to be redistributed within the SCU. Remedies will include management of erosion and bedload transport (particularly downslope) but engineered solutions may differ among alternatives. For example, erosion may be addressed by revegetating the shoreline or by armoring. Sediment transport may be addressed by stabilizing sediment (e.g., through armoring) or by changing the slope conditions.

The groundwater-to-surface water pathway within the SCU is the primary contaminant transport mechanism affecting the selection and implementation of remedial technologies. Ninety-two percent of groundwater from the upland portion of the AOI discharges within the groundwater discharge zone (see Figure 9-2), which overlaps with all or part of SMAs 3, 4, 5, 6, 7, 9, 10. Groundwater flows may be controlled by constructing barriers that deflect or retard groundwater flow; dissolved contaminant migration may be addressed by containment or treatment. The rate of groundwater discharge influences the degree to which contaminants will be adsorbed into and retained by different types of cap material. Furthermore, technologies that would be effective where groundwater discharge rates to Lake Union are high might not be equally effective where discharge rates are low, and vice versa.

10.2.4. Property Ownership and Land Use

Limitations imposed on and by property owners can affect remedial alternative selection. Gas Works Park and Harbor Patrol, which constitute the majority of the upland portion of the GWPS, are owned by the City of Seattle. The park is managed by Seattle Parks and Recreation (SPR) and Seattle Police Harbor Patrol is managed by the City's FAS. However, ownership and use of the SCU is more varied, as shown on Figure 1-3 of the RI. the State of Washington[120] owns and the WDNR manages the majority of the SCU, including the upland and aquatic portions of Waterway 19 in the eastern portion of the SCU and Waterway 20 in the western portion of the SCU. The City owns property along the east and west shorelines, private entities own Gas Works Park Marina adjacent to Waterway 19, and King County owns an in-water property immediately west of Waterway 20. See Section 1.2 for additional details on property ownership.

Generally, Lake Union is a public waterway used for recreation, vessel navigation, and net fishing. This diversity of ownership and uses and the required coordination adds a level of complexity to the implementation of remedies.

10.2.4.1. Gas Works Park

The expectation carried through this FS is that the current use of the Gas Works Park will continue and that alternatives developed for cleanup action, therefore, need to accommodate use of the property as an urban park. The current City prohibition on land based shoreline water access will be re-evaluated by the City following construction.

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[120] Property owned by the State of Washington is managed by the Washington Department of Natural Resources (WDNR).

10.2.4.2. Harbor Patrol

The expectation carried through this FS is that the current use of Harbor Patrol will continue. Alternatives developed for cleanup action were therefore, structured to accommodate the use of the property as a base for all water-related emergency response in the City, and for marine fire response and any other requested assistance. Future improvements may include a boat ramp for Harbor Patrol's use. Communication with Harbor Patrol during subsequent cleanup planning and design phases will consider future property improvements.

10.2.4.3. Gas Works Park Marina

The AOI encompasses a portion of the in-water property and associated docks of the Gas Works Park Marina. The location and construction of the marina docks are considered in the development of management units and cleanup alternatives. The expectation for this FS is that the current use of Gas Works Park Marina will continue.

10.2.4.4. Waterway 20

Waterway 20 in the western portion of the AOI is owned by the State of Washington and is managed by WDNR. The Waterway includes both in-water and upland areas. The upland portion of Waterway 20 is fenced with a locked gate and is currently used by Harbor Patrol for storage. A small craft boat ramp is also located on the upland portion of Waterway 20. In coordination with WDNR, a plan is being developed by the Wallingford Community Council and the Center for Wooden Boats (which occupies the adjacent Metro Lake Union South Yard property), to redevelop the upland and shoreline of Waterway 20 to include a larger public beach and hand-carry boat ramp, while maintaining the existing boat ramp for use by Harbor Patrol. The anticipated redevelopment and future uses have been considered in the development of management units and cleanup alternatives in this FS. Communication with WDNR during subsequent cleanup planning and design phases will consider future property improvements.

10.2.4.5. Metro Lake Union South Yard Property (Center for Wooden Boats)

The Metro Lake Union South Yard property at the northwest corner of the AOI is currently leased by the Center for Wooden Boats from King County. The Center for Wooden Boats has plans to redevelop the property for a small craft facility, which will include new docks and boat launching facilities. The anticipated redevelopment and future uses have been considered in the development of management units and cleanup alternatives in this FS. Communication with King County during subsequent cleanup planning and design phases will consider future property improvements.

10.2.4.6. Northlake Shipyard

The Northlake Shipyard falls mostly outside of the AOI, however, the area leased from WDNR, including a portion of one of the shipyard docks and an area commonly used for vessel storage, does extend into the AOI (Figure 1-3). The current uses associated with the Northlake Shipyard are not expected to change in the future and are considered in the development of management areas and cleanup alternatives.

10.3. Management Areas

The management areas established for the FS are identified on Figure 10-1 and described in the following sections. Summary descriptions of the management areas are presented in Table 10-1. Most landmarks discussed in this section are shown on Figures 1-3 or 10-1 of the RI.

10.3.1. GWMA-1

GWMA-1 comprises the area of upland groundwater between the Play Area and Lake Union impacted by arsenic releases associated with the former Thylox process. This area is downgradient of the Play Area Interim Action where arsenic-impacted groundwater was treated. The interim action is documented in the Play Area Interim Action Monitoring Report (GeoEngineers 2021). GWMA-1 is approximately 0.17 acres and includes the shoreline area immediately upland of Lake Union (Figure 10-1). GWMA-1 includes arsenic in groundwater at concentrations greater than the preliminary cleanup level. The arsenic in upland groundwater is not expected to impact sediment or surface water and so is being addressed in the FS as a source control measure.

There are no over-water structures, operating terminals, or berths in GWMA-1. The area is accessible to construction equipment from the upland portion of GWPS but would require an access agreement with SPR.

10.3.2. SMA-1

SMA-1 consists of an approximately 0.54-acre uncapped bank soil area along approximately 1,000 linear feet of the eastern park shoreline (Figure 10-1). SMA-1 also includes the upland portion of the tar mound, northeast of the Play Barn, along the shoreline. SMA-1 is accessible to park users for recreation.

The bank soil area is susceptible to erosion and transport of contaminants to the adjacent lakeshore sediment. Direct contact with uncapped bank soil containing tar and PAHs at concentrations greater than preliminary cleanup levels is a potential exposure pathway for park users.

There are no over water structures, operating terminals, or berths in SMA-1. The area is accessible to construction equipment from the upland portion of GWPS but would require access agreements with SPR and WDNR for the portion of SMA-1 that is within Waterway 19.

10.3.3. SMA-2

SMA-2 consists of an approximately 0.16-acre uncapped bank soil area along approximately 400 linear feet of the shoreline adjacent to Kite Hill in the southwestern area of the park (Figure 10-1). SMA-2 is accessible to park users for recreation.

The bank soil area is susceptible to erosion and transport of contaminants to the adjacent lakeshore sediment. Direct contact with uncapped bank soil containing tar and PAHs at concentrations greater than preliminary cleanup levels is a potential exposure pathway for park users.

There are no over water structures, operating terminals, or berths in SMA-2. The area is accessible to construction equipment from the upland portion of GWPS but would require an access agreement with SPR.

10.3.4. SMA-3

SMA-3 consists of an approximately 1.0-acre area of lakeshore sediment along the eastern shoreline north of the Till Ridge[121] generally between elevations OHWM and +10' (USACE) (Figure 10-1). The southern boundary of SMA-3 was established at +10' (USACE), which corresponds to the approximate maximum water depth that a cofferdam could be installed for removal alternatives. SMA-3 includes a portion of

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[121] The till ridge is shown on Figure 3B-5 of RI Appendix 2B.

Waterway 19 in the eastern portion of GWPS owned by the State of Washington and managed by WDNR. SMA-3 is accessible to park users for recreation (beach play and wading) and for net fishing and is used for shallow draft vessel navigation. However, as noted in Section 3.2.8.4, entering the water, and launching boats from the park are currently prohibited, as are swimming, fishing, and wading (in accordance with SMC 18.12.070). Following cleanup, the City will re-evaluate the need for these prohibitions.

SMA-3 is among the areas most susceptible to erosion and physical transport of contaminants. SMA-3 includes the lakeshore portion of the GWPS through which the majority of upland groundwater discharges to Lake Union. Offshore groundwater can become recontaminated or cannot attenuate where it flows through subsurface sediment contamination. Offshore groundwater with mobile contaminant concentrations greater than preliminary cleanup levels may be discharged to surface water. PAH and arsenic concentrations in SMA-3 sediment are greater than preliminary cleanup levels. The area is a potential risk to park users (beach play and wading) and net fishers from exposure to impacted sediment at shoreline. Sediments within SMA-3 demonstrate benthic toxicity.

There are no over water structures, operating terminals, or berths in SMA-3. The area is accessible to construction equipment from both the upland portion of GWPS and Lake Union but would require access agreements with SPR and WDNR.

10.3.5. SMA-4

SMA-4 consists of an approximately 0.28-acre area of nearshore sediment between the Prow and Harbor Patrol generally between elevations OHWM and +10’ (USACE) (Figure 10-1). The southern boundary of SMA-4 was established at +10’ (USACE), which corresponds to the approximate maximum water depth that a cofferdam could be installed to facilitate sediment removal alternatives. SMA-4 is accessible to park users for recreation (wading) and for net fishing and is used for shallow draft vessel navigation. However, as noted in Section 3.2.8.4, entering the water, and launching boats from the park are prohibited, as are swimming, fishing, and wading (in accordance with SMC 18.12.070). Following cleanup, the City will re-evaluate the need for these prohibitions..

SMA-4 is among the areas most susceptible to erosion and physical transport of contaminants. SMA-4 includes the lakeshore portion of the GWPS through which the majority of upland groundwater discharges to Lake Union. Offshore groundwater can become recontaminated or cannot attenuate where it flows through subsurface sediment contamination. Offshore groundwater with mobile contaminant concentrations greater than preliminary cleanup levels may be transported to surface water. PAH concentrations in SMA-4 sediment are greater than preliminary cleanup levels. The area is a potential risk to park users (wading) and to net fishers from exposure to impacted sediment. Sediments within SMA-4 demonstrate benthic toxicity.

There are no over water structures, operating terminals, or berths in SMA-4. The area is accessible to construction equipment from both the upland portion of GWPS and Lake Union but would require an access agreement with SPR.

10.3.6. SMA-5

SMA-5 consists of an approximately 0.60-acre area of lakeshore sediment area between the western extent of the Park shoreline and the northwest corner of the AOI generally between elevations OHWM and +5’ (USACE) (Figure 10-1). The southern boundary of SMA-5 was established at +5’ (USACE) to preserve the bathymetry if necessary, as part of the remedy implementation with water depth of at least 15 feet to facilitate vessel operations at Harbor Patrol and the Metro Lake Union South Yard. SMA-5 is accessible for net fishing. A portion of Waterway 20, included within SMA-5, is proposed for public access including wading and small vessel use post-cleanup.[122] Other uses include vessel navigation and moorage including Harbor Patrol and Center for Wooden Boats[123] activities.

SMA-5 includes the lakeshore portion of Harbor Patrol and Waterway 20, which includes a boat ramp. SMA-5 is the area of the GWPS most susceptible to erosion and physical transport of contaminants. In addition, the lakeshore portion of SMA-5 is an area of high groundwater discharge to Lake Union. Offshore groundwater can become recontaminated or cannot attenuate where it flows through subsurface sediment contamination. Offshore groundwater with mobile contaminant concentrations greater than preliminary cleanup levels may be transported to surface water. PAH concentrations in SMA-5 sediment are greater than preliminary cleanup levels. The area is a potential risk to the public (wading) and to net fishers from exposure to impacted sediment. Sediments within SMA-5 demonstrate benthic toxicity.

Active marine operations including structures and berths are present along the shoreline. Constructed shoreline and in-water structures and facility operational requirements may affect implementability of some remediation technologies. The area is accessible to construction equipment from Lake Union but would require access agreements with the City, King County and WDNR.

10.3.7. SMA-6

SMA-6 consists of an approximately 2.3-acre lakeshore and lake slope sediment area offshore of the Prow extending to approximately elevation -5’ (USACE) (Figure 10-1). The limits of SMA-6 were delineated to include areas of shallow sediment contamination with physical and chemical properties that do not prohibit dredging. SMA-6 excludes areas of NAPL-impacted sediment and thick, soft sediment, which are determined to be conditions prohibitive of dredging as described in Section 11.

SMA-6 is less influenced by physical transport and high groundwater discharge. PAH concentrations in SMA-6 sediment are greater than preliminary cleanup levels. Sediments within SMA-6 demonstrate benthic toxicity. The area is accessible for recreation (beach play and wading) and is used for net fishing. However, as noted in Section 3.2.8.4, entering the water, and launching boats from the park are prohibited, as are swimming, fishing, and wading (in accordance with SMC 18.12.070. Following cleanup, the City will re-evaluate the need for these prohibitions.

A concrete seawall and associated promenade along the shoreline, referred to as the “Prow” are in SMA-6. The need to maintain the structural integrity of the seawall may limit implementability of remediation technologies near the wall. Given the age of this structure and the unknown below-grade condition, dredging of sediment in front of the seawall may significantly compromise its structural integrity. Access to the sediment area from the shoreline is also limited by the structures. SMA-6 is accessible from the water but would require an access agreement with WDNR.

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[122] A portion of Waterway 20 is included within the Public-Use Conceptual Plan being developed in coordination with the Wallingford Community Council, Center for Wooden Boats, and Harbor Patrol at the direction and under the oversight of WDNR.

[123] The Center for Wooden Boats occupies the adjacent Metro Lake Union South Yard property (see Figure 1-3 of the RI).

10.3.8. SMA-7

SMA-7 includes an approximately 2.0-acre sediment area in the eastern offshore portion of the GWPS. Approximate elevations are between +10' and -17' (USACE) (Figure 10-1). A small portion of SMA-7 to the northeast contains the privately-owned Gas Works Park Marina. SMA-7 is accessible for net fishing and is used for vessel navigation and moorage including Gas Works Park Marina activities.

SMA-7 includes the steep lake slope portion of GWPS north of the till ridge and south of Waterway 19 (see Figure 3B-5 in Appendix 3B for location of till ridge). Relative to the bank and lakeshore zone, the lake slope environment is deeper, farther offshore, less influenced by groundwater discharge and less influenced by erosive forces. Because of the lower-energy environment, the lake slope zone of SMA-7 also is subject to deposition of soft sediment, particularly along the lower slope. Offshore groundwater can become recontaminated or cannot attenuate where it flows through subsurface sediment contamination. Offshore groundwater with mobile contaminant concentrations greater than preliminary cleanup levels may be transported to surface water. PAH and arsenic concentrations in SMA-7 sediment are greater than preliminary cleanup levels and shallow subsurface NAPL is present along the lake slope. There is a potential for vertical migration of NAPL to the sediment surface through dissolution and ebullition. The area is a potential risk to net fishers from exposure to impacted sediment. Sediments within SMA-7 demonstrate benthic toxicity.

There are no operating terminals or berths present in SMA-7. Docks and dock infrastructure at the Gas Works Park Marina may affect implementability of some sediment technologies. The area is accessible to construction equipment from Lake Union but would require access agreements with the WDNR and Gas Works Park Marina.

10.3.9. SMA-8

SMA-8 consists of an approximately 0.59-acre sediment area associated with NAPL Area 8[124] offshore of the Prow. SMA-8 is generally between +5' and -15' (USACE) (Figure 10-1). SMA-8 is accessible for net fishing and is used for vessel navigation.

SMA-8 includes the lakeshore and lake slope portion of NAPL Area 8 offshore of the Prow. SMA-8 is less influenced by physical transport and high groundwater discharge. PAH concentrations in SMA-8 sediment are greater than preliminary cleanup levels and shallow subsurface NAPL is present in the area. There is a potential for vertical migration of NAPL to the sediment surface through dissolution and ebullition. The area is a potential risk to net fishers from exposure to impacted sediment. Sediments within SMA-8 demonstrate benthic toxicity.

There are no over water structures, operating terminals, or berths in SMA-8. The area is accessible to construction equipment from Lake Union but would require an access agreement with WDNR.

10.3.10. SMA-9

SMA-9 includes an approximately 2.8-acre sediment area offshore of the western park shoreline, including the area adjacent to the Harbor Patrol bulkhead. Approximate elevations are between +10' and -18' (USACE) offshore of SMA-4 and between +5' and -18' (USACE) offshore of SMA-5 (Figure 10-1). SMA-9 is

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[124] NAPL Area 8 is shown on Figure 2-16A of the RI.

accessible for net fishing and is used for vessel navigation and moorage including Harbor Patrol and Metro Lake Union South Yard activities.

SMA-9 includes the lake slope portion of Lake Union offshore of Harbor Patrol, Waterway 20, and the Metro Lake Union facility. Relative to the lakeshore zone, the lake slope environment is deeper, farther offshore, and less influenced by erosive forces. Because of its lower-energy environment, the lake slope zone of SMA 9 also is subject to deposition of soft sediment, particularly along the lower slope as it approaches the deeper, flat lake bottom zone. PAH concentrations in SMA-9 sediment are greater than preliminary cleanup levels and shallow subsurface NAPL is present along the lake slope. There is a potential for vertical migration of NAPL to the sediment surface through dissolution and ebullition. The area is a potential risk to net fishers from exposure to impacted sediment. Sediments within SMA-9 demonstrate benthic toxicity.

Active marine operations including structures and berths are present within SMA-9. Constructed shoreline and in-water structures and facility operational requirements may affect implementability of some remediation technologies. The area is accessible to construction equipment from Lake Union but would require access agreements with the City, King County and WDNR.

10.3.11. SMA-10

SMA-10 consists of an approximately 0.55-acre sediment area in the northeastern area of the SCU generally at +10’ on the nearshore side and between +0’ and -16’ (USACE) offshore. (Figure 10-1). SMA-10 primarily includes the privately-owned Gas Works Park Marina. SMA-10 is used for vessel navigation and moorage including Gas Works Park Marina activities.

SMA-10 includes the lake slope portion of the Gas Works Park Marina. Due to its protected off-shore location, SMA-10 is less influenced by groundwater discharge and erosive forces. Because of its protected, lower-energy environment, the lake slope zone of SMA 10 also is subject to deposition of soft sediment, particularly in the deeper portions of the marina as it approaches the deeper, flat lake bottom zone. PAH concentrations in SMA-10 sediment are greater than preliminary cleanup levels.

Docks and dock infrastructure at the Gas Works Park Marina may affect implementability of some remediation technologies. The area is accessible to construction equipment from Lake Union but would require access agreements with the Gas Works Park Marina and WDNR.

10.3.12. SMA-11

SMA-11 consists of an approximately 6.2-acre sediment area in the south and eastern parts of the SCU generally between -5’ and -20’ (USACE) offshore of SMA-6 and between the OHWM and elevation -23’ (USACE) offshore of the till ridge shoreline (Figure 10-1). SMA-11 is accessible for recreation (beach play and wading) and for net fishing and is used for vessel navigation. However, as noted in Section 3.2.8.4, entering the water, and launching boats from the park are prohibited, as are swimming, fishing, and wading (in accordance with SMC 18.12.070. Following cleanup, the City will re-evaluate the need for these prohibitions.

SMA-11 includes the till ridge[125] and the steep lake slope area to the south and west of the till ridge. Relative to the bank and lakeshore zone, the lake slope environment is deeper, farther offshore, and less influenced by groundwater discharge and erosive forces. Because of its lower-energy environment, the lake slope zone of SMA-11 also is subject to deposition of soft sediment, particularly along the lower slope. The till ridge, a portion of which falls within the lakeshore zone, is included in SMA-11 with the steep lake slope areas because the remedy for both areas is expected to be the same. PAH concentrations in SMA-11 sediment are greater than preliminary cleanup levels. The area is a potential risk to park users (beach play and wading) and to net fishers from exposure to impacted sediment.

There are no over water structures, operating terminals, or berths in SMA-11. The area is accessible to construction equipment from Lake Union but would require an access agreement with WDNR.

10.3.13. SMA-12

SMA-12 consists of an approximately 7.2-acre sediment area in the western portion of the SCU, between SMA-9 and SMA-13 and generally between elevations between -18' and -20' (USACE) (Figure 10-1). SMA-12 is accessible for net fishing and is used for vessel navigation and moorage including Northlake Shipyard Yard activities.

SMA-12 lies completely within the lake bottom zone, which is deeper, farther offshore, and less influenced by erosive forces relative to the lake slope and lakeshore areas. Because of its lower-energy environment, the lake bottom zone of SMA-12 also is subject to deposition of soft sediment with high water content. However, contaminant concentrations are not expected to naturally recover to the degree necessary to achieve preliminary cleanup levels within an acceptable timeframe. PAH and arsenic concentrations in SMA-12 sediment are greater than preliminary cleanup levels, and co-located shipyard-related metals concentrations are also elevated. Shallow subsurface NAPL is present in SMA-12 and there is a potential for vertical migration of NAPL to the sediment surface through dissolution and ebullition. The area is a potential risk to net fishers from exposure to impacted sediment. Sediments within SMA-12 demonstrate benthic toxicity.

Active marine operations including structures and berths are present along the western portion of SMA-12, associated with the Northlake Shipyard, and affect implementability of some remediation technologies. The area is accessible to construction equipment from Lake Union but would require access agreements with King County and WDNR.

10.3.14. SMA-13

SMA-13 consists of an approximately 10-acre sediment area at the western limits of the SCU, off-shore of SMA-12 (Figure 10-1). SMA-13 is accessible for net fishing and is used for vessel navigation.

SMA-13 includes the lake bottom portion along the western SCU boundary. The area is deeper, farther offshore, and less influenced by erosive forces. Because of its lower-energy environment, the lake bottom zone of SMA-13 also is subject to deposition of thick, soft sediment with high water content. However, contaminant concentrations are not expected to naturally recover to the degree necessary to achieve preliminary cleanup levels within an acceptable timeframe. PAH and arsenic concentrations in SMA-13

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[125] The till ridge is shown on Figure 3B-5 of RI Appendix 2B.

sediment are greater than preliminary cleanup levels, and co-located shipyard-related metals concentrations are also elevated. The area is a potential risk to net fishers from exposure to impacted sediment. Sediments within SMA-13 demonstrate benthic toxicity.

There are no over water structures, operating terminals, or berths in SMA-13. The area is accessible to construction equipment from Lake Union but would require an access agreement with WDNR.

10.3.15. SMA-14

SMA-14 consists of an approximately 23-acre sediment area at the southern limits of the SCU (Figure 10-1). SMA-14 is accessible for net fishing and is used for vessel navigation.

SMA-14 includes the lake bottom portion along the southern SCU boundary. The area is deeper, farther offshore, and less influenced by erosive forces. This generally quiescent area, while somewhat affected by prop wash, is subject to long-term deposition of thick, soft sediment with high water content. As a result, SMA-14 is expected to naturally recover to achieve preliminary cleanup levels within an acceptable timeframe. Arsenic and cPAH concentrations in SMA-14 sediment are greater than preliminary cleanup levels. The area is a potential risk to net fishers from exposure to impacted sediment.

There are no over water structures, operating terminals, or berths in SMA-14. The area is accessible to construction equipment from Lake Union but would require an access agreement with WDNR.

11.0 IDENTIFICATION AND SCREENING OF REMEDIATION TECHNOLOGIES, AND INSTITUTIONAL CONTROLS

This section identifies and evaluates potentially applicable remediation technologies for the various contaminants, media, and conditions present within the SCU for the purpose of developing cleanup action alternatives in accordance with MTCA requirements specified at WAC 173-340-350. The technology screening process focuses on determining the most appropriate method to address remaining arsenic in upland groundwater for protection of sediment and surface water and on technologies for addressing contaminated sediment requiring remediation. The screening process is documented in Table 11-1 (arsenic in upland groundwater AKART evaluation) and Table 11-2 (sediment remediation technology evaluation).

Because of the range of conditions across the SCU and resulting range of applicable of technologies, the technology screening process considered the applicability of remediation technologies to the specific conditions within each of the identified management areas rather than for broad application of the technologies across the SCU. This approach results in a greater clarity for developing cleanup action alternatives for the SCU. The conditions that affect the applicability of remediation technologies within each of the management areas (GWMA-1 and SMA-1 through SMA-14) are described in Section 10. Table 11-3 presents the applicability of the retained technologies to the range of conditions within the SCU. Table 11-4 summarizes the remediation technologies that are retained for each management area based on environmental and use conditions.

This section also identifies institutional controls that may be required. Institutional controls are measures undertaken to limit or prohibit activities that may interfere with the integrity of the cleanup action or may result in exposure to contamination. Institutional controls are required by MTCA when cleanup actions leave contamination in place. Section 11.4 further discusses institutional controls.

11.1. Technology Screening Process

The MTCA procedures for conducting feasibility studies do not directly address screening of technologies but do provide guidance for screening out assembled alternatives prior to evaluation. Technology screening considered the complexity of contaminant distribution, contaminated media properties and other site conditions within the SCU that affect the applicability and performance of remediation technologies. The goal of the technology screening process is to ensure that the alternatives assembled in the next step of the feasibility study process are based on a set of technologies that are effective and implementable for the various conditions.

The remediation technology screening process is conducted within Tables 11-1 and 11-2, with the results discussed in the following sections and summarized in Tables 11-3 and 11-4. Technologies were evaluated independently as well as relative to other similar technologies with respect to the three primary screening criteria—effectiveness, implementability, and relative cost. For the technology screening process, effectiveness considered the ability to protect human health and the environment during and following construction and to meet preliminary cleanup levels. The evaluation of technology implementability included both technical and administrative feasibility – including the availability of products, services, and equipment needed to implement the technology safely and effectively, the ability to obtain necessary permits and regulatory and public acceptance. Cost is also considered at the technology screening level, but to a lower degree than effectiveness and implementability in favor of deferring the consideration of cost to the evaluation of alternatives. However, when multiple similar technologies are being evaluated, cost is considered to reduce the number of similar technologies used to develop alternatives.

Some technologies were not retained for further evaluation because they are not applicable or effective for conditions within a management unit or would be too difficult to implement (logistical issues would be difficult to overcome or implementation would exacerbate environmental conditions). Some technologies were not retained due to the administrative challenges (for example, siting and permitting restrictions for construction of on-site disposal facility to contain or dewater dredged sediment). The technology screening process used for this FS considered the varied conditions (contaminant, media, site use, etc.) present within the SCU and screened out or retained technologies for conditions based on the expected effectiveness and implementability for that condition.

11.2. Screening of Groundwater Arsenic Technologies for AKART

The majority of the upland groundwater contaminants have been addressed by the cleanup actions associated with the 1999 Consent Decree, described in Section 2.2. However, the 1999 Consent Decree predates the discovery of historical arsenic releases from the Thylox process at the Play Area. Supplemental investigation activities that focused on arsenic in the vicinity of the Thylox process area were conducted between 2013 and 2016 where releases associated from the Thylox process had impacted groundwater. In 2015, planning began to implement an interim action to address arsenic in groundwater within the footprint of the Play Area, where a renovation project was being planned by the City. An interim action was completed between 2016 and 2020 and is documented in the Play Area Interim Action Monitoring Report (GeoEngineers 2021). The interim action resulted in significant reduction of dissolved arsenic within the Play Area, but arsenic remains above preliminary cleanup levels within the Play Area as well as, downgradient of the Play Area outside the limits of the interim action. The arsenic remaining in upland groundwater associated with releases from the former Thylox process is described in Section 5.2.2.1.4 of the RI.

Section 9 proposes a CPOC for arsenic as close as technically possible to the location where groundwater flows to Lake Union, based upon meeting the conditions outlined in WAC 173-340-720(8)(d)(i). One of these conditions is that AKART be used for groundwater before discharge to surface water. The use of CPOCs for groundwater adjacent to surface water is addressed in the 2017 Implementation Memorandum No. 16, titled “Developing Conditional Points of Compliance at MTCA Sites Where Groundwater Discharges to Surface Water” (Ecology 2017c). The AKART requirement for the use of CPOCs is generally similar to the process required for industrial discharges to surface water, as described in Ecology’s Water Quality Program Permit Writer’s Manual (Ecology 2018). The AKART process is primarily technology-based with the goal of preventing discharges of contaminants to surface water, but also involves engineering and economic judgement. Selection of a treatment approach that meets the requirements of AKART is more stringent than the process for selection of the preferred alternative in the FS that is permanent to the maximum extent practicable using the disproportionate cost analysis method (Ecology 2017c). To identify a treatment approach for arsenic in upland groundwater that meets AKART, a range of treatment technologies specifically for arsenic in groundwater were evaluated as shown in Table 11-1. This evaluation included technologies ranging from MNA to in-situ treatment methods and barrier technologies, and considered effectiveness, implementability, and relative cost to select technologies that would be applicable and effective under conditions at the GWPS. The goal of the AKART evaluation is to develop an overall strategy for arsenic in groundwater that would be applied consistently as a common element of all alternatives evaluated in this FS. This differs from the goal of technology screening, which is to select a larger set of technologies that would be developed into alternatives for evaluation in the FS.

The technology evaluation presented in Table 11-1 resulted in the selection of two groundwater treatment technologies to be conducted as a combined strategy for groundwater treatment in both the fill and outwash units. In-situ treatment by chemical fixation was selected for arsenic in the outwash unit groundwater downgradient of the Play Area and the fill unit groundwater within and immediately downgradient of the Play Area, where dissolved arsenic concentrations remain high (greater than 10,000 ug/L) and indicators of thioarsenates (high pH, high sulfide, thioarsenate arsenic species) remain.

For fill unit groundwater downgradient of the Play Area where dissolved arsenic exceeds the cleanup level by a lower degree and geochemical conditions have returned to neutral pH, monitored natural attenuation was selected for treatment of dissolved arsenic.

A description of the retained technologies for arsenic in upland groundwater is presented in the following sections.

11.2.1. In-situ Chemical Fixation

In-situ treatment is defined as in-place treatment of contaminants without removing the contaminated medium from its natural or native location (Watts 1998). These technologies have been proven successful within the upland Play Area (GeoEngineers 2021) and are expected to effectively treat arsenic in upland groundwater downgradient of the Play Area. In-situ chemical fixation refers to a group of in-situ chemical treatment methods that facilitate the precipitation and/or adsorption of dissolved contaminants to the degree necessary to permanently partition the target contaminant in the solid phase. This process generally involves the placement of a reagent in-situ to manipulate groundwater geochemistry, including oxidation/reduction or pH/alkalinity conditions.

Fixation can be a cost-effective treatment option depending on the size of the area requiring treatment and the subsurface characteristics. A geochemical evaluation (Appendix 2B, Attachment 2B-2) was completed to determine the nature and extent of arsenic impacts in soil and groundwater and to characterize subsurface geochemical conditions as they affect arsenic fate and transport. Results from the geochemical evaluation provided the basis for arsenic treatability tests to develop amendments that can achieve cleanup objectives.

The application of in-situ chemical fixation for arsenic in groundwater involves manipulating local geochemistry for the purpose of reducing arsenic solubility and mobility. Modification of geochemical conditions to reduce arsenic solubility can be achieved using low-pH iron-based amendments, such as ferrous iron, which reacts with existing dissolved sulfide in groundwater to form an insoluble iron sulfide precipitate. Following the geochemical evaluation described above, treatability testing was completed to evaluate the suitability of reagents for remediation of arsenic in groundwater at the Play Area. The results of the treatability testing were documented in the Interim Action Work Plan (GeoEngineers 2017). Treatability testing determined that soluble iron salts such as ferrous sulfate are capable of significantly reducing dissolved arsenic concentrations through precipitation and adsorption. The addition of the acidic soluble iron reagent solution reduces the high pH conditions present because of the release of Thylox solution and provides excess iron to precipitate with the high sulfide concentrations in Play Area groundwater.

The ferrous sulfate treatment method evaluated in the treatability study was used successfully for arsenic in groundwater at the Play Area during the Play Area Interim Action completed between 2017 and 2020. The results of the interim action are described briefly in Section 5.2.2.1.4 and more completely in the Play Area Interim Action Monitoring Report (GeoEngineers 2021). The results of the interim action showed that in-situ chemical fixation treatment can be efficiently and effectively implemented to reduce arsenic concentrations in groundwater within the upland portion of the AOI. As a result, this technology is retained as a treatment strategy for arsenic in upland groundwater. This technology would be applied within and downgradient of the former Thylox process area where groundwater in the deep outwash and shallow fill units contains elevated arsenic concentrations and geochemical conditions are indicative of remaining Thylox solution and thioarsenate species of arsenic. Specifically, in-situ treatment of fill groundwater would be conducted in the area immediately surrounding and downgradient of the Kelly Filter, where high concentrations of arsenic remain in the pathway of the downward migration of Thylox solution to the outwash unit. The in-situ treatment of outwash groundwater would be conducted between the Play Area and the shoreline, or as far beyond the shoreline as possible without releasing reagent directly to Lake Union. In-situ chemical fixation will be included in the alternatives evaluated in this FS to meet the AKART condition for establishing a CPOC for arsenic in upland groundwater under WAC 173-340-720(8)(d)(i).

11.2.2. Monitored Natural Attenuation

Natural attenuation relies on a combination of physical, chemical and biological processes to reduce the concentrations of contaminants in groundwater (EPA 2012). Specific natural processes that can facilitate the reduction of contaminant concentrations in groundwater include biodegradation, sorption, dilution, evaporation, and chemical reactions that modify the mobility or toxicity of the contaminants. MNA as a treatment technology uses these natural processes without assistance to reduce contaminant concentrations in groundwater, while monitoring is conducted to document the effectiveness of the processes.

Natural attenuation of inorganic contaminants does not involve destruction of the contaminants but relies on the existing natural geochemical conditions to promote precipitation and/or adsorption outside the source area where conditions may favor dissolution of the inorganic contaminants. Dissolved arsenic in groundwater at the Play Area has been demonstrated to behave in this manner, particularly in downgradient areas outside the direct influence of released sodium thioarsenate solution and the associated alkaline conditions. The geochemical evaluation (Appendix 2B, Attachment 2B-2) conducted for arsenic at the Play Area indicates that conditions are favorable for precipitation and adsorption of elevated dissolved arsenic associated with upgradient releases from the Thylox process. Specifically, high concentrations of naturally occurring iron and high concentrations of sulfide present from the breakdown of thioarsenates has resulted in the precipitation of iron-sulfide minerals. This precipitation process has sequestered arsenic in the mineralized forms described in the geochemical evaluation, but these precipitated minerals also sequester dissolved arsenic by adsorption. In areas downgradient of high concentration arsenic and alkaline conditions associated with the thioarsenate source, the presence of these precipitates in soil effectively attenuate lower concentrations of arsenic by adsorption. This is observed in fill unit groundwater as arsenic concentrations in groundwater decline substantially as groundwater travels from the Play Area through fill soil toward the shoreline.

Groundwater MNA is retained for use as an element of the overall strategy to treat dissolved arsenic downgradient of the Play Area. MNA for arsenic would be used for fill unit groundwater downgradient of higher arsenic concentrations proposed to be treated using in-situ chemical fixation, where concentrations are lower, but still above preliminary cleanup levels.

11.3. Screening of Sediment Remediation Technologies

This section presents the screening process for sediment remediation technologies to be used to develop cleanup action alternatives for contaminated sediment within the SCU. The range of technologies evaluated was drawn from those listed in SMS (WAC 173-204- 570[4][b]) for cleanup of contaminated sediment and information from several guidance documents including:

- Palermo et al. (1998) Guidance for In-Situ Subaqueous Capping of Contaminated Sediments
- EPA (2005) Contaminated Sediment Remediation Guidance for Hazardous Waste Sites
- USACE (2008) Technical Guidelines for Environmental Dredging of Contaminated Sediments
- EPA (2013) Use of Amendments for In-situ Remediation at Superfund Sediment Sites
- Interstate Technology and Regulatory Council (2014) Contaminated Sediments Remediation
- EPA (2014b) Contaminated Site Cleanup Information (CLU-IN) website
- Ecology (2021) SCUM guidance

Several categories of sediment remediation technologies were evaluated, including in-situ treatment, removal, capping, natural recovery, and institutional controls. Within each of these categories, multiple individual technologies were evaluated and screened against contaminant conditions and respective cleanup goals, other environmental conditions associated with contaminated sediment, and current and future uses within and adjacent to the SCU. Due to the varied conditions of sediments within the SCU, many of the technologies evaluated are applicable only to specific conditions, areas, or contaminants.

The sections below describe the screening process for sediment remediation technologies. Table 11-2 presents the overall screening process for sediment remediation technologies. Table 11-3 presents the applicability of the retained technologies to the range of conditions within the SCU and Table 11-4 summarizes the remediation technologies that are retained for each SMA based on environmental and use conditions.

11.3.1. Sediment and Debris Removal

Multiple sediment removal technologies were evaluated in the technology screening process and have been retained for consideration in this FS for at least two purposes: removal of lakeshore sediment to accommodate placement of cap material and removal of contaminated sediment for mass removal. The removal technologies retained for inclusion in cleanup action alternatives include land-based excavation, mechanical dredging, and hydraulic dredging. Each of these removal technologies will require the use of environmental protection best management practices (BMPs) to prevent impacts to surface water within and outside the immediate area of removal activity. These BMPs would range from common stormwater pollution prevention elements for upland construction to bottom-anchored silt curtains for offshore dredging. Specific BMPs are not addressed separately in this technology screening process but are considered integral to the individual removal technologies.

The technology screening resulted in all three removal technologies being retained for inclusion in cleanup action alternatives due to their applicability for varying conditions within the SCU, as presented in Table 11-2. Table 11-3 presents the specific conditions for which the removal technologies are retained. Further discussion of each of the retained removal technologies is presented in the following sections.

11.3.1.1. Land-Based Excavation

Land-based excavation is retained for removal of bank soil and nearshore sediment using common land-based earthwork equipment during low-water periods or behind a dewatered cofferdam. Land-based excavation would be used in conjunction with cofferdams and dewatering techniques, resulting in a lower risk for releasing contaminants to surface water relative to traditional dredging methods that remove sediment through the water column. However, this technology has depth limitations associated with available cofferdam technologies. For the purpose of evaluating the applicability and cost of land-based excavation, the cofferdam method effectiveness to dewater the excavation is assumed to be limited to a water depth of 10 feet. Land-based excavation is retained for nearshore conditions where the upland area adjacent to the sediment removal is accessible, available, and suitable for conducting excavation activities and is generally limited to areas adjacent to Gas Works Park.

11.3.1.2. Mechanical Dredging

Mechanical dredging is a common environmental dredging method for removal of sediment in offshore environments where removal is accomplished through the water column. Mechanical dredging utilizes a bucket mounted on a fixed-arm excavator or deployed via a crane and cable; the work platform can be floating, on the shoreline or on a dock. Dredging methods considered for use within the SCU are limited to established and proven methods for removal of contaminated sediment, designed for minimal loss of material during operation.

Dredging buckets vary in purpose and size. Conventional dredge buckets are typically used to dig out material for navigation purposes with little regard to resuspension of sediment whereas enclosed/environmental buckets are typically used when it is necessary to control release of dredged material. For the purpose of evaluating dredging technologies, enclosed/environmental buckets are considered feasible for large-scale contaminant removal, although final selection of mechanical dredging equipment would be identified by the contractor based on the performance criteria of the specifications. Navigation/conventional bucket types may not be feasible for contaminant removal on a large scale because they create irregular cratered sediment surfaces, leave behind residual material and release sediment throughout the water column during operation. Conventional dredge buckets are heavy and can penetrate into consolidated sediment and can more effectively remove both large debris and debris-laden sediment. However, when removing larger debris, the jaws of the mechanical dredge bucket may not completely close, resulting in higher sediment resuspension (USACE 2008).

Physical Conditions Affecting Feasibility of Mechanical Dredging – Effectiveness and efficiency of mechanical dredging methods are influenced by physical conditions such as the presence of structures, debris, degree of slope, water depth, slope stability and sediment characteristics. This section describes the analysis of physical conditions that are expected to affect the feasibility of sediment removal by mechanical dredging within the SCU.

- Debris – The presence of debris in the dredge area affects the ability of dredge buckets to remove sediment without releasing and subsequently resuspending contaminated material. Even moderately sized debris can preclude full closure of the bucket. Overall, the presence of offshore debris creates a significant challenge for removal of contaminated sediment. Locations of offshore debris, trash and other miscellaneous objects are depicted in Figure 3-5.

- Over-water and Underwater Structures – Permanent structures that may impede dredging include the docks and pilings (as well as their supporting underwater cables and wires) within Waterways 19 and 20, Gas Works Park Marina, and Harbor Patrol and the bulkhead associated with the Prow. To prevent undermining or otherwise weakening the Prow structure, dredging would be restricted in the area immediately in front of the bulkhead. The areas characterized by docks, piles, cable supports, etc. will restrict the access and feasibility of some mechanical dredging equipment, such as cable-arm methods. Furthermore, dredging in these areas could risk the undermining or weakening existing structures.
- Soft Sediment – Soft sediment presents significant limitations to effective dredging of contaminated sediment. The fluid properties of very soft sediment (fluid mud) in the lake bottom and portions of the lake slope area of the SCU are highly susceptible to suspension during dredging operations. Fluid mud is disturbed by the process of grabbing a bucket of sediment for removal but can also be resuspended by the hydraulic forces of the dredge bucket movement—both the hydraulic shock wave that precedes the bucket as it approaches the bottom and disperses sediment and the resulting vacuum and flow created by raising the bucket through the water column. As a result, contaminated fluid mud residuals would flow into or be redeposited in the cut area and be resuspended. Once resuspended, the fluid mud plume is capable of being transported outside of the dredge prism before settling. Limiting dredging in fluid mud areas to the use of tight-closing environmental buckets can prevent some resuspension of very soft sediment that would otherwise flow out of the gaps of a conventional dredge bucket. However, environmental bucket performance is adversely impacted by the presence of debris, which is prevalent in the SCU, thereby preventing complete closure of the bucket and eliminating the benefit of this method.

  Dredging BMPs would be required for environmental dredging to reduce impacts to the surrounding environment as a result of disturbed sediment and localized mobilization of sediment contaminants to the water column. Due to the water depths where a thick layer of soft sediment is present, use of common hanging silt curtains may only be partially effective to minimize release of suspended sediments or fluid mud at the sediment surface as they would not extend fully to the sediment surface. More innovative dredging BMPs like anchored full-depth silt curtains and bubble walls/curtains may reduce the transport of suspended sediment to areas outside the dredging footprint. However, these methods would likely not contain denser mud waves at the sediment surface generated by dredging soft sediment, will have reduced effectiveness for dissolved contaminants and NAPL mobilized by dredging, and will be negatively impacted by wind and wake generated waves and flow of water through the ship canal. These BMPs also do not reduce suspended solids within the dredging area, resulting in recontamination of the dredge prism upon resettling of sediment and transport to other areas if the BMPs are removed too early.

  For the purpose of selecting areas that may be feasible to dredge, only areas with less than 3-feet thickness of soft sediment (fluid mud) were considered for dredging. The less-than-3-foot thickness constraint is based on the assumed “bite” of an environmental dredge bucket and the need to contact underlying consolidated sediment to effectively remove the overlying soft sediment. As shown on Figure 11-1, areas with thicker deposits of soft sediment beginning about 100 to 300 feet from shore are not considered suitable for dredging. However, given the potential for debris within the SCU, dredging of soft sediment is expected to result in some degree of resuspension of contaminated sediment. Additional discussion of the soft sediment conditions and the considerations for dredging soft sediment within the SCU are presented in Appendix 11A.

- Steep Slopes – Sediment areas with slopes greater than 5H:1V were considered steep for this analysis and mapped as shown on Figure 11-2. Steep slopes are confined to the nearshore area within 150 feet of the shoreline. The use of environmental buckets attached to a cable-arm in areas with steep slopes is not considered feasible as the bucket cannot conform to the slope to make a precise cut. As a result, the potential for incomplete removal and potential release and resuspension is high (USACE 2008). Fixed-arm excavators, whether land-based or barge-mounted, that use an articulated clamshell bucket could be used in steep areas along the shoreline, given adequate access.
- Dense Sediment – When a layer of contaminated sediment sits immediately atop a hard layer that contaminants cannot penetrate, there is no intervening layer of clean sediment and thus no opportunity for the overdredging needed to ensure complete removal of the targeted contaminated sediment and associated dredging residuals (USACE 2008). This circumstance is particularly problematic when the contaminated sediment layer is thin (0 to 1 foot thick) overlying a dense layer, as is found in the area of the glacial till ridge[126] that extends southeast from the shoreline east of the Prow.
- Slope Stability – The fill material underlying the bank and shoreline and the upper portion of adjacent steep slopes are generally stable and can likely support cut slopes of 2H:1V, as evidenced by similar existing slopes (Appendix 11B). However, soft sediment deposited along the lower slope and on the lake bottom is much less stable because of high water content and can likely support only cuts of 5H:1V or flatter. Dredging in soft sediment would likely result in significant contaminant redistribution downslope from the point of dredging or in dredge cut side-slope failure. In addition, to achieve relatively flat dredge cuts in soft sediment a much greater volume of sediment outside of the targeted removal area would need to be removed. See Appendix 11B for further discussion regarding slope stability within the SCU.
- Use of Spuds – Removal of targeted sediment requires that dredging equipment maintain position. For most environmental dredging operations in nearshore areas, the position of the dredge is maintained using spuds. Typically, large steel columns that penetrate through the dredge (spuds) are lowered into the sediment to hold the barge in place. For proper anchoring, the steel columns must penetrate through softer sediment into a denser layer. Given the prevalence of soft sediment at the Site, the spuds may have to be driven and withdrawn through several feet of soft material. The ensuing disturbance of sediment and potentially shallow subsurface NAPL could create a pathway for contaminant release and redistribution. Setting spuds in the thick layer of soft sediment prevalent outside of the nearshore zone could lead to significant resuspension of contaminated sediment. Given these issues with the use of spuds, alternative positioning methods may be required to minimize sediment disturbances.

Contaminant Distribution Factors Affecting Applicability of Dredging – in addition to the physical constraints described above, the distribution and form of contaminants within the SCU pose difficulties that are expected to limit the areas where dredging is feasible without a high risk of release and redistribution of contaminants.

- NAPL – For a number of reasons, the presence of DNAPL within the dredge prism poses serious challenges. The process of dredging sediment containing DNAPL would very likely result in mobilization of contaminants to surface water and sediment beyond the dredge limits. The majority of the DNAPL is subsurface, within or isolated below cPAH-impacted sediment targeted for dredging. Dredging could

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[126] The till ridge is shown on Figure 3B-5 of RI Appendix 2B.

expose less weathered DNAPL that, once exposed, would undergo phase separation and mobilization of a lighter fraction including benzene and naphthalene; their mobilization, in turn, would cause significant water and air quality impacts. DNAPL has likely come to rest near the interface between soft sediment and denser till or fill or occurs as thin “stringers” that are difficult to accurately delineate. This distribution would impede complete removal with an environmental bucket, resulting in significant releases of contaminants to the water column during dredging and residual contamination within and potentially beyond the area being dredged. Backfill or capping material placed after dredging would also be at risk for recontamination. Common dredging BMPs are unlikely to reliably limit NAPL mobilization and dispersion, given the high water content of the sediment, presence of a significant amount of debris, and other factors. Dredging within and near the footprint of NAPL impacted sediment directly through the water column is infeasible without the use of cofferdams to dewater the area being dredged and limit transportation of released contaminants.

- TPAH – The primary sediment contaminants within the SCU are PAHs and arsenic. The most widespread sediment contaminant group is TPAHs. In many areas of the SCU, TPAH concentrations exceeding the cleanup level extend to approximately 20 feet below mudline and are typically higher at depth than at the surface. Source removal in these areas would require dredging to depths that are infeasible for complete removal. The depths required to achieve complete removal of sediment with TPAH concentrations above preliminary cleanup levels would generate significant unstable side cuts unless the dredge prism was expanded to a much broader area. These TPAH impacts are also present in deeper, dense sediment that cannot be dredged using environmental dredging methods, as well as in deeper soft sediment that poses a high risk of contaminant dispersion during dredging. Where the sediment TPAH concentrations increase with depth, TPAH concentrations in the exposed sediment at the limits of feasible dredging would be higher than at the existing mudline, thus requiring the use of the same or more robust capping methods to contain the exposed sediment as would be required if the area was not dredged.

Mechanical dredging is retained for inclusion in cleanup action alternatives in this FS, but only for specific conditions within the SCU based on the discussion above. Mechanical dredging is retained for conditions that can be efficiently and effectively dredged using environmental dredging methods and that will not pose a high risk of dispersing contaminants outside the area being dredged or beyond the limits of the SCU. Mechanical dredging is screened out for consideration where conditions are not suitable for dredging based on the discussion above, primarily areas of thick, soft sediment and areas where NAPL and TPAH source areas may be present.

11.3.1.3. Hydraulic Dredging

Hydraulic dredging is the process of removing sediment as a slurry through entrainment of water. The fundamental component of hydraulic dredging is the use of a hydraulic pump that provides suction at the point of dredging to remove the mixture of sediment and surface water and propel the extracted slurry to the surface point of discharge. The material generated by hydraulic dredging is generally low-solids, high-fluid slurry that can be removed by suction and transported by pipe from the point of dredging to the location for dewatering and/or treatment (USACE 2008).

Hydraulic dredging can rely purely on the suction of the hydraulic pump to generate enough fluid flow to entrain the sediment targeted for dredging. However, the addition of components such as cutterheads, augers, and water jets may be necessary to dislodge consolidated sediment to allow extraction by the hydraulic pump. The scale of hydraulic dredging varies greatly as well. Small scale operations using purely suction, operated manually by divers (diver-assisted hydraulic dredging), can achieve efficient removal of low volumes of sediment around structures and in areas where more aggressive removal methods may damage structures. Hydraulic dredging methods are also applicable for large scale removal projects where large cutter heads operate on a submerged ladder that is swept across the sediment surface to complete removal.

Hydraulic dredging relies on the extraction and transport of sediment as a high-fluid mixture. The benefit of this hydraulic process is that the extracted slurry flows contained through a network of pipes and pumps from the point of dredging to the point of discharge, containment, or treatment. Hydraulic dredging is commonly used for maintenance or navigation dredging of clean sediment that allows the piped slurry to be pumped to an upland settling facility (pond, tank, etc.) and the decanted fluids discharged without treatment. However, for environmental dredging scenarios, the high-fluid slurry results in a significant increase in the volume of wastewater generated. The use of hydraulic dredging of contaminated sediment typically requires containing and dewatering the extracted slurry, as well as treatment of the separated water, in addition to off-site disposal of the contaminated dewatered sediment targeted for dredging.

Despite the suction process involved in hydraulic dredging and the waste stream being contained as it is pumped from the point of dredging, hydraulic dredging does have the potential to generate suspended solids and other contaminant releases during dredging, as well as leave behind residuals following dredging. When using a cutterhead to dislodge sediment for removal, some sediment, and contaminants, can be displaced beyond the influence of the removal by suction. The cutting and plowing action, particularly with the use of a swinging side-to-side dredging action, can generate more high-fluid sediment than can be extracted. This can result in suspended sediment within the water column as well as a layer of sediment left behind as the suction head advances. This layer is referred to as the spillage layer and will be an unconsolidated mixture of the contaminated sediment. Effective dredging will require that this spillage layer be removed during subsequent passes of the dredge. Contaminants present in the sediment targeted for dredging, particularly organic contaminants and NAPL that would not immediately settle in the spillage layer, have a high potential to disperse beyond the immediate dredging footprint, potentially impacting areas that have already been dredged or capped, as well as areas outside the SCU.

Because hydraulic dredging generates such a high-volume water waste stream, large scale implementation for contaminated sites can be cost prohibitive due to the volume of wastewater requiring treatment and/or disposal and requirements for a large upland footprint for the treatment and dewatering process. Within the SCU, the use of large-scale hydraulic dredging would require a large portion of the park for dewatering and water treatment. In addition, the use of large-scale hydraulic dredging relying on cutterhead methods would likely exacerbate contaminant conditions due to the presence of organic contaminants, including NAPL, in shallow subsurface sediment that would be disturbed by the dredging. Because of these factors, hydraulic dredging is not retained for large-scale application across the majority of the SCU. However, hydraulic dredging, in the form of small-scale diver-assisted dredging, is retained as a potential removal technology for inclusion in cleanup action alternatives in this FS. Specifically, in nearshore areas where mechanical dredging would not be feasible due to accessibility issues, diver-assisted dredging could be used to remove sediment in scenarios where dredging is used to prepare the lake bottom for capping.

11.3.2. In-situ Treatment

In-situ treatment for sediment is defined in Ecology’s SCUM (2021) as the use of chemical amendments or reagents in sediment remediation, either by placement or mixing of the amendments directly with the sediment or by mixing the amendments within cap material that would be placed immediately over the sediment. This section focuses on the technologies available for amendments or reagents that would be used for in-situ treatment. The technologies that were retained for inclusion in cleanup action alternatives in this FS include several amendment technologies that would be implemented in conjunction with capping methods discussed below in Section 11.3.3. In-situ treatment technologies that involved mixing the amendments with sediment were evaluated but screened out due to the expectation that mixing amendments with sediment would exacerbate contaminant mobility and would result in contaminant release before the amendments could be effective. The sections below describe the various in-situ treatment amendments retained for inclusion in cleanup action alternatives in this FS. To avoid releases from mixing the contaminated sediments, the in-situ treatment amendments are applied to the sediment surface to enhance the chemical isolation and attenuation functions of a cap. More detail regarding capping methods that may incorporate amendments is outlined below in Section 11.3.3.

11.3.2.1. Activated Carbon

Activated carbon (AC) is widely used for remediation applications, including sediment remediation projects. Activated carbon strongly partitions soluble organic contaminants to the solid phase, reducing concentrations in the aqueous phase, and thus mobility, and reduces the bioavailability of contaminants. Activated carbon can adsorb a wide range of hydrocarbons but is most commonly used for dissolved lighter end hydrocarbons, including naphthalene and benzene. Activated carbon is not generally used for scenarios where NAPL may be intercepted, as the high concentrations will foul the matrix and quickly utilize the adsorption capacity.

The use of activated carbon for in-situ sediment remediation involves incorporating a layer, or a mixture, of activated carbon with sand to create a cap that achieves treatment by adsorption of dissolved phase hydrocarbons (benzene, naphthalene, some PAHs). Activated carbon can be mixed or implemented in series with other amendments to bind additional contaminants in the sediments, such as NAPL. The lightweight nature of common granulated activated carbon (GAC) can make it difficult to effectively place as a uniform sand/AC mixture through the water column, but advances in AC materials have addressed this issue and it can be placed as mats or other forms using proprietary materials.

11.3.2.2. Organoclay

Organoclay is a bentonite clay that is chemically modified from hydrophilic to organophilic to absorb organic contaminants, including NAPLs. Organoclay has been developed as a sediment remediation technology for sites with potentially mobile NAPL, effectively blocking the migration of NAPL mobilized by groundwater flow or ebullition through a sediment cap. Organoclay can also be used for dissolved organic contaminants, in particular higher molecular weight organics such as dissolved PAHs.

The use of organoclay as a cap amendment involves incorporating a layer or a mixture, of granular organoclay with sand to create a cap that achieves treatment by absorption of NAPL and adsorption of dissolved phase PAHs. The elements of the conventional sand cap, described more completely in Section 11.3.3 below, would provide the needed barrier to direct contact exposure at the point of compliance as well as protection of the amended cap components.

11.3.2.3. Zero-Valent Iron

Zero-valent (ZVI) is an established chemical treatment reagent/amendment for several contaminants, including arsenic. ZVI particles have a reactive surface that can promote the precipitation and adsorption of dissolved arsenic. Treatability testing in support of the Play Area Interim Action Work Plan (GeoEngineers

2017) tested the performance of remediation of dissolved arsenic by ZVI and determined that dissolved arsenic in upland groundwater has a strong affinity for adsorbing on ZVI. Treatability testing indicated that arsenic is strongly sequestered into ZVI in stable sulfide phases formed by the corrosion of iron.

Similar to other in-situ methods described above, in-situ treatment using ZVI involves incorporating a layer, or a mixture, of granular ZVI with sand to create a cap that treats mobile dissolved arsenic in sediment by precipitation and adsorption.

11.3.3. Sediment Capping

Sediment capping is a common containment technology that involves placement of clean material over contaminated sediment. Caps stabilize the underlying sediment to prevent disturbance, resuspension, and transport of contaminants to other areas and reduce migration of dissolved contaminants to the sediment biologically active zone and the overlying water column, thus preventing exposure to ecological and human receptors. Caps can also be designed to enhance habitat functions.

Capping Objectives and Performance Considerations – Caps meet the objectives of physical, chemical, and biological isolation by placing cap material (commonly clean dredged sediment or upland sourced pit-run sand or gravel) of various thicknesses on the sediment surface; amendments, as described above in Section 11.3.2, or geotextiles (e.g., fabric layers or media-filled mats) can also be used to provide specific cap functions. Conventional sand caps are generally effective where the contaminants of concern tend to be strongly bound to sediment, groundwater flux is low, no mobile NAPL is present, and erosive forces are fairly weak (ITRC 2014). Where these conditions are not met, effective caps can still be designed. A thick conventional sand cap can provide greater retardation of contaminant flux or mobile NAPL than a conventional 2-foot-thick layer of sand. In some cases, thick caps can serve as a containment/sequestration layer for mobile NAPL or provide capillary resistance for NAPL entry into the capping layer, depending on the size of the capping material. Amendments such as activated carbon or organophilic clay can provide chemical treatment and isolation functions but with a thinner cap profile. Geotextiles can be used to stabilize sediment and introduce amendments or treatment materials within the cap profile. Geotextiles can also serve as biological barriers, depending on the design and performance objectives.

The final cap construction will need to meet specific requirements for preservation of upland, shoreline or surface water acreage, navigation depths, and habitat. Cap composition must accommodate current and planned (to the extent known) uses of the SCU and adjacent upland areas, as well as local natural processes (e.g., bioturbation, consolidation, erosion, groundwater flow) and conditions (e.g., slope, bathymetry). These factors, in addition to contaminant isolation and attenuation requirements, typically result in a layered approach to capping, as recommended by USACE and EPA (Palermo et al. 1998; EPA 2005).

Cap Placement Considerations – Caps can be placed above the mudline or below-grade following partial removal of contaminated sediment; the latter applies where above-grade capping would interfere with navigation or other aquatic uses, habitat, and bed stability. Cap placement technologies vary based on the type of material being placed, water depth, and the geotechnical properties of the in-place contaminated sediment. Typical distribution of cap material involves releasing material at the surface of or within the water column and allowing it to settle to the bottom. Release mechanisms include dumping from a barge or hopper, hydraulic spreading (washing from a barge), broadcasting, and pumping a slurry through a floating or fixed pipeline or diffuser. Cap material can be directly placed on the bottom by a tremie tube, by a barge or land-based backhoe or dredge bucket, or by divers (USACE 2008). If amendment or treatment materials are to be incorporated in the cap, additional mixing or handling will be required prior to placement, unless the amendments are introduced as a discrete layer to the cap.

Short-term risks associated with cap placement include disturbance and resuspension of contaminated sediment, displacement of potentially contaminated porewater into the water column upon sediment consolidation and smothering of benthic communities and aquatic vegetation. The degree of resuspension is affected by the type of material being placed, the method of placement, the degree of consolidation of the in-place sediment and contact or potential impact of the capping material with bottom materials. If clean dredged sediment or denser material is to be used for capping, sediment descent rates can be higher, which can disturb the contaminated sediment. Hydraulic placement or use of diffuser or baffle/spreader plates can mitigate contaminated sediment resuspension.

Where the sediment to be capped is very soft (such as fluid mud), cap materials can sink into and mix with the contaminated sediment, reducing the cap's intended degree of chemical and physical isolation. Phased placement of cap materials in thin lifts or layers can strengthen the underlying contaminated sediment through consolidation as well as limit mixing and recontamination of the cap. Caps have been successfully built in this manner where sediment has extremely low shear strength or bearing capacity (ITRC 2014). Hydraulic spreading or other methods of delivery that result in even placement can result in less deformation and destabilization of the cap surface, which also serves to limit mixing and recontamination of cap material.

Consolidation of contaminated sediment by placement of cap material can result in a short-term displacement of porewater, which may impact surface water quality. Amendment or treatment materials can be incorporated to reduce this impact as can limiting the placement rate of the cap material. Capping material consisting of natural sediment may also mitigate dissolved contaminant release, as its higher organic carbon content promotes adsorption of dissolved contaminants.

Where a thick cap is constructed, temporary loss of the benthic community and aquatic vegetation is inevitable, although subsequent recruitment would provide some degree of restoration. Incorporation of habitat material as part of the cap surface can enhance recolonization by benthic invertebrates and aquatic vegetation; benthic community recovery occurs within months to years. Thinner caps (less than or equal to the depth of the biologically active zone) can be placed in thin lifts to limit smothering and accelerate benthic community recovery.

Cap Performance Considerations – Five discrete cap performance considerations were evaluated for capping technologies and process options within the SCU: mixing/consolidation of underlying sediment, physical isolation, chemical isolation/attenuation, erosion, and bioturbation:

- Mixing/Consolidation Layer – In areas where the existing sediment surface is soft and easily disturbed, the cap material must be placed slowly to gradually mix with and consolidate the existing sediment. Otherwise, the sediment could be displaced, the cap material could simply pass through the soft sediment, or the cap material could promote differential consolidation and settlement. Placement of sand capping material on soft sediment will be performed at a slow rate, which has been shown to consistently consolidate the soft sediment within the SCU (Appendix 11B), creating a base strong enough to support the remaining cap material. Appendix 11B presents an evaluation of capping procedures for lake bottom soft sediment, indicating that placement of cap material slowly, as layers, will allow consolidation of the capped sediment. The thickness of the mixing/consolidation layer will be determined during cap design based on specific characteristics of the in-situ sediment and the cap material.

- Physical Isolation – The primary cap layer is designed to isolate the contaminated sediment from the biologically active zone (assumed to be 10 cm) at the cap surface and the overlying surface water. In areas of insignificant groundwater flow and contaminant diffusion through the existing sediment, the cap design needs to meet the respective preliminary cleanup levels at the points of compliance, while achieving physical stability and suitable thickness considering bioturbation, as noted below.
- Chemical Isolation/Attenuation – In areas where groundwater discharge through the existing sediment could transport contaminants from the sediment to surface water, chemical isolation or attenuation must be designed into the cap. This chemical isolation or attenuation may come from additional cap thickness, inclusion of an impermeable or low-permeable layer or incorporating in-situ treatment methods described in Section 11.3.2 to retard contaminant transport (i.e., organoclay for NAPL or zero valent iron for arsenic).
- Erosion – Cap construction needs to consider erosive forces. Under some conditions, this process can be addressed by adding cap material that will essentially be sacrificed to erosive forces and regularly replaced. Most often, the cap is stabilized by an armor layer. The cap construction within the SCU will consider the erosive forces acting on the shoreline and bank surfaces within the lakeshore area, the deeper sloped portions of the lake slope, as well as the deep, flat lake bottom areas of the lake. The highest erosive forces are observed from the bank down to approximately 10 feet of water depth in lakeshore areas, with forces resulting from wind-driven waves, vessel wakes, and prop wash. The highest forces from wind-driven waves occur where the shoreline is aligned east/west normal to the common north/south direction (fetch) of Lake Union waves. Wind-generated waves in the north-south direction are stronger than boat wakes and would drive armoring of granular cap material. Wind-generated waves are not expected to affect cap material stability where the cap surface would be below 10-foot water depth. Prop wash driven disturbances from larger boats travelling through the Ship Canal observed even in the deepest lake bottom regions of Lake Union will be considered in cap design. Further discussion of hydrodynamic conditions within the SCU is presented in Appendix 3G. Cap design considerations for developing the alternatives in this FS included armor sizing based on the hydrodynamic conditions in Appendix 3G.
- Bioturbation – Cap design and construction also needs to account for the effects of aquatic organisms living in or on sediment. Bioturbation can mix underlying sediment with cap material as organisms burrow, entrain overlying water through respiration or burrow irrigation, and ingest and excrete sediment, among other processes. The bioturbation layer of the cap design lies above the chemical isolation/attenuation component and will be accounted for in the overall cap thickness. Bioturbation effects are anticipated to be limited in Lake Union due to its seasonal anoxic conditions; benthic communities tend to be composed of very small, annual species that do not burrow deeply into the sediment.

The conditions affecting cap construction and performance vary significantly within the SCU. The lakeshore areas are exposed to greater hydrodynamic forces from wind- and boat-generated waves, have steeper slopes, discharge more groundwater to Lake Union and are characterized by significant surface and subsurface debris. Lake slope areas farther from the shoreline are less affected by hydrodynamic forces but are relatively more affected by issues of slope stability and of sediment strength and bearing capacity.

Lake bottom areas within the SCU are minimally affected by hydrodynamic forces and large-scale slope stability, but the presence and thickness of soft sediment constrain the applicability of capping methods because of mixing and local stability issues during cap placement.

Retained Capping Technologies – Capping methods that physically isolate contaminated sediment as well as those that chemically isolate/attenuate contaminants have been retained for consideration in this FS. The retained capping technologies are conventional sand cap, low-permeability cap, and amended caps (using in-situ treatment methods described in Section 11.3.2). For transitioning from technology screening to development of cleanup action alternatives, the low-permeability and amended capping technologies are grouped together and termed “enhanced” capping.

Further discussion of the application of the capping methods are described below and in Section 12 as they are applied to the individual alternatives. The general applicability of retained capping technologies for the various conditions within the SCU is presented in Table 11-3. The applicability of retained capping technologies for the various SMAs is presented in Table 11-4.

- Conventional Sand Cap – The design thickness of a conventional cap varies based on specific conditions. The sand cap provides a physical barrier between the sediment biologically active zone and/or surface water and the underlying contaminated sediment, while also providing clean media through which contaminants subject to transport by advection and diffusion attenuate; however, the low-organic content of a conventional sand cap limits the degree of attenuation, particularly for organic contaminants. Conventional sand capping is suitable technology for implementation across broad areas of the SCU; thick sand caps are considered for areas with shallow subsurface NAPL or areas of higher contaminant flux.
- Low-Permeability (Enhanced) Cap– To simplify development and evaluation of cleanup action alternatives, low-permeability caps and amended sand caps are grouped together and termed enhanced caps. Low-permeability caps are engineered to retard or prevent the flow of groundwater through the contaminated sediment and into the sediment biologically active zone or surface water. A low-permeability cap may be constructed to direct groundwater flow away from sediment with higher concentrations of mobile contaminants that may become entrained in migrating groundwater. Low-permeability capping methods may utilize an engineered clay cap, a proprietary product such as AquaBlok®, a geomembrane/composite cap or grout mats. The low-permeability cap would effectively prevent groundwater-mediated migration or release of contaminants in sediment and porewater into the water column. Clay caps and AquaBlok® could be implemented in the deeper areas of the lake slope where sediment is of suitable strength. Low-permeability geomembranes and grout mats could be implemented in the nearshore areas. Gas collection strips may be installed beneath the low-permeability geomembrane liner to allow passive release of potential gas build-up below the liner. This would prevent gas build-up and discharge and potential damage to the cap. Low-permeability caps are included for the nearshore areas with high groundwater flux or deeper areas with shallow subsurface NAPL subject to mobilization by groundwater flow or ebullition.
- Amended Sand (Enhanced) Cap – To simplify development and evaluation of cleanup action alternatives, amended sand caps and low-permeability caps are grouped together and termed enhanced caps. Amended sand caps combine in-situ treatment methods described in Section 11.3.2 with the isolation elements of a conventional sand cap. The cap design can include specialized materials to treat mobile contaminants or NAPL. Various types of amendments (e.g., activated carbon,

organophilic clay, ZVI) attenuate the flux of contaminants from the underlying contaminated sediment to the overlying water column. Activated carbon amendments would be used for areas affected principally by benzene and naphthalene. Organoclay would be used for areas affected principally by naphthalene, cPAHs and NAPL. ZVI would be used in areas affected principally by arsenic. Strategic layering of amendments can provide treatment where multiple contaminant profiles are present.

11.3.4. Natural Recovery Processes

The natural recovery of sediment refers to 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 and increased isolation of contaminated sediment over-time. When natural recovery is expected to yield sediment that meets cleanup goals within an acceptable time period MNR can be considered. This cleanup approach requires long-term monitoring to demonstrate the rate of recovery and ensure that cleanup goals are met within an acceptable time period. The monitoring program associated with a MNR remedy typically includes a combination of physical and chemical testing of sediments collected on planned time intervals within the recovery area.

Appendix 11C presents the lines of evidence demonstrating that natural recovery of sediments is taking place within the SCU. The appendix also includes analyses to support the use of MNR as a feasible remediation technology. While Appendix 11C focuses on natural recovery in the lake bottom portion of the SCU, the same natural recovery processes that are occurring within the lake bottom portion of the SCU are also occurring in the lake bottom outside of the SCU. In other words, it is expected that natural recovery has occurred, and is continuing to occur in the lake bottom surface sediments outside of the SCU.

Where natural sediment recovery rates are too low or existing sediment concentrations too high to achieve preliminary cleanup levels within an acceptable time period solely by natural recovery processes, these processes can be accelerated by placement of a thin layer of clean material (commonly the equivalence of a 6-inch layer of clean sand). The thin layer of material is not intended to isolate contaminants, as in capping, but rather is expected to mix with surface sediment as a result of natural processes such as bioturbation. Continued natural deposition will further reduce contaminant concentrations. This enhanced natural recovery (ENR) process allows cleanup goals to be met in an acceptable time period; as with MNR, long-term monitoring is conducted to document the rate of recovery and success in meeting cleanup objectives.

MNR and ENR have been retained as components of the cleanup action alternatives for areas where sediment concentrations are elevated and natural recovery processes or enhanced natural recovery processes are expected to meet cleanup goals within an acceptable time period. Due to uncertainties in the existing surface sediment chemical concentrations based on the age of the data, areas where MNR and ENR may be applied will be confirmed during the future remedial design step in the cleanup process.

11.4. Institutional Controls

Institutional controls are actions undertaken to limit or prohibit activities that may interfere with the integrity of the cleanup action or may result in exposure to contamination. They are required by MTCA when cleanup actions leave contamination in place and may include:

- Physical measures - fencing

- Use restrictions - legal restrictions limiting the use of the property or resources (e.g., environmental covenants prohibiting cap disturbance without prior written approval from Ecology)
- Maintenance requirements - requirements for inspection, monitoring and repairs
- Educational programs - measures to provide information about the presence of contamination and ways to limit exposure
- Financial assurances - mechanisms that provide funds to cover all costs associated with the operation and maintenance of the cleanup action

Institutional controls are retained as a component of cleanup action alternatives that leave contamination in place.

12.0 DEVELOPMENT OF CLEANUP ACTION ALTERNATIVES

This section describes the cleanup action alternatives that were developed using the remedial technologies that were retained in the technology screening presented in Section 11. The cleanup action alternatives are designed to meet MTCA and SMS minimum requirements. The alternatives are presented in sufficient detail to allow a comparative evaluation for the FS. However, as is common in the cleanup process, agency decisions, input from the public and other stakeholders, permit requirements, and pre-design investigation data may modify the cleanup action alternatives from descriptions presented below to meet the site-specific cleanup requirements determined by Ecology.

Various treatment, removal and containment technologies are included to achieve the cleanup action objectives. The key concepts of each alternative are shown in the matrix below.

CLEANUP ACTION ALTERNATIVES CONCEPTS

Key Concepts of the Cleanup Action Alternatives	Alt-1	Alt-2	Alt-3	Alt-4	Alt-5	Alt-6	Alt-7	Alt-8
Treat arsenic in upland groundwater between the Play Area and the shoreline	●	●	●	●	●	●	●	●
Excavate and cap exposed upland bank soil to prevent direct-contact exposure and erosion	●	●	●	●	●	●	●	●
Dredge nearshore contaminated sediment to the degree necessary to maintain lake surface area after capping	●	●	●					
Dredge nearshore contaminated sediment to a greater degree to increase mass removal in nearshore areas				●	●	●	●	●
Dredge offshore areas for the purpose of removing contaminant mass							●	●
Contain sediment contaminants by capping	●	●	●	●	●	●	●	●
Use enhanced capping methods, including low-permeability and/or amended capping to increase containment and provide in-situ treatment		●	●	●	●	●	●	●
Utilize natural recovery where contaminant concentrations are moderate to low and sediment deposition is occurring	●	●	●	●	●	●	●	●

Technologies utilized for each of the cleanup action alternatives as applied to each SMA are summarized in Table 12-1. The approximate quantities of the various technologies used to estimate costs for each alternative are also presented in Table 12-1. The sections below describe the approach and primary components of each alternative, along with key assumptions and rationale for inclusion in the FS.

Each of the cleanup action alternatives relies to some degree on capping, utilizing conventional and/or enhanced capping methods. The performance of a conventional sand cap in the lakeshore region, where groundwater discharge through sediment is greatest, would depend on underlying sediment and the porewater concentrations of the lighter fraction organic contaminants, such as benzene and naphthalene, that can more easily migrate through a clean sand cap. Where an alternative calls for conventional sand capping of shallow NAPL-impacted sediment and areas of NAPL at the toe of the lake slope, cap thickness is specified as greater than 3 feet rather than the standard 2 feet (for cost estimating purposes, the thicker sand cap is assumed to be 4-feet thick). The additional thickness accommodates slope adjustments and provides additional attenuation and containment of contaminants in the NAPL. Where an alternative calls for capping in an area of soft sediment or fluid mud, the cap would be placed in thin lifts to consolidate the underlying sediment. Appendix 11B includes an evaluation of capping methods for soft sediment.

As described in Section 11, enhanced capping includes low-permeability capping methods (composite liners, granular bentonite, grout mats, etc.) as well as amended capping methods that use various treatment amendments that are mixed into the cap material. Several of the alternatives use one or both of these enhanced capping methods. In scenarios where a low-permeability cap is proposed along the lakeshore, groundwater discharge would increase relative to baseline conditions in the area immediately offshore of the low-permeability cap. Attenuation of the more mobile contaminants in the area of increased groundwater discharge is achieved by using amended cap methods along the edge of the adjacent low-permeability cap.

Natural recovery processes are utilized in depositional areas with relatively low contaminant concentrations where existing data indicate that natural recovery is occurring. In the natural recovery areas (SMA 13 and SMA 14), MNR and ENR (e.g., as 6 inches of sand) will address the GWPS COCs relative to the preliminary cleanup standards and also act to reduce ALU COC concentrations within the SCU.

The excavation and capping of bank soils, in situ chemical fixation and monitored natural attenuation in groundwater, and storm drain modifications each address potential sources of sediment contamination.

12.1. Common Elements to the Cleanup Action Alternatives

The cleanup action alternatives share several common elements. These common elements are not called out in the description detail of the individual alternatives (Sections 12.2 through 12.8); however, their costs are included in the total estimated cost for each alternative.

The following elements are common to all alternatives:

- Excavate, stabilize, and cap exposed bank soil (SMAs -1 and 2) – Exposed cPAH contaminated soil along the bank of Gas Works Park would be capped with a vegetated soil cap to prevent direct exposure to park users and to prevent erosion into Lake Union. Before the cap is installed, bank soil within the park will be excavated or graded as necessary to allow the final bank topography to transition to the selected sediment remedy. For scenarios where nearshore sediment is excavated or dredged to a greater depth to increase mass removal, the bank soil would also be excavated to a greater degree to facilitate transition between areas immediately above and below the OHW.

- Excavate tar mound on eastern shoreline (SMA-1) – Areas of exposed tar in the northeast portion of the GWPS (i.e., the tar mound) would be excavated to prevent direct contact by park users and to remove a source of sediment contamination. The excavated areas would be graded and capped to match elevations of adjacent upland and in-water elements of the cleanup action.

- Treat arsenic in upland groundwater (GWMA-1) – Dissolved arsenic in groundwater between the Play Area and Lake Union shoreline present at concentrations greater than preliminary cleanup level would be treated to the extent feasible to reduce concentrations in the upland near the original source of arsenic to groundwater, the Thylox process area. The highest concentrations of dissolved arsenic are present in a localized area of shallow fill groundwater within the Play Area (Well MW-45S on Figure 59) and in the deep outwash groundwater immediately upgradient of the GWPS shoreline downgradient of the Play Area and will be treated using in-situ chemical fixation. Dissolved arsenic concentrations within the fill unit are significantly lower downgradient of the Play Area than concentrations within the Play Area and are lower than concentrations in the underlying outwash groundwater. Within the fill unit downgradient of the Play Area, dissolved arsenic will be addressed using monitored natural attenuation.
- Monitor groundwater (GWMA-1)–Groundwater performance monitoring would be conducted as an element of the arsenic treatment described above. Groundwater monitoring would continue following completion of treatment to evaluate long-term conditions associated with arsenic in upland groundwater.
- Offsite Disposal – All excavated/dredged material is assumed to be disposed of offsite at permitted Subtitle C or D landfills, with the exception of material requiring treatment by incineration. It is assumed that 75 percent of material removed from tar mound and shoreline bank areas will be disposed at a Subtitle C landfill and 25 percent at an incineration facility. Sediment removed from the remainder of the SCU is assumed to be split between Subtitle D landfill (75 percent of material) and Subtitle C landfill (25 percent of material). Material that is removed is assumed to be transported by barges to a rail facility for subsequent transport to the Ecology-approved and permitted Subtitle C or Subtitle D landfill facilities. During the project bidding phase, the selected contractor will propose the detailed means and methods for transport of removed materials and disposal at approved permitted off-site disposal facilities.
- Restore shoreline habitat to existing conditions – The alternatives involve construction within the bank area of Gas Works Park and include restoring the shoreline to existing conditions. Additional habitat enhancements that may be required in the future by permitting agencies are not yet known and are not included in the alternatives.
- Collect supplemental data – The alternatives assume that a pre-design investigation will be completed to evaluate current surface sediment concentrations and recalculate natural recovery rates for lake bottom SMAs. The results of the investigation will be used to confirm assumptions regarding conditions within the SCU for GWPS COCs as well as co-located ALU COCs.[127] The surface sediment data and natural recovery rates will be used to confirm restoration timeframes for areas where natural recovery methods are proposed. The pre-design investigation will also include collection of subsurface sediment, upland groundwater, offshore groundwater, and porewater samples to inform design of the remedy that will be selected by Ecology in the CAP.

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[127] ALU COCs, along with GWPS COCs, were identified using surface sediment data from samples collected within the sediment portion of the AOI. The difference between the two sets of COCs is that the GWPS COCs are site-related and the ALU COCs are not.

- Apply institutional controls – All alternatives leave contaminants in place, therefore institutional controls are required. Institutional controls will likely include use restrictions, maintenance requirements, and financial assurances. Specific institutional controls for the cleanup action ultimately selected by Ecology will be defined during future steps in the cleanup process.
- Storm drain modifications – For each of the alternatives, storm drains discharging to the SCU will be modified, where necessary, to prevent infiltration and discharge of contaminated soil. Studies to evaluate potential recontamination by storm drains have been conducted since 2007 (see RI Section 6.7 and Appendix 6B for details). These studies are summarized in Appendix 12A, along with a description of steps taken to address issues indicated by the storm drain solids data and anticipated next steps.

12.2. Cleanup Action Alternative 1

Cleanup Action Alternative 1 utilizes conventional sand capping and natural recovery processes in combination with the common elements described above to achieve preliminary cleanup standards in the SCU. Figure 12-1 presents a plan view of the Alternative 1 cleanup components.

Under Alternative 1, conventional sand capping would be utilized in both nearshore and offshore areas to address direct contact with sediment contaminants. The conventional sand cap would consist of a 2-foot-thick layer of sand cap material in addition to an armor layer described below. The cap would provide containment of contaminated sediment to achieve preNatural recovery proliminary cleanup levels at the nearshore direct-contact sediment point of compliance of depth interval 0 to 45 cm. In areas of NAPL-impacted sediment and areas with higher potential for advective transport, the conventional sand cap material would be thickened to greater than 3 feet to increase the degree of contaminant attenuation. Where capping is planned in an area of soft sediment or fluid mud, the cap would be placed in thin lifts to consolidate the underlying sediment.

Debris removal would be completed as needed to assist placement of cap material. Capped areas would include placement of armor material to stabilize underlying cap material. The thickness and grain size of armor would be based on expected forces associated with wind-generated waves and boat prop wash, ranging from a thick layer of angular rock armor to a thin layer of gravel- to cobble-size aggregate. For cost estimating purposes, shallow (above elevation +10 feet USACE) capped areas in the lakeshore area are expected to require larger 12-inch- to 18-inch-diameter angular rock, infilled with sand/gravel habitat substrate. Deeper (below +10 feet USACE) capped areas are expected to require only thin layers of smaller gravel- to cobble-sized material because of the limited potential for disturbance, associated primarily with boat prop wash.

Removal of sediment would be completed in nearshore areas adjacent to the upland (SMA-3 and SMA-4) where feasible to facilitate placement of cap material without modifications to shoreline elevations. Nearshore sediment removal in SMA-3 and SMA-4 would be conducted in the dry using a cofferdam, with the excavation area falling generally between the OHWM and a water depth of approximately 10 feet, which is considered a reasonable limit for a lake cofferdam not affected by tidal fluctuations. Removal would likely be conducted using land-based excavation methods and would remove sediment located behind the cofferdam and upland bank soil as needed to place cap material while preserving lake surface area and shoreline elevations following capping.

In the nearshore areas (water depth less than 15 feet) outside of the shoreline of Gas Works Park where marine facilities that may be impacted by placement of cap materials (SMA-5 and SMA-10), partial dredging will be conducted prior to capping to minimize shallowing of the lake and to maintain adequate water depth for marina, Harbor Patrol, and/or shipyard activities where necessary. This approach allows for preservation of current and future uses.

Natural recovery processes (ENR and MNR) are utilized in depositional lake bottom areas with relatively low contaminant concentrations.

SMA-specific components of Alternative 1 are described in the sections below.

12.2.1. GWMA-1, SMA-1 and SMA 2 Components of Alternative 1

The cleanup elements for GWMA-1, SMA-1 and SMA 2 are common to the cleanup action alternatives and are described in Section 12.1.

12.2.2. SMA-3 Components of Alternative 1

Specific cleanup elements for SMA-3 under Alternative 1 are as follows:

- Partial excavation/dredging within area located above approximately +12 feet USACE elevation to facilitate cap placement without modifying the location of the OHWM and reducing the footprint of Lake Union.
- Armored 2-foot conventional sand cap for containment of sediment contaminants.
- Armored >3-foot conventional sand cap in areas of potential advective transport of more mobile contaminants (i.e., arsenic, benzene, and naphthalene) in porewater and enhanced containment and attenuation of contaminants in shallow NAPL areas (i.e., NAPL Area 14).

12.2.3. SMA-4 Components of Alternative 1

Specific cleanup elements for SMA-4 under Alternative 1 are as follows:

- Partial dredging within area above approximately +12 feet USACE elevation to facilitate cap placement without modifying the location of the OHWM and reducing the footprint of Lake Union.
- Armored 2-foot conventional sand cap for containment of sediment contaminants.
- Armored >3-foot conventional sand cap in areas of potential advective transport of more mobile contaminants (i.e., benzene and naphthalene) in porewater and enhanced containment and attenuation of contaminants in shallow NAPL areas (i.e., NAPL Area 5B).

12.2.4. SMA-5 Components of Alternative 1

Specific cleanup elements for SMA-5 under Alternative 1 are as follows:

- Partial dredging to facilitate cap placement without modifying the location of the OHWM and reducing the footprint of Lake Union.

- Partial dredging within area above approximately +5 USACE elevation, where necessary based on site uses to facilitate placement of cap material in water depths less than 15 feet and minimize disruption to facility operations.
- Armored 2-foot conventional sand cap for containment of sediment contaminants.
- Armored >3-foot conventional sand cap in areas of potential advective transport of more mobile contaminants (i.e., benzene and naphthalene) in porewater and enhanced containment and attenuation of contaminants in shallow NAPL areas (i.e., NAPL Area 5B).

12.2.5. SMA-6 Components of Alternative 1

Specific cleanup elements for SMA-6 under Alternative 1 are as follows:

- Armored 2-foot conventional sand cap for containment of sediment contaminants.

12.2.6. SMA-7 Components of Alternative 1

Specific cleanup elements for SMA-7 under Alternative 1 are as follows:

- Armored 2-foot conventional sand cap for containment of sediment contaminants outside areas of shallow NAPL and high concentrations of mobile sediment contaminants.
- Armored >3-foot conventional sand cap in areas of potential transport of more mobile contaminants (i.e., arsenic, benzene, and naphthalene) in porewater and enhanced containment and attenuation of contaminants in shallow NAPL areas (i.e., NAPL Area 14 and NAPL Area 15).

12.2.7. SMA-8 Components of Alternative 1

Specific cleanup elements for SMA-8 under Alternative 1 are as follows:

- Armored >3-foot conventional sand cap in areas of shallow NAPL (NAPL Area 8) for enhanced containment and attenuation of contaminants in shallow NAPL areas.

12.2.8. SMA-9 Components of Alternative 1

Specific cleanup elements for SMA-9 under Alternative 1 are as follows:

- Armored >3-foot conventional sand cap to provide greater attenuation of more mobile contaminants (i.e., benzene and naphthalene) in porewater and enhanced containment and attenuation of contaminants in shallow NAPL areas (i.e., NAPL Area 3 and NAPL Area 5B).

12.2.9. SMA-10 Components of Alternative 1

Specific cleanup elements for SMA-10 under Alternative 1 are as follows:

- Partial dredging within Marina above approximately +12 feet USACE elevation to accommodate cap placement and facilitate site uses.
- Armored 2-foot conventional sand cap for containment of sediment contaminants.

12.2.10. SMA-11 Components of Alternative 1

Specific cleanup elements for SMA-11 under Alternative 1 are as follows:

- Armored 2-foot conventional sand cap for containment of sediment contaminants.

12.2.11. SMA-12 Components of Alternative 1

Specific cleanup elements for SMA-12 under Alternative 1 are as follows:

- Armored 2-foot conventional sand cap for containment of sediment contaminants outside areas of shallow NAPL and high concentrations of mobile sediment contaminants.
- Armored >3-foot conventional sand cap in areas of potential transport of more mobile contaminants (i.e., benzene and naphthalene) in porewater and enhanced containment and attenuation of contaminants in shallow NAPL areas (i.e., NAPL Areas 1, 2, 3, and 5B).

12.2.12. SMA-13 Components of Alternative 1

SMA-13, in the lake bottom portion of the SCU, is a depositional area of relatively low level contamination that is not expected to naturally recover to the degree necessary to achieve preliminary cleanup levels within an acceptable timeframe. Therefore, Alternative 1 in SMA-13 relies on ENR (placing a thin (6-inch) layer of sand) to accelerate natural recovery processes.

12.2.13. SMA-14 Components of Alternative 1

SMA-14, which is in the lake bottom portion of the SCU, is a depositional area of relatively low level contamination that is expected to naturally recover to achieve preliminary cleanup levels within an acceptable timeframe. Therefore, Alternative 1 in SMA-14 relies on MNR to verify natural recovery processes.

12.3. Cleanup Action Alternative 2

Cleanup Action Alternative 2 combines conventional and enhanced capping methods with natural recovery and the common elements described in Section 12.1 to achieve preliminary cleanup standards in the SCU. Figure 12-2 presents a plan view of the Alternative 2 cleanup components.

Under Alternative 2, the nearshore area of highest groundwater flux (SMAs 3 through 5) is addressed by enhanced capping methods to increase the reliability of contaminant attenuation. Enhanced capping would consist of low-permeability and/or amended cap methods designed to redirect groundwater discharging through contaminated sediment and/or treating contaminants by cap amendments to prevent discharge to surface water. The cap amendments used for enhanced capping would consist of a variety of material selected for the specific contaminants being addressed, such as activated carbon for mobile organic contaminants (i.e., benzene and naphthalene), ZVI for arsenic, and organoclay for shallow NAPL.

SMAs 6 through 14 are addressed in Alternative 2 in the same manner as Alternative 1, using conventional sand capping and natural recovery methods. Across the lake slope sediment and portions of the lake bottom, where groundwater discharge is limited, conventional sand capping will contain contaminated sediment and allow for adequate attenuation of the primarily diffusion-driven transport of contaminants in porewater. Areas where contaminant concentrations are higher, such as offshore areas with shallow NAPL, would use a thicker sand cap (> 3-foot) to prevent migration.

Similar to Alternative 1, partial dredging would be completed in nearshore areas (SMA-3 and SMA-4) to facilitate placement of cap material without modifications to shoreline elevations. In addition, partial dredging would be completed in areas with marine facilities (SMA-5 and SMA-10) where necessary, to facilitate placement of cap material in water depths less than 15 feet to minimize disruptions to facility operations.

Similar to Alternative 1, natural recovery processes are included in depositional areas with relatively low contaminant concentrations where sedimentation rates and incoming sediment quality are adequate to achieve preliminary cleanup standards immediately following construction. In the lake bottom, ENR (e.g., 6 inches of sand) would address sediment contaminants at concentrations moderately higher than preliminary cleanup levels and MNR would address contaminants in sediment above preliminary cleanup levels but at or below ALU concentrations.

The combination of capping, ENR, and MNR will achieve preliminary cleanup standards immediately following construction. For the purposes of this FS, it is assumed that Alternative 2 will achieve the screening levels for co-located ALU COCs within a reasonable timeframe[128].

SMA-specific components of Alternative 2 are described in the sections below.

12.3.1. GWMA-1, SMA-1 and SMA 2 Components of Alternative 2

The cleanup elements for GWMA-1, SMA-1 and SMA 2 are common to the cleanup action alternatives and described in Section 12.1.

12.3.2. SMA-3 Components of Alternative 2

Specific cleanup elements for SMA-3 under Alternative 2 are as follows:

- Partial dredging within area above approximately +12 feet USACE elevation to accommodate cap placement.
- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 2 enhanced capping in SMA-3 is assumed to include the following elements:
    - Organoclay-amended capping in areas of shallow NAPL (i.e., NAPL Area 14) for containment and attenuation of contaminants in NAPL.
    - ZVI-amended capping in areas of arsenic impacts with the potential to discharge to surface water.
    - Activated carbon-amended capping in areas of potential mobile organic contaminants (i.e., benzene and naphthalene).
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.3.3. SMA-4 Components of Alternative 2

Specific cleanup elements for SMA-4 under Alternative 2 are as follows:

- Partial dredging within area above approximately +12 feet USACE elevation to accommodate cap placement.

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[128] The assumption concerning co-located ALU COCs achieving screening levels within a reasonable timeframe will be evaluated during the future pre-design investigation.

- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 2 enhanced capping in SMA-4 is assumed to include the following elements:
    - Organoclay-amended capping in areas of shallow NAPL (i.e., NAPL Area 5B) for containment and attenuation of contaminants in NAPL.
    - Activated carbon-amended capping in areas of potential mobile organic contaminants (i.e., benzene and naphthalene).
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.3.4. SMA-5 Components of Alternative 2

Specific cleanup elements for SMA-5 under Alternative 2 are as follows:

- Partial dredging to facilitate cap placement without modifying the location of the OHWM and reducing the footprint of Lake Union.
- Partial dredging within area above approximately +5 USACE elevation, where necessary based on site uses, to facilitate placement of cap material in water depths less than 15 feet and minimize disruption to facility operations.
- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 2 enhanced capping in SMA-4 is assumed to include the following elements:
    - Organoclay-amended capping in areas of shallow NAPL (i.e., NAPL Area 5B) for containment and attenuation of contaminants in NAPL.
    - Activated carbon-amended capping in areas of potential mobile organic contaminants (i.e., benzene and naphthalene).

12.3.5. SMA-6 to SMA-14 Components of Alternative 2

Specific cleanup elements for SMAs-6 to -14 under Alternative 2 are equivalent to those listed under Alternative 1.

12.4. Cleanup Action Alternative 3

Cleanup Action Alternative 3 combines conventional and enhanced capping methods with natural recovery and the common elements described in Section 12.1 to meet preliminary cleanup standards in the SCU. Figure 12-3 presents a plan view of the Alternative 3 cleanup components.

Alternative 3 includes an extensive application of enhanced capping methods to increase reliability of containment and attenuation of more mobile contaminants. Similar to Alternative 2, the nearshore SMAs with the highest groundwater flux and highest potential for transport of sediment contaminants are addressed by enhanced capping methods. In addition, adjacent offshore SMAs with the potential for contaminant transport to surface water and areas of shallow NAPL are addressed by enhanced capping methods.

The extensive areas of enhanced capping in Alternative 3, as shown on Figure 12-3, include a blend of low-permeability capping and amended capping to contain and attenuate contaminants in sediment and porewater. The low-permeability capping would use a thin cap profile to direct groundwater discharge farther offshore away from shallow NAPL and areas with higher concentrations of sediment contaminants and funnels it through a band of permeable amended cap materials for treatment.

Like Alternative 2, amended sand cap material would be used at the terminus of low-permeability cap areas, at the localized zone of higher groundwater discharge. The amendment would consist of material, such as activated carbon or ZVI, capable of treating benzene, naphthalene, and arsenic that would otherwise be transported in sediment porewater. Alternative 3 expands further on the application of cap amendments to treat contaminants in the lake slope and portions of lake bottom areas. Alternative 3 utilizes organoclay-amended capping in lake slope and lake bottom areas of shallow NAPL rather than thick sand capping to provide additional treatment capability and a thinner cap profile.

Across the lake slope sediment and portions of the lake bottom, where groundwater discharge is limited and shallow NAPL is not expected, conventional sand capping will contain contaminated sediment and allow for adequate attenuation of the primarily diffusion-driven transport of contaminants in porewater.

Similar to Alternative 1, partial dredging would be completed in nearshore areas (SMA-3 and SMA-4) to facilitate placement of cap material without modifications to shoreline elevations. In addition, partial dredging would be completed in areas with marine facilities (SMA-5 and SMA-10) where necessary, to facilitate placement of cap material in water depths less than 15 feet to minimize disruptions to facility operations.

Similar to Alternative 1, natural recovery processes are included in depositional areas with relatively low contaminant concentrations where sedimentation rates and incoming sediment quality are adequate to achieve preliminary cleanup standards immediately following construction. In the lake bottom, ENR (e.g., 6 inches of sand) would address sediment contaminants at concentrations moderately higher than preliminary GWPS cleanup levels/ALU screening levels and MNR would address contaminants in sediment above preliminary cleanup levels/screening levels but at or below ALU concentrations.

The combination of capping, ENR, and MNR will achieve preliminary cleanup standards immediately following construction. For the purposes of this FS, it is assumed that Alternative 3 will achieve screening levels for co-located ALU COCs within a reasonable timeframe[129].

SMA-specific components of Alternative 3 are described in the sections below.

12.4.1. GWMA-1, SMA-1 and SMA 2 Components of Alternative 3

The cleanup elements for GWMA-1, SMA-1 and SMA 2 are common to the cleanup action alternatives and described in Section 12.1.

12.4.2. SMA-3 Components of Alternative 3

SMA-3 components under Alternative 3 are addressed in a similar manner as Alternative 2, using conventional and low-permeability capping methods with dredging as needed to accommodate the cap.

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[129] The assumption concerning co-located ALU COCs achieving screening levels within a reasonable timeframe will be evaluated during the future pre-design investigation.

Specific cleanup elements for SMA-3 under Alternative 3 are as follows:

- Partial dredging within area above approximately +12 feet USACE elevation to accommodate cap placement.
- Thin-profile low-permeability cap for containment of sediment contaminants and for redirection of groundwater away from contaminated sediment towards the amended cap band at the outer edge of SMA-3 for treatment of arsenic, benzene, and naphthalene in porewater.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.4.3. SMA-4 Components of Alternative 3

SMA-4 components under Alternative 3 are primarily addressed using enhanced capping methods with dredging as needed to accommodate the cap. Specific cleanup elements for SMA-4 under Alternative 3 are as follows:

- Partial dredging within area above approximately +12 feet USACE elevation to accommodate cap placement.
- Thin-profile low-permeability cap for containment of sediment contaminants and for redirection of groundwater away from contaminated sediment towards the amended cap band at the outer edge of SMA-4 for treatment of benzene and naphthalene in porewater.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.4.4. SMA-5 Components of Alternative 3

Specific cleanup elements for SMA-5 under Alternative 3 are as follows:

- Partial dredging to facilitate cap placement without modifying the location of the OHWM and reducing the footprint of Lake Union.
- Partial dredging within area above approximately +5 USACE elevation, where necessary based on site uses, to facilitate placement of cap material in water depths less than 15 feet and minimize disruption to facility operations.
- Thin-profile low-permeability cap for containment of sediment contaminants and for redirection of groundwater away from contaminated sediment towards the amended cap band at the outer edge of SMA-5 for treatment of benzene and naphthalene in porewater.

12.4.5. SMA-6 Components of Alternative 3

Specific cleanup elements for SMA-6 under Alternative 3 are equivalent to those listed under Alternative 1.

12.4.6. SMA-7 Components of Alternative 3

Specific cleanup elements for SMA-7 under Alternative 3 are as follows:

- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 3 enhanced capping in SMA-7 is assumed to include the following elements:

    - Organoclay-amended capping in areas of shallow NAPL (NAPL Area 14 and 15) for containment and attenuation of contaminants in NAPL.
    - ZVI-amended capping in areas of arsenic impacts at the toe of the low-permeability cap used in SMA-3.
    - Activated carbon-amended capping in areas of benzene and naphthalene impacts at the toe of the low-permeability cap used in SMA-3.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.4.7. SMA-8 Components of Alternative 3

Specific cleanup elements for SMA-8 under Alternative 3 are as follows:

- Enhanced cap amended with organoclay in areas of shallow NAPL (i.e., NAPL Area 8) for containment and attenuation of contaminants in NAPL.

12.4.8. SMA-9 Components of Alternative 3

Specific cleanup elements for SMA-9 under Alternative 3 are as follows:

- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 3 enhanced capping in SMA-9 is assumed to include the following elements:
    - Organoclay-amended capping in areas of shallow NAPL (i.e., NAPL Areas 3 and 5B) for containment and attenuation of contaminants in NAPL.
    - Activated carbon-amended capping in areas of benzene and naphthalene impacts at the toe of the low-permeability cap used in SMA-4 and SMA-5.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.4.9. SMA-10 and SMA-11 Components of Alternative 3

Cleanup elements for SMA-10 and SMA-11 under Alternative 3 are equivalent to those listed under Alternative 1.

12.4.10. SMA-12 Components of Alternative 3

Specific cleanup elements for SMA-12 under Alternative 3 are as follows:

- Enhanced cap amended with organoclay in areas of shallow NAPL (i.e., NAPL Areas 1 to 3 and NAPL Area 5B) for containment and attenuation of contaminants in NAPL.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.4.11. SMA-13 and SMA-14 Components of Alternative 3

Cleanup elements for SMA-13 and SMA-14 under Alternative 3 are equivalent to those listed under Alternative 1.

12.5. Cleanup Action Alternative 4

Cleanup Action Alternative 4 combines conventional and enhanced capping methods with natural recovery processes and the common elements described in Section 12.1 to meet preliminary cleanup standards in the SCU. Alternative 4 utilizes components from previous alternatives in nearshore and offshore areas with the addition of expanded nearshore dredging for greater contaminant mass reduction. Partial dredging will be completed in nearshore areas to facilitate placement of cap material without modifications to shoreline elevations similar to Alternative 1. Under Alternative 4, additional nearshore dredging will be completed in the SMAs adjacent to the park (SMA-3 and SMA-4) where feasible to remove additional contaminant mass and reduce potential for contaminant transport in the nearshore zone of greatest groundwater flux. Figure 12-4 presents a plan view of the Alternative 4 cleanup components.

Under Alternative 4 the areas of the highest potential contaminant mass flux at nearshore SMAs 3, 4, and 5 are addressed by enhanced capping methods to increase the reliability of contaminant attenuation. Similar to Alternatives 2 and 3, enhanced capping consists of low-permeability and/or amended cap methods designed to redirect groundwater discharging through contaminated sediment and/or treating contaminants by cap amendments to prevent discharge to surface water. The specific assumptions for enhanced capping in each SMA that are used to develop cost estimates for this alternative are described below. Outside SMAs 3, 4, and 5, the components of Alternative 4 are equivalent to Alternative 1.

Similar to Alternative 1, natural recovery processes are included in depositional areas with relatively low contaminant concentrations where sedimentation rates and incoming sediment quality are adequate to achieve preliminary cleanup standards immediately following construction. In the lake bottom, ENR (e.g., as 6 inches of sand) would address sediment contaminants at concentrations moderately higher than preliminary GWPS cleanup levels/ALU screening levels and MNR would address contaminants in sediment above preliminary cleanup levels/screening levels but at or below ALU concentrations.

The combination of capping, dredging ENR, and MNR will achieve preliminary cleanup standards immediately following construction. For the purposes of this FS, it is assumed that Alternative 4 will achieve screening levels for co-located ALU COCs within a reasonable timeframe[130].

SMA-specific components of Alternative 4 are described in the sections below.

12.5.1. GWMA-1, SMA-1 and SMA 2 Components of Alternative 4

The cleanup elements for GWMA-1, SMA-1 and SMA 2 are common to the cleanup action alternatives and described in Section 12.1.

12.5.2. SMA-3 Components of Alternative 4

Specific cleanup elements for SMA-3 under Alternative 4 are as follows:

- Partial excavation/dredging within area above approximately +12 feet USACE elevation.

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[130] The assumption concerning co-located ALU COCs achieving screening levels within a reasonable timeframe will be evaluated during the future pre-design investigation.

  - Excavate to a depth based on contaminant mass rather than cap thickness, with a maximum depth corresponding to the cofferdam base elevation to prevent undermining the cofferdam.
  - Excavate additional upland bank soil to the extent feasible to facilitate the transition between the areas above and below the OHW.
- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 4 enhanced capping in SMA-3 is assumed to include the following elements:
  - Organoclay-amended capping in areas of shallow NAPL (i.e., NAPL Area 14) for containment and attenuation of contaminants in NAPL.
  - ZVI-amended capping in areas of arsenic impacts with the potential to discharge to surface water.
  - Activated carbon-amended capping in areas of potential mobile organic contaminants (i.e., benzene and naphthalene).
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.5.3. SMA-4 Components of Alternative 4

Specific cleanup elements for SMA-4 under Alternative 4 are as follows:

- Partial excavation/dredging within area above approximately +12 feet USACE elevation.
  - Excavate to a depth based on contaminant mass rather than cap thickness, with a maximum depth corresponding to the cofferdam base elevation to prevent undermining the cofferdam.
  - Excavate additional upland bank soil to the extent feasible to facilitate the transition between the areas above and below the OHW.
- Thin-profile low-permeability cap in western portion of SMA-4, where potential for contaminant flux is greatest for containment of sediment contaminants and for redirection of groundwater away from contaminated sediment towards the amended cap band at the outer edge of SMA-4 for treatment of benzene and naphthalene in porewater.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.5.4. SMA-5 Components of Alternative 4

Specific cleanup elements for SMA-5 under Alternative 4 are as follows:

- Partial dredging to facilitate cap placement without modifying the location of the OHWM and reducing the footprint of Lake Union.
- Partial dredging within area above approximately +5 USACE elevation, where necessary based on site uses, to facilitate placement of cap material in water depths less than 15 feet to minimize disruption to facility operations.
- Thin-profile low-permeability cap in eastern portion of SMA-5, where potential for contaminant flux is greatest for containment of sediment contaminants and for redirection of groundwater away from

contaminated sediment towards the amended cap band at the outer edge of SMA-5 for treatment of benzene and naphthalene in porewater.

- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.5.5. Additional dredging for mass removal, like what is proposed for SMA-4, is not included in SMA-5 due to lower contaminant concentrations relative to SMA-4 and limited additional environmental benefit relative to additional cost. SMA-6 to SMA-8 Components of Alternative 4

Cleanup elements for SMAs-6 to -8 under Alternative 4 are equivalent to those listed under Alternative 1.

12.5.6. SMA-9 Components of Alternative 4

Capping methods used for SMA-9 include both conventional and enhanced methods, with the focused application of enhanced capping methods offshore of the areas of enhanced capping in SMA-4 and SMA-5. Specific cleanup elements for SMA-9 under Alternative 4 are as follows:

- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 4 enhanced capping in SMA-9 is assumed to include the following elements:
  - Organoclay-amended capping in areas of shallow NAPL (i.e., NAPL Areas 3 and 5B) for containment and attenuation of contaminants in NAPL.
  - Activated carbon-amended capping in areas of benzene and naphthalene impacts at the toe of the low-permeability cap used in SMA-4 and SMA-5.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.5.7. SMA-10 to SMA-14 Components of Alternative 4

Cleanup elements for SMAs-10 to -14 under Alternative 4 are equivalent to those listed under Alternative 1.

12.6. Cleanup Action Alternative 5

Cleanup Action Alternative 5 combines conventional and enhanced capping methods with natural recovery and the common elements described in Section 12.1 to meet preliminary cleanup standards in the SCU. Alternative 5 utilizes components from previous alternatives in nearshore and offshore areas with the addition of expanded nearshore dredging for greater contaminant mass reduction. Alternative 5 expands the scope of enhanced capping used in Alternative 4 to additional offshore areas (SMA-7 and SMA-8) where shallow NAPL and high concentration sediment contaminants are present. Similar to Alternative 4, nearshore dredging would be completed in the SMAs adjacent to the Park (SMA-3 and SMA-4) where feasible to remove additional contaminant mass and reduce potential for contaminant transport in the nearshore zone of greatest groundwater flux. Figure 12-5 presents a plan view of the Alternative 5 cleanup components.

Under Alternative 5, the area of the highest groundwater flux at SMAs-3, 4 and 5 are addressed by enhanced capping methods to increase the reliability of contaminant attenuation. In addition, offshore areas of shallow NAPL and high sediment contaminant concentrations that may be susceptible to migration in SMA-7, -8, and -9 are also addressed by enhanced capping to increase the reliability of containment and utilize thinner cap profiles. Under this scenario, low-permeability caps would be used in the nearshore areas (SMA-3, -4, and -5) to direct groundwater discharge farther offshore away from shallow NAPL and areas with higher concentrations of sediment contaminants. Areas adjacent to the low-permeability capping (SMA-7 and SMA-9) would use a band of permeable amended cap material for treatment similar to Alternative 2. In addition, under Alternative 5, organoclay-amended capping would be utilized for SMA-8 to address areas of shallow NAPL rather than thick sand capping to provide additional treatment capability with a thinner cap profile.

Similar to Alternative 1, natural recovery processes are included in depositional areas with relatively low contaminant concentrations where sedimentation rates and incoming sediment quality are adequate to achieve preliminary cleanup standards immediately following construction. In the lake bottom, ENR (e.g., as 6 inches of sand) would address sediment contaminants at concentrations moderately higher than preliminary GWPS cleanup levels/ALU screening levels and MNR would address contaminants in sediment above preliminary cleanup levels/screening levels but at or below ALU concentrations.

The combination of capping, dredging, ENR, and MNR will achieve preliminary cleanup standards immediately following construction. For the purposes of this FS, it is assumed that Alternative 5 will achieve screening levels for co-located ALU COCs within a reasonable timeframe[131].

SMA-specific components of Alternative 5 are described in the sections below.

12.6.1. GWMA-1, SMA-1 and SMA 2 Components of Alternative 5

The cleanup elements for GWMA-1, SMA-1 and SMA 2 are common to the cleanup action alternatives and described in Section 12.1.

12.6.2. SMA-3 Components of Alternative 5

Specific cleanup elements for SMA-3 under Alternative 5 are as follows:

- Partial excavation/dredging within area above approximately +12 feet USACE elevation.
  - Excavate to a depth based on contaminant mass rather than cap thickness, with a maximum depth corresponding to the cofferdam base elevation to prevent undermining the cofferdam.
  - Excavate additional upland bank soil to the extent feasible to facilitate the transition between the areas above and below the OHW.
- Thin-profile low-permeability cap for containment of sediment contaminants and for redirection of groundwater away from contaminated sediment towards the amended cap band at the outer edge of SMA-3 for treatment of arsenic, benzene, and naphthalene in porewater.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

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[131] The assumption concerning co-located ALU COCs achieving screening levels within a reasonable timeframe will be evaluated during the future pre-design investigation.

12.6.3. SMA-4 to SMA-6 Components of Alternative 5

Cleanup elements for SMAs-4 to -6 under Alternative 5 are equivalent to those listed under Alternative 4.

12.6.4. SMA-7 Components of Alternative 5

Specific cleanup elements for SMA-7 under Alternative 5 are as follows:

- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 5 enhanced capping in SMA-7 is assumed to include the following elements:
    - Organoclay-amended capping in areas of shallow NAPL (NAPL Area 14 and 15) for containment and attenuation of contaminants in NAPL.
    - ZVI-amended capping in areas of arsenic impacts at the toe of the low-permeability cap used in SMA-3.
    - Activated carbon-amended capping in areas of benzene and naphthalene impacts at the toe of the low-permeability cap used in SMA-3.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.6.5. SMA-8 Components of Alternative 5

Specific cleanup elements for SMA-8 under Alternative 5 are as follows:

- Enhanced cap methods in areas of shallow NAPL (NAPL Area 8) for enhanced containment and attenuation of NAPL contaminants. For cost estimating purposes the Alternative 5 enhanced capping is assumed to consist of organoclay-amended capping for containment and attenuation of contaminants in NAPL.

12.6.6. SMA-9 to SMA-14 Components of Alternative 5

Cleanup elements for SMAs-9 to -14 under Alternative 5 are equivalent to those listed under Alternative 4.

12.7. Cleanup Action Alternative 6

Cleanup Action Alternative 6 combines conventional and enhanced capping methods with natural recovery and the common elements described in Section 12.1 to meet preliminary cleanup standards in the SCU. Alternative 6 utilizes conventional and enhanced cap methods from previous alternatives in nearshore and offshore areas with the addition of expanded nearshore dredging for contaminant mass reduction. Similar to Alternatives 4 and 5, partial dredging would be completed in nearshore areas to facilitate placement of cap material and where feasible would be expanded to remove deeper impacted sediment in the nearshore areas of SMAs-3 and -4 to reduce the contaminant mass within the zone of highest groundwater flux. Figure 12-6 presents a plan view of the Alternative 6 cleanup components.

Under Alternative 6, the area of the highest groundwater flux at SMAs-3, 4 and 5 and adjacent areas immediately offshore in SMA-7 and SMA-9 are addressed by enhanced capping methods. Nearshore areas of high groundwater flux would be capped by low-permeability methods with thin cap profile to contain and attenuate contaminants in sediment and porewater. The low-permeability cap would direct groundwater discharge farther offshore away from shallow NAPL and areas with higher concentrations of sediment contaminants and funnel it through a band of permeable amended cap material in adjacent offshore areas of SMA-7 and SMA-9 for treatment. Alternative 6 uses amended capping methods to a greater degree relative to Alternatives 1 through 5. All other components of Alternative 6 in offshore areas are addressed in a similar manner as Alternative 4.

Similar to Alternative 1, natural recovery processes are included in depositional areas with relatively low contaminant concentrations where sedimentation rates and incoming sediment quality are adequate to achieve preliminary cleanup standards immediately following construction. In the lake bottom, ENR (e.g., as 6 inches of sand) would address sediment contaminants at concentrations moderately higher than preliminary GWPS cleanup levels/ALU screening levels and MNR would address contaminants in sediment above preliminary cleanup levels/screening levels but at or below ALU concentrations.

The combination of capping, dredging, ENR, and MNR will achieve preliminary cleanup standards immediately following construction. For the purposes of this FS, it is assumed that Alternative 6 will achieve screening levels for co-located ALU COCs within a reasonable timeframe[132].

SMA-specific components of Alternative 6 are described in the sections below.

12.7.1. GWMA-1, SMA-1 and SMA 2 Components of Alternative 6

The cleanup elements for GWMA-1, SMA-1 and SMA 2 are common to the cleanup action alternatives and described in Section 12.1.

12.7.2. SMA-3 Components of Alternative 6

Specific cleanup elements for SMA-3 under Alternative 6 are equivalent to Alternative 5 and include the following:

- Partial excavation/dredging within area above approximately +12 feet USACE elevation.
    - Excavate to a depth based on contaminant mass rather than cap thickness, with a maximum depth corresponding to the cofferdam base elevation to prevent undermining the cofferdam.
    - Excavate additional upland bank soil to the extent feasible to facilitate the transition between the areas above and below the OHW.
- Thin-profile low-permeability cap for containment of sediment contaminants and for redirection of groundwater away from contaminated sediment towards the amended cap band at the outer edge of SMA-3 for treatment of arsenic, benzene, and naphthalene in porewater.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.7.3. SMA-4 Components of Alternative 6

SMA-4 components under Alternative 6 are primarily addressed using enhanced capping methods with dredging conducted to greater depths relative to Alternative 3 to achieve greater mass removal as well as

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[132] The assumption concerning co-located ALU COCs achieving screening levels within a reasonable timeframe will be evaluated during the future pre-design investigation.

accommodate the proposed capping. Specific cleanup elements for SMA-4 under Alternative 6 are as follows:

- Partial excavation/dredging within area above approximately +12 feet USACE elevation.
    - Excavate to a depth based on contaminant mass rather than cap thickness, with a maximum depth corresponding to the cofferdam base elevation to prevent undermining the cofferdam.
    - Excavate additional upland bank soil to the extent feasible to facilitate the transition between the areas above and below the OHW.
- Thin-profile low-permeability cap for containment of sediment contaminants and for redirection of groundwater away from contaminated sediment towards the amended cap band at the outer edge of SMA-4 for treatment of benzene and naphthalene in porewater.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.7.4. SMA-5 Components of Alternative 6

SMA-5 components under Alternative 6 primarily rely on enhanced capping methods with dredging conducted as necessary to prevent shallowing of water depth within the nearshore marina and shipyard uses. Additional dredging for mass removal, like what is proposed for SMA-4, is not included in SMA-5 due to lower contaminant concentrations relative to SMA-4 and limited additional environmental benefit relative to additional cost.

Specific cleanup elements for SMA-5 under Alternative 6 are as follows:

- Partial dredging to facilitate cap placement without modifying the location of the OHWM and reducing the footprint of Lake Union.
- Partial dredging within area above approximately +5 USACE elevation, where necessary based on site uses, to facilitate placement of cap material in water depths less than 15 feet to minimize disruption to facility operations.
- Thin-profile low-permeability cap for containment of sediment contaminants and for redirection of groundwater away from contaminated sediment towards the amended cap band at the outer edge of SMA-5 for treatment of benzene and naphthalene in porewater.

12.7.5. SMA-6 to SMA-7 Components of Alternative 6

The cleanup action elements for SMAs-6 to -7 under Alternative 6 are equivalent to those used for Alternative 5.

12.7.6. SMA-8 Components of Alternative 6

Cleanup elements for SMA-8 under Alternative 6 are equivalent to those listed under Alternative 1.

12.7.7. SMA-9 Components of Alternative 6

Cleanup elements for SMAs-9 under Alternative 6 are equivalent to those listed under Alternative 3 and include the following:

- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 6 enhanced capping in SMA-9 is assumed to include the following elements:
    - Organoclay-amended capping in areas of shallow NAPL (i.e., NAPL Areas 3 and 5B) for containment and attenuation of contaminants in NAPL.
    - Activated carbon-amended capping in areas of benzene and naphthalene impacts at the toe of the low-permeability cap used in SMA-4 and SMA-5.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.7.8. SMA-10 through SMA-14 Components of Alternative 6

Cleanup elements used for SMAs-10 through SMA-14 under Alternative 6 are equivalent to those listed under Alternative 1.

12.8. Cleanup Action Alternative 7

Cleanup Action Alternative 7 builds upon the components of other alternatives by incorporating offshore mass removal of contaminated sediment to the maximum extent feasible with broad application of enhanced capping methods. By contrast, the other alternatives include removal only as necessary to accommodate a cap, maintain water depths to minimize disruptions to facilities or to achieve additional mass reduction of contaminated sediment in nearshore areas. Figure 12-7 presents a plan view of the Alternative 7 cleanup components.

As described in Section 11.3.1.2, it is not technically feasible to remove sediment in many areas of the SCU due to existing physical and chemical conditions including the presence of thick, soft sediment, shallow NAPL, and steep slopes. The dredging scope for Alternative 7, developed on the basis of avoiding these conditions, is presented on Figure 12-7. Dredging in eastern and western portions of the Site would be similar to those described in Alternatives 4 through 6. Under Alternative 7, a broad area off the southern shoreline of Gas Works Park (SMA-6) consisting of primarily lakeshore sediment will be dredged for mass removal of contaminated sediment. This area was determined to be suitable for dredging due to the absence of NAPL and soft sediment at significant thicknesses, and the expected feasibility of removing moderately contaminated sediment to a reasonable depth while leaving a surface with relatively low contamination. However, because SMA-6 falls adjacent to the Prow, dredging will not be conducted immediately against this structure to prevent undermining or damaging the existing shoreline structures therefore, leaving a band of undredged sediment along the Prow to be capped.

Under Alternative 7 offshore areas SMA-13 and SMA-14, with relatively low contaminant concentrations and depositional conditions, are addressed in the same manner as Alternative 1 through 6, by ENR and MNR, respectively.

The combination of capping, dredging, ENR, and MNR will achieve preliminary cleanup standards immediately following construction. For the purposes of this FS, it is assumed that Alternative 7 will achieve screening levels for co-located ALU COCs within a reasonable timeframe[133].

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[133] The assumption concerning co-located ALU COCs achieving screening levels within a reasonable timeframe will be evaluated during the future pre-design investigation.

SMA-specific components of Alternative 7 are described in the sections below.

12.8.1. GWMA-1, SMA-1 and SMA 2 Components of Alternative 7

The cleanup elements for GWMA-1, SMA-1 and SMA 2 are common to the cleanup action alternatives and described in Section 12.1.

12.8.2. SMA-3 to SMA-5 Components of Alternative 7

Cleanup elements for SMAs-3 to -5 under Alternative 7 are equivalent to those listed under Alternative 6.

12.8.3. SMA-6 Components of Alternative 7

Cleanup elements for SMA-6 under Alternative 7 are as follows:

- Dredging for removal of cPAH-impacted sediment. Dredging is assumed to remove an average of 5 feet of sediment.
- Armored 2-foot conventional sand cap for capping areas that are not dredged and backfilling the dredged areas.

12.8.4. SMA-7 Components of Alternative 7

The cleanup action elements for SMA-7 under Alternative 7 are equivalent to Alternatives 5 and 6 and include the following:

- Enhanced cap methods in areas of shallow NAPL and potential contaminant discharge to surface water as a result of groundwater flux through contaminated sediment. For cost estimating purposes the Alternative 7 enhanced capping in SMA-7 is assumed to include the following elements:
    - Organoclay-amended capping in areas of shallow NAPL (NAPL Area 14 and 15) for containment and attenuation of contaminants in NAPL.
    - ZVI-amended capping in areas of arsenic impacts at the toe of the low-permeability cap used in SMA-3.
    - Activated carbon-amended capping in areas of benzene and naphthalene impacts at the toe of the low-permeability cap used in SMA-3.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.8.5. SMA-8 Components of Alternative 7

Specific cleanup elements for SMA-8 under Alternative 7 are as follows:

- Enhanced cap methods in areas of shallow NAPL (NAPL Area 8) for enhanced containment and attenuation of NAPL contaminants. For cost estimating purposes the Alternative 7 enhanced capping is assumed to consist of organoclay-amended capping for containment and attenuation of contaminants in NAPL.

12.8.6. SMA-9 Components of Alternative 7

Cleanup elements for SMA-9 under Alternative 7 are equivalent to those listed under Alternative 6.

12.8.7. SMA-10 Components of Alternative 7

Specific cleanup elements for SMA-10 under Alternative 7 are as follows:

- Dredging within area above approximately +15 feet USACE elevation.
    - Excavate to a depth based on contaminant mass rather than cap thickness, to remove as much contaminated sediment below the Marina structures as possible.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.8.8. SMA-11 Components of Alternative 7

Cleanup elements for SMA-11 under Alternative 7 are equivalent to those listed under Alternative 1.

12.8.9. SMA-12 Components of Alternative 7

Specific cleanup elements for SMA-12 under Alternative 7 are as follows:

- Enhanced cap amended with organoclay in areas of shallow NAPL (i.e., NAPL Areas 1 to 3 and NAPL Area 5B) for containment and attenuation of contaminants in NAPL.
- Armored 2-foot conventional sand cap for containment of cPAHs and other low-mobility contaminants in sediment.

12.8.10. SMA-13 and SMA-14 Components of Alternative 7

Cleanup elements for SMAs-13 and SMA-14 under Alternative 7 are equivalent to those listed under Alternative 1.

12.9. Cleanup Action Alternative 8

Cleanup Action Alternative 8 builds upon Alternative 7 by incorporating broad application of capping and enhanced natural recovery methods in the off-shore, lake bottom areas of SMA-13 and SMA-14. Figure 12-8 presents a plan view of the Alternative 8 cleanup components.

Under Alternative 8, the majority of the SCU is addressed by the same methods and to the same degree as described for Alternative 7, including the larger dredging scale relative to Alternatives 1 through 6. Under Alternative 8, conventional sand capping and ENR are included in offshore areas SMA-13 and SMA-14 respectively. By contrast, Alternative 1 through 7 include ENR for SMA-13 and MNR for SMA-14. Relative to the thin (6-inch) layer of sand utilized in the other alternatives, the armored conventional sand cap (2-foot) in SMA-13 would contain low level contaminant concentrations. Relative to MNR utilized in the other alternatives, ENR in SMA-14 would accelerate natural recovery processes.

SMA-specific components of Alternative 8 are described in the sections below.

12.9.1. GWMA-1, SMA-1 and SMA 2 Components of Alternative 8

The cleanup elements for GWMA-1, SMA-1 and SMA 2 are common to the cleanup action alternatives and described in Section 12.1.

12.9.2. SMA-3 through SMA-12 Components of Alternative 8

Cleanup elements for SMAs-3 to -12 under Alternative 8 are equivalent to those listed under Alternative 7.

12.9.3. SMA-13 Components of Alternative 8

Specific cleanup elements for SMA-13 under Alternative 8 are as follows:

- Armored 2-foot conventional sand cap for containment of sediment contaminants.

12.9.4. SMA-14 Components of Alternative 8

SMA-14, in the lake bottom portion of the SCU, is a depositional low level contaminant area that is expected to naturally recover to meet preliminary cleanup levels within an acceptable timeframe. However, Alternative 8 in SMA-14 relies on ENR to accelerate natural recovery processes.

13.0 EVALUATION OF CLEANUP ACTION ALTERNATIVES

This section presents the evaluation criteria and evaluation results for the eight cleanup alternatives developed for the SCU.

13.1. Evaluation of SMS Minimum Requirements

Cleanup actions performed under the SMS are evaluated based on the minimum requirements specified in WAC 173-204-570[3]. SMS requires evaluation of cleanup action 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, public access, and recreation aesthetics. Adverse environmental impacts to be considered include construction-related water and sediment quality degradation, habitat value or acreage loss, and land use or access restrictions. The evaluation of alternatives for net environmental benefit and for adverse environmental impacts is addressed through the following SMS evaluation criteria (minimum requirements):

- Protect human health and the environment.
- Comply with all applicable laws, as defined in WAC 173-204-505(2).
- Comply with sediment cleanup standards specified in WAC 173-204-560 through 173-204-564.
- Use permanent solutions to the maximum extent practicable, as specified in WAC 173-204-570(4).
- Provide a reasonable restoration timeframe with preference for alternatives that provide for a shorter restoration timeframe. Appendix 13A provides further discussion of the restoration timeframe for the eight alternatives developed in this FS, including achievement of cleanup levels for GWPS COCs and screening levels for ALU COCs.[134] Alternatives that achieve cleanup standards within 10 years of completion of construction of the active components of the cleanup action are presumed to have a reasonable restoration timeframe (SCUM 2021).
- Implement effective source controls where needed with preference for source control measures more effective at minimizing future accumulation of contaminants in sediment caused by discharges.
- Meet the requirements for implementation of a sediment recovery zone (WAC 173-204-590) if cleanup standards cannot be achieved within 10 years.
- Provide for permanent cleanup action where technically feasible instead of relying exclusively on MNR or institutional controls and monitoring. Where institutional controls are used, they must comply with WAC 173-340-440 to include measures that control exposures and ensure the integrity of the cleanup action.
- Provide an opportunity for review and comment by affected landowners and the general public consistent with the public participation plan, and consider concerns identified in these comments.
- Include long-term monitoring to ensure remedy effectiveness.
- Provide periodic review of remedy effectiveness where elements of a cleanup action include containment, enhanced or natural recovery, institutional controls, sediment cleanup levels based on practical quantitation limits, or sediment recovery zones.

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[134] ALU COCs, along with GWPS COCs, were identified using surface sediment data from samples collected within the sediment portion of the AOI. The difference between the two sets of COCs is that the GWPS COCs are site-related and the ALU COCs are not.

In addition to the above minimum requirements, SMS stipulates that the evaluation of sediment cleanup actions shall provide sufficient information to fulfill the SEPA requirements (Chapter 43.21C RCW) for the proposed preferred remedy. This information includes discussions of significant short- and long-term environmental impacts; significant irrevocable commitments of natural resources; significant alternatives, including mitigation measures; and significant environmental impacts that cannot be mitigated. A SEPA analysis of environmental impacts will be undertaken for the cleanup action ultimately selected by Ecology. The SEPA evaluation and determination will be provided for public review in parallel with public review of the draft CAP.

Table 13-1 presents the SMS evaluation criteria (minimum requirements) for the eight cleanup action alternatives. As identified in Table 13-1, the eight cleanup action alternatives meet the SMS minimum requirements for sediment cleanup actions. With regard to the minimum requirement that cleanup actions use permanent solutions to the maximum extent practicable, this is determined by a disproportionate cost analysis of the alternatives as described in the following sections.

13.2. Disproportionate Cost Analysis Process

One of the minimum requirements of cleanup actions under MTCA and SMS is to use permanent solutions to the maximum extent practicable (WAC 173-204-570[4]). By definition (WAC 173-340-200), permanent remedies, once implemented, require no additional action to meet cleanup standards. A practicable cleanup action is 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 incremental benefits when compared to lower-cost alternatives.

The tool specified in MTCA and SMS to achieve this is the disproportionate cost analysis (DCA), which compares benefits and costs of alternatives to determine which alternative uses permanent solutions to the maximum extent practicable. Consistent with MTCA and SMS, the DCA process for this RI/FS evaluates benefits and costs to make a relative comparison of cleanup action alternatives, identifying the alternative whose incremental costs are not disproportionate to its incremental benefits. The identified cleanup action alternative is permanent to the maximum extent practicable.

13.2.1. Evaluation Criteria

The following criteria defined in WAC 173-340-360(3)(f) and WAC 173-204-570(4) are used to evaluate and compare each cleanup action alternative when conducting the DCA, six benefit criteria plus a cost criterion:

- Protectiveness
- Permanence
- Long-term effectiveness
- Management of short-term risks
- Technical and administrative implementability
- Consideration of public concerns
- Cost

The environmental benefit criteria are the same in MTCA and SMS except for the long-term effectiveness criterion. It differs slightly as detailed below.

These criteria form the basis of the DCA evaluation and alternatives comparison to determine whether a cleanup action is permanent to the maximum extent practicable. The individual criteria are described below.

- **Protectiveness** – Considers the overall protection of human health and the environment. Specific factors considered as contributing to overall protection of human health and the environment, include the following:
    - The degree to which existing risks are reduced;
    - The degree of improvement in overall environmental quality; and,
    - The potential risks to the integrity of the remedy from climate change impacts.
- **Permanence** – Addresses the extent to which permanent reductions in contaminant toxicity, mobility or volume are achieved. The adequacy of destroying, reducing, or eliminating hazardous substance releases and sources is considered, along with the degree of irreversibility of waste treatment and the characteristics and quantity of treatment residuals generated.
- **Long-term effectiveness** – The SMS guidance for evaluating long-term effectiveness provides several factors for assessing the effectiveness of the alternative over the long term:
    - Degree of certainty that the alternative will be successful;
    - Long-term reliability of the alternative, including consideration for the potential for impacts to the cleanup action as a result of the effects of climate change;
    - Magnitude of residual risks to human health and aquatic life following implementation of the alternative;
    - Effectiveness of source controls for ongoing discharges;
    - Management of residuals from treatment;
    - Risks at disposal sites;

  As a guide for evaluating long-term effectiveness, SMS lists the following hierarchy of technologies in descending order:

    1. Source control in combination with other cleanup technologies.
    2. Beneficial reuse of sediment.
    3. Treatment to immobilize, destroy or detoxify contaminants. This includes the reduction of risk to human health and aquatic life by making contaminants less bio-available.
    4. Dredging and disposal in an upland engineered facility that minimizes subsequent releases and exposures to contaminants.
    5. Dredging and disposal in a nearshore, in-water confined aquatic disposal facility.
    6. Containment in-place with an engineered cap.
    7. Dredging and disposal at an open-water disposal site approved by applicable state and federal agencies.
    8. Enhanced natural recovery.
    9. Monitored natural recovery.
    10. Institutional controls and monitoring.

- **Management of short-term risks** – Addresses the risk to human health and the environment associated with the alternative during construction and implementation and considers the effectiveness of measures taken to manage these risks. Risks can occur from worker or public exposure to contaminants, other releases of contaminants to the environment, and physical hazards created by construction and related materials management. Risks associated with invasive technologies such as dredging can include localized recontamination and potential off-site migration of contaminants.
- **Technical and administrative implementability** – Addresses the technical likelihood that an alternative can be implemented. Technical implementability factors include the degree to which the alternative uses proven technologies, the availability of materials and services, the operation and maintenance requirements, and the integration with existing operations and other cleanup actions. Administrative implementability factors include the potential for landowner cooperation and access, administrative and regulatory requirements such as permitting.
- **Consideration of public concerns** – Assesses the degree to which community concerns are addressed and the ways in which the alternative addresses those public concerns. Prior to public review of the FS, it is difficult to judge the response by the public to each alternative. As a surrogate for the degree to which community concerns are met prior to review by the community, the protectiveness scores for the alternatives will be used for this criterion as protection of human health and the environment is assumed to be the primary concern of the public. This criterion will be re-evaluated following public review of the draft FS.
- **Cost**- The estimated cost to implement the alternative, including direct and indirect costs to complete construction, the net present value of any long-term expenses, and agency oversight costs that are recoverable from the responsible parties. Section 13.3.7 and Appendix 13B describe the cost estimating process for the alternatives.

13.2.2. Benefit Scoring and Weighting Factors

The benefits of an alternative are evaluated based on the six benefit criteria. For each criterion, an alternative is scored on a scale 1 to 10: a score of 1 indicates the alternative is considered to satisfy the elements of the criterion to the lowest degree and a score of 10 indicates the alternative is considered to satisfy the elements of the criterion to the highest degree. For each alternative, the individual criterion scores are then weighted to emphasize more critical criteria, as outlined in Ecology's SCUM guidance (Ecology 2021):

BENEFIT CRITERIA WEIGHTING FACTORS

Benefit 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

Consistent with other MTCA aquatic remediation projects, the criteria that are most directly associated with the primary goals and objectives of the cleanup (e.g., protectiveness, permanence, long-term effectiveness) are more heavily weighted than the other criteria. The weighted benefit scores for each alternative are then summed to create a total weighted benefit score for each alternative.

13.2.3. Relative Benefit to Cost Ratio

A relative benefit-to-cost ratio is used to compare the cleanup action alternatives to determine whether costs are disproportionate to benefits. To calculate the relative benefit-to-cost ratio for each alternative, the total weighted relative benefit score is divided by the cost. Alternatives are then compared from least cost to highest cost. Alternatives whose incremental benefits are disproportionate to the incremental cost produce lower relative benefit/cost ratios. The cleanup action alternative with the highest benefit/cost ratio is permanent to the maximum extent practicable.

13.3. Disproportionate Cost Analysis: Cleanup Action Alternatives Benefit Evaluation and Costs

Evaluation of cleanup action alternatives against the benefit criteria are provided in this section along with a discussion of costs associated with the cleanup action alternatives.

The eight alternatives described in Section 12 are evaluated against the benefit criteria described in Section 13.2.1, with each criterion scored on a scale from 1, the lowest to 10, the highest degree of satisfying the criteria. The raw scores and rationale for the scores for each criterion are presented in Table 13-2. For each alternative, scores for the individual benefit criteria are then weighted according to the factors described in Section 13.2.2, and then summed to develop a total weighted relative benefit score for the alternative. The weighted scores and scoring totals for each alternative are summarized in Table 13-3. A discussion of the scoring considerations for each criterion and the cost of each alternative is presented in the sections that follow.

13.3.1. Protectiveness

The eight alternatives provide a range of protectiveness as a result of the immediate reduction of risk following source control (excavation and capping of shoreline bank soil, excavation of the tar mound, treatment of arsenic in groundwater, storm drain modifications, and sediment removal) and capping of sediment with the highest concentrations of contaminants and in areas more susceptible to exposure. The factors associated with protectiveness are addressed as follows:

- **Degree to which risks are reduced** – All alternatives will achieve a permanent reduction of exposure risk on a point-by-point basis across capped areas (SMA-1 through SMA-12) immediately following cleanup construction (see Appendix 13A). Alternative 8, which incorporates extensive application of enhanced capping methods as well as the greatest degree of soil and sediment removal to reduce risk with the highest degree of certainty has the greatest degree of protectiveness. For alternatives with progressively lower application of enhanced capping, replaced by a thick conventional sand cap, an incremental decrease in the certainty of risk reduction is assumed, particularly for areas of highest contaminant mobility. The extent of excavation/dredging also affected scores for protectiveness due to the effect on reduction of risk. In particular, increasing nearshore sediment excavation/dredging to achieve a higher degree of mass removal was assumed to effectively increase the certainty of risk reduction by removing contaminants within the nearshore zone of advective transport. Risk to receptors is minimal within natural recovery areas (SMA-13 and SMA-14) as cleanup levels are met on a point-by-point basis in SMA-13 (for benthic COCs) and on a SWAC basis across the SCU (for direct contact and bioaccumulation COCs) immediately following cleanup construction under the scenarios in Alternatives 1 through 8 (see Appendix 13A). Alternative 8 also provides a slight incremental increase in protectiveness relative to other alternatives due to the use of capping across SMA-13 and ENR in SMA-14.

- **Degree of improvement to overall environmental quality** – As described above, all alternatives reduce existing risks at the GWPS, thus improving environmental quality associated with contaminated media. All alternatives also result in an improvement to aquatic habitat as a result of partial dredging along the shoreline, where possible, to accommodate cap material placement without a net loss of lake surface area. The sediment removal and subsequent cap construction will replace steep shoreline structure armored with large riprap with shallower slopes and smaller substrate more suitable to priority aquatic species such as out-migrating salmonids. The potential to impact off-site areas during construction also factors into the effect on overall environmental quality and the protectiveness score. The use of dredging of contaminated sediment through the water column, particularly the large-scale dredging in SMA-6 associated with Alternatives 7 and 8, increases the potential to mobilize contaminants beyond the immediate work area, thus off-setting the benefits of the additional dredging to some degree.
- **The potential risks to the integrity of the remedy from climate change impacts** – The primary local effect of climate change, sea level rise, is not expected to affect the cleanup action because the lake level of Lake Union is controlled by the Ballard Locks.

The raw scores for protectiveness range from 4 (Alternative 1) to 9 (Alternative 8). Alternative 1 scores lower than other alternatives for protectiveness as it relies more heavily on sand capping, without incorporating higher-cost enhanced capping technologies, and represents a lower degree of removal for the purpose accommodating cap placement. Alternatives 2 through 6 score slightly higher because they include varying degrees of enhanced capping technologies in nearshore areas and expanded offshore areas with shallow NAPL, in addition to MNR, ENR, shoreline in-situ groundwater treatment, sand capping and removal of tar mound and lakeshore contaminated sediment. Alternatives 4 through 8 include additional lakeshore dredging to increase contaminant mass removal. Alternative 8 scores higher for protectiveness as a result of the extensive capping of contaminated sediment, including the greatest use of enhanced capping in nearshore areas and offshore areas with shallow NAPL, ENR, shoreline in-situ groundwater treatment, removal of tar mound and lakeshore and offshore contaminated sediment to the maximum extent practicable.

13.3.2. Permanence

The eight alternatives provide a range of permanence given the use of capping, limited source removal and source control (excavation and capping of shoreline bank soil, excavation of the tar mound, treatment of arsenic in groundwater, storm drain modifications, and sediment removal). The factors associated with permanence are addressed as follows:

- **Degree of reduction of toxicity, mobility, or volume of hazardous substances** – Expanded nearshore dredging in Alternatives 3 through 7 removes a higher mass of contaminants in zone of highest mass flux, but still represents a small portion of total site mass. The offshore dredging included in Alternatives 7 and 8 further increases the degree of reduction of volume of hazardous substances at the GWPS, but at the risk of mobilizing contaminants and increasing the affected area. Capping methods are expected to reduce mobility of contaminants. The certainty of this reduction of mobility progressively increases for alternatives that utilize enhanced capping methods to address areas of advective transport and shallow NAPL.

- **Adequacy of destroying, reducing, or eliminating hazardous substance releases and sources** – The alternatives use a limited level of contaminant destruction, however natural attenuation processes appear to be treating lighter end organic contaminants in groundwater. Arsenic in upland groundwater is expected to be chemically treated to low mobility forms by in-situ methods in all alternatives. Additional storm drain modifications will reduce contaminant releases in all the alternatives. Prevention of releases is accomplished by capping, with an increased certainty of reduced mobility with the increased use of enhanced capping methods. Nearshore dredging removes contaminant mass in areas of greatest mass flux.
- **Degree of irreversibility of waste treatment** – The alternatives involve a limited amount of treatment of wastes generated during cleanup. Sediment and upland soil removed and disposed of off-site are not expected to require treatment prior to disposal, except for limited quantities that may require incineration, which is irreversible. In-situ groundwater arsenic treatment has been demonstrated to be reliable and geochemically irreversible based on treatability testing. In-situ treatment by cap amendments used in enhanced capping methods have been demonstrated reliable in the long term for treating respective contaminants.

Raw permanence scores range from 4 (Alternative 1) to 8.5 (Alternative 8). Like the protectiveness score, the permanence score reflects higher confidence that the shoreline in-situ treatment, greater use of capping and capping amendments, and greater removal of more-highly contaminated sediment in Alternative 8 will yield a more permanent cleanup action. The intermediate alternatives (Alternatives 2 through 7) score in the middle due to their variation in scope of nearshore dredging and application of enhanced capping to varying degrees. Alternative 1 scores the lowest as a result of extensive use of conventional sand capping to contain sediment contaminants and lack of enhanced capping.

13.3.3. Long-term Effectiveness

The eight alternatives provide a range of long-term effectiveness based on MTCA and SMS guidance. Each of the alternatives include source control, effective containment of contaminated media, and some degree of removal and disposal in an upland engineered facility. Source control measures include excavation and capping of shoreline bank soil, excavation of the tar mound, treatment of arsenic in groundwater, storm drain modifications, and sediment removal.

The factors that inform the long-term effectiveness score for the alternatives are as follows:

- **Degree of certainty that the alternative will be successful** – Containment methods are proven and can reliably contain contaminants. Enhanced capping methods provide predictable performance to incrementally increase long-term effectiveness of alternatives that include varying degrees of enhanced capping. The degree of removal of nearshore sediment affects long-term effectiveness by removing incrementally more contaminant mass in the areas of greatest mass flux which provides an incremental increase in cleanup action performance. Established monitoring methods will be included with the cleanup action and will allow performance monitoring over the lifespan of the cleanup action.
- **Long-term reliability of the alternative, including consideration of the potential for impacts to the cleanup action as a result of the effects of climate change** – Capping methods proposed are established methods that can be designed to be stable and reliable in the long term. The use of

enhanced capping methods will increase the reliability of contaminant containment, particularly were applied to areas of groundwater flux. Increased excavation/dredging, particularly in the nearshore areas with highest groundwater flux, increases the long-term reliability of the alternatives due to the increased mass reduction in the area of highest mobility. The primary effects of climate change at the GWPS, sea level rise, is not expected to affect the long-term effectiveness of the cleanup action as the lake level for Lake Union is controlled by the Ballard Locks.

- **Magnitude of residual risks to human health and aquatic life following implementation of the alternative** – GWPS cleanup levels and ALU screening levels are expected to be met immediately following cleanup construction for all alternatives. The institutional controls that may be included in the alternative can be effectively implemented and enforced. Alternative 8, which uses capping and ENR at SMAs 13 and 14, respectively, has a slight incremental increase in long-term effectiveness due to additional capping, despite being applied to areas of low-concentration contaminants.
- **Effectiveness of source controls for ongoing discharges** – Source control methods such as storm drain modifications and treatment of arsenic in upland groundwater are expected to be the same across all alternatives.

The raw scores range from 3.5 (Alternative 1) to 7.5 (Alternative 8). Reliance of Alternative 1 on conventional capping with limited removal results in the lowest raw score, despite the technology's proven simplicity and effectiveness. Enhanced capping provides treatment, which SMS guidance identifies as offering greater long-term effectiveness (see Section 13.2.1) and improves the scores for Alternatives 2 to 6. The increased scope of nearshore dredging under Alternatives 4 through 8 also increases the score for long-term effectiveness. Broader application of conventional sand capping and enhanced capping with dredging to the maximum extent feasible, raises the long-term effectiveness for Alternative 8.

13.3.4. Management of Short-term Risks

The eight alternatives provide a range for management of short-term risks. The construction methods proposed are common and frequently used for sediment remediation with moderate risks that can be mitigated by isolating the work zone and communicating with affected property owners and park users about work zones, closure areas, and closure periods. Cofferdams and other BMPs associated with the capping and dredging will be designed to manage contaminants that may be mobilized during respective construction elements. Alternatives that involve enhanced capping, which uses a thin profile and significantly less material imported and placed, will reduce the potential for mobilizing contaminants during cap placement and reduce the short-term impacts associated with transport of material to the GWPS relative to thick sand capping.

Low to moderate potential for mobilization will result from capping and limited nearshore dredging. The use of cofferdams and other BMPs for dredging and slow capping methods will effectively prevent mobilization of contaminants. The addition of offshore dredging in Alternatives 7 and 8 will pose a greater risk of mobilizing contaminants to Lake Union due to the deeper dredge depth and the addition of off-shore dredging in the deeper water of SMA-6. Alternatives 7 and 8 will require additional BMPs designed for off-shore dredging to minimize suspension of contaminated sediments and mobilization to the water column.

The scores for management of short-term risks range from 4.5 (Alternative 8) to 7.5 (Alternative 3). The lower score for Alternative 8 is the result of the addition of sediment dredging in deeper water of the lake slope (SMA-6) and significantly increased cap and ENR material placed in SMAs 13 and 14. The dredging in SMA-6 included in Alternatives 7 and 8 significantly increases the volume of traditional dredging through the water column, which comes with an increased risk of resuspension and dredging residuals relative to Alternative 6. Alternative 8 also includes additional short-term impacts associated with significantly increased volume of imported cap material relative to all other alternatives. Alternatives 1, 2, and 4 through 7 score in the middle (raw scores range from 5 to 7) as they reflect local impacts associated with import and placement of large volumes of cap material and associated risks. The highest raw score of 7.5 assigned to Alternative 3 reflects the expansive use of enhanced capping technologies with a lower degree of dredging relative to Alternatives 4 through 8, resulting in significantly reduced volume of cap material and reduced short term risks associated with import and placement of large volumes of cap material and reduced impacts associated with dredging.

13.3.5. Technical and Administrative Implementability

The eight alternatives provide a narrow range of technical and administrative implementability. Each of the alternatives are technically and administratively implementable and involve comparable logistical, regulatory and land use challenges.

Administrative implementability is expected to be similar among the alternatives. Achieving acceptance from stakeholders and permitting agencies is expected to be feasible and will require coordination during future planning and design phases of the project.

Technical implementability varies slightly between the eight alternatives. Enhanced capping methods are relatively innovative and more specialized than conventional sand capping, but the associated materials and contractors are expected to be readily available. The expanded capping and dredging scope of Alternative 8 is expected to increase the construction duration, potentially extending a full season due to restrictions of the in-water work window. The substantial offshore dredging scope included in Alternative 8 is a commonly available and proven technology but will require implementation of water quality BMPs to prevent releases to the water column.

Alternative 8 was assigned the lowest score (6) because of the complexity and duration associated with the larger dredging area. Alternatives 1 through 5 and 7 score in the middle (raw score range of 6 to 7) for this criterion due to the use of common cap technologies and placement methods. In addition to using common cap technologies and placement methods, Alternative 6 reflects the expansive use of enhanced capping technologies that reduce the volume of overall cap material to be imported and placed. Therefore, Alternative 6 scores the highest (raw score of 7) for this criterion.

13.3.6. Consideration of Public Concerns

Public concerns are not yet known. For the purposes of completing this RI/FS for public review, it is assumed that public concerns would likely focus on the protectiveness of the cleanup action alternatives. Therefore, the benefit scores for the public concern criterion are assumed to be the same as the scores assigned for the protectiveness criterion. Scores for the public concern criterion will be reviewed and revised as necessary after receiving public comments on the RI/FS.

13.3.7. Cost

Cleanup action alternative costs were developed consistent with the requirements of WAC 173-340-360(3)(f)(iii) for DCA analysis. EPA feasibility study cost estimating guidance (EPA 2000) was also considered at a general level for development of cost categories and assumptions. Detailed cost breakdowns for the alternatives are presented in Appendix 13B, including direct capital costs for construction, monitoring, and operations and maintenance (O&M). Indirect costs cover design, management, and regulatory oversight. The cost estimates include appropriate contingencies and discount rates for net present value calculations. Long-term costs include operation and maintenance, monitoring, equipment replacement and maintenance of institutional controls. Cost estimates are for a 30-year period and are established to be accurate within a range of -30 percent to +50 percent given the assumptions presented.

Estimated net present worth costs range from $60,160,000 for Alternative 1 to $93,930,000 for Alternative 8.

13.4. Disproportionate Cost Analysis: Cleanup Action Alternatives Relative Benefit to Cost Ratios

In accordance with 13.2.3 above, a relative benefit-to-cost ratio is used to compare the cleanup action alternatives to determine whether costs are disproportionate to benefits. The relative benefit-to-cost ratio for each alternative is calculated by dividing the total weighted relative benefit score by the cost. Alternatives are then compared from least cost to highest cost. Alternatives whose incremental benefits are disproportionate to the incremental cost produce lower benefit-to-cost ratios. The cleanup action alternative with the highest benefit to-cost-ratio is permanent to the maximum extent practicable.

Table 13-3 presents the total weighted relative benefit score for each alternative calculated using the raw score and respective weighting factor for each criterion. Also presented in Table 13-3, and on Figure 13-1, are the costs for each alternative and the relative benefit-to-cost ratio.

The total weighted relative benefit scores for the alternatives range from 4.4 (Alternative 1) to 7.9 (Alternative 8) as shown on Table 13-3 and Figure 13-1. This range of scores reflects, in part, the influence of large areas of MNR, ENR and capping elements common to multiple alternatives. The relatively close range also reflects that all alternatives meet the minimum requirements of MTCA and SMS and use technologies that achieve relatively similar levels of protectiveness, permanence and long-term effectiveness (i.e., the most heavily weighted criteria) as described below.

Under MTCA and SMS, costs must be considered when selecting the alternative that is permanent to the maximum extent practicable. As described in Section 13.3.7, the estimated costs for the eight alternatives range from $60,160,000 (Alternative 1) to $93,930,000 (Alternative 8). 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 on Figure 13-1 by comparing the benefit-to-cost ratios, as expressed by the formula:

$$Benefit/Cost\ Ratio = Total\ Weighted\ Relative\ Benefit\ Score\ \div (Cost \div \$50{,}000{,}000)$$

The cost for each alternative was normalized to increments of $50,000,000 to generate a range of values similar to the range of the total benefit scores.

The resulting benefit-to-cost ratios for the eight alternatives are shown in Table 13-3 and plotted on Figure 13-1 with the corresponding values for the total weighted relative benefit scores and cost. Alternative 6 has the highest benefit-to-cost ratio (5.2) and Alternative 1 has the lowest (3.7). Although the total weighted relative benefit score for Alternative 8 is higher than the total weighted relative benefit score for Alternative 6, the incremental cost required to achieve this benefit for Alternative 8 is disproportionate, as represented by the benefit-to-cost ratio of 4.3 for Alternative 8, compared to the 5.2 benefit-to-cost ratio for Alternative 6. Therefore, Alternative 8 is disproportionately costly relative to Alternative 6 and not considered to be practicable. Alternatives 1 through 5 provide lower benefits than Alternative 6, but also have lower benefit-to-cost ratios (range of 3.7 to 4.6), indicating that Alternative 6 is not disproportionately costly relative to these alternatives.

Based on this analysis, Alternative 6 is determined to be permanent to the maximum extent practicable.

13.5. Preferred Cleanup Action Alternative

Cleanup Action Alternative 6 will meet cleanup standards through a combination of excavation and capping of shoreline bank soil, shallow tar removal, treatment of arsenic in groundwater, sediment removal and capping, and enhanced and monitored natural recovery. The estimated cost is $73,000,000. Cleanup Action Alternative 6 is expected to meet cleanup standards for GWPS COCs immediately following construction and, for the purposes of this FS, it is assumed that it will comply with screening levels for co-located ALU COCs within a reasonable timeframe (assumption to be verified during future remedial design).

Cleanup Action Alternative 6 meets the minimum requirements for sediment cleanup actions (WAC 173-204-570(3)), as described in Section 13.1 and Table 13-1. The minimum requirements are summarized below:

- Protect human health and the environment;
- Comply with all applicable laws;
- Comply with sediment cleanup standards;
- Use permanent solutions to the maximum extent practicable;
- Provide a reasonable restoration timeframe;
- Implement effective source controls;
- Provide for permanent cleanup action where technically feasible;
- Provide an opportunity for review and comment by affected landowners and the general public;
- Include long-term monitoring to ensure remedy effectiveness; and,
- Provide periodic review of remedy effectiveness.

With regard to the minimum requirement to use permanent solutions to the maximum extent practicable, this was evaluated through the DCA process described in Section 13.3, and presented in Tables 13-2 and 13-3 and Figure 13-1. The DCA compared benefits and costs for all alternatives and determined that Alternative 6 has the highest degree of benefit without disproportionate costs and therefore is permanent to the maximum extent practicable,

Because Alternative 6 meets all the minimum requirements for sediment cleanup actions under SMS, it is identified as the preferred cleanup action alternative.

14.0 NEXT STEPS IN THE CLEANUP PROCESS

Following Ecology response to public comments on this RI/FS, it will be finalized. Ecology will then select a cleanup action for the SCU based on the information in the RI/FS. That selected cleanup action will be described in a CAP that is part of a legal agreement between Ecology, PSE and the City. The legal agreement will require design and implementation of the CAP and will be issued for public review.

15.0 REFERENCES

ACOE et al. 2016. Dredged Material Evaluation and Disposal Procedures User Manual. August 2016.

AECOM. 2010. Gas Works Park, Kite Hill Soil Cover Project, drawing J14-80.00, topographic base map.

Ahlquist, Norman E. 1954. Gas Works Waste Disposal. Seattle Gas Company.

AMEC. 2010. 2010 Groundwater Compliance Monitoring Report, Gas Works Park Site, Seattle, Washington. May 2010.

Anchor QEA, LLC. 2012. Restoration and Enhancement Plan, Final, City of Seattle Shoreline Master Program. Seattle, Washington.

Anchor QEA, LLC. 2018. Mudline discharge data.

Applied Geotechnology, Inc. 1993. Draft Remedial Investigation/Feasibility Study, Facilities North Site, Seattle, Washington.

API. 2006. API Interactive LNAPL Guide. Version 2.0.4. Available at www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl/interactive-guide. Accessed October 2, 2017. February 2006.

Barnes et al. 1978. Barnes, RS, PB Birch, DE Spyridakis, and WR Schell, 1978. Changes in Sedimentation Histories of Lakes Using Lead-210 as a Tracer of Sinking Particulate Matter (IAEA-SM-288/45). [In] Isotope Hydrology 1978. Proceedings of an International Symposium on Isotope Hydrology, held 19-23 June 1978 in Neuherberg, Germany. Volume II. Pages 875-898.

Brocher, T. M., R. E. Wells, A. P. Lamb, and C. S. Weaver. 2017, Evidence for distributed clockwise rotation of the crust in the northwestern United States from fault geometries and focal mechanisms, Tectonics, 36, doi:10.1002/ 2016TC004223.

CH2M Hill. 1975. Water Circulation Studies of Lake Washington.

CHRIS database. 1988. Fein-Marquart Associates, Inc. 7215 York Rd. Baltimore, MD; and OHM/TADS (Oil and Hazardous Materials/Technical Assistance Data System) Database. 1988. Fein-Marquart Associates, Inc. 72112 York Rd, Baltimore, MD.

Chrzastowski, M. 1981. Historical Changes to Lake Washington and Route of the Lake Washington Ship Canal, King County, Washington. Open File Report 81-1182. Department of the Interior, United States Geological Survey.

City of Seattle. 2002. Side-scan sonar survey. November 2002.

City of Seattle. 2003. Seattle's Urban Blueprint for Habitat Protection and Restoration. City of Seattle's Salmon Team.

City of Seattle. 2005. Northwest Corner topography.

City of Seattle. 2013a. Cheshiahud Lake Union Loop Trail Map. Seattle Parks Foundation and City of Seattle.

City of Seattle. 2013b. City of Seattle Zoning Map. City of Seattle.

City of Seattle. 2015. Shoreline Master Program. Seattle Municipal Code (SMC) 23.60A. June 15, 2015.

City of Seattle. Ship Canal Water Quality Project. http://www.seattle.gov/util/EnvironmentConservation/Projects/ShipCanalWaterQuality/index.htm.

Climate Impacts Group. 2015. Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. *State of Knowledge: Climate Change in Puget Sound*. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. University of Washington, Seattle.

Cole and Machno. 1971. Cole, Dale W, and Peter S Machno. Myrtle Edwards Park -A Study of the Surface and Subsurface Soil Materials.

Cubbage, J. 1992. A Survey of Contaminants in Sediment in Lake Union and Adjoining Waters (Salmon Bay, Lake Washington Ship Canal, and Portage Bay). Washington State Department of Ecology.

Eberhard-Karls-University of Tuebingen. 2012. Center for Applied Geoscience (ZAG), Sigwartstr, 10, D-72076 Tuebingen, Germany.

EcoCompliance. 2007-2009. Groundwater Monitoring Reports.

Edublogs.org, http://oliver2014.global2.vlc.edu.au/category/science/. Accessed 2017.

ENSR/AECOM. 2007. Using Gauging Data to Improve Site Conceptual Models at LNAPL-Impacted Remediation Sites, Mobile Interval of LNAPL for Unconfined Hydrostatic Conditions. Modified. 2007.

Environment Agency. 2003. An Illustrated Handbook of DNAPL Transport and Fate in the Subsurface, R&D Publication 133. www.environment-agency.gov.uk. 2003. Available at https://clu-in.org/conf/itrc/dnaplpa/dnapl_handbook_final.pdf.

Equipoise Corporation. 1999. Prospective Purchaser Agreement Cleanup Action Plan, Nortar/Former ATCO Facility at 1700 North Northlake Way, Seattle, Washington.

Floyd|Snider. 2007. Gas Works Sediment Area - Joint Source Control Evaluation. Prepared for the City of Seattle Public Utilities.

Floyd|Snider.2008a. Gas Works Park Northest Corner Invetigation Data Report. Prepared for the City of Seattle Public Utilities. April 15.

Floyd|Snider. 2008b. Letter to Mr. Pete Rude, Seattle Public Utilities, regarding August 2008 Tar Seep Investigation. October 13.

Floyd|Snider. 2009. Gas Works Sediment Area - Initial Source Control Screening Investigation of Storm Drains.

Floyd|Snider. 2010a. Gas Works Park – Storm Drain Source Control Evaluation Phase 3 Data Report.

Floyd|Snider. 2010b. Gas Works Sediment Area – Gas Works Park Northeast Corner Source Control Data Report.

Floyd|Snider. 2011. Memorandum – Storm Drain Source Control Evaluation Phase 3 Data Report Addendum.

Floyd|Snider. 2012a. Gas Works Park – Stormwater Conveyance System Status Update.

Floyd|Snider. 2012b. Memorandum – Storm Drain Source Control Evaluation Phase 3 Data Report Addendum 2 - Waterway #20.

Foster, Richard. 1943. Sources of Pollution in Lake Washington Canal and Lake Union. State of Washington Pollution Commission.

Foster and Wheeler, Inc. 1998. Draft Cleanup Action Plan, Former Chevron Bulk Plant 100-1327, Facilities North/King County Metro Transit Lake Union Site.

Garry Struthers Associates. 1999. Police Harbor Patrol UST Site Assessment Report. Seattle UST Central Group.

GeoEngineers. 2010. Monitoring Well Installation Report, Gas Works Sediment Area, Seattle, Washington.

GeoEngineers. 2015. Supplemental Investigation Data Report Addendum, Gas Works Park Site. May 1, 2015.

GeoEngineers. 2015. Kite Hill Construction Completion Report. Gas Works Park Site, Seattle, Washington. Prepared for Puget Sound Energy. October 19, 2015.

GeoEngineers. 2017. Play Area Groundwater Treatment Interim Action Work Plan, Gas Works Park Site, Seattle, Washington. Prepared for Puget Sound Energy, August 1, 2017.

GeoEngineers, Inc. 2021. Play Area Interim Action Monitoring Report. Gas Works Park Site, Seattle, Washington. August 13, 2021.

GeoEngineers, Inc. 2022. Play Area Interim Action Construction Completion Report. Gas Works Park Site, Seattle, Washington. January 13, 2022.

Graves, David. 2014. “Seattle Parks Department, Personal Communication.” March 7, 2014.

Graves, David. 2020. “Seattle Parks Department, Personal Communication.” February 21, 2020.

Grette & Associates. 2005. Underwater diving and video. February 2005.

GWSA Technical Team. 2011a. Revised Geologic Conceptual Site Model Package, Gas Works Sediment Area.

GWSA Technical Team. 2011b. Revised Hydrogeologic Conceptual Site Model.

Hart Crowser, Inc. 2011. Urban Seattle Area Soil Dioxin and PAH Concentrations Initial Summary Report.

Hart Crowser, Inc. 2012a. Gas Works Park Uplands Remedial Investigation, Seattle, Washington.

Hart Crowser, Inc. 2012b. Biological Evaluation of Northlake Shipyard Sand Blast Grit Dredging - Interim Action. Seattle, Washington.

Hart Crowser, Inc. 2012c. Gas Works Park NE Corner Capping Project, Seattle, Washington.

Hart Crowser, Inc. 2014. Construction Completion Report, Sandblast Grit Removal, Interim Remedial Action, Northlake Shipyard Site.

HDR, Inc. 1988a and 1988b. Environmental Testing for Gas Works Park Play Barn, Investigation Report, and Focused Field Investigation and Irrigation Feasibility Study, Gas Works Park, Seattle, Washington.

Herrera 2016. Technical Memorandum. Waterway #20 Upland Soil Sampling. June 30, 2016.

Hong, Lei, and Richard G Luthy. 2005. Draft Final Report II - Identification of Black Carbon Material in Sediments from Lake Union. Stanford, California: Stanford Univerisity, Department of Civil and Environmental Engineering.

Houck, Doug. 2004. Telephone conversation. July 29, 2004.

Howard et al. 1991. Howard, PH, RS Boethling, WF Jarvis, WM Meyland, and EM Michalenko. 1991. Handbook of Environmental Degradation Rates. Chelsea, Michigan: Lewis Publishers.

ILIAD, Inc. 2012. Operation and Maintenance for Gas Works Park NE Corner Capping Project.

Interstate Technology and Regulatory Council (ITRC). 2003. “An Introduction to Characterizing Sites Contaminated with DNAPLs.” Prepared by The Interstate Technology & Regulatory Council Dense Nonaqueous Phase Liquids Team. September 2003.

Interstate Technology and Regulatory Council (ITRC). 2009. “Evaluating LNAPL Remedial Technologies for Achieving Project Goals.” Prepared by The Interstate Technology & Regulatory Council LNAPLs Team. December 2009. Available at http://www.itrcweb.org/GuidanceDocuments/LNAPL-2.pdf.

Interstate Technology and Regulatory Council (ITRC). 2014. Contaminated Sediment Remediation, Remedy Selection for Contaminated Sediment, CS-2. Washington, DC: ITRC Contaminated Sediments Team.

Kelly, Richard. 1996. Completed NPDES Permit Application Questionnaire Supplementing Form 2C for Shipbuilding and Repair Facilities. Northlake Shipyard, Inc.

King County. Major Lakes Monitoring Program. httP://green2.kingcounty.gov/lakes/LakeUnion.aspx.

King County. 2011. 2011 Annual Revalue Report, Commercial Waterfront Specialty Area 12, King County Department of Assessments Accounting Division, Lloyd Hara, Assessor.

King County, and City of Seattle. 2013. Letter of Intent Related to the Current and Potential Future Use of Certain Property Located at North Lake Union by the Center for Wooden Boats.

Krupka, KM, and WJ Martin. 2001. Subsurface Contaminant Focus Area: Monitored Natural Attenuation (MNA) – Programmatic, Technical, and Regulatory Issues. Pacific Northwest National Laboratory.

Lake Union Park Working Group. http://www.atlakeunionpark.org/about-lake/common-creatures.

Landolt Busch and Associates. 1991. Lake Union Fish Histopathology Study.

Lide, DR. 1992. *CRC Handbook of Chemistry and Physics*. 73 ed.

Mass, Cliff. 2013. The Weather of the Pacific Northwest. University of Washington Press, Seattle, Washington.

Mazzotti, S., L. J. Leonard, J. F. Cassidy, G. C. Rogers, and S. Halchuk. 2011. Seismic hazard in western Canada from GPS strain rates versus earthquake catalog, of Geophysical Research, Solid Earth, v.116, B12310, 17 p., doi:10.1029/2011JB008213.

McCaffrey, R., A. I. Qamar, R. W. King, R. Wells, G. Khazaradze, C. A. Williams, C. W. Stevens, J. J. Vollick, and P. C. Zwick. 2007. Fault locking, block rotation and crustal deformation in the Pacific Northwest, Geophysical Journal International, v.169, p.1315–1340, doi:10.1111/j.1365-246X.2007.03371.x.

McCaffrey R., R.W. King, S.J. Payne, and M. Lancaster, 2013, Active tectonics of northwestern US inferred from GPS-derived surface velocities. Journal of Geophysical Research, Solid Earth, v. 118, p.1−15. DOI: 10.1029/2012JB009473.

McCrory, P. A., J. L. Blair, F. Waldhauser, and D. H. Oppenheimer. 2012. Juan de Fuca slab geometry and its relation to Wadati-Benioff zone seismicity, Journal of Geophysical Research, v. 117, B09306, doi:10.1029/2012JB009407.

National Fire Protection Association 70. National Electric Code.

National Oceanographic and Atmospheric Administration. 2016. Endangered and Threatened Species; Designation of Critical Habitat for Lower Columbia River Coho Salmon and Puget Sound Steelhead; Final Rule. Federal Register 81(36):9252-9325. February 24, 2016.

Ongerth and Pane. 1985. Draft Evaluation of Health Risk for Public Use of Gas Works Park.

Palermo, MR, S Maynord, J Miller, and D Reible. 1998. Permeable Reactive Barrier: Technology Update. Chicago, Illinois: Great Lakes National Program Office.

Parametrix, Inc. 1999. Gas Works Park Environmental Cleanup, Cleanup Action Plan and SEPA Checklist, Volume 4 (Volume 4 of FFS) Includes ThermoRetec 1999 Memorandum to the Department of Ecology Re: Extremely Hazardous Waste.

Parametrix, Inc. 2002. Multibeam bathymetry surveys. December 2002.

Parametrix and Key. 1998. Draft Gas Works Park Environmental Cleanup, Focused Feasibility Study Report Volumes 1 and 2.

Pratt, T.L., K.G. Troost, J.K Odum, and W.J. Stephenson. 2015, Kinematics of shallow backthrusts in the Seattle fault zone, Washington State: Geosphere, v. 11, no. 6, p. 1948–1974, doi:10.1130/GES01179.1.

Public Law 92-583. 1972. Coastal Zone Management Act.

Public Law 94-265. 1976. Magnuson-Stevens Fishery Conservation and Management Act.

Puget Sound Air Pollution Control Agency. Clean Air Regulations.

RETEC. 1999. Bathymetry generated from side-scan sonar surveys.

RETEC. 2001. Construction Completion Report.

RETEC. 2002. Nearshore bathymetry survey. October 2002.

RETEC. 2004. Gas Works Park Sediment Area Chemical Data Package.

RETEC. 2020. Nearshore singlebeam bathymetry survey. October 2020.

RETEC/SAIC. 1999. Towed underwater video survey. November 1999

Richard, Michael. 1983. *Seattle's Gas Works Park: The History, The Designer, The Plant, The Park, Map and Tour*.

Richard Haag Associates, Inc (Haag). 1971. A Report Substantiating the Master Plan for Myrtle Edwards Park, City of Seattle.

Richard Haag Associates, Inc. (Haag). 1973a. Concrete and Demolition Work Plan.

Richard Haag Associates, Inc. (Haag). 1973b. Layout Plan Excavation and Demolition.

Richard Haag Associates, Inc. (Haag). 1973c. Demolition Section 3.

Richard Haag Associates, Inc. (Haag). 1975. Site Plan.

Richard Haag Associates, Inc. (Haag). 1997. Gas Works Park, Site Plan, Lake Union Earthwork, hand edited with volumes excavated. University of Washington Special Collections Library. Seattle, Washington.

Rusa Fels, Patricia, and Christy Edstrom. 2012. Gas Works Park, National Register of Historic Places Registration Form.

Sabol, MA, GL Turney, and GN Ryals. 1988. Evaluation of Available Data on the Geohydrology, Soil Chemistry, and Ground-Water Chemistry of Gas Works Park and Surrounding Region, Seattle, Washington. Prepared in cooperation with the WA Department of Ecology.

Sanborn Fire Insurance. 1919. Sanborn Fire Insurance Map 1905-1950.

Seattle Gas Company. 1938. General Plan, Lake Station. June 1938.

Seattle Gas Company. 1953. General Plan, Lake Station. April 1949, revised June 1953.

Seattle Department of Parks and Recreation (Parks and Recreation). 1984. Memorandum to Health Advisory Committee from Park Department Subject Summary of the History of Gas Works Park.

Seattle Department of Parks and Recreation (Parks and Recreation). 2005. Northwest Corner Improvements, Gas Works Park, As-Built Set.

Seattle Department of Parks and Recreation (Parks and Recreation). 2018. As-Built Set.

Seattle Department of Planning and Development (DPD). 2012. DPD Map Books 76, 77, 90, and 91. City of Seattle, Department of Planning & Development.

Seattle Gas Company. 1949. General Plan of Lake Station.

Seckel, GR, and M Jr. Rattray. 1953. Studies on Lake Washington Ship Canal. Department of Oceanography, University of Washington.

St. Amant, Glen. 2007. Personal communication in a meeting, January 18, 2007.

Technical Resources, Inc. 1989. Fifth Annual Report on Carcinogenicity. Rockville, MD.

Tetra Tech. 1985. Gas Works Park Supplemental Soils Testing Phase I Surface Soils Analysis.

Tetra Tech. 2006. Multibeam bathymetry surveys. October 2006.

ThermoRETEC. 2000. Final Engineering Design Report, Gas Works Park MGP Site.

ThermoRETEC. 2001. Construction Completion Report, Gas Works Park Site, Seattle, Washington.

Tomlinson, RD, RJ Jr Morrice, ECS Duffield, and RI Matsuda. 1977. A Baseline Study of the Water Quality, Sediments, and Biota of Lake Union, Municipality of Metropolitan Seattle.

Treaty of Medicine Creek. 10 Stat. 1132.

Treaty of Point Elliott. 12 Stat. 927.

Troost et. al. 2005. The geologic map of Seattle, a progress report, U.S. Geological Survey, Open-file report 2005-1252, scale 1:24,000.

Tver, David F. and Richard W. Barry. 1980. The Petroleum Dictionary. Van Nostrand Reinhold Company.

U.S. Army Corps of Engineers (USACE). 1937. 1937 Permit: Seattle Gas Company Piling Installation.

U.S. Army Corps of Engineers (USACE). 2008. Technical Guidelines for Environmental Dredging of Contaminated Sediments. edited by MR Palermo, PR Schroder, TJ Estes and NR Francingues.

U.S. Coast and Geodetic Survey. 1899. Shoreline survey.

U.S. Environmental Protection Agency (EPA). 1988. US Production of Manufactured Gasses: Assessment of Past Disposal Practices. Research Triangle Institute.

U.S. Environmental Protection Agency (EPA). 1989. Wetland Actions Plan.

U.S. Environmental Protection Agency (EPA). 1992. Directive No. 9283.1-06, Considerations in Ground-Water Remediation at Superfund Sites and RCRA Facilities – Update. May 27, 1992. Available at https://semspub.epa.gov/work/HQ/174509.pdf.

U.S. Environmental Protection Agency (EPA). 1995. Expanded Site Inspection Report, Washington Natural Gas – Seattle Plant, (WAD 980639280), Seattle, Washington.

U.S. Environmental Protection Agency (EPA). 1996. Deferral Agreement. Washington Natural Gas – Seattle Plant (aka Gas Works Park) Site. July 15, 1996.

U.S. Environmental Protection Agency (EPA). 1999. OSWER Directive 9200.4-17: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. Washington D.C.

U.S. Environmental Protection Agency (EPA). 2000. A Guide to Developing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. OSWER 9355.0-75, EPA 2000.

U.S. Environmental Protection Agency (EPA). 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency (EPA). 2012. A Citizen's Guide to Monitored Natural Attenuation. edited by Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency (EPA). 2013. Use of Amendments for In-Situ Remediation at Superfund Sediment Sites. Office of Superfund Remediation and Technology Innovation.

U.S. Environmental Protection Agency (EPA). 2014a. Lower Duwamish Waterway Superfund Site Record of Decision.

U.S. Environmental Protection Agency (EPA). 2014b. "Contaminated site clean-up information (CLU-IN) website - in situ chemical reduction." http://clu-in.org/techfocus/default.focus/sec/In_Situ_Chemical_Reduction/cat/Overview/.

U.S. Fish and Wildlife Service (USFWS). 2008. Celedonia, M.T., R.A. Tabor, S. Sanders, D.W. Lantz, and I. Grettenberger 2008. Movement and Habitat Use of Juvenile Chinook Salmon and Two Predatory Fishes in Lake Washington and Lake Washington Ship Canal: 2004–05 Acoustic Tracking Studies. US Fish & Wildlife Service, Western Washington Fish & Wildlife Office, Lacey, Washington.

Vaccaro, JJ, AJ Hansen, MA Jones. 1998. Hydrogeologic Framework of the Puget Sound Aquifer System, Washington and British Columbia: U.S. Geological Survey Professional Paper 1424-D, 77p., 1 sheet.

Washington Department of Archaeology & Historic Preservation (WDAHP). 2013. Historic Register Report, Gas Works Park.

Washington Department of Ecology (Ecology). 1991. Memorandum to Michael Spencer re: Metro Lake Union Tank Farm SHA. March 27.

Washington Department of Ecology (Ecology). 1992. Chemicals of Special Concern in Washington State, by Ellen Atkinson. Publication 92-66. July 1992.

Washington Department of Ecology (Ecology). 1994. Natural Background Soil Metals Concentrations in Washington State.

Washington Department of Ecology (Ecology). 1997. Agreed Order No. 97-TC-148--Gas Works Park Site issued to the City of Seattle and Puget Sound Energy. August 1.

Washington Department of Ecology (Ecology). 1998. Department of Ecology, Plaintiff, v. King County and Chevron USA Inc., Defendant. State of Washington Superior Court.

Washington Department of Ecology (Ecology). 1999. Department of Ecology, Plaintiff, v. The City of Seattle and Puget Sound Energy, Consent Decree—99-2-52532-952A. State of Washington Superior Court. December 28.

Washington Department of Ecology (Ecology). 2000. History of Park Development.

Washington Department of Ecology (Ecology). 2005a. Agreed Order DE 2008—Gas Works Park Sediment Site issued to the City of Seattle and Puget Sound Energy. State of Washington Superior Court. March 18.

Washington Department of Ecology (Ecology). 2005b. Focus on Developing Surface Water Cleanup Standards Under the Model Toxics Control Act.

Washington Department of Ecology (Ecology). 2013. Approval of Request to Amend Agreed Order DE 2008--Gas Works Park Sediment Site. March 15. Letter from Libby Goldstein, Ecology, to Ray Hoffman, City of Seattle, and Steve Secrist, Puget Sound Energy.

Washington Department of Ecology (Ecology). 2016. Guidance for Remediation of Petroleum Contaminated Sites, Toxics Cleanup Program. Publication No. 10-09-057. Revised June 2016.

Washington Department of Ecology (Ecology). 2017a. Gas Works Park Second Amendment to Agreed Order no. DE 2008. Issued to City of Seattle and Puget Sound Energy. Effective April 26, 2017.

Washington Department of Ecology (Ecology). 2017b. Gas Works Park Third Amendment to Agreed Order No. DE 2008. Issued to City of Seattle and Puget Sound Energy. Effective October 16, 2017.

Washington Department of Ecology (Ecology). 2017c. Implementation Memorandum No 16, Developing Conditional Points of Compliance at MTCA Sites Where Groundwater Discharges to Surface Water. Revised December 29, 2017.

Washington Department of Ecology (Ecology). 2018. Water Quality Program Permit Writer's Manual. Publication No. 92-109. Revised July 2018.

Washington Department of Ecology (Ecology). 2019a. Master CLARC Spreadsheet. May 2019.

Washington Department of Ecology (Ecology). 2019b. Sediment Cleanup User's Manual; Guidance for Implementing the Provisions of the Sediment Management Standards, Chapter 173-204 WAC. Publication No. 12-09-057. Second Revision December 2019.

Washington Department of Ecology (Ecology). 2021. Sediment Cleanup Users Manual (SCUM): Guidance for Implementing the Cleanup Provisions of the Sediment Management Standards, Chapter 173-204 WAC. Publication No. 12-09-057. Revised December 2021.

Washington Department of Ecology. 2022. Natural Background Groundwater Arsenic Concentrations in Washington State, Study Results. Publication No. 14-09-044. January 2022.

Washington Department of Fisheries. Habitat Management Policy (POL 410).

Washington Department of Health Drinking Water Division Sentry Database. 2003-2010.

Washington Pollution Control Commission (WPCC). 1946. Memorandum Number 102, Oil Pollution of Lake Union by the American Tar Company.

Washington Pollution Control Commission (WPCC). 1958. Inter Office Memorandum, Subject Oil Spill in Lake Union.

Washington State Board of Appraisers of Tide and Shore Lands and Commissioner of Public Lands. 1907. Lake Union & Lake Washington Shore Lands.

Washington State Constitution. Articles XV, XVII, XXVII. Public Trust Doctrine.

Watts, Richard J. 1998. Hazardous Wastes: Sources, Pathways, Receptors. John Wiley and Sons, Inc.

Wilson JL, SH Conrad, WR Mason, W Peplinski, and E Hagan. 1990. Laboratory Investigation of Residual from Spills, Leaks, and Disposal of Hazardous Waste in Groundwater. U.S. EPA, April.

Yake, B, D Norton, and M Stinson. 1986. Application of the Triad Approach to Freshwater Sediment Assessment: An initial Investigation of the Sediment Quality near Gas Works Park, Lake Union. Washington State Department of Ecology, Water Quality Investigations Section.