Appendix B
Geotechnical Evaluation

April 2024
Harris Avenue Shipyard Cleanup

ANCHOR QEA

Appendix B
Geotechnical Evaluation

Prepared for Washington State Department of Ecology

April 2024
Harris Avenue Shipyard Cleanup

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ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ARCS	Assessment & Remediation of Contaminated Sediments
ASCE	American Society of Civil Engineers Standard
bgs	below ground surface
CFA	continuous flight auger
CSZ	Cascadia Subduction Zone
EDR	*Sediment Engineering Design Report*
FS	factor of safety
K_h	horizontal seismic coefficient
LRFD	Load and Resistance Factor Design
MHHW	mean higher high water
MLLW	mean lower low water
MSL	mean sea level
NOAA	National Oceanic and Atmospheric Administration
psf	pounds per square foot
Site	Harris Avenue Shipyard
SLIDE	Rocscience SLIDE 6.0 software
SPT	Standard Penetration Test
USGS	U.S. Geological Survey

1 Introduction

This Geotechnical Evaluation appendix presents the geotechnical engineering investigation and design evaluations that have been completed (or that will be completed in the future) for the Harris Avenue Shipyard Cleanup project in Bellingham, Washington. The Geotechnical Evaluation is an appendix to the *Sediment Engineering Design Report* (EDR; Anchor QEA 2024).

1.1 Site Description

The Harris Avenue Shipyard (Site) is located at 201 Harris Avenue within the Fairhaven district of Bellingham, Washington (Figure B-1). The Site is located within a multi-land use designation area and consists of a commercial core; mixed use residential development; nearby single-family residential neighborhood; marine industrial waterfront; ferry, bus, and train terminals; and historical buildings with a tourist district (City of Bellingham 2012). Portions of the upland and in-water areas of the Site have been used both historically and recently for industrial purposes.

The Site consists of approximately 5 acres of upland and 5 acres of in-water area, totaling 10 acres, and is zoned by the City of Bellingham for water-dependent industrial use. The in-water portion of the Site includes two piers, a marine railway and two supporting adjacent overwater walkways, one new and one older, and various mobile cranes. Industrial properties owned by the Port are present to the east and southeast of the Site. The Bellingham Cruise Terminal is located further to the east and is operated by the Port as the southern terminus for the Alaska State Ferry.

The upland potions of the Site are bordered on the north and west by Bellingham Bay and on the south by Marine Park and the BNSF Railway rail lines.

1.2 Purpose

As part of the cleanup process, the Site will undergo various remediation activities. The purpose of this appendix is to document the geotechnical subsurface investigations that have been performed to date as well as the pending geotechnical engineering design evaluations that will be completed as the engineering design phases for the in-water portions of the Site progress.

1.3 Report Organization

The information contained in this Geotechnical Evaluation appendix has been organized in the following manner:

- Section 1 provides general background and overview information for the Site.
- Section 2 describes the geotechnical Site investigation completed in April 2022 and discusses the subsurface conditions underlying the Site.
- Section 3 discusses the geotechnical engineering analyses that will be performed (during the engineering design phase of the project) for each of the following design elements:

- *Dredge Prism Side Slopes*. Includes a discussion of the impact of dredging on shoreline features and evaluates slope stability for dredge cuts.
- *Shoreline Backfill Material Placement Considerations*. Includes estimates for consolidation of the soft sediments underlying the areas where backfill material will be placed, an evaluation bearing capacity for backfill material placement, and the stability of backfill material on slopes.
- *Source Control and Replacement Bulkhead Design*. Includes active, passive, and seismic earth pressures for source control and shoreline replacement bulkhead designs.
- *Geotechnical Engineering Recommendations for Other Structures*. Includes active, passive, and soil modulus parameters for the structural evaluation of existing, pile supported, over-water structures (i.e., Harris Ave Pier, East Marine Walkway, and West Dock).
- *Slope Stability*. Includes an evaluation of the factor of safety for post-dredge and post-backfill material placement scenarios of dredge prism side slopes, shorelines, and shoreline source control and bulkhead structures.
- *Seismicity*. Includes an evaluation of seismic hazards for source control and replacement shoreline bulkhead design and effects of seismicity with respect to remedial design features.

This design appendix has been prepared prior to completion of specific geotechnical engineering design evaluations that will support the final design for the in-water cleanup activities at the Site. The Geotechnical Evaluation appendix will be updated following completion of engineering design activities and evaluations, and results of the evaluations will be presented in detail in a future draft of this appendix. Construction considerations relevant to the implementation of Site cleanup activities will also be presented in a future draft of this appendix.

2 Site and Subsurface Conditions

The following subsections summarize the subsurface information collected from geotechnical borings performed within the Site.

2.1 Subsurface Investigation

Three geotechnical borings (HS-01GB, HS-02GB, and HS-03GB) were completed within the shoreline and adjacent upland Site area immediately adjacent to the failing bulkhead, near the western pier, and at the marine railway (Figure B-2). Borings were completed between April 27, 2022, and April 29, 2022, using a track-mounted sonic drill rig with a 6-inch-diameter, 5-foot-length steel core barrel. Sonic drilling techniques were used for this subsurface investigation due to the need for collection of continuous boring and potential presence of cultural and archaeological items of interest at the Site.

Sonic borings were advanced in 5-foot sections, and each 5-foot section of sonic core barrel was advanced to a Standard Penetration Test (SPT) interval and removed to sample subsurface soil. Soil was extruded from the sonic core barrel into a plastic liner, and the depth interval was labeled for boring log processing. Following collection of each 5-foot subsurface soil interval, an 18-inch steel split spoon sampler was attached to the drill rod and lowered into the borehole. Once the split spoon sampler was resting at the bottom of the borehole under its own weight, an SPT was performed using a 140-lb auto hammer, and blow counts were measured for each 6-inch increment over the full length of the split spoon sampler, unless refusal was encountered. SPT resistance (N-values) were recorded as the total number of blows needed for the sampler to be driven into the second and third interval of the SPT test (i.e., final foot of sampling interval). The split spoon sampler was then removed, and another sonic core section was advanced to an additional 5-foot depth interval. Where heaving sands were encountered, sands were manually cleared out of the borehole using an additional pass with an empty sonic core barrel.

HS-01GB was advanced to a final depth of 26.5 feet below ground surface (bgs), HS-02GB was advanced to a final depth of 101.5 feet, and HS-03GB was advanced to a final depth of 61.5 feet bgs. Once glacial till was encountered within boring HS-02GB, SPT intervals were adjusted to 10 feet until termination. Boreholes were decommissioned by filling each hole with bentonite chips to approximately 6 inches bgs and then filled with on-site surface material (i.e., gravel and/or sand) in accordance with state regulations (Washington Administrative Code 173-160). Following completion of the sonic borings and decommissioning, GPS coordinates at each borehole location were collected.

Each sonic boring was continuously examined and photographed in sections to develop a lithologic boring log. Physical characteristics of each core section were noted on a soil boring log, including moisture, density, color, texture, mineral composition, and recovery, in accordance with ASTM D2488.

Additionally, the following parameters were noted on the boring logs:

- Penetration depth
- Sample recovery (%)
- Odor (e.g., hydrogen sulfide, petroleum, or other)
- Visual stratification, structure, and texture
- Presence of organic matter and/or debris (e.g., wood chips or fibers, concrete, or metal debris)
- Evidence of biological activity (e.g., detritus, shells, tubes, bioturbation, or live or dead organisms)
- Visual presence of oil sheen

Boring logs from the field investigation can be found in Attachment B-1. Discrete samples were collected from the split spoon samplers as well as discrete lithologic units and placed into zip-top plastic bags for testing at a geotechnical laboratory. Samples were labeled with the boring ID, depth, date, and time or sampling and stored in a cooler for safe shipment to the laboratory. Select soil samples were submitted to Geotesting Express Inc. in Acton, Massachusetts, for the following testing to be performed:

- Unit weight (bulk density) (ASTM D7263)
- Grain size distribution (ASTM D6913 and D7928)
- Moisture content (ASTM D2216)
- Atterberg limits (ASTM D4318)

Results of the geotechnical laboratory testing can be found in Attachment B-2.

2.1.1 Site Soil Lithologies

This subsection describes the generalized subsurface soil profiles near the existing Site bulkhead and surrounding areas and engineering properties that will be used for completion of future engineering design evaluations. Subsurface soil intervals and lithologies reflect the information and observations presented on the boring logs included in Attachment B-1. The key characteristics of the major subsurface soil units encountered during this investigation effort are described as follows from the ground surface downward:

- **Sand to Silty Sand with Gravel (SM to SP).** At the surface, in two of the three borings (HS-01GB and HS-02GB), silty sand with gravel was observed. This unit is approximately 5 to 13 feet thick and consists of generally loose, moist, brown silty sand with medium-sized rounded gravels. Gravel content was observed to decrease with depth.
- **Sandy Silt (ML).** Beneath the surface layer of silty sand with gravel is a layer of sandy silt. This unit was also observed at the surface of boring HS-03GB. The soil unit is approximately 4 to 10 feet thick and consists of moist to wet, grey to brown sandy silt with occasional rounded gravels. Shell hash and wood debris were also observed in various lenses within this unit.

- **Cohesive Soil (CL and ML).** At depths ranging from approximately 10 to 20 feet bgs, a cohesive layer of soil was encountered in soil borings HS-01GB and HS-02GB. This layer is approximately 2 to 2.2 feet thick and varies in composition from medium stiff clay to soft silt.
- **Silty Sand (SM).** Beneath the sandy silt (or the cohesive soil in borings HS-01GB and HS-02GB), a unit of silty sand (approximately 30 feet in thickness) was observed in all borings. This unit was generally dense, moist to wet, and grey to brown in color with occasional orange mottling.
- **Unsorted Sand and Silt and Gravels (Till).** The deepest soil unit encountered to the termination of HS-02GB and HS-03GB is dense till material. This soil unit is often referred to as Bellingham glaciomarine drift, or Bellingham drift, and consists of grey unsorted silty sand, gravel, and clay. The till unit was not encountered in HS-01GB because that boring was terminated at a shallower depth.

2.2 Sea Level and Nearshore Groundwater

The Site is open to Bellingham Bay and is subjected to tidal fluctuations and seasonal variations in tides. According to the National Oceanic and Atmospheric Administration (NOAA), this region of Puget Sound experiences a mean higher high water (MHHW) of +8.51 feet and a mean sea level (MSL) of +4.95 feet. Both values are measured relative to the mean lower low water (MLLW), which serves as the vertical datum at +0.00 feet (NOAA 2003).

The groundwater elevations nearest to the shoreline are influenced by the tide as seawater transmits through the soil during high and low water stages. For analysis purposes, the groundwater elevation for the shoreline of the waterway is assumed to be static and equal to the sea level. For high and low water scenarios, the MHHW and MLLW values are assumed, respectively. The geotechnical design evaluations that will be completed during the design phase of the project (as described in Section 3) will make assumptions regarding elevation of groundwater considering tidal interactions, and specific assumptions will be documented in a future version of this Geotechnical Evaluation appendix.

3 Geotechnical Design Evaluations

This section discusses the geotechnical design evaluations and analyses that will be performed for the project design elements mentioned in Section 1.3:

- Dredge prism side slopes
- Shoreline backfill material placement
- Source control and replacement bulkhead design
- Geotechnical recommendations for other structural elements
- Slope stability
- Seismicity

The various remedial components will be evaluated by computing factors of safety during the analysis and evaluations. Target factor of safety values will be assumed for the design of dredge prism side slopes, bulkhead and other structure designs, slope stability analyses, and seismic hazards based on various references (Duncan and Wright 2005; WSDOT 2011; Fang 1991), as described in each subsection below.

3.1 Dredge Prism Side Slopes

Dredging is planned at the Site locations shown in Figure B-2. The evaluation of the submerged dredge prism side slopes will include areas to be backfilled (or not backfilled) to assess stable slope angles for the range of conditions present throughout the Site. The stability of the submerged dredge prism side slopes will be evaluated using limit equilibrium methods implemented by the Rocscience SLIDE 6.0 software (SLIDE). Further discussion of slope stability using SLIDE, including evaluation of nearshore dredge prism side slopes, is provided in Section 3.5.

3.1.1 Stability of Submerged Dredge Prism Side Slopes

Assessment of the dredge design will include slope stability analysis of dredge prism side slopes for short-term and long-term scenarios for nearshore slopes that are backfilled and for offshore slopes and dredge transition areas where no backfill material will be placed. Submerged side slope grades will be identified during the engineering design phase of the project and assessed to evaluate the factor of safety.

Geologic models will be developed and representative soil parameters will be compared to geologic cross sections that will be developed during completion of design activities. Nearshore dredge areas will be backfilled to restore approximate pre-construction shoreline elevations and all dredge prism side slopes will be assumed to be fully submerged.

The analysis will consider both short-term and long-term stability. For the backfilled nearshore slope area, the most critical short-term condition will be the scenario immediately following placement of the full thickness of backfill material but before the underlying sediment has fully consolidated (i.e., the undrained case). For purposes of the slope stability analysis of the short-term condition, it will be assumed that the underlying soils will exhibit undrained behavior and without significant strength gain from consolidation. This assumption is conservative because strength gain would occur during placement of the first layer of backfill material and increase as subsequent lifts of backfill material are placed during construction.

The long-term scenario will be represented by drained behavior conditions following backfill material placement and considering strength gain from consolidation of underlying sediments. For this scenario, the soils will be assumed to behave under drained conditions.

Input parameters for slope stability analysis of dredge prism side slopes will be developed using the available geotechnical data collected at the Site. Results of the slope stability analysis will be presented as factors of safety against failure for backfilled and non-backfilled slope areas for short- and long-term conditions.

3.2 Shoreline Backfill Material Placement Considerations

Backfill material will be placed in shoreline areas of the Site, as shown in Figure B-4, to restore approximate pre-construction elevations. Backfill material properties including material unit weights and placement thicknesses will be developed during completion of the engineering design phase for the project.

3.2.1 Bearing Capacity

Bearing capacity for the backfill material placement areas will be evaluated using methods described in Appendix C of the Assessment & Remediation of Contaminated Sediments (ARCS) Program *Guidance for In situ Subaqueous Capping of Contaminated Sediments* (Palermo et al. 1998). When backfill (or sediment cover) material is placed on the surface of soft sediments, there is a potential for a bearing capacity failure directly through the in situ sediment. The initial cap lift thickness must be thin enough to prevent a bearing capacity failure resulting from the weight of the cover.

In typical foundation design problems, a factor of safety of 3.0 is used for calculations where there is potential for structural damage or impact to human safety as suggested in the ARCS guidance. However, the guidance does not distinguish between short-term and long-term bearing capacity considerations. Because of the transient nature of short-term loading, lower factors of safety are often considered acceptable in geotechnical engineering design. Experience on other projects involving placement of backfill material indicates that a factor of safety of 3.0 can be overly conservative when considering construction lift thickness requirements. Because life, safety, and structural stability will not be design considerations for the cleanup project elements, and due to the short duration of construction, a factor of safety of 1.5 is typically considered appropriate for use in this analysis for evaluating the design of backfill material lift thickness. Subaquatic backfill material placement has been successfully demonstrated at multiple sites when designed using a bearing capacity factor of safety of 1.5.

This analysis will evaluate the steady state, short-term stability of the backfill material and soft sediments during construction. Once backfill material has been placed, the strength of the in situ fine-grained sediments will increase in shear strength due to consolidation. Thus, the long-term stability of the backfill material against bearing capacity failure will be greater than the short-term stability.

An observational approach will be implemented during construction to evaluate the performance of the recommended backfill material lift thickness and to evaluate the possibility of localized bearing capacity failures, should they occur. This observational approach will include review and evaluation of the contractor and Port of Bellingham progress surveys. Should results of the survey review indicate that localized bearing capacity failures may be occurring, then contractor means and methods for placement of the backfill material will be revisited. Changes to means and methods may include requirements for placement of material at slower rates or in thinner lift intervals.

3.2.2 Consolidation

The load from the placed backfill material will result in consolidation of the underlying sediments. The compressible layers that exist at the Site are silts and clays. Compressible properties for these materials will be estimated using empirical correlations to the index properties and standard penetration testing data measured during completion of the Pre-Remedial Design Investigation and collection of Site geotechnical data.

To assess consolidation of the backfill material, geologic profiles will be developed near study locations where backfill material placement activities are planned. At these locations, consolidation will be evaluated where the compressible deposits are expected to be thickest. Results of this geotechnical engineering design evaluation will identify post-dredging compressible layer thicknesses and associated range of anticipated long-term settlement or consolidation that may occur.

3.3 Replacement Bulkhead Design

The recommendations contained in this section are provided in support of the waterfront wall that will be constructed along the northern shoreline of the Site, adjacent to the active shipyard use areas.

3.3.1 Lateral Earth Pressures for Shoreline Structures

Lateral earth pressures will be estimated using the soil parameters developed during engineering design from analysis of the available geotechnical data. In the development of these recommended earth pressure parameters, two cases for the static earth pressures will be evaluated:

- **Post-Dredge.** This case represents a temporary condition where the unbraced wall height is at a maximum. Shoreline backfilling has not yet been performed, meaning the additional passive earth pressure provided by the backfill material is not present. Clay and organic silt materials, if present, are assumed to behave undrained. A factor of safety of 1.3 is recommended for structural analyses of this case.

  A factor of safety of 1.3 is appropriate for this evaluation due to the implementation of additional engineering controls that further mitigate the risk of slope movement or structure displacement. These engineering controls include a requirement for offset of surcharge associated with upland operations, upland soil removal adjacent to the wall to reduce active loading, and limited exposure time in the temporary condition through requirement of cap material placement immediately following completion of shoreline dredging and excavation activities.

- **Post-Backfilling.** This case represents the final configuration of the shoreline and the condition immediately after placement of the shoreline backfill material. Shoreline backfill material placement will take place in front of the waterfront wall, meaning an additional passive earth pressure will be provided. The clay and organic silt, if present, will be assumed to exhibit undrained behavior. A factor of safety of 1.5 will be applied for structural analyses of this case.

The earth pressure theory assumed for both static cases described above is Rankine theory (Fang 1991). Rankine earth pressure theory assumes that there is no interface wall friction between the structural element and the soil. This generally produces estimates for the active and passive earth pressure that are conservative. Earth pressure diagrams for these two static cases will be developed and presented following completion of engineering design activities.

Additionally, seismic earth pressures will be developed for scenarios where backfill is both non-liquefied and liquefied. For the non-liquefied case, the Mononobe and Okabe methodology will be used to determine the seismic increment exerted on the walls during a design-level earthquake event.

Section 3.6 presents a more detailed discussion of seismicity, which includes ground motion parameters, liquefaction, and post-liquefaction residual strength, as well as further discussion of the seismic earth pressures.

3.4 Geotechnical Engineering Recommendations for Other Structures

3.4.1 Earth Pressures and Soil Modulus for Pile-Supported Structures

Dredging near the existing dock structures could result in an unbalanced lateral earth pressure at the face of the outermost piles. Earth pressures and soil modulus parameters will be developed to allow the structural engineer to assess potential structural issues related to the unbalanced lateral earth pressure at these structures.

Analysis of the MCI pier will consider all berth areas, where different dredge depths are planned. The maximum over-dredge allowance of 2 feet (for permitting purposes) will be assumed for all cases.

Soil modulus parameters will be requested by the structural engineer for use in their model. Estimates of horizontal soil modulus for both cohesive and cohesionless soils will be performed using the guidance provided in the American Association of State Highway and Transportation Officials (AASHTO) 2010 Load and Resistance Factor Design (LRFD) Bridge Design and Specifications.

3.4.2 Pile Foundation Design

Pile installation at the Site will include construction of the replacement marine railway structure and associated overwater access piers.

3.4.3 Pile Selection

A variety of pile types are commonly used to support structures. Broadly categorized, pile types typically used to support heavy loads include continuous flight auger (CFA), drilled shafts, and driven piles. Although installation of CFA and drilled shaft piles typically causes less ground vibration than driven pile installation, these pile types require removal, management, and disposal of site soils or sediments, which can be costly if these materials are contaminated. Driven piles typically require minimal management of site soils and will be considered for the support of structures for this project.

There are three classes of driven piles commonly used for foundation support: timber, concrete, and steel. The appropriate pile type will be evaluated and selected for use as engineering design evaluations are completed for the project.

3.4.3.1 Vertical Pile Capacity

Structures associated with the replacement marine railway structure will utilize pile foundations. Pile foundations carry vertical compressive loads by a combination of friction along the pile sides and by end bearing at the tip. Vertical uplift loads are resisted by friction alone. For planning purposes, factored (i.e., allowable) vertical compressive and uplift capacities will be developed for various pile diameters and material types in accordance with AASHTO (2010).

3.4.3.2 Lateral Pile Capacity

We understand that LPILE computer software will be used to evaluate the lateral response of piles if they are needed for construction of planned Site structures. Recommended LPILE parameters will be developed for static design during completion of engineering design activities, and recommended elevation ranges over which these parameters should be used at various locations around the Site will be provided.

3.4.3.3 Pile Vertical Spring Constant

Assessment of pile vertical spring constant recommendations will be developed to support structural design of the marine railway replacement structure. These recommendations will be developed once more information is known about the capacity and loading requirements for the structures in coordination with the development of structural design.

3.4.3.4 Pile Installation

The recommended pile capacities to be developed during engineering design will be based on observed soil and sediment conditions; the soil and sediment conditions may vary in consistency and type at actual pile installation locations. It is anticipated that piles may be advanced using both vibratory and impact hammer methods and may encounter soft to stiff cohesive soils, which could make pile advancement difficult. It is important to bear in mind that excessive vibrating or impact driving can damage the piles. A reasonable selection of the pile size and vibratory and impact hammers can reduce pile damage during advancement. If the contractor elects to discontinue pile advancement due to refusal or slow advancement prior to reaching or nearing the design tip elevation, consultation with the geotechnical engineer is recommended to determine the shorter piles' adequacy for carrying design loads.

Furthermore, it is recommended that a geotechnical engineer be present during pile installation activities. The engineer will observe the contractor's operation, collect and interpret the installation data, and observe all pile installation. With careful observation of pile installation operations, it is possible to monitor variations in subsurface conditions and verify that the required penetration depths and capacities are achieved. Pilings that may be subjected to potential vertical loads will be proof tested at completion of installation.

3.5 Slope Stability

The remediation includes dredging near waterfront facilities and shorelines. Dredging removes sediments that support the toe of the slope and hence the resisting force against a potential sliding mass. To assess slope stability, geologic models will be developed for each of the site areas described in Section 1 of this report.

Slope stability modeling will be performed using Rocscience SLIDE 6.0 software that utilizes limit equilibrium methods of analysis. The soil model for limit equilibrium analysis is a rigid, perfectly plastic soil model. The assumptions inherent to this model are that the anticipated sliding mass remains rigid (i.e., non-deformable) and the soil strength along the slip plane is fully mobilized at failure. While this analysis method does not directly represent the true behavior of the soil during a slope failure, it is intended to provide a reasonable indication of the overall stability of a slope and is generally accepted as the standard of practice for this type of assessment.

The inter-slice force functions that will be used in the analysis are Morgenstern-Price (1965) and Spencer (1967). These two methods satisfy both force and moment equilibrium and have been used in common practice for more than 40 years. For each loading condition and respective wall condition that will be analyzed, both methods will be applied to a suite of potential failure planes that pass beneath the toe of the waterfront wall. The failure plane with the lowest factor of safety will then be compared to the respective design criteria.

In addition to the slope stability analysis performed for the shorelines and waterfront structures, an assessment of post-dredge sloughing of slopes underneath the Site pier structures will be performed. The intent of the analysis is to estimate a range of long-term, post-dredge stable slope angles.

The waterfront wall will also be assessed for the seismic condition. The factors of safety criteria for slope stability assessment that will be used are summarized in Table B-1.

3.5.1 Information and Assumptions

Soil and sediment strength parameters for different material types (cohesionless and cohesive) will be developed during engineering design using available Site geotechnical and laboratory data. These parameters will include material total unit weight, effective internal friction angle, minimum undrained shear strength (cohesion), and undrained strength ratio for all materials encountered at the Site.

Short- and long-term factors of safety for static and seismic conditions will be developed and compared to target factors of safety at the different Site areas to demonstrate that planned remediation activities will satisfy recommended factor of safety requirements and thresholds.

Table B-1
Slope Stability Factor of Safety Criteria

Condition	Description	Criteria
Short-Term, Static	Also referred to as the temporary case, the short-term static condition is represented by two scenarios: • post-dredge • post-backfill material placement Modeling of the short-term condition assumes undrained shear strength parameters for cohesive soil layers and drained strength parameters for cohesionless soil layers.	Minimum FS = 1.3 (Duncan and Wright 2005) Surcharge = TBD psf above the waterfront wall Surcharge = 100 psf for shoreline slopes
Long-Term, Static	This condition represents the final, post-construction configuration and assumes sufficient consolidation of subgrade soils as well as slow failure, such that drained conditions are appropriate. Modeling of these conditions assumes drained shear strength parameters for all soil layers.	Minimum FS = 1.5 (Duncan and Wright 2005) Surcharge = TBD psf above the waterfront wall Surcharge = 100 psf above shoreline slopes
Seismic	A pseudostatic slope stability analysis is performed. The seismic coefficient is assumed to be one-half the spectral acceleration at a 0-second period of the design response spectrum (K_h = 0.121 g). Modeling of the seismic condition assumes undrained shear strength parameters for cohesive soil layers and drained strength parameters for cohesionless soil layers.	Minimum FS = 1.1 (WSDOT 2011) Surcharge = TBD psf above the waterfront wall

Notes:
FS: factor of safety
K_h : horizontal seismic coefficient
psf: pounds per square foot

3.6 Seismicity

The project location lies in a seismically active region and is characterized by four principal sources for strong ground shaking (earthquakes): three associated with the Cascadia Subduction Zone (CSZ) and one resulting from relatively shallow crustal zones.

The seismic hazard analysis to be performed during engineering design is currently planned to be based on the seismic site class and associated ground motion parameters developed using American Society of Civil Engineers Standard 7 2010 (ASCE 7-10; the code) with supplemental guidance from U.S. Geological Survey (USGS) resources. The ASCE 7-10 procedure for developing design-level ground motion parameters results in a seismic demand that is similar to the demand from an earthquake with a 10% probability of occurrence in 50 years (i.e., 475-year event). The ASCE 7-10 procedure is commonly used nationwide and has been successfully used on many projects in the greater Puget Sound area.

3.6.1 Seismic Parameters

Code-based seismic design is typically used when upland structures are present and life-safety is a concern. Seismic design criteria for remedial actions have not been developed. In light of this, the seismic analysis of the remedial design will consider ASCE 7-10 to be appropriately conservative for the evaluation of non-structural elements even though life-safety is not a concern.

Ground motion parameters will be developed using ASCE 7-10 specifications with guidance from USGS resources. Specific seismic design recommendations that will be developed include determination of seismic site class and design category and development of ground motion parameters.

3.6.2 Seismic Hazards

The seismic hazards planned for evaluation during engineering design include the following:

- Surface fault rupture
- Liquefaction potential
- Post-liquefaction stability
- Seismic slope stability
- Permanent seismic slope displacements

Recommendations to mitigate the risks associated with these hazards will be developed following completion of the engineering design evaluations. Seismic issues for dredging and capping will be evaluated to estimate potential permanent seismic slope displacements during a design-level event.

3.6.3 Seismic Earth Pressure

Recommended earth pressure diagrams for seismic scenarios will be developed to evaluate seismic behavior of both liquefiable and non-liquefiable soils and sediments. These earth pressure diagrams will be utilized by the structural engineer for development of design requirements associated with Site structures and seismic considerations.

3.6.4 Permanent Seismic Slope Displacements

The permanent seismic slope displacement of the shorelines, submerged slopes, and the waterfront wall will be evaluated for the ASCE 7-10 design event (DE) using the methodology proposed in Bray and Travasarou (2007). All analysis to be performed will be based on the final, post-construction condition of the remedial design (i.e., post-material placement). Two required parameters for the analysis, yield coefficient and slope height, will be derived using limit equilibrium procedures to support this analysis. Other required input parameters will be obtained from the response spectrum of the DE developed from the ASCE 7-10 code, USGS online resources, and SPT blow counts from nearby geotechnical borings.

4 References

A complete set of references utilized for the development of geotechnical engineering design recommendations will be provided following completion of planned engineering design activities and geotechnical engineering evaluations.

Figures

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ANCHOR QEA

Figure B-1
Site Vicinity Map

Geotechnical Evaluation
Harris Avenue Shipyard Cleanup

LEGEND:

- Sediment Management Unit [1]
- Upland Site Boundary
- Interim Action Completed
- Harbor Line

Bathymetry (2022)

- Major Contour (5' Interval)
- Minor Contour (1' Interval)

Sediment Sample Locations

- Geotechnical Boring

0 100
Feet

NOTES:

1. SMU boundaries are those identified in the Cleanup Action Plan as amended following completion of the PRDI.
2. Horizontal datum: Washington State Plane North Zone, North American Datum of 1983, U.S. Survey Feet.
3. Aerial image is Whatcom County, 2022.
4. Bathymetry is NW Hydro, August 2022. Elevations are mean lower low water, feet.

ABBREVIATIONS:

SMU: Sediment Management Unit
PRDI: Pre-Remedial Design Investigation

Publish Date: 2024/03/22, 5:04 PM | User: dlockwood
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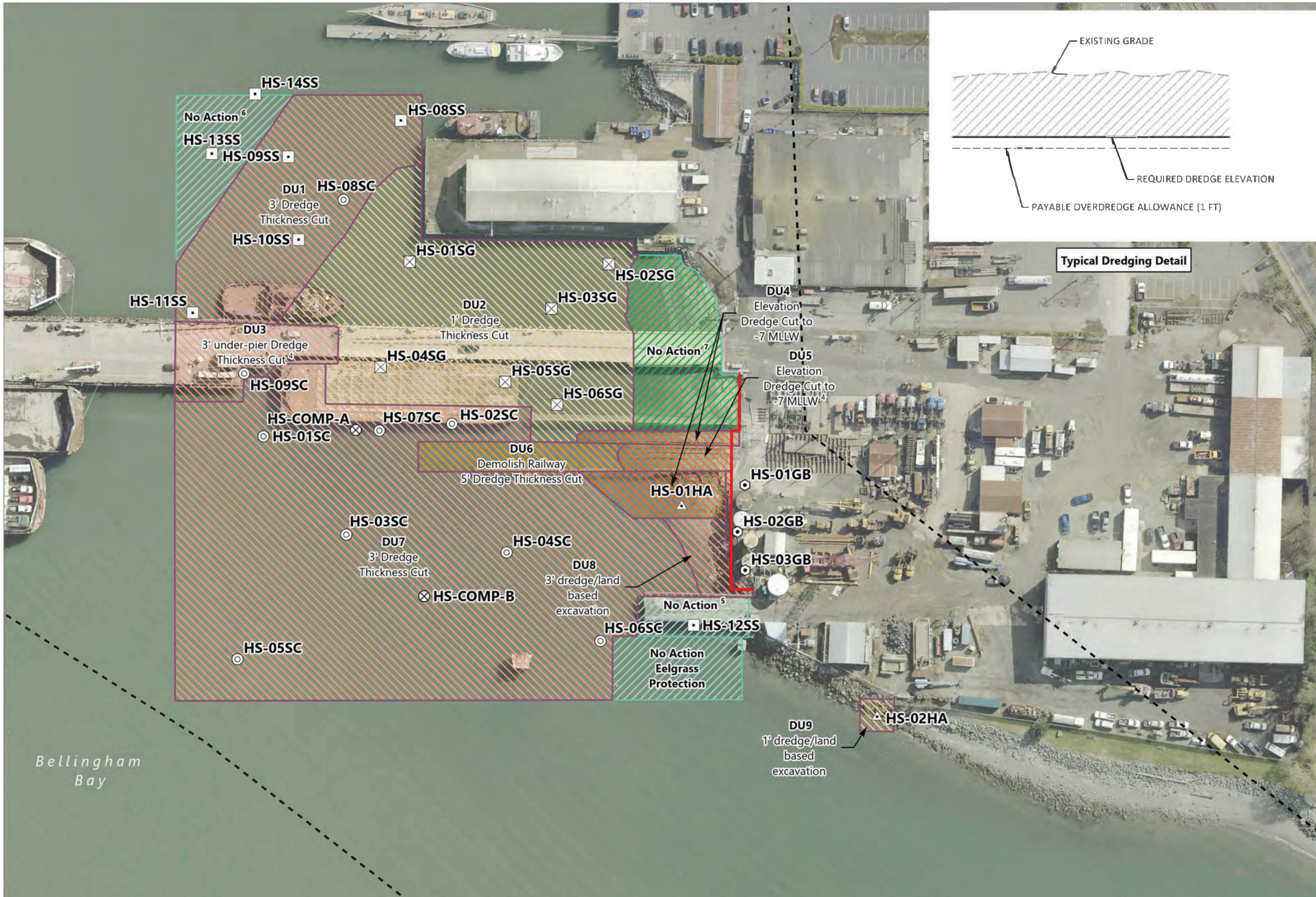
Figure B-2
Geotechnical Boring Locations

Geotechnical Evaluation
Harris Avenue Shipyard Cleanup



LEGEND:

Dredge Unit

Dredge Unit Cut Thickness/Elevation

1' Thickness Cut

3' Thickness Cut

5' Thickness Cut

7' MLLW Elevation Cut

No Action Area

Site Cleanup Levels Met

Proposed Bulkhead

Harbor Line

0 100
Feet

NOTES:

1. Dredge Unit boundaries are preliminary and may be adjusted during final design and permitting.
2. Horizontal datum: Washington State Plane North Zone, North American Datum of 1983, U.S. Survey Feet.
3. Aerial image is Whatcom County, 2022.
4. Area was previously proposed for capping but will be remediated via removal.
5. Based on results of PRDI sampling, no action is required under the stub pier to meet site cleanup levels.
6. Based on results of PRDI sampling, no action is required in this area to meet site cleanup levels.
7. Interim actions within this area met site cleanup levels.

ABBREVIATIONS:

DU: Dredge Unit
MLLW: Mean Lower Low Water
PRDI: Pre-Remedial Design Investigation

Publish Date: 2024/04/03, 1:33 PM | User: emueller
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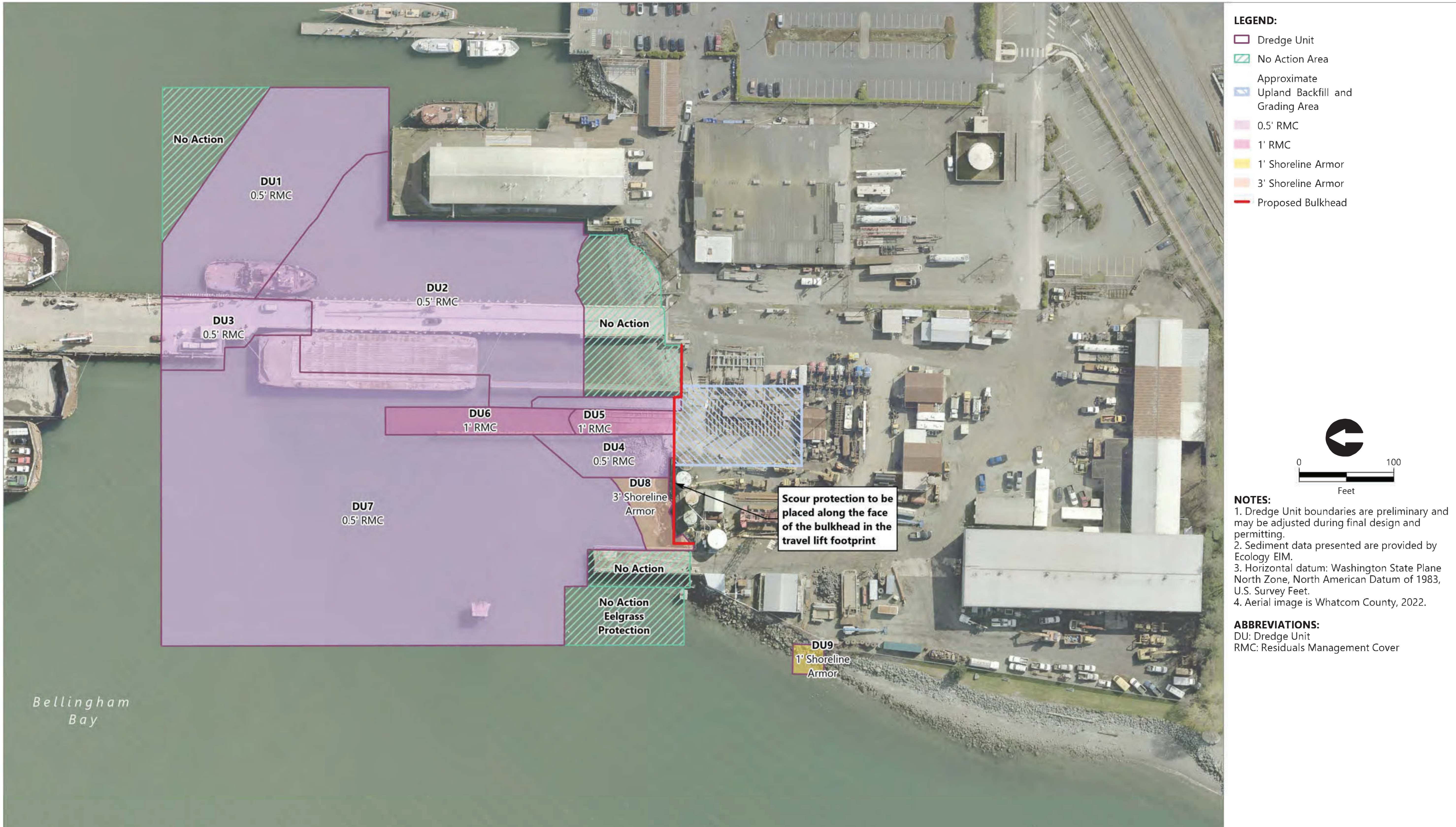
Figure B-3
Dredge/Excavation Plan

Geotechnical Evaluation
Harris Avenue Shipyard Cleanup



NOTES:
1. Dredge Unit boundaries are preliminary and may be adjusted during final design and permitting.
2. Sediment data presented are provided by Ecology EIM.
3. Horizontal datum: Washington State Plane North Zone, North American Datum of 1983, U.S. Survey Feet.
4. Aerial image is Whatcom County, 2022.

ABBREVIATIONS:
DU: Dredge Unit
RMC: Residuals Management Cover

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Figure B-4
Material Placement Site Plan

Geotechnical Evaluation
Harris Avenue Shipyard Cleanup

Attachment B-1

Geotechnical Boring Logs

Soil Boring Log

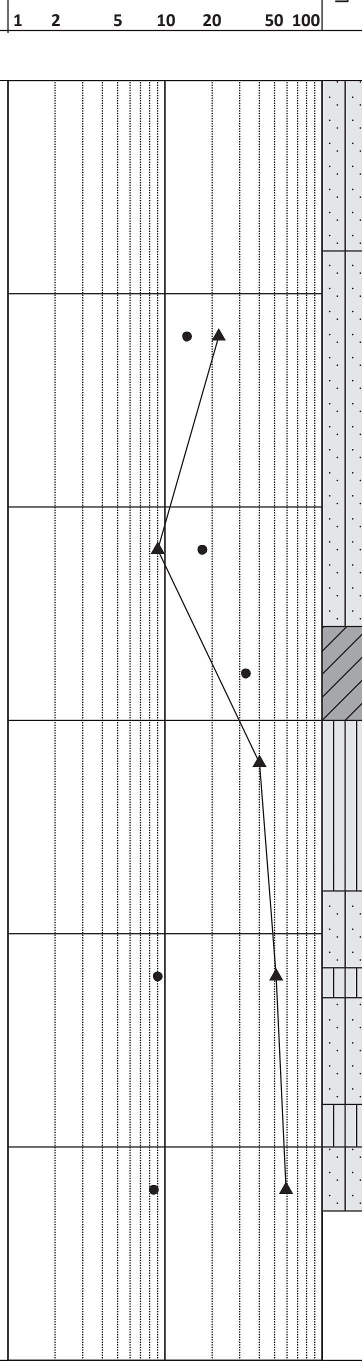
HS-01GB

Project #: 210007-02.01	Project: Harris Avenue Shipyard Cleanup	Location: Bellingham, Washington
Client: Port of Bellingham	Logged By: Sam Giannakos	N/LAT: **632265.795303** E/LONG: **1234499.842924**
Contractor: Holt Services	Horiz. Datum: Washington State Plane Feet	Collection Date: **4/29/22**
Method: Direct Push	Vert. Datum: NAVD88	Total Depth (ft): **26.5**
Hammer: 140-lb Auto Hammer	Sampler(s): 2-inch OD/1.375-inch ID Split Spoon	Observed Water Table Depth (ft): **9.8**
Hammer Efficiency (%): UNKNOWN	2-inch Dual Tube Liner	Ground Surface Elevation (ft): **X**

Depth (ft)	Elevation (ft)	Sample Name	Sample Type	Blow Counts	Soil Description	Lab Test
0	0				0 to 0.1 ft: Beach sand cover. 0.1 to 0.5 ft: Concrete pad (boat ramp). 1.0 to 4.0 ft: Loose, moist, brown, SILTY SAND (SM) with occasional rounded gravels.	
5	-5	HS-01GB-05-6.5	Split Spoon	10 15 7	4.0 to 12.8 ft: Medium stiff, moist, grey, SANDY SILT (SM), fine-grained sand, occassional gravel.	MC, GS BD
10	-10	HS-01GB-10-11.5	Split Spoon	1 4 5	@9.8 ft: Grades to wet.	MC
		HS-01GB-12.8-15			12.8 to 15.0 ft: Medium stiff, moist, grey, CLAY with SAND (CL).	MC, AL
15	-15	HS-01GB-15-16.5	Split Spoon	9 17 23	15.0 to 19.0 ft: Loose, wet, grey, SANDY SILT (ML), with substantial shells, heavy sheen.	MC, GS SG
20	-20	HS-01GB-20-21.5	Split Spoon	15 29 22	19.0 to 20.8 ft: Dense, moist, brownish grey, SILTY SAND (SM), with gravel . 20.8 to 21.5 ft: Hard, moist, grey with brownish orange mottling, SILT (ML). 21.5 to 24.0 ft: Dense, moist, grey, SILTY SAND (SM), occassional gravel.	MC, GS SG
25	-25	HS-01GB-25-26.5	Split Spoon	18 24 30	24.0 to 25.0 ft: Hard, moist, grey, SILT (ML). 25.0 to 26.5 ft: Hard, moist, grey with brownish orange mottling, SILTY SAND (SM), occassional gravel. End of Boring at 26.5 feet.	MC, AL
30	-30					

Samples and descriptions are in recovered depths.
Classification scheme: USCS

Uncorrected Standard Penetration Resistance (blows per foot) and Moisture Content (%)



Lithology

▲ SPT N-Value
● Moisture Content (%)
☒ Split Spoon

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Seattle, WA 98101

Notes: 1) MC: Moisture Content, GS: Grain Size, AL: Atterberg Limits, SG: Specific Gravity, OC: Organic Content, BD: Bulk Density.
2) 15-16.5 ft: No recovery in split spoon. Driller reports large gravel in shoe, blow counts unreliable.

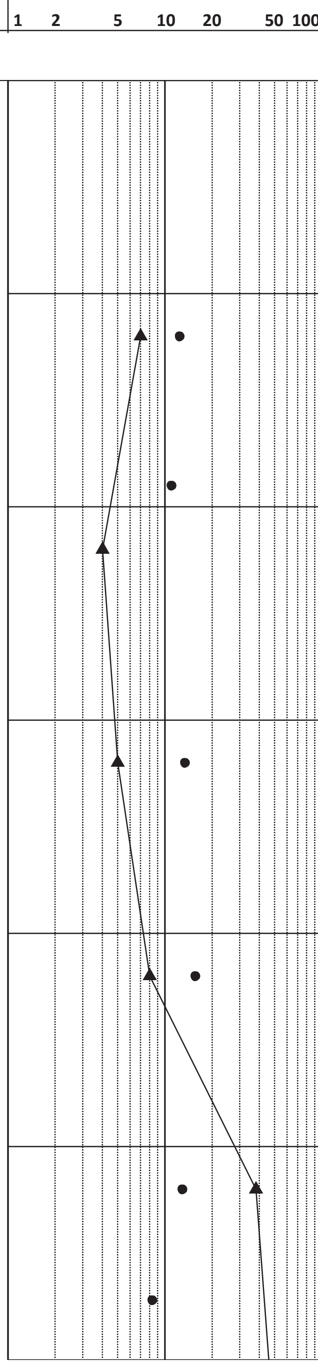
Soil Boring Log

HS-02GB

Project #: 210007-02.01	Project: Harris Avenue Shipyard Cleanup	Location: Bellingham, Washington
Client: Port of Bellingham	Logged By: Sam Giannakos	N/LAT: **632273.059396** E/LONG: **1234454.273134**
Contractor: Holt Services	Horiz. Datum: Washington State Plane Feet	Collection Date: **4/28/22**
Method: Direct Push	Vert. Datum: NAVD88	Total Depth (ft): **101.5**
Hammer: 140-lb Auto Hammer	Sampler(s): 2-inch OD/1.375-inch ID Split Spoon	Observed Water Table Depth (ft): **N/A**
Hammer Efficiency (%): UNKNOWN	2-inch Dual Tube Liner	Ground Surface Elevation (ft): **X**

Depth (ft)	Elevation (ft)	Sample Name	Sample Type	Blow Counts	Soil Description (Samples and descriptions are in recovered depths. Classification scheme: USCS)	Lab Test
0	0				0 to 5.0 ft: Loose, moist, brown, SAND (SP), trace silt, substaintial gravel from 0 to 2.5 feet, occasiaonal gravel from 2.5 to 5.0 feet.	
5	-5	HS-02GB-5-6.5	Split Spoon	4 4 3	5.0 to 12.3 ft: Medium stiff, moist, brown, SANDY SILT (ML), occasional gravel.	MC
		HS-02GB-9-10				MC, SG
10	-10		Split Spoon	2 2 2		
					12.3 to 16.8 ft: Loose, moist, light grey, SILTY SAND (SM), moderate gravel.	
15	-15	HS-02GB-15-16.5	Split Spoon	1 2 3		MC
					16.8 to 18.5 ft: Soft, moist, dark grey, SILT (ML).	
					18.5 to 25 ft: Loose, wet, grey, SILTY SAND (SM), substantial shells, occassional gravel. @18.5-19.0 ft: Strong hydrocarbon-like odor, substaintial sheen.	
20	-20	HS-02GB-20-21.5	Split Spoon	7 4 4		MC, BD
					@23.0-24.5 ft: Layer of substantial gravel. @24.8 to 25.0 ft: Lens of soft, moist, sandy silt.	
25	-25	HS-02GB-25-26.5	Split Spoon	9 15 23	25.0 to 50 ft: Dense, wet, olive grey, SILTY SAND (SM), medium-grained sand. @26.7 to 40.5 ft: Grades to moist, brownish grey, occassional gravel.	MC
		HS-02GB-26.7-30.5				MC, SG
30	-30					

Uncorrected Standard Penetration Resistance (blows per foot) and Moisture Content (%)



▲ SPT N-Value
● Moisture Content (%)
☒ Split Spoon

Notes: 1) MC: Moisture Content, GS: Grain Size, AL: Atterberg Limits, SG: Specific Gravity, OC: Organic Content, BD: Bulk Density.
2) 10-11.5 ft: No recovery in split spoon.Trace silty sand in shoe.

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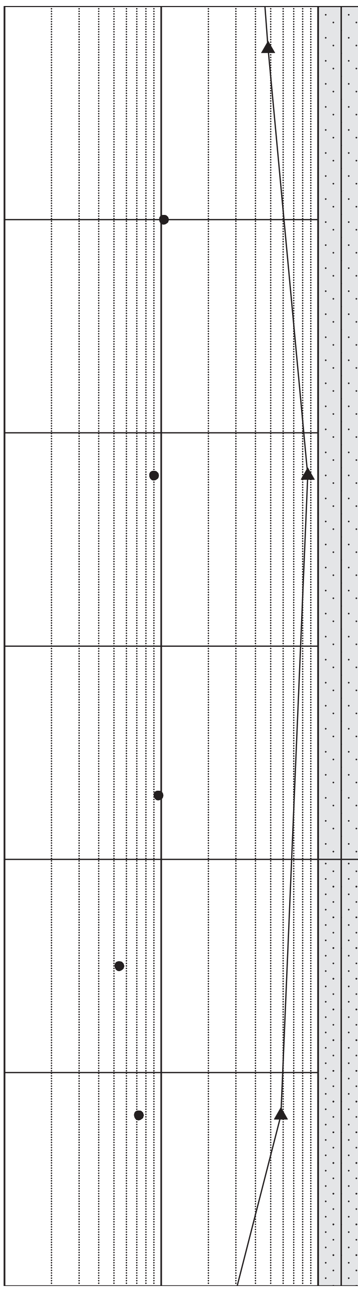
Soil Boring Log
HS-02GB

Project #: 210007-02.01	Project: Harris Avenue Shipyard Cleanup	Location: Bellingham, Washington
Client: Port of Bellingham	Logged By: Sam Giannakos	N/LAT: **632273.059396** E/LONG: **1234454.273134**
Contractor: Holt Services	Horiz. Datum: Washington State Plane Feet	Collection Date: **4/28/22**
Method: Direct Push	Vert. Datum: NAVD88	Total Depth (ft): **101.5**
Hammer: 140-lb Auto Hammer	Sampler(s): 2-inch OD/1.375-inch ID Split Spoon	Observed Water Table Depth (ft): **N/A**
Hammer Efficiency (%): UNKNOWN	2-inch Dual Tube Liner	Ground Surface Elevation (ft): **X**

Depth (ft)	Elevation (ft)	Sample Name	Sample Type	Blow Counts	Soil Description	Lab Test
30	-30		Split Spoon	12 18 30	25.0 to 50 ft: Dense, moist, brownish grey, SILTY SAND (SM), occassional gravel. @30.5-31.0 ft: Stiff, moist, grey, coarse silt, with brown mottling. @31.0-34.0 ft: Dense, moist, grey, sand. @32.2 ft: Increase in silt content.	
35	-35	HS-02GB-34.5-35.5				MC
40	-40	HS-02GB-40-41.5	Split Spoon	11 42 44	@40.5 ft: grades to very dense, varying content of sand and gravel up to 3-inches.	MC, AL BD
45	-45				@47.0 ft: grades to dense, brown mottling, coarse.	
		HS-02GB-49-50				MC
50	-50	HS-02GB-50-55			50.0 to 101.5 ft: Very dense, moist, dark grey, SAND WITH SILT (SP-SM), multicolored medium-grains, varying amounts of silt and gravel. Glacial till.	MC, GS
55	-55	HS-02GB-55-56.5	Split Spoon	24 29 29		MC, SG
60	-60					

Uncorrected Standard Penetration Resistance (blows per foot) and Moisture Content (%)



Lithology

Soil Description: Samples and descriptions are in recovered depths. Classification scheme: USCS

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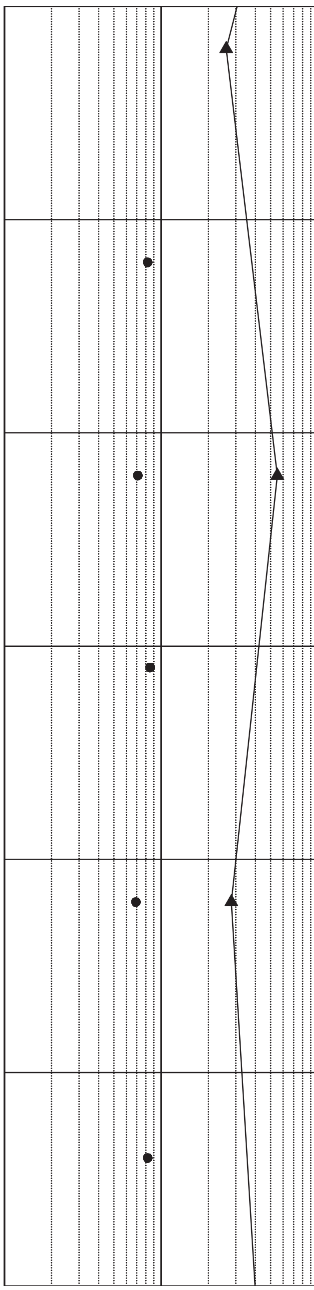
▲ SPT N-Value
● Moisture Content (%)
☒ Split Spoon

Notes: 1) MC: Moisture Content, GS: Grain Size, AL: Atterberg Limits, SG: Specific Gravity, OC: Organic Content, BD: Bulk Density.
2) 10-11.5 ft: No recovery in split spoon.Trace silty sand in shoe.

Soil Boring Log
HS-02GB

Project #: 210007-02.01	Project: Harris Avenue Shipyard Cleanup	Location: Bellingham, Washington
Client: Port of Bellingham	Logged By: Sam Giannakos	N/LAT: **632273.059396** E/LONG: **1234454.273134**
Contractor: Holt Services	Horiz. Datum: Washington State Plane Feet	Collection Date: **4/28/22**
Method: Direct Push	Vert. Datum: NAVD88	Total Depth (ft): **101.5**
Hammer: 140-lb Auto Hammer	Sampler(s): 2-inch OD/1.375-inch ID Split Spoon	Observed Water Table Depth (ft): **N/A**
Hammer Efficiency (%): UNKNOWN	2-inch Dual Tube Liner	Ground Surface Elevation (ft): **X**

Depth (ft)	Elevation (ft)	Sample Name	Sample Type	Blow Counts	Uncorrected Standard Penetration Resistance (blows per foot) and Moisture Content (%) 1 2 5 10 20 50 100	Lithology	**Soil Description** Samples and descriptions are in recovered depths. Classification scheme: USCS	Lab Test
60	-60		Split Spoon	14 16 10			50.0 to 101.5 ft: Very dense, moist, dark grey, SAND WITH SILT (SP-SM), multicolored medium-grains, varying amounts of silt and gravel. Glacial till.	
							@62 ft: Grades to medium dense.	
65	-65	HS-02GB-65-66.5						mc
							@68 ft: Grades to finer sand.	
							@70 ft: Significant heaving sands.	
70	-70	HS-02GB-70-71.5	Split Spoon	9 31 24			@71 ft: Grades to very dense.	MC, GS
75	-75	HS-02GB-75-76						MC, BD
							@78.6 ft: Grades to siltier.	
80	-80	HS-02GB-80-81.5	Split Spoon	35 17 11			@81.0 ft: Grades to medium dense.	MC
85	-85	HS-02GB-86-88						MC
90	-90							



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- ▲ SPT N-Value
- ● Moisture Content (%)
- ☒ Split Spoon

Notes: 1) MC: Moisture Content, GS: Grain Size, AL: Atterberg Limits, SG: Specific Gravity, OC: Organic Content, BD: Bulk Density.
2) 10-11.5 ft: No recovery in split spoon.Trace silty sand in shoe.

Soil Boring Log

HS-02GB

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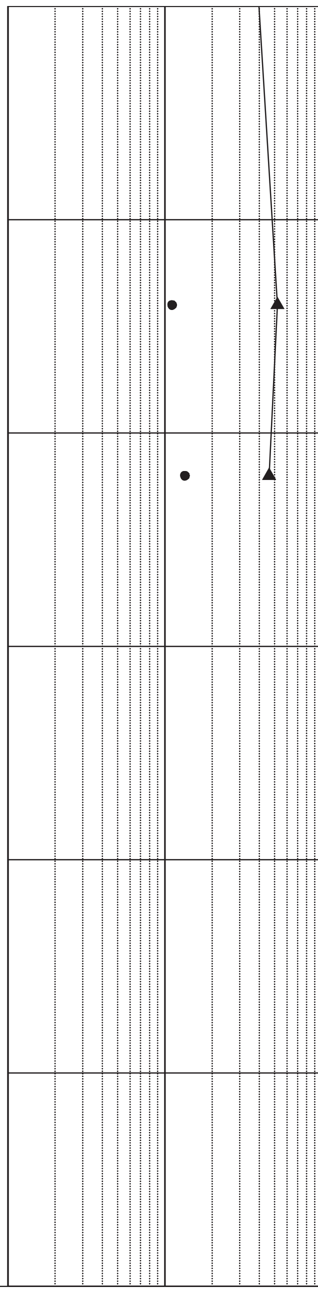
Client: Port of Bellingham	Logged By: Sam Giannakos	N/LAT: **632273.059396** E/LONG: **1234454.273134**
Contractor: Holt Services	Horiz. Datum: Washington State Plane Feet	Collection Date: **4/28/22**
Method: Direct Push	Vert. Datum: NAVD88	Total Depth (ft): **101.5**
Hammer: 140-lb Auto Hammer	Sampler(s): 2-inch OD/1.375-inch ID Split Spoon	Observed Water Table Depth (ft): **N/A**
Hammer Efficiency (%): UNKNOWN	2-inch Dual Tube Liner	Ground Surface Elevation (ft): **X**

Depth (ft)	Elevation (ft)	Sample Name	Sample Type	Blow Counts	Uncorrected Standard Penetration Resistance (blows per foot) and Moisture Content (%)	Lithology	**Soil Description** Samples and descriptions are in recovered depths. Classification scheme: USCS	Lab Test
90	-90		Split Spoon				50.0 to 101.5 ft: Medium dense, moist, dark grey, SAND WITH SILT (SP-SM), multicolored medium-grains, varying amounts of silt and gravel. Glacial till.	
95	-95	HS-02GB-96-97		9 26 26			@96.0 ft: Grades to very dense.	MC, AL GS
							@100.0 ft: Grades to medium dense.	
100	-100	HS-02GB-100-101.5	Split Spoon	9 26 20				MC, AL
							End of Boring at 101.5 feet.	
105	-105							
110	-110							
115	-115							
120	-120							



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Seattle, WA 98101

▲ SPT N-Value
● Moisture Content (%)
☒ Split Spoon

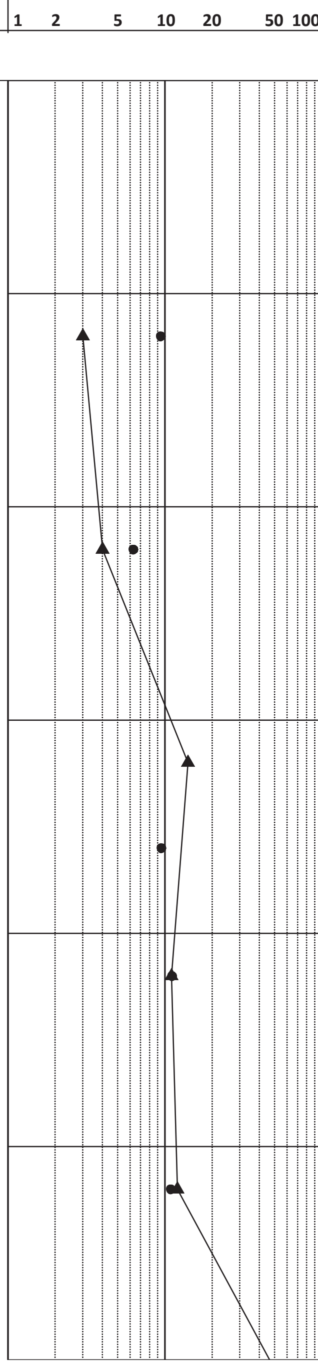
Notes: 1) MC: Moisture Content, GS: Grain Size, AL: Atterberg Limits, SG: Specific Gravity, OC: Organic Content, BD: Bulk Density.
2) 10-11.5 ft: No recovery in split spoon.Trace silty sand in shoe.

Soil Boring Log

HS-03GB

Project #: 210007-02.01	Project: Harris Avenue Shipyard Cleanup	Location: Bellingham, Washington
Client: Port of Bellingham	Logged By: Sam Giannakos	N/LAT: **632265.494451** E/LONG: **1234416.846371**
Contractor: Holt Services	Horiz. Datum: Washington State Plane Feet	Collection Date: **4/27/22**
Method: Direct Push	Vert. Datum: NAVD88	Total Depth (ft): **61.5**
Hammer: 140-lb Auto Hammer	Sampler(s): 2-inch OD/1.375-inch ID Split Spoon	Observed Water Table Depth (ft): **N/A**
Hammer Efficiency (%): UNKNOWN	2-inch Dual Tube Liner	Ground Surface Elevation (ft): **X**

Depth (ft)	Elevation (ft)	Sample Name	Sample Type	Blow Counts	Uncorrected Standard Penetration Resistance (blows per foot) and Moisture Content (%)	Lithology	**Soil Description** Samples and descriptions are in recovered depths. Classification scheme: USCS	Lab Test
0	0						0.0 to 10.0 ft: Loose, moist, brown, SANDY SILT (ML), medium-grained sand, gravels up to 4-inches.	
5	-5	HS-03GB-5-6.5	Split Spoon	3 1 2			@5.0 to 7.0 ft: Substantial wood debris.	MC, AL GS, BD
10	-10	HS-03GB-10-11.5	Split Spoon	3 2 2			10.0 to 29.5 ft: Loose, wet, olive grey, SAND WITH SILT (SP-SM), coarse-grained sand, occassional gravel. @11.8 ft: Grades to fine-grained sand. @13.5 ft: Lens of wet, tan sandy silt.	MC, GS
15	-15		Split Spoon	2 7 7			@16.0 ft: Grades to medium dense, moist, medium-grained sand.	
		HS-03GB-16-20						MC
20	-20	HS-03GB-20-21.5	Split Spoon	5 6 5			@21.5 to 23.5 ft: Lens of loose, wet, light grey, concrete-mix-like material.	MC, BD
25	-25	HS-03GB-25-26.5	Split Spoon	4 6 6			@28.3 to 28.5 ft: Lens of large gravels and small cobbles. @28.5-29.5 ft: Lens of grey sandy coarse silt.	MD, GS
30	-30							



▲ SPT N-Value
● Moisture Content (%)
⊠ Split Spoon

Notes: 1) MC: Moisture Content, GS: Grain Size, AL: Atterberg Limits, SG: Specific Gravity, OC: Organic Content, BD: Bulk Density.

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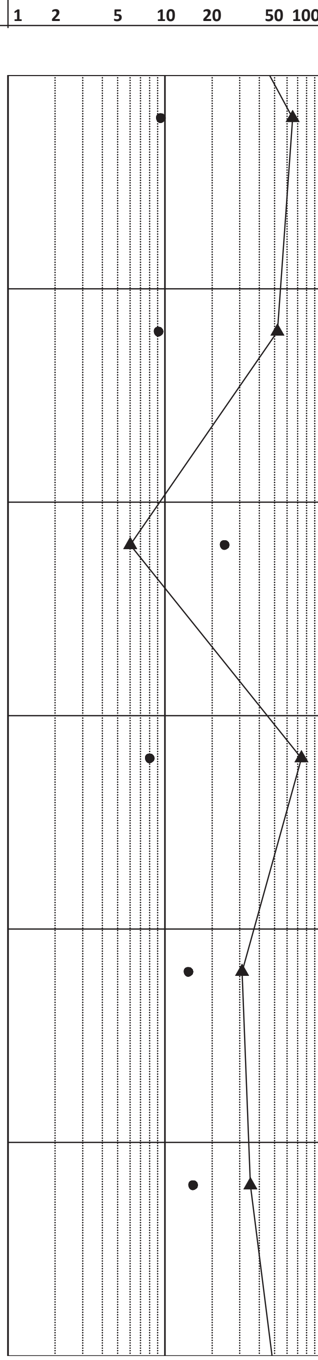
Seattle, WA 98101

Soil Boring Log

HS-03GB

Project #: 210007-02.01	Project: Harris Avenue Shipyard Cleanup	Location: Bellingham, Washington
Client: Port of Bellingham	Logged By: Sam Giannakos	N/LAT: **632265.494451** E/LONG: **1234416.846371**
Contractor: Holt Services	Horiz. Datum: Washington State Plane Feet	Collection Date: **4/27/22**
Method: Direct Push	Vert. Datum: NAVD88	Total Depth (ft): **61.5**
Hammer: 140-lb Auto Hammer	Sampler(s): 2-inch OD/1.375-inch ID Split Spoon	Observed Water Table Depth (ft): **N/A**
Hammer Efficiency (%): UNKNOWN	2-inch Dual Tube Liner	Ground Surface Elevation (ft): **X**

Depth (ft)	Elevation (ft)	Sample Name	Sample Type	Blow Counts	Uncorrected Standard Penetration Resistance (blows per foot) and Moisture Content (%)	Lithology	Soil Description Samples and descriptions are in recovered depths. Classification scheme: USCS	Lab Test
30	-30	HS-03GB-30-31.5	Split Spoon	31 35 30			29.5 to 46.5 ft: Very dense, moist, greyish brown, SILTY SAND (SM), coarse silt, fine-grained sand. @40 ft: Grades to loose. @31.5 to 32.8 ft: Lens of dense, moist, grey, sand.	MC
35	-35	HS-03GB-35-36.5	Split Spoon	17 27 25				MC, GS
40	-40	HS-03GB-40-41.5	Split Spoon	3 3 3				MC
45	-45	HS-03GB-45-46.5	Split Spoon	33 31 43				MC, GS BD
							46.5 to 61.5 ft: Very dense, moist, dark grey, SAND WITH SILT (SP-SM), multicolored medium-grains, varying amounts of silt and gravel. Glacial till.	
50	-50	HS-03GB-50-51.5	Split Spoon	2 2 29			@49.5 ft: Grades to dense.	MC
55	-55	HS-03GB-55-56.5	Split Spoon	7 14 21			@54.0 ft: Grades to siltier. @57.0 ft: Increased gravel content. @58.6 ft: Grades to siltier.	MC
60	-60							



▲ SPT N-Value
● Moisture Content (%)
☒ Split Spoon

Notes: 1) MC: Moisture Content, GS: Grain Size, AL: Atterberg Limits, SG: Specific Gravity, OC: Organic Content, BD: Bulk Density.

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Soil Boring Log

HS-03GB

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Hammer: 140-lb Auto Hammer	Sampler(s): 2-inch OD/1.375-inch ID Split Spoon	Observed Water Table Depth (ft): **N/A**
Hammer Efficiency (%): UNKNOWN	2-inch Dual Tube Liner	Ground Surface Elevation (ft): **X**

Depth (ft)	Elevation (ft)	Sample Name	Sample Type	Blow Counts	Uncorrected Standard Penetration Resistance (blows per foot) and Moisture Content (%)	Lithology	Soil Description Samples and descriptions are in recovered depths. Classification scheme: USCS	Lab Test
60	-60	HS-03GB-60-61.5	Split Spoon	18 24 28			46.5 to 61.5 ft: Very dense, moist, dark grey, SAND WITH SILT (SP-SM), multicolored medium-grains, varying amounts of silt and gravel. Glacial till.	MC, AL SG
							End of Boring at 61.5 feet.	
65	-65							
70	-70							
75	-75							
80	-80							
85	-85							
90	-90							

Chart scale: 1 2 5 10 20 50 100

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Seattle, WA 98101

▲ SPT N-Value
● Moisture Content (%)
☒ Split Spoon

Notes: 1) MC: Moisture Content, GS: Grain Size, AL: Atterberg Limits, SG: Specific Gravity, OC: Organic Content, BD: Bulk Density.

Attachment B-2

Geotechnical Laboratory Report

GeoTesting EXPRESS

Boston
New York
Atlanta
Chicago
Los Angeles
Houston

www.geotesting.com

Transmittal

TO:

Sam Giannakos
Anchor QEA, LLC
1201 3rd Ave, Suite 2600
Seattle, WA 98101

DATE: 2/1/2023	GTX NO: 315464
RE: Harris Shipyard Cleanup	

COPIES	DATE	DESCRIPTION
	2/1/2023	**May 2022 Laboratory Test Report**

REMARKS:

SIGNED:

Jonathan Campbell, Laboratory Manager

APPROVED BY:

Joe Tomei, Vice President and Director of Testing Services

GeoTesting EXPRESS

Boston
New York
Atlanta
Chicago
Los Angeles
Houston

www.geotesting.com

February 1, 2023

Sam Giannakos
Anchor QEA, LLC
1201 3rd Ave, Suite 2600
Seattle, WA 98101

RE: Harris Shipyard Cleanup, (GTX-315464)

Dear Sam Giannakos:

Enclosed are the test results you requested for the above referenced project. GeoTesting Express, Inc. (GTX) received 35 samples from you on 5/11/2022.

GTX performed the following tests on these samples:

35 ASTM D2216 - Moisture Content
7 ASTM D4318 - Atterberg Limits
9 ASTM D6913/D7928 - Grain Size Analysis - Sieve and Hydrometer
7 ASTM D7263 - Density (Unit Weight) of Soil Specimens
6 ASTM D854 - Specific Gravity

A copy of your test request is attached.

The results presented in this report apply only to the items tested. This report shall not be reproduced except in full, without written approval from GeoTesting Express. The remainder of these samples will be retained for a period of sixty (60) days and will then be discarded unless otherwise notified by you. Please call me if you have any questions or require additional information. Thank you for allowing GeoTesting Express the opportunity of providing you with testing services. We look forward to working with you again in the future.

Respectfully yours,

Jonathan Campbell
Laboratory Manager

Boston
New York
Atlanta
Chicago
Los Angeles
Houston

www.geotesting.com

Geotechnical Test Report **2/1/2023**

GTX-315464
Harris Shipyard Cleanup

Client Project No.: 210007-02.01

Prepared for:

Anchor QEA, LLC

GeoTesting EXPRESS

Client: Anchor QEA, LLC			
Project: Harris Shipyard Cleanup			
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: ---	Tested By:	ckg
Sample ID: ---	Test Date: 05/18/22	Checked By:	ank
Depth : ---	Test Id: 668235		

Laboratory Determination of Density (Unit Weight) of Soil Specimens by ASTM D7263

Boring ID	Sample ID	Depth	Visual Description	Bulk Density pcf	Moisture Content %	Dry Density pcf	*
---	HS-2GB-20-21.	---	Moist, gray silty sand with gravel	136.0	15.62	117.6	(1)
---	HS-2GB-40-41.	---	Moist, olive gray silty sand with gravel	130.1	8.954	119.4	(2)
---	HS-)2GB-75-7€	---	Moist, gray silty sand with gravel	138.0	8.484	127.2	(3)
---	HS-01GB-5-6.5	---	Moist, olive gray silty sand	134.2	13.79	118.0	(4)
---	HS-03GB-5-6.5	---	Moist, brown sandy silt with gravel	100.9	5.309	95.82	(5)
---	HS-3GB-20-21.	---	Moist, gray silty sand with gravel	147.3	11.10	132.5	(6)
---	HS-3GB-45-46.	---	Moist, olive sand with silt and gravel	146.7	7.981	135.9	(7)

* Sample Comments

(1): Method B-Volumetric, Reconstituted (compacted)
(2): Method B-Volumetric, Reconstituted (compacted)
(3): Method B-Volumetric, Reconstituted (compacted)
(4): Method B-Volumetric, Reconstituted (compacted)
(5): Method B-Volumetric, Reconstituted (compacted)
(6): Method B-Volumetric, Reconstituted (compacted)
(7): Method B-Volumetric, Reconstituted (compacted)

Notes: Moisture Content determined by ASTM D2216.

GeoTesting EXPRESS

Client:	Anchor QEA, LLC		
Project:	Harris Shipyard Cleanup		
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: ---	Tested By:	ckg
Sample ID: ---	Test Date: 05/18/22	Checked By:	bfs
Depth : ---	Test Id: 668182		

Moisture Content of Soil and Rock - ASTM D2216

Boring ID	Sample ID	Depth	Description	Moisture Content, %
---	HS- 01GB-5-6.5	---	Moist, olive gray silty sand	13.8
---	HS- 01GB-10-11.5	---	Moist, gray silty sand with gravel	17.3
---	HS- 01GB-12.8-15	---	Moist, gray clay with sand	32.8
---	HS- 01GB-20-21.5	---	Moist, olive silty sand with gravel	9.0
---	HS- 01GB-25-26.5	---	Moist, gray silty sand with gravel	8.5
---	HS- 02GB-9-10	---	Moist, gray sandy silt with gravel	11.0
---	HS- 02GB-15-16.5	---	Moist, olive gray silty sand with gravel	13.4
---	HS- 02GB-20-21.5	---	Moist, gray silty sand with gravel	15.6
---	HS- 02GB-25-26.5	---	Moist, olive gray silty sand with gravel	12.9
---	HS- 02GB-26.7-30.5	---	Moist, olive gray silty sand with gravel	8.3

Notes: Temperature of Drying : 110° Celsius

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GeoTesting EXPRESS

Client:	Anchor QEA, LLC				
Project:	Harris Shipyard Cleanup				
Location:				Project No:	GTX-315464
Boring ID:	---	Sample Type:	---	Tested By:	ckg
Sample ID:	---	Test Date:	05/18/22	Checked By:	bfs
Depth :	---	Test Id:	668190		

Moisture Content of Soil and Rock - ASTM D2216

Boring ID	Sample ID	Depth	Description	Moisture Content,%
---	HS-02GB-34.5-35.5	---	Moist, olive gray silty sand with gravel	10.4
---	HS- 02GB-40-41.5	---	Moist, olive gray silty sand with gravel	9.0
---	HS- 02GB-47-50	---	Moist, olive gray silty sand with gravel	9.6
---	HS- 02GB-50-55	---	Moist, olive gray gravel with sand	5.4
---	HS- 02GB-55-56.5	---	Moist, olive gray sand with silt and gravel	7.2
---	HS- 02GB-5-6.5	---	Moist, olive brown sandy silt	12.4
---	HS- 02GB-65-66.5	---	Moist, olive gray silty sand with gravel	8.2
---	HS- 02GB-70-71.5	---	Moist, olive gray sand with silt and gravel	7.1
---	HS- 02GB-75-76	---	Moist, gray silty sand with gravel	8.5
---	HS- 02GB-80-81.5	---	Moist, gray silty sand with gravel	6.9

Notes: Temperature of Drying : 110º Celsius

GeoTesting EXPRESS

Client:	Anchor QEA, LLC				
Project:	Harris Shipyard Cleanup				
Location:				Project No:	GTX-315464
Boring ID:	---	Sample Type:	---	Tested By:	ckg
Sample ID:	---	Test Date:	05/23/22	Checked By:	bfs
Depth :	---	Test Id:	668203		

Moisture Content of Soil and Rock - ASTM D2216

Boring ID	Sample ID	Depth	Description	Moisture Content,%
---	HS- 02GB-86-88	---	Moist, gray silty sand with gravel	8.2
---	HS- 02GB-9-10	---	Moist, gray sandy silt with gravel	11.0
---	HS- 02GB-96-97.5	---	Moist, gray silty sand with gravel	11.1
---	HS- 02GB-100-101.5	---	Moist, olive gray silty sand with gravel	13.4
---	HS- 03GB-10-11.5	---	Moist, olvie gray sand with silt and gravel	6.3
---	HS- 03GB-16-20	---	Moist, olive gray sand with silt and gravel	9.5
---	HS- 03GB-20-21.5	---	Moist, gray silty sand with gravel	11.1
---	HS- 03GB-25-26.5	---	Moist, olive sand with silt and gravel	10.9

Notes: Temperature of Drying : 110° Celsius

GeoTesting EXPRESS

Client:	Anchor QEA, LLC				
Project:	Harris Shipyard Cleanup				
Location:				Project No:	GTX-315464
Boring ID:	---	Sample Type:	---	Tested By:	ckg
Sample ID:	---	Test Date:	05/18/22	Checked By:	bfs
Depth :	---	Test Id:	668210		

Moisture Content of Soil and Rock - ASTM D2216

Boring ID	Sample ID	Depth	Description	Moisture Content, %
---	HS- 03GB-30-31.5	---	Moist, olive silty sand with gravel	9.4
---	HS- 03GB-35-36.5	---	Moist, olive sand with silt and gravel	9.1
---	HS- 03GB-40-41.5	---	Moist, olive gray silty sand	24.0
---	HS- 03GB-45-46.5	---	Moist, olive sand with silt and gravel	8.0
---	HS- 03GB-50-51.5	---	Moist, olive gray sand with silt and gravel	14.1
---	HS- 03GB-55-56.5	---	Moist, olive gray silty sand	15.1
---	HS- 03GB-5-6.5	---	Moist, brown sandy silt with gravel	5.3
---	HS- 03GB-60-61.5	---	Moist, olive silty sand with gravel	9.4

Notes: Temperature of Drying : 110º Celsius

Client:	Anchor QEA, LLC				
Project:	Harris Shipyard Cleanup				
Location:				Project No:	GTX-315464
Boring ID:	---	Sample Type:	---	Tested By:	ckg
Sample ID:	---	Test Date:	05/20/22	Checked By:	jsc
Depth :	---	Test Id:	668242		

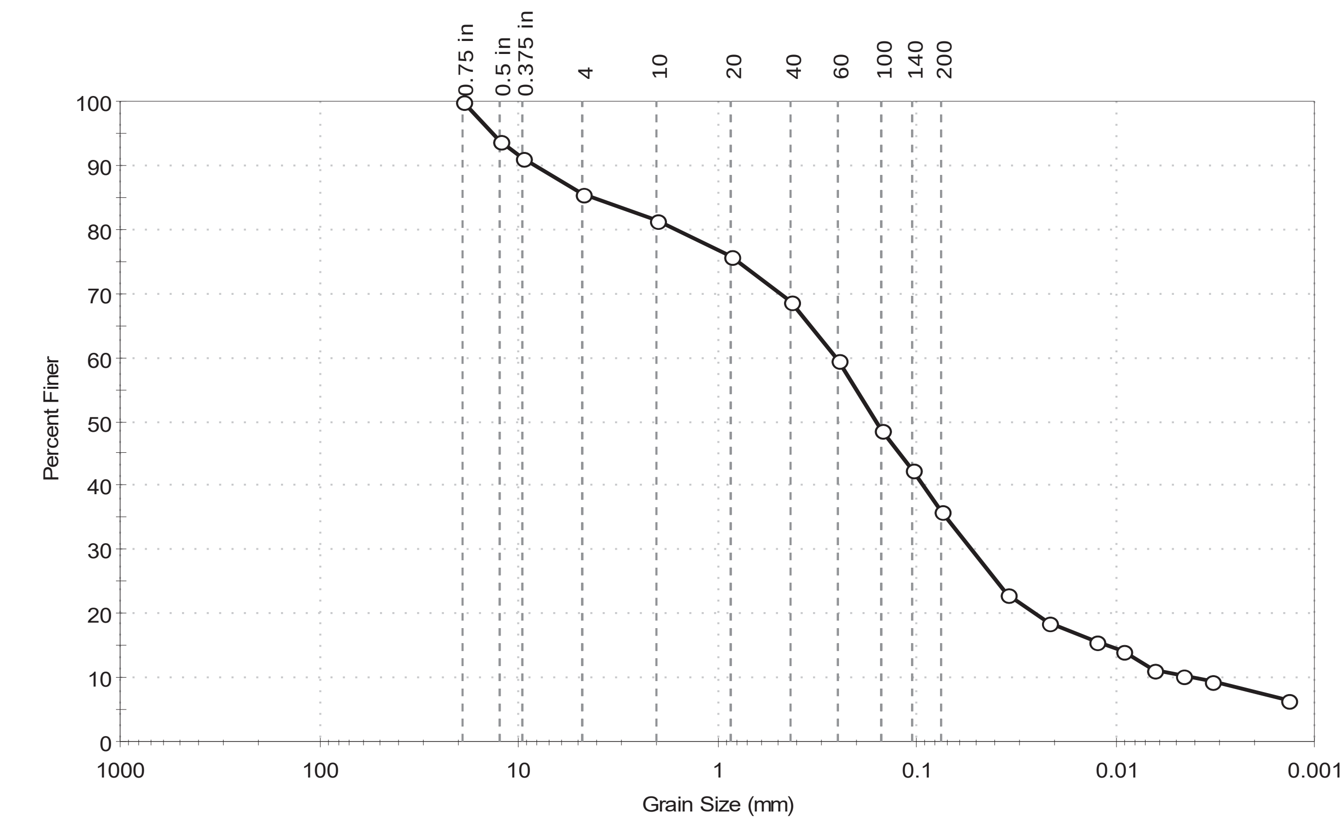
Specific Gravity of Soils by ASTM D854

Boring ID	Sample ID	Depth	isual Description	Speci ic ra it	Comment
---	HS- 02GB-9-10	---	Moist, gray sandy silt with gravel	2.73	
---	HS-02GB-26.7-30.5	---	Moist, olive gray silty sand with gravel	2.77	
---	HS-02GB-55-56.5	---	Moist, olive gray sand with silt and gravel	2.70	
---	HS-01GB-20-21.5	---	Moist, olive silty sand with gravel	2.76	
---	HS-03GB-5-6.5	---	Moist, brown sandy silt with gravel	2.74	
---	HS-03GB-60-61.5	---	Moist, olive silty sand with gravel	2.70	

Notes: Specific Gravity performed by using method B oven dried specimens of ASTM D854
Moisture Content determined by ASTM D2216.

Client:	Anchor QEA, LLC
Project:	Harris Shipyard Cleanup
Location:	
Project No:	GTX-315464
Boring ID:	---
Sample ID:	HS-01GB-5-6.5
Depth :	---
Sample Type:	bag
Test Date:	05/23/22
Test Id:	668222
Tested By:	ckg
Checked By:	bfs
Test Comment:	---
isual Description:	Moist, olive gray silty sand
Sample Comment:	---

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	14.4	49.7	35.9

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
0.75 in	19.00	100		
0.5 in	12.50	94		
0.375 in	9.50	91		
4	4.75	86		
10	2.00	81		
20	0.85	76		
40	0.42	69		
60	0.25	59		
100	0.15	49		
140	0.11	42		
200	0.075	36		
Hydrometer	Particle Si e mm	Percent iner	Spec. Percent	Complies
---	0.0349	23		
---	0.0216	19		
---	0.0127	16		
---	0.0091	14		
---	0.0065	11		
---	0.0046	10		
---	0.0033	10		
---	0.0014	7		

Coe icients

D_{85}	4.2488 mm	D_{30}	0.0528 mm
D_{60}	0.2579 mm	D_{15}	0.0111 mm
D_{50}	0.1601 mm	D_{10}	0.0040 mm
C_u	64.475	C_c	2.702

Classi ication

ASTM N/A

AASHT Silty Soils A-4 0

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mi er

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: 200 Sieve

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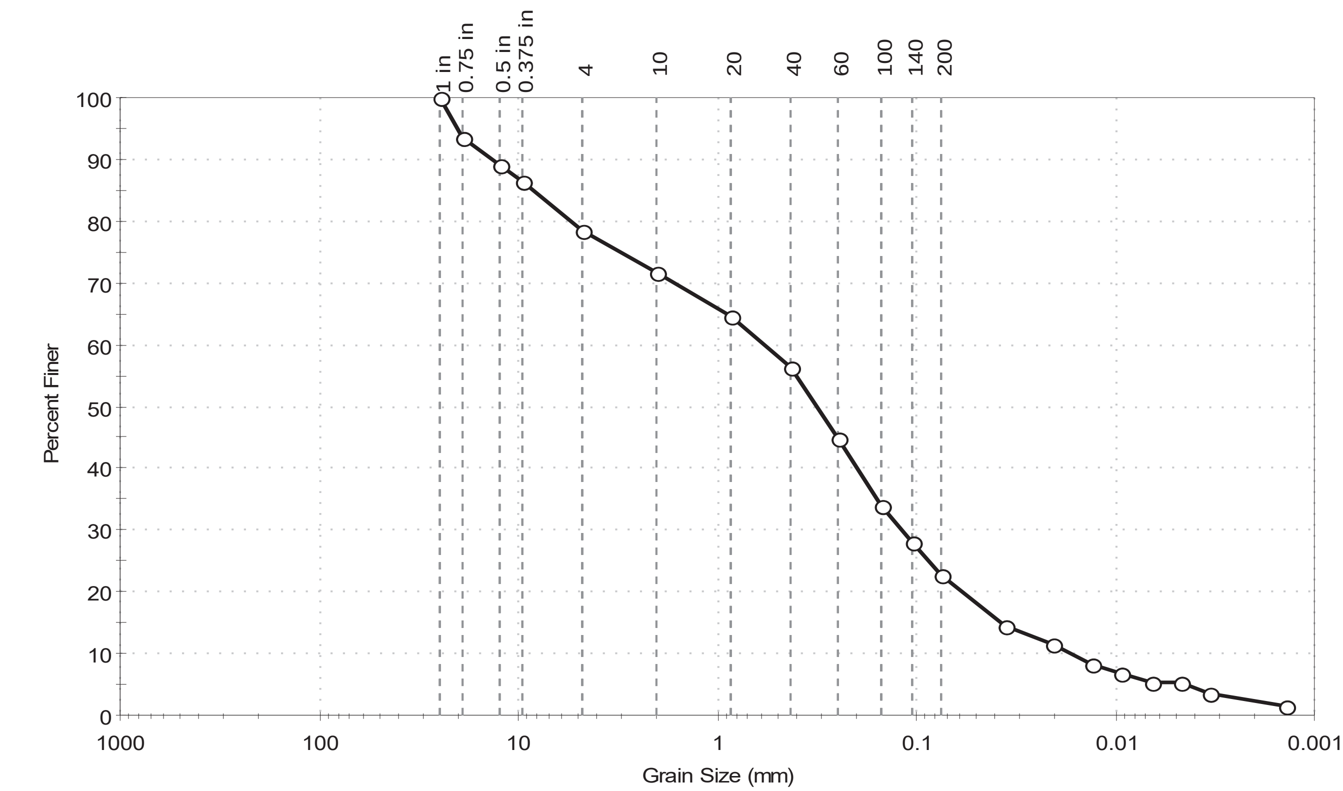
GeoTesting EXPRESS

Client: Anchor QEA, LLC			
Project: Harris Shipyard Cleanup			
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: bag	Tested By:	ckg
Sample ID: HS-01GB-20-21.5	Test Date: 05/23/22	Checked By:	bfs
Depth : ---	Test Id: 668224		

Test Comment: ---
isual Description: Moist, olive silty sand with gravel
Sample Comment: ---

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	21.5	55.7	22.8

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
1 in	25.00	100		
0.75 in	19.00	93		
0.5 in	12.50	89		
0.375 in	9.50	86		
4	4.75	79		
10	2.00	72		
20	0.85	65		
40	0.42	56		
60	0.25	45		
100	0.15	34		
140	0.11	28		
200	0.075	23		
Hydrometer	Particle Si e mm	Percent iner	Spec. Percent	Complies
---	0.0356	15		
---	0.0208	11		
---	0.0131	8		
---	0.0095	7		
---	0.0067	5		
---	0.0047	5		
---	0.0034	4		
---	0.0014	1		

Coe icients

D_{85}	8.4154 mm	D_{30}	0.1190 mm
D_{60}	0.5817 mm	D_{15}	0.0371 mm
D_{50}	0.3168 mm	D_{10}	0.0168 mm
C_u	34.625	C_c	1.449

Classi ication

ASTM N/A

AASHT Silty Gravel and Sand A-2-4 0

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mi er

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: 200 Sieve

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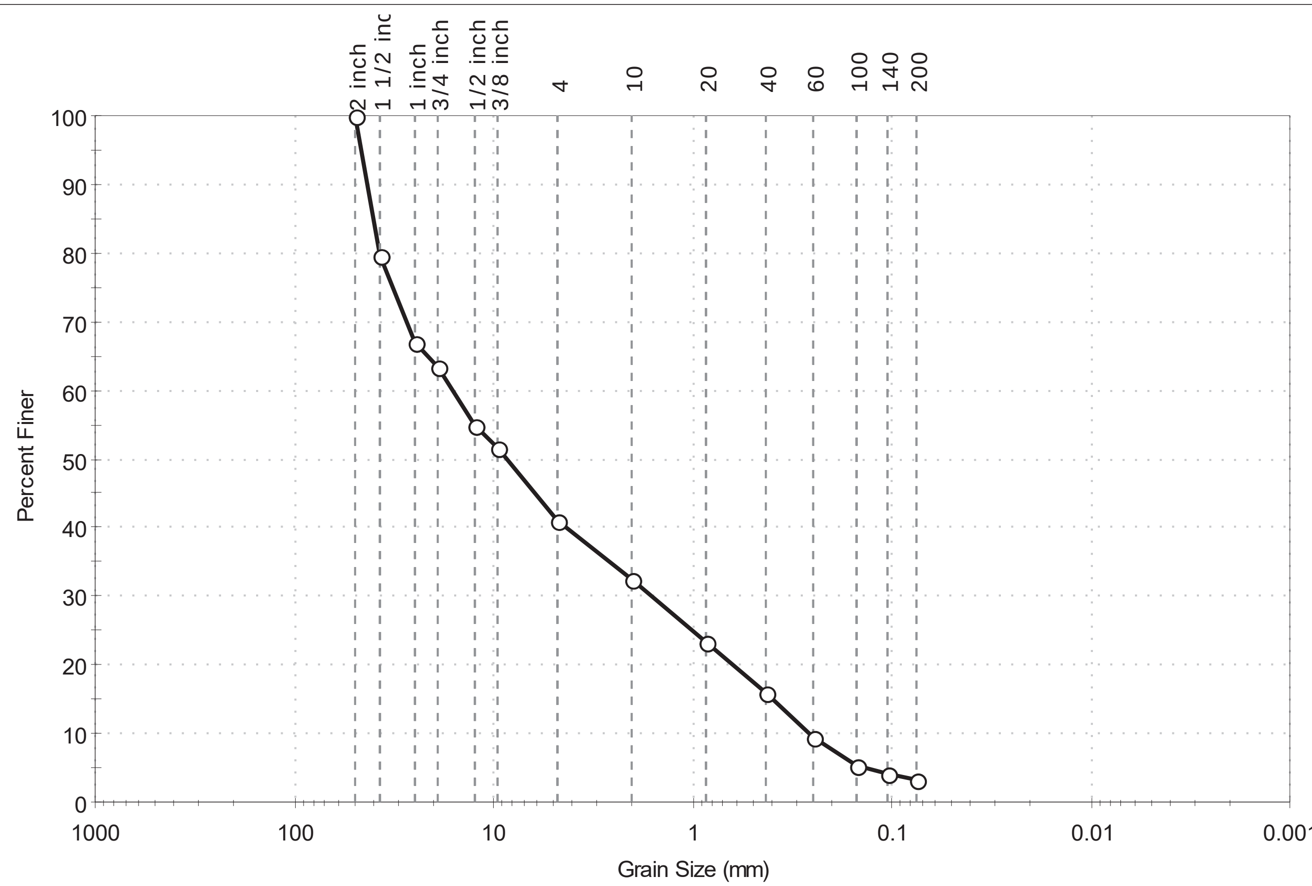
Client:	Anchor QEA, LLC				
Project:	Harris Shipyard Cleanup				
Location:				Project No:	GTX-315464
Boring ID:	---	Sample Type:	bag	Tested By:	ckg
Sample ID:	HS-02GB-50-55	Test Date:	05/23/22	Checked By:	bfs
Depth :	---	Test Id:	668219		
Test Comment:	---				
isual Description:	Moist, olive gray gravel with sand				
Sample Comment:	---				

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	58.9	37.8	3.3

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
2 inch	50.00	100		
1 1/2 inch	37.50	80		
1 inch	25.00	67		
3/4 inch	19.00	63		
1/2 inch	12.50	55		
3/8 inch	9.50	52		
4	4.75	41		
10	2.00	32		
20	0.85	23		
40	0.42	16		
60	0.25	9		
100	0.15	5		
140	0.11	4		
200	0.075	3.3		

Coe icients

D_{85}	40.4392 mm	D_{30}	1.6093 mm
D_{60}	16.0796 mm	D_{15}	0.3922 mm
D_{50}	8.5766 mm	D_{10}	0.2635 mm
C_u	61.023	C_c	0.611

Classi ication

ASTM Poorly graded GRA EL with Sand GP

AASHT Stone ragments, Gravel and Sand A-1-a 1

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

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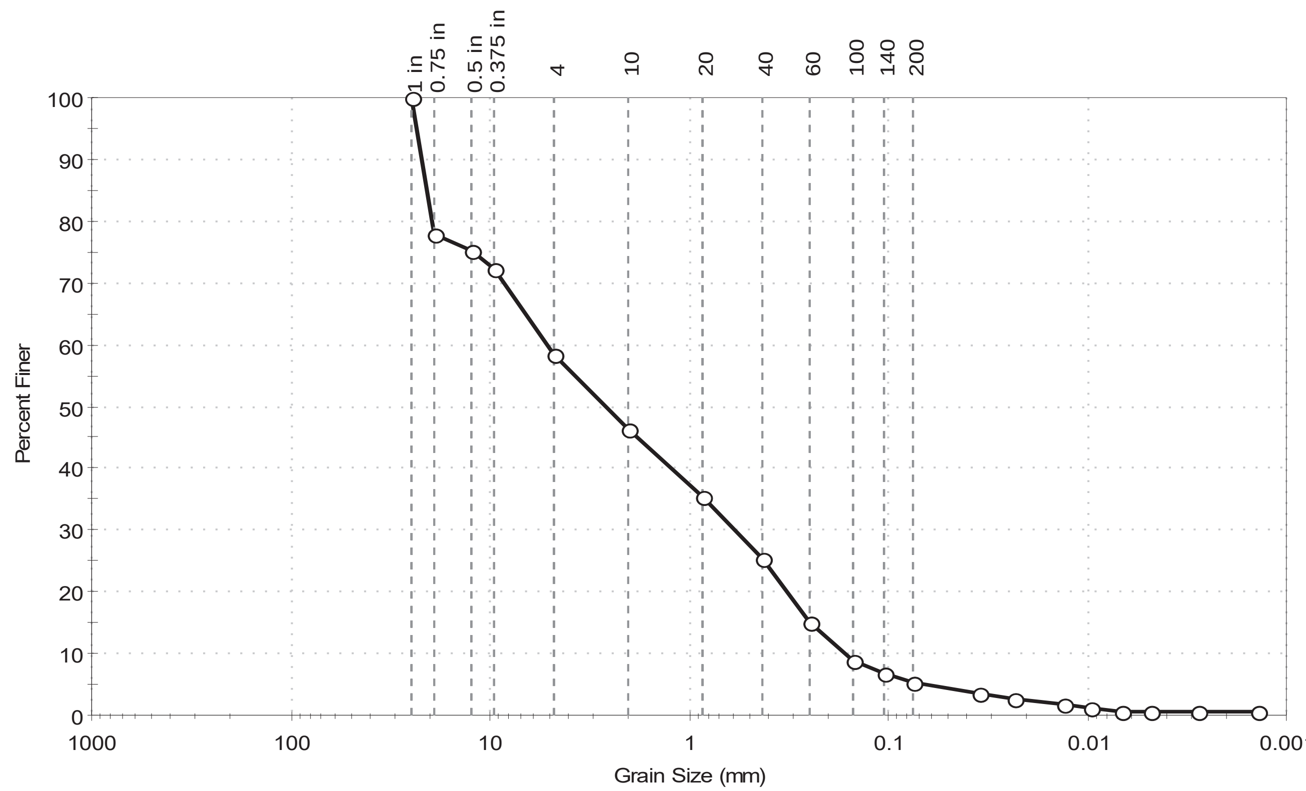
Client:	Anchor QEA, LLC		
Project:	Harris Shipyard Cleanup		
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: bag	Tested By:	ckg
Sample ID: HS-02GB-70-71.5	Test Date: 05/20/22	Checked By:	bfs
Depth : ---	Test Id: 668220		

Test Comment: ---

isual Description: Moist, olive gray sand with silt and gravel

Sample Comment: ---

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	41.7	53.0	5.3

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
1 in	25.00	100		
0.75 in	19.00	78		
0.5 in	12.50	75		
0.375 in	9.50	72		
4	4.75	58		
10	2.00	46		
20	0.85	35		
40	0.42	25		
60	0.25	15		
100	0.15	9		
140	0.11	7		
200	0.075	5.3		
Hydrometer	Particle Si e mm	Percent iner	Spec. Percent	Complies
---	0.0353	3		
---	0.0234	3		
---	0.0132	2		
---	0.0096	1		
---	0.0068	1		
---	0.0048	1		
---	0.0028	1		
---	0.0014	1		

Coe icients

D_{85}	20.7778 mm	D_{30}	0.5860 mm
D_{60}	5.1666 mm	D_{15}	0.2473 mm
D_{50}	2.6014 mm	D_{10}	0.1655 mm
C_u	31.218	C_c	0.402

Classi ication

ASTM N/A

AASHT Stone ragments, Gravel and Sand A-1-a 1

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mi er

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: 200 Sieve

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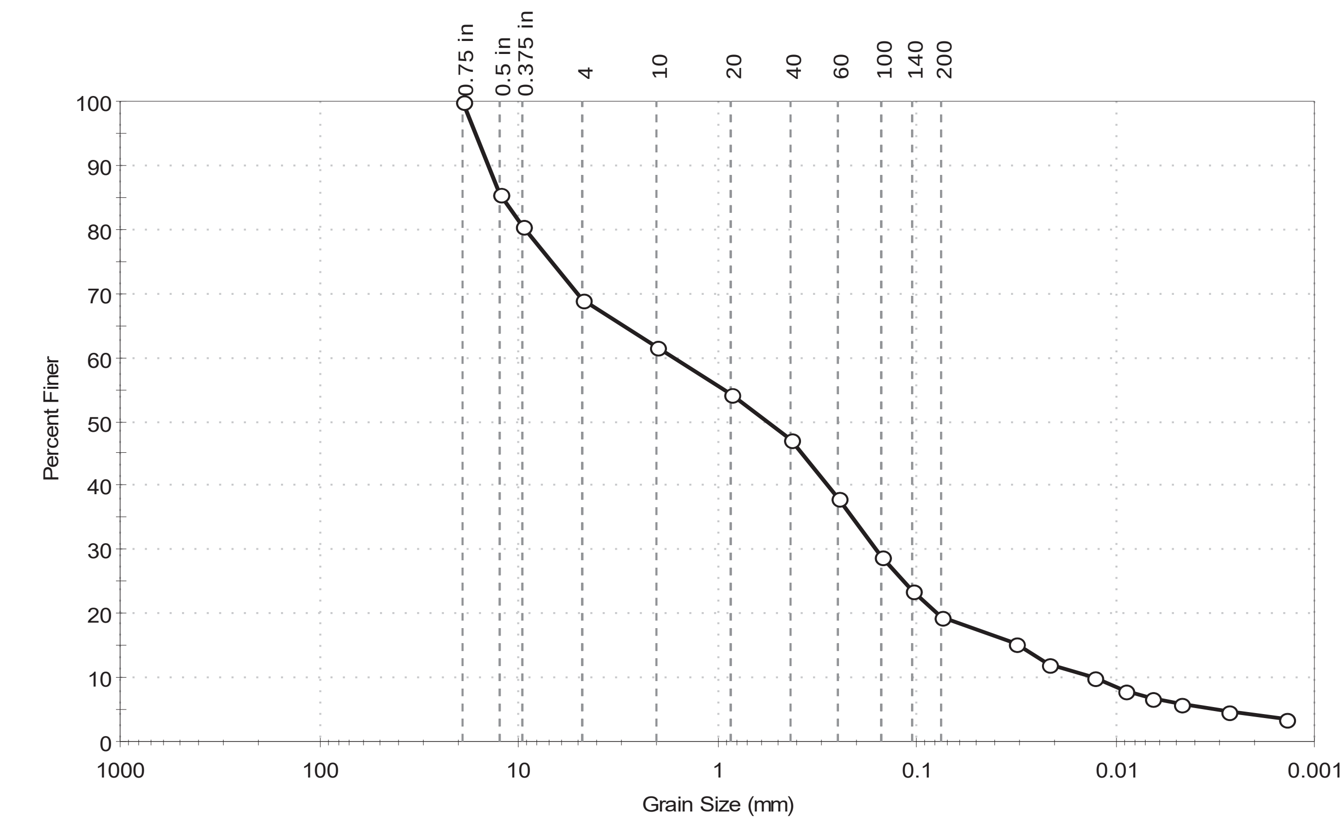
Client:	Anchor QEA, LLC
Project:	Harris Shipyard Cleanup
Location:	
Project No:	GTX-315464
Boring ID:	---
Sample ID:	HS-02GB-96-97.5
Depth :	---
Sample Type:	bag
Test Date:	05/23/22
Test Id:	668221
Tested By:	ckg
Checked By:	bfs
Test Comment:	---
isual Description:	Moist, gray silty sand with gravel
Sample Comment:	---

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	30.9	49.7	19.4

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
0.75 in	19.00	100		
0.5 in	12.50	86		
0.375 in	9.50	80		
4	4.75	69		
10	2.00	62		
20	0.85	54		
40	0.42	47		
60	0.25	38		
100	0.15	29		
140	0.11	24		
200	0.075	19		
Hydrometer	Particle Si e mm	Percent iner	Spec. Percent	Complies
---	0.0322	15		
---	0.0217	12		
---	0.0130	10		
---	0.0090	8		
---	0.0066	7		
---	0.0047	6		
---	0.0027	5		
---	0.0014	4		

Coe icients

D_{85}	12.1336 mm	D_{30}	0.1598 mm
D_{60}	1.6312 mm	D_{15}	0.0305 mm
D_{50}	0.5534 mm	D_{10}	0.0128 mm
C_u	127.437	C_c	1.223

Classi ication

ASTM Silty SAND with Gravel SM

AASHT Stone ragments, Gravel and Sand A-1-b 0

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mi er

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: 200 Sieve

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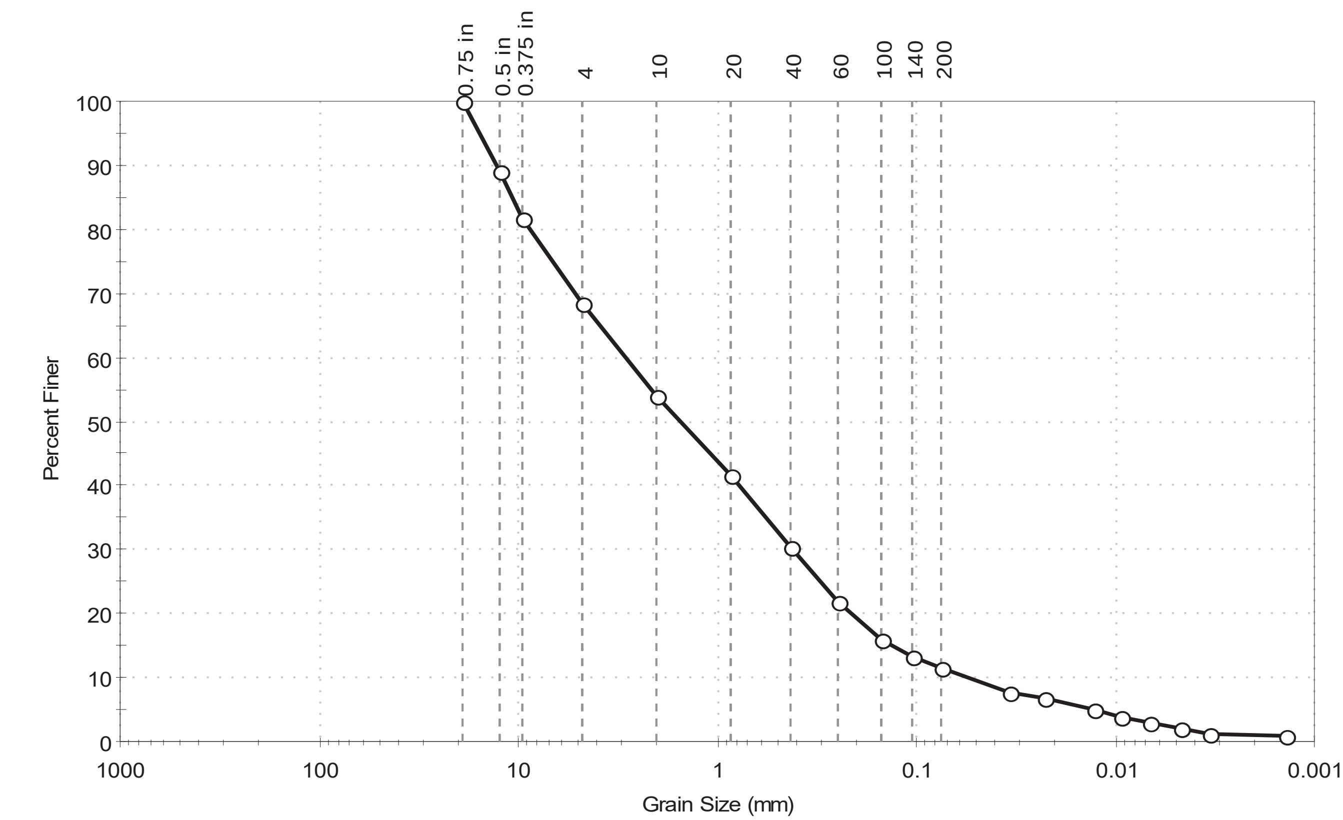
Client:	Anchor QEA, LLC		
Project:	Harris Shipyard Cleanup		
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: bag	Tested By:	ckg
Sample ID: HS-03GB-10-11.5	Test Date: 05/23/22	Checked By:	bfs
Depth : ---	Test Id: 668225		
Test Comment:	---		
isual Description:	Moist, olvie gray sand with silt and gravel		
Sample Comment:	---		

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	31.6	56.9	11.5

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
0.75 in	19.00	100		
0.5 in	12.50	89		
0.375 in	9.50	82		
4	4.75	68		
10	2.00	54		
20	0.85	42		
40	0.42	30		
60	0.25	22		
100	0.15	16		
140	0.11	13		
200	0.075	11		
Hydrometer	Particle Si e mm	Percent iner	Spec. Percent	Complies
---	0.0341	8		
---	0.0230	7		
---	0.0130	5		
---	0.0094	4		
---	0.0067	3		
---	0.0047	2		
---	0.0034	1		
---	0.0014	1		

Coe icients

D_{85}	10.7542 mm	D_{30}	0.4177 mm
D_{60}	2.8714 mm	D_{15}	0.1349 mm
D_{50}	1.5170 mm	D_{10}	0.0555 mm
C_u	51.737	C_c	1.095

Classi ication

ASTM N/A

AASHT Stone ragments, Gravel and Sand
A-1-b 0

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mi er

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: 200 Sieve

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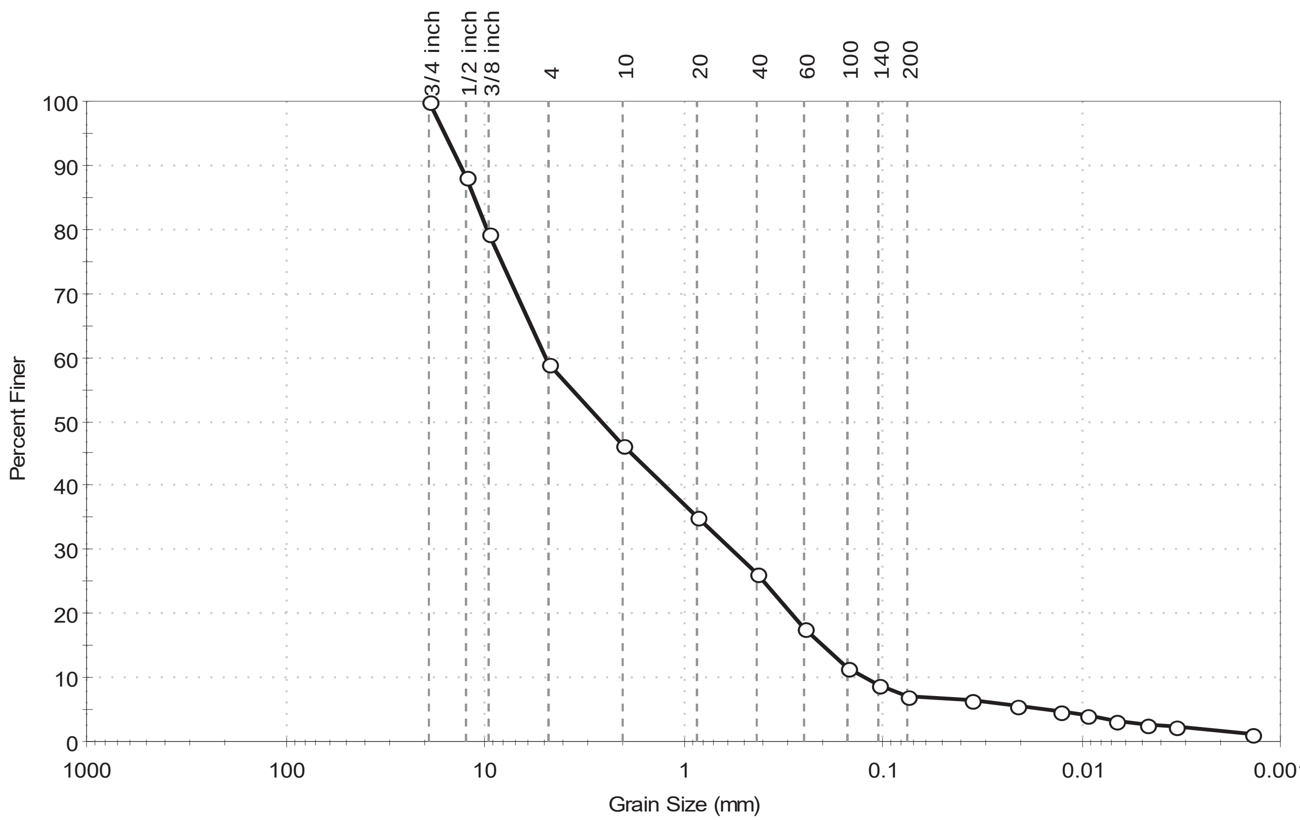
Client:	Anchor QEA, LLC
Project:	Harris Shipyard Cleanup
Location:	
Project No:	GTX-315464
Boring ID:	---
Sample Type:	bag
Tested By:	ckg
Sample ID:	HS-03GB-25-26.5
Test Date:	05/23/22
Checked By:	bfs
Depth :	---
Test Id:	668226
Test Comment:	---
isual Description:	Moist, olive sand with silt and gravel
Sample Comment:	---

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	40.9	52.0	7.1

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
3/4 inch	19.00	100		
1/2 inch	12.50	88		
3/8 inch	9.50	79		
4	4.75	59		
10	2.00	46		
20	0.85	35		
40	0.42	26		
60	0.25	18		
100	0.15	11		
140	0.11	9		
200	0.075	7.1		
Hydrometer	Particle Si e mm	Percent iner	Spec. Percent	Complies
---	0.0357	6		
---	0.0210	6		
---	0.0130	5		
---	0.0094	4		
---	0.0067	3		
---	0.0047	3		
---	0.0033	2		
---	0.0014	1		

Coe icients

D_{85}	11.2819 mm	D_{30}	0.5683 mm
D_{60}	4.8933 mm	D_{15}	0.2002 mm
D_{50}	2.5787 mm	D_{10}	0.1243 mm
C_u	39.367	C_c	0.531

Classi ication

ASTM N/A

AASHT Stone ragments, Gravel and Sand
A-1-a 1

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mi er

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: 200 Sieve

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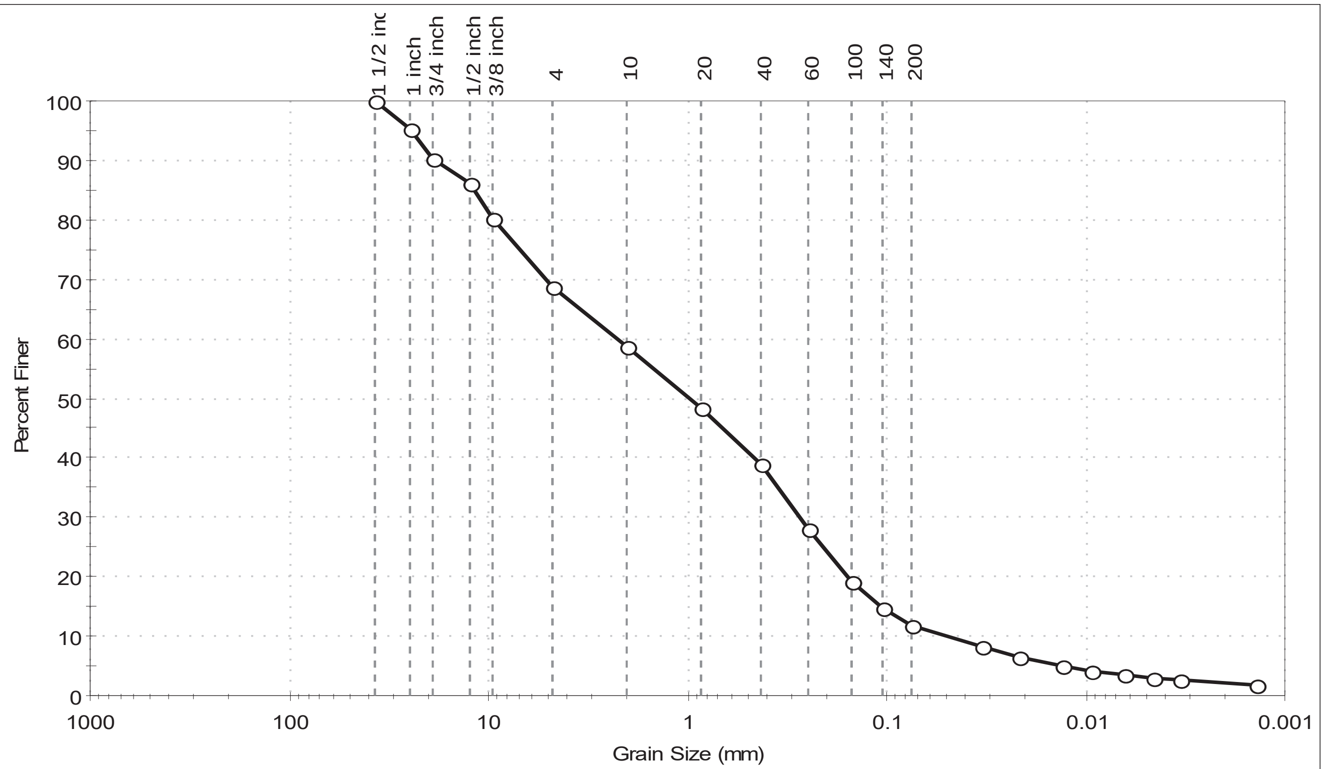
Client:	Anchor QEA, LLC		
Project:	Harris Shipyard Cleanup		
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: bag	Tested By:	ckg
Sample ID: HS-03GB-35-36.5	Test Date: 05/23/22	Checked By:	bfs
Depth : ---	Test Id: 668227		

Test Comment: ---
isual Description: Moist, olive sand with silt and gravel
Sample Comment: ---

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	31.3	56.9	11.8

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
1 1/2 inch	37.50	100		
1 inch	25.00	95		
3/4 inch	19.00	90		
1/2 inch	12.50	86		
3/8 inch	9.50	80		
4	4.75	69		
10	2.00	59		
20	0.85	48		
40	0.42	39		
60	0.25	28		
100	0.15	19		
140	0.11	15		
200	0.075	12		
Hydrometer	Particle Si e mm	Percent iner	Spec. Percent	Complies
---	0.0335	8		
---	0.0216	7		
---	0.0132	5		
---	0.0094	4		
---	0.0065	3		
---	0.0047	3		
---	0.0034	3		
---	0.0014	2		

Coe icients

D_{85}	11.8224 mm	D_{30}	0.2740 mm
D_{60}	2.2221 mm	D_{15}	0.1071 mm
D_{50}	0.9653 mm	D_{10}	0.0502 mm
C_u	44.265	C_c	0.673

Classi ication

ASTM N/A

AASHT Stone ragments, Gravel and Sand
A-1-b 0

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mi er

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: 200 Sieve

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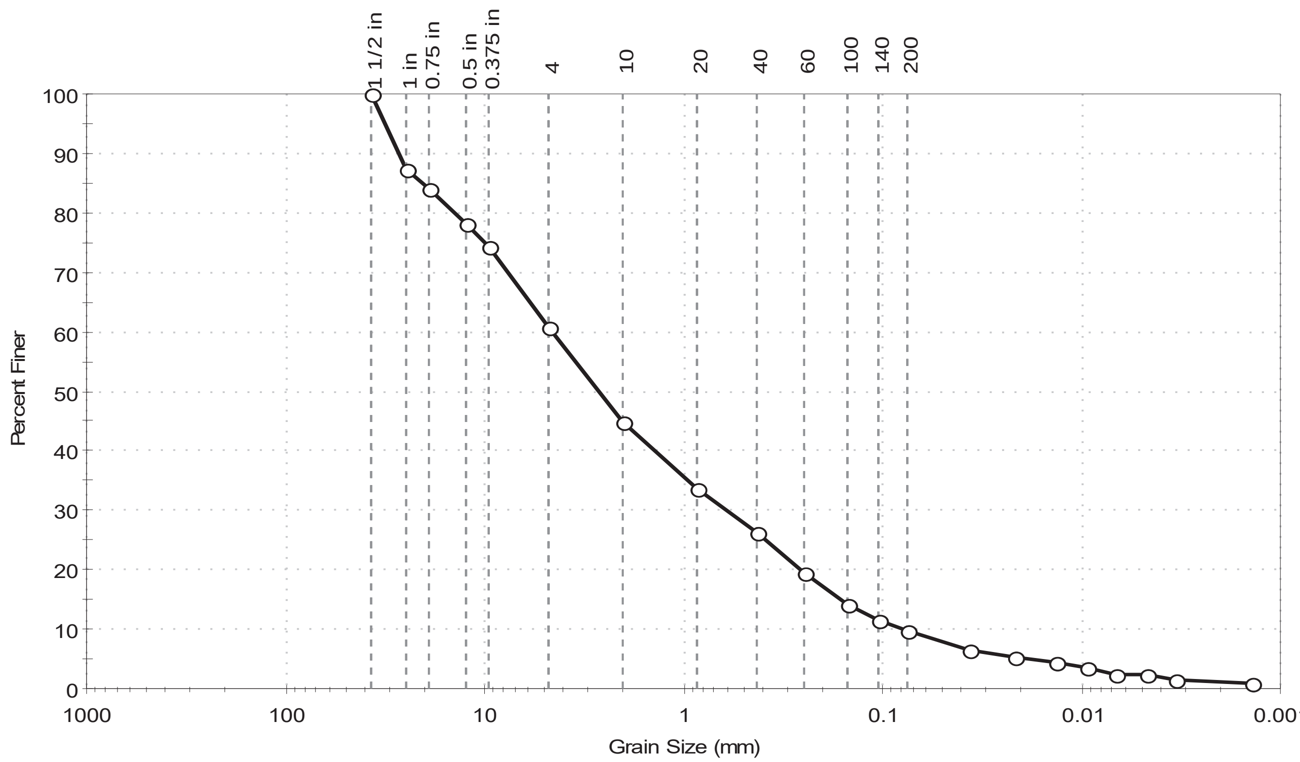
Client: Anchor QEA, LLC			
Project: Harris Shipyard Cleanup			
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: bag	Tested By:	ckg
Sample ID: HS-03GB-45-46.5	Test Date: 05/23/22	Checked By:	bfs
Depth : ---	Test Id: 668228		

Test Comment: ---

isual Description: Moist, olive sand with silt and gravel

Sample Comment: ---

Particle Si e Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	39.2	51.2	9.6

Sie e ame	Sie e Si e, mm	ercent iner	Spec ercent	Complies
1 1/2 in	37.50	100		
1 in	25.00	87		
0.75 in	19.00	84		
0.5 in	12.50	78		
0.375 in	9.50	74		
4	4.75	61		
10	2.00	45		
20	0.85	34		
40	0.42	26		
60	0.25	19		
100	0.15	14		
140	0.11	12		
200	0.075	9.6		
Hydrometer	Particle Si e mm	Percent iner	Spec. Percent	Complies
---	0.0364	6		
---	0.0215	5		
---	0.0133	4		
---	0.0094	3		
---	0.0067	2		
---	0.0047	2		
---	0.0034	1		
---	0.0014	1		

Coe icients

D_{85}	20.5484 mm	D_{30}	0.6053 mm
D_{60}	4.5465 mm	D_{15}	0.1625 mm
D_{50}	2.6398 mm	D_{10}	0.0804 mm
C_u	56.549	C_c	1.002

Classi ication

ASTM N/A

AASHT Stone ragments, Gravel and Sand
A-1-a 1

Sample est Description

Sand/Gravel Particle Shape : ANG LAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mi er

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: 200 Sieve

printed 5/23/2022 2:48:02 PM

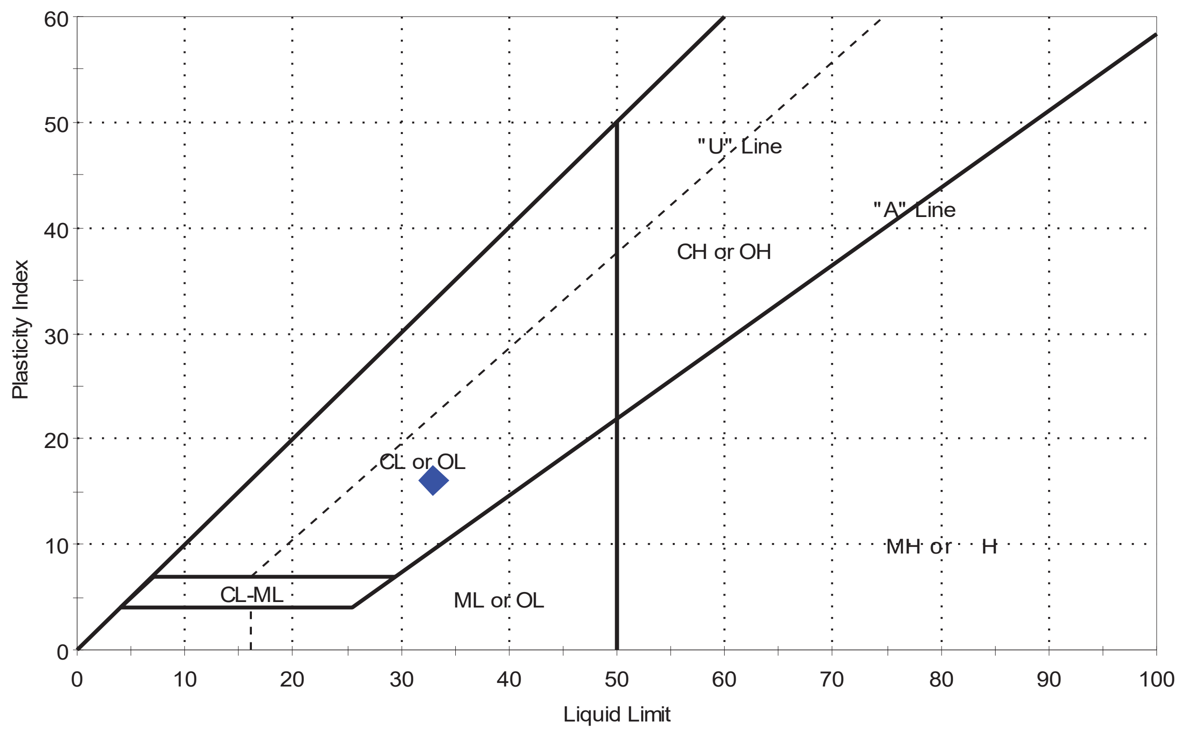
Client: Anchor QEA, LLC
Project: Harris Shipyard Cleanup
Location: Project No: GTX-315464

Boring ID:	---	Sample Type:	bag	Tested By:	cam
Sample ID:	HS-01GB-12.8-15	Test Date:	05/17/22	Checked By:	bfs
Depth :	---	Test Id:	668214		

Test Comment: ---
isual Description: Moist, gray clay with sand
Sample Comment: ---

Atterberg Limits - ASTM D4318

Plasticity Chart



S m ol	Sample ID	Boring	Depth	atural Moisture Content,%	i ui imit	lastic imit	lasticit In e	i ui it In e	Soil Classi ication
◆	HS-01GB-12.8-15	---	---	33	33	17	16	1	

Sample Prepared using the ET method

Dry Strength: ER HIGH
Dilatancy: SL
Toughness: L

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Client:	Anchor QEA, LLC		
Project:	Harris Shipyard Cleanup		
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: bag	Tested By:	cam
Sample ID: HS-01GB-25-26.5	Test Date: 05/17/22	Checked By:	bfs
Depth : ---	Test Id: 668215		
Test Comment:	---		
isual Description:	Moist, gray silty sand with gravel		
Sample Comment:	---		

Atterberg Limits - ASTM D4318

Sample Determine to e non plastic

S m ol	Sample ID	Boring	Depth	atural Moisture Content, %	i ui imit	lastic imit	lasticit In e	i ui it In e	Soil Classi ication
	HS-01GB-25-26.5	---	---	8	n/a	n/a	n/a	n/a	

Dry Strength: L

Dilatancy: RAPID

Toughness: n/a

The sample was determined to be Non-Plastic

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GeoTesting EXPRESS

Client:	Anchor QEA, LLC			
Project:	Harris Shipyard Cleanup			
Location:			Project No:	GTX-315464
Boring ID: ---		Sample Type: bag	Tested By:	cam
Sample ID: HS-02GB-40-41.5		Test Date: 05/18/22	Checked By:	bfs
Depth : ---		Test Id: 668211		
Test Comment:	---			
isual Description:	Moist, olive gray silty sand with gravel			
Sample Comment:	---			

Atterberg Limits - ASTM D4318

Sample Determine to e non plastic

S m ol	Sample ID	Boring	Depth	atural Moisture Content,%	i ui imit	lastic imit	lasticit In e	i ui it In e	Soil Classi ication
◆	HS-02GB-40-41.5	---	---	9	n/a	n/a	n/a	n/a	

Dry Strength: L

Dilatancy: RAPID

Toughness: n/a

The sample was determined to be Non-Plastic

printed 5/23/2022 3: 8:2 PM

Client:	Anchor QEA, LLC		
Project:	Harris Shipyard Cleanup		
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: bag	Tested By:	cam
Sample ID: HS-02GB-96-97.5	Test Date: 05/17/22	Checked By:	bfs
Depth : ---	Test Id: 668212		
Test Comment:	---		
isual Description:	Moist, gray silty sand with gravel		
Sample Comment:	---		

Atterberg Limits - ASTM D4318

Sample Determine to e non plastic

S m ol	Sample ID	Boring	Depth	atural Moisture Content,%	i ui imit	lastic imit	lasticit In e	i ui it In e	Soil Classi ication
◆	HS-02GB-96-97.5	---	---	11	n/a	n/a	n/a	n/a	Silty SAND with Gravel SM

53 Retained on 40 Sieve

Dry Strength: L

Dilatancy: RAPID

Toughness: n/a

The sample was determined to be Non-Plastic

Client:	Anchor QEA, LLC				
Project:	Harris Shipyard Cleanup				
Location:				Project No:	GTX-315464
Boring ID:	---	Sample Type:	bag	Tested By:	cam
Sample ID:	HS-02GB-100-101.5	Test Date:	05/17/22	Checked By:	bfs
Depth :	---	Test Id:	668213		
Test Comment:	---				
isual Description:	Moist, olive gray silty sand with gravel				
Sample Comment:	---				

Atterberg Limits - ASTM D4318

Sample Determine   to   e non plastic

S m ol	Sample ID	Boring	Depth	atural Moisture Content, %	i ui imit	lastic imit	lasticit In e	i ui it In e	Soil Classi ication
◆	HS-02GB-100-101.5	---	---	13	n/a	n/a	n/a	n/a	

Dry Strength: L

Dilatancy: RAPID

Toughness: n/a

The sample was determined to be Non-Plastic

Client:	Anchor QEA, LLC			
Project:	Harris Shipyard Cleanup			
Location:			Project No:	GTX-315464
Boring ID: ---		Sample Type: bag	Tested By:	cam
Sample ID: HS-03GB-5-6.5		Test Date: 05/18/22	Checked By:	bfs
Depth : ---		Test Id: 668216		
Test Comment:	---			
isual Description:	Moist, brown sandy silt with gravel			
Sample Comment:	---			

Atterberg Limits - ASTM D4318

Sample Determine to e non plastic

S m ol	Sample ID	Boring	Depth	atural Moisture Content,%	i ui imit	lastic imit	lasticit In e	i ui it In e	Soil Classi ication
◆	HS-03GB-5-6.5	---	---	5	n/a	n/a	n/a	n/a	

Dry Strength: L

Dilatancy: RAPID

Toughness: n/a

The sample was determined to be Non-Plastic

GeoTesting EXPRESS

Client:	Anchor QEA, LLC		
Project:	Harris Shipyard Cleanup		
Location:		Project No:	GTX-315464
Boring ID: ---	Sample Type: bag	Tested By:	cam
Sample ID: HS-03GB-60-61.5	Test Date: 05/18/22	Checked By:	bfs
Depth : ---	Test Id: 668217		
Test Comment:	---		
isual Description:	Moist, olive silty sand with gravel		
Sample Comment:	---		

Atterberg Limits - ASTM D4318

Sample Determine to e non plastic

S m ol	Sample ID	Boring	Depth	atural Moisture Content,%	i ui imit	lastic imit	lasticit In e	i ui it In e	Soil Classi ication
◆	HS-03GB-60-61.5	---	---	9	n/a	n/a	n/a	n/a	

Dry Strength: L

Dilatancy: RAPID

Toughness: n/a

The sample was determined to be Non-Plastic

Chain of Custody Record & Laboratory Analysis Request

Laboratory Number: Geotesting Express
Date: May 9, 2022
Project Name: Harris Shipyard Cleanup
Project Number: 210007-02.01
Project Manager: Derek Ormerod
Phone Number: 360-715-2721
Shipment Method: Fedex

ANCHOR QEA

					Test Parameters					
Line	Field Sample ID	Collection Date/Time		Matrix	No. of Containers	Moisture Content (ASTM D2216)	Atterberg Limits (ASTM D4318)	Grain Size (ASTM D6913/D7928)	Density (ASTM D 7263)	Specific Gravity ASTM D854)	Comments/Preservation
1	HS-02GB-5-6.5	4/28/2022	0850	Soil	1	x					Soil in Ziplock Bag
2	HS-02GB-9-10	4/28/2022	0855	Soil	1	x				x	Soil in Ziplock Bag
3	HS-02GB-15-16.5	4/28/2022	0920	Soil	1	x					Soil in Ziplock Bag
4	HS-02GB-20-21.5	4/28/2022	0945	Soil	1	x			x		Soil in Ziplock Bag
5	HS-02GB-25-26.5	4/28/2022	1020	Soil	1	x					Soil in Ziplock Bag
6	HS-02GB-26.7-30.5	4/28/2022	1045	Soil	1	x				x	Soil in Ziplock Bag
7	HS-02GB-34.5-35.5	4/28/2022	1050	Soil	1	x					Soil in Ziplock Bag
8	HS-02GB-40-41.5	4/28/2022	1130	Soil	1	x	x		x		Soil in Ziplock Bag
9	HS-02GB-47-50	4/28/2022	1145	Soil	1	x					Soil in Ziplock Bag
10	HS-02GB-50-55	4/28/2022	1410	Soil	1	x		x			Soil in Ziplock Bag
11	HS-02GB-55-56.5	4/28/2022	1445	Soil	1	x				x	Soil in Ziplock Bag
12	HS-02GB-70-71.5	4/29/2022	0750	Soil	1	x		x			Soil in Ziplock Bag
13	HS-02GB-75-76	4/29/2022	0815	Soil	1	x			x		Soil in Ziplock Bag
14	HS-02GB-80-81.5	4/29/2022	0855	Soil	1	x					Soil in Ziplock Bag
15	HS-02GB-96-97.5	4/29/2022	1040	Soil	1	x	x	x			Soil in Ziplock Bag
16	HS-02GB-100-101.5	4/29/2022	1135	Soil	1	x	x				Soil in Ziplock Bag

Notes:

Relinquished By: Sam [signature]
Signature/Printed Name
Company: Anchor QEA, LLC
5/9/2022 900
Date/Time

Received By: [signature] Shannon Pitcuch
Signature/Printed Name
Company: GTX
5/10/22 3:30
Date/Time

Relinquished By: [signature]
Signature/Printed Name
Company:
Date/Time

Received By:
Signature/Printed Name
Company:
Date/Time

Distribution: A copy will be made for the laboratory and client. The Project file will retain the original.

Chain of Custody Record & Laboratory Analysis Request

Laboratory Number: Geotesting Express
Date: May 9, 2022
Project Name: Harris Shipyard Cleanup
Project Number: 210007-02.01
Project Manager: Derek Ormerod
Phone Number: 360-715-2721
Shipment Method: Fedex

ANCHOR QEA

Line	Field Sample ID	Collection Date/Time		Matrix	No. of Containers	Moisture Content (ASTM D2216)	Atterberg Limits (ASTM D4318)	Grain Size (ASTM D6913/D7928)	Density (ASTM D 7263)	Specific Gravity ASTM D854)	Comments/Preservation
1	HS-01GB-5-6.5	4/29/2022	1430	Soil	1	x		x	x		Soil in Ziplock Bag
2	HS-01GB-10-11.5	4/29/2022	1445	Soil	1	x					Soil in Ziplock Bag
3	HS-01GB-12.8-15	4/29/2022	1455	Soil	1	x	x				Soil in Ziplock Bag
4	HS-01GB-15-16.5	4/29/2022	1505	Soil	1	x		x		x	Soil in Ziplock Bag
5	HS-01GB-20-21.5	4/29/2022	1530	Soil	1	x		x		x	Soil in Ziplock Bag
6	HS-01GB-25-26.5	4/29/2022	1550	Soil	1	x	x				Soil in Ziplock Bag
7	HS-03GB-5-6.5	4/27/2022	0800	Soil	1	x	x		x	x	Soil in Ziplock Bag
8	HS-03GB-10-11.5	4/27/2022	0815	Soil	1	x		x			Soil in Ziplock Bag
9	HS-03GB-16-20	4/27/2022	0850	Soil	1	x					Soil in Ziplock Bag
10	HS-03GB-20-21.5	4/27/2022	0900	Soil	1	x			x		Soil in Ziplock Bag
11	HS-03GB-25-26.5	4/27/2022	0920	Soil	1	x		x			Soil in Ziplock Bag
12	HS-03GB-30-31.5	4/27/2022	1000	Soil	1	x					Soil in Ziplock Bag
13	HS-03GB-35-36.5	4/27/2022	1110	Soil	1	x		x			Soil in Ziplock Bag
14	HS-03GB-40-41.5	4/27/2022	1245	Soil	1	x					Soil in Ziplock Bag
15	HS-03GB-45-46.5	4/27/2022	1330	Soil	1	x		x	x		Soil in Ziplock Bag
16	HS-03GB-50-51.5	4/27/2022	1425	Soil	1	x					Soil in Ziplock Bag
17	HS-03GB-55-56.5	4/27/2022	1530	Soil	1	x					Soil in Ziplock Bag
18	HS-03GB-60-61.5	4/27/2022	1625	Soil	1	x	x			x	Soil in Ziplock Bag

Notes:

Relinquished By:	Company: Anchor QEA, LLC	Received By:	Company: GTX
Sam [signature]	5/9/2022 900	[signature] Shannon Pitcuch	5/10/22 3:30
Signature/Printed Name	Date/Time	Signature/Printed Name	Date/Time

Relinquished By:	Company:	Received By:	Company:
Signature/Printed Name	Date/Time	Signature/Printed Name	Date/Time

Distribution: A copy will be made for the laboratory and client. The Project file will retain the original.

GeoTesting
EXPRESS

WARRANTY and LIABILITY

GeoTesting Express (GTX) warrants that all tests it performs are run in general accordance with the specified test procedures and accepted industry practice. GTX will correct or repeat any test that does not comply with this warranty. GTX has no specific knowledge as to conditioning, origin, sampling procedure or intended use of the material.

GTX may report engineering parameters that require us to interpret the test data. Such parameters are determined using accepted engineering procedures. However, GTX does not warrant that these parameters accurately reflect the true engineering properties of the *in situ* material. Responsibility for interpretation and use of the test data and these parameters for engineering and/or construction purposes rests solely with the user and not with GTX or any of its employees.

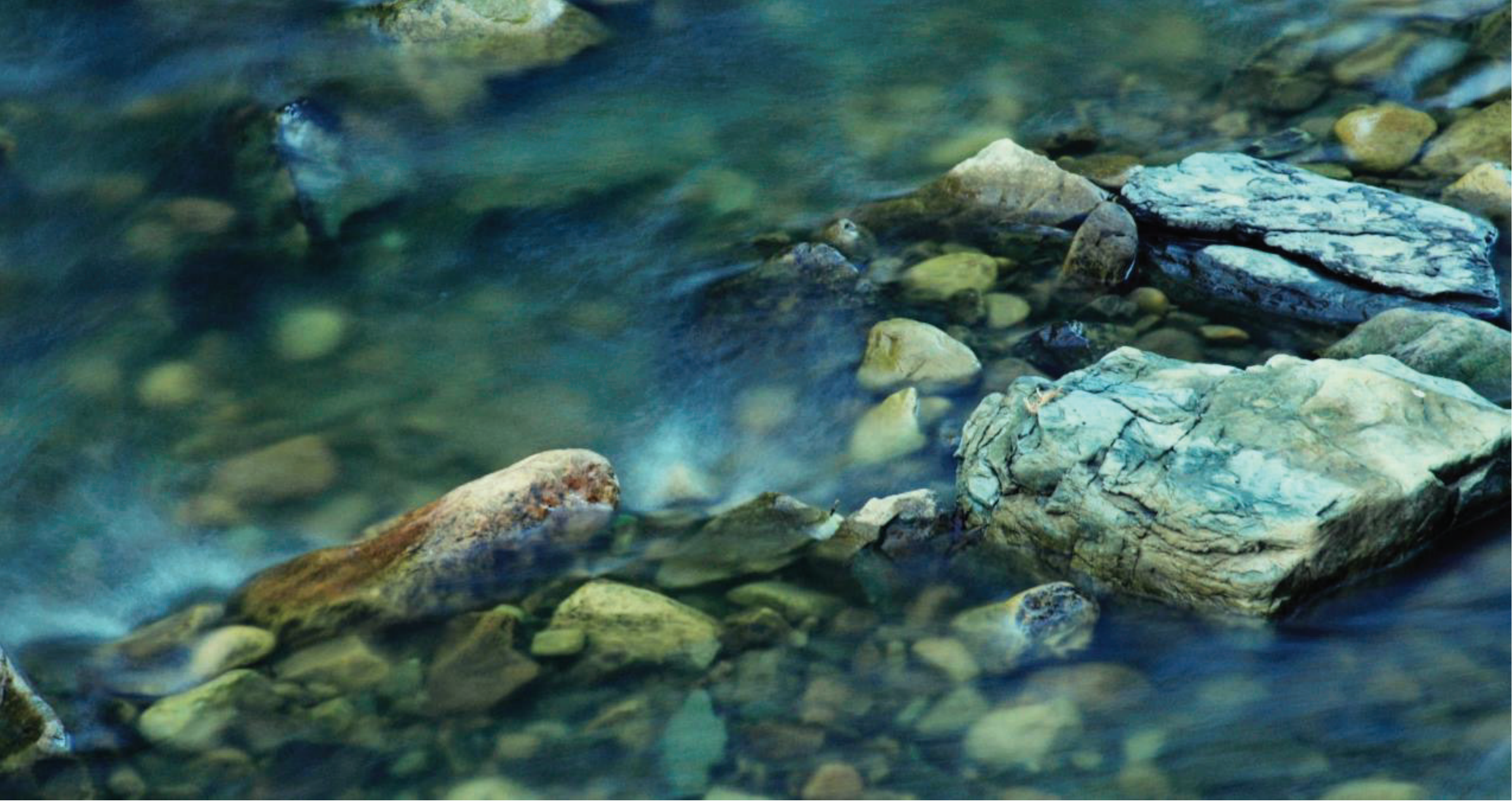
GTX's liability will be limited to correcting or repeating a test which fails our warranty. GTX's liability for damages to the Purchaser of testing services for any cause whatsoever shall be limited to the amount GTX received for the testing services. GTX will not be liable for any damages, or for any lost benefits or other consequential damages resulting from the use of these test results, even if GTX has been advised of the possibility of such damages. GTX will not be responsible for any liability of the Purchaser to any third party.

Commonly Used Symbols

A	pore pressure parameter for $\Delta\sigma_1 - \Delta\sigma_3$
B	pore pressure parameter for $\Delta\sigma_3$
CAI	CERCHAR Abrasiveness Index
CIU	isotropically consolidated undrained triaxial shear test
CR	compression ratio for one dimensional consolidation
CSR	cyclic stress ratio
C_c	coefficient of curvature, $(D_{30})^2 / (D_{10} \times D_{60})$
C_u	coefficient of uniformity, D_{60}/D_{10}
C_c	compression index for one dimensional consolidation
C_α	coefficient of secondary compression
c_v	coefficient of consolidation
c	cohesion intercept for total stresses
c'	cohesion intercept for effective stresses
D	diameter of specimen
D	damping ratio
D_{10}	diameter at which 10% of soil is finer
D_{15}	diameter at which 15% of soil is finer
D_{30}	diameter at which 30% of soil is finer
D_{50}	diameter at which 50% of soil is finer
D_{60}	diameter at which 60% of soil is finer
D_{85}	diameter at which 85% of soil is finer
d_{50}	displacement for 50% consolidation
d_{90}	displacement for 90% consolidation
d_{100}	displacement for 100% consolidation
E	Young's modulus
e	void ratio
e_c	void ratio after consolidation
e_o	initial void ratio
G	shear modulus
G_s	specific gravity of soil particles
H	height of specimen
H_R	Rebound Hardness number
i	gradient
I_S	Uncorrected point load strength
$I_{S(50)}$	Size corrected point load strength index
H_A	Modified Taber Abrasion
H_T	Total hardness
K_o	lateral stress ratio for one dimensional strain
k	permeability
LI	Liquidity Index
m_v	coefficient of volume change
n	porosity
PI	plasticity index
P_c	preconsolidation pressure
p	$(\sigma_1 + \sigma_3) / 2$, $(\sigma_v + \sigma_h) / 2$
p'	$(\sigma'_1 + \sigma'_3) / 2$, $(\sigma'_v + \sigma'_h) / 2$
p'_c	p' at consolidation
Q	quantity of flow
q	$(\sigma_1 - \sigma_3) / 2$
q_f	q at failure
q_o, q_i	initial q
q_c	q at consolidation

S_r	Post cyclic undrained shear strength
T	temperature
t	time
U, UC	unconfined compression test
UU, Q	unconsolidated undrained triaxial test
u_a	pore gas pressure
u_e	excess pore water pressure
u, u_w	pore water pressure
V	total volume
V_g	volume of gas
V_s	volume of solids
V_s	shear wave velocity
V_v	volume of voids
V_w	volume of water
V_o	initial volume
v	velocity
W	total weight
W_s	weight of solids
W_w	weight of water
w	water content
w_c	water content at consolidation
w_f	final water content
w_l	liquid limit
w_n	natural water content
w_p	plastic limit
w_s	shrinkage limit
w_o, w_i	initial water content
α	slope of q_f versus p_f
α'	slope of q_f versus p_f'
γ_t	total unit weight
γ_d	dry unit weight
γ_s	unit weight of solids
γ_w	unit weight of water
ε	strain
ε_{vol}	volume strain
ε_h, ε_v	horizontal strain, vertical strain
μ	Poisson's ratio, also viscosity
σ	normal stress
σ'	effective normal stress
σ_c, σ'_c	consolidation stress in isotropic stress system
σ_h, σ'_h	horizontal normal stress
σ_v, σ'_v	vertical normal stress
σ'_{vc}	Effective vertical consolidation stress
σ_1	major principal stress
σ_2	intermediate principal stress
σ_3	minor principal stress
τ	shear stress
φ	friction angle based on total stresses
φ'	friction angle based on effective stresses
φ'_r	residual friction angle
φ_{ult}	φ for ultimate strength

Appendix C
Coastal Engineering and Propeller Wash Evaluation Summary



April 2024
Harris Avenue Shipyard Cleanup

Appendix C
Coastal Engineering and Propeller Wash Evaluation Summary

Prepared for Washington State Department of Ecology

April 2024
Harris Avenue Shipyard Cleanup

Appendix C
Coastal Engineering and Propeller Wash Evaluation Summary

Prepared for
Washington State Department of Ecology
Bellingham Field Office
913 Squalicum Way No. 101
Bellingham, Washington 98225

Prepared by
Anchor QEA
20 Bellwether Way, Suite 101
Bellingham, Washington 98225

Prepared on behalf of
Port of Bellingham
1801 Roeder Avenue
Bellingham, Washington 98227

Project Number: 210007-02.01
\\fuji\anchor\Projects\Port of Bellingham\Harris Avenue Shipyard Cleanup\8_Eng_Design_Rpt\In-Water EDR\Appendices\Appendix C - Coastal-Prop Wash\Appendix C - Coastal Engineering and Prop Wash_20240404.docx

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TABLES

FIGURES

ABBREVIATIONS

ACES	Automated Coastal Engineering System
EDR	Engineering Design Report
fps	foot per second
hp	horsepower
MLLW	mean lower low water
mph	miles per hour
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
RCP	Representative Concentration Pathway
Site	Harris Avenue Shipyard Site
SLR	sea level rise
SMU	sediment management unit
USACE	U.S. Army Corps of Engineers

1 Introduction

The Coastal Engineering and Propeller Wash Evaluation Summary presents the design and evaluations for the Harris Avenue Shipyard Cleanup project in Bellingham, Washington. This report is an appendix to the *Sediment Engineering Design Report* (EDR; Anchor QEA 2024).

1.1 Site Description

The Harris Avenue Shipyard Site (Site) is located at 201 Harris Avenue within the Fairhaven district of Bellingham, Washington (Figure C-1). The Site is in an area designated as multi-use and consists of a commercial core; mixed use residential development; nearby single-family residential; marine industrial waterfront; ferry, bus, and train terminals; and intact historical buildings with a tourist district (City of Bellingham 2012). Portions of the upland and in-water areas have been used historically and recently for industrial purposes.

The Site consists of approximately 5 acres of upland and 5 acres of in-water area, totaling 10 acres, and is zoned by the City of Bellingham for water-dependent industrial use. The in-water portion of the Site includes two piers, a former marine railway and two supporting adjacent overwater walkways, and various mobile cranes. Industrial properties owned by the Port of Bellingham are present to the east and southeast of the Site. Properties to the east of the Site and their current uses include the former Arrowac Fisheries, Inc. warehouse on the uplands, and a parking lot. Farther to the east is the Bellingham Cruise Terminal, operated by the Port as the southern terminus for the Alaska State Ferry.

The upland potions of the shipyard are bordered on the north and west by Bellingham Bay and on the south by Marine Park and the BNSF Railway rail lines. Shoreline erosion has been observed along the northern portion of the Site.

1.2 Purpose

This appendix summarizes the coastal analyses performed to determine the stable armor sizing that will be appropriate to develop cover materials designed to withstand propeller wash and wind waves. Areas of concern identified for cover material placement include along the former marine railway (sediment management unit [SMU] 4a and SMU 4b), beneath the West Dock (SMU 3b), in an isolated area beneath the Harris Avenue Pier approximately 450 feet from shore (SMU 3a), and along the intertidal zone of the shoreline (SMU 2). The former marine railway is to be demolished and replaced with a vessel berthing structure, here referred to as the travel lift, consisting of two finger piers and travel lift equipment to transfer boats to and from the water.

1.3 Report Organization

This appendix is organized as follows:

- Section 1: Introduction
- Section 2: Site Conditions
- Section 3: Coastal Design Evaluations
- Section 4: References

2 Site Conditions

2.1 Current Site Tidal Levels

Tidal heights in the adjacent Bellingham Bay were obtained from the closest National Oceanic and Atmospheric Administration (NOAA) tidal station No. 9449211 located in Bellingham, Washington, approximately 1.8 miles north of the Site on the east side of Bellingham Bay. Table C-1 summarizes tidal datums relative to mean lower low water (MLLW) and North American Vertical Datum of 1988 (NAVD88) based on NOAA tidal station No. 9449211.

Table C-1
Tidal Datums at Bellingham Bay, Washington (NOAA Tidal Station No. 9449211)

Tidal Datum	Elevation (feet relative to MLLW)	Elevation (feet relative to NAVD88)
Highest observed water level	+10.42	+9.92
Mean higher high water	+8.51	+8.01
Mean high water	+7.79	+7.29
Mean sea level	+4.95	+4.45
Mean low water	+2.35	+1.85
Mean lower low water	+0.00	-0.50

Source: NOAA 2021

Based on NOAA's online vertical datum transformation tool, Vdatum,[1] the conversion between MLLW and NAVD88 at the Site is -0.50 foot, as shown in Table C-1. The evaluations in this appendix were performed under MLLW level conditions.

2.2 Floodplain Setting

The Harris Avenue Shipyard is located outside of the Federal Emergency Management Agency regulatory floodway.

[1] "VDatum is a free software tool being developed jointly by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS). VDatum is designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums - allowing users to convert their data from different horizontal/vertical references into a common system and enabling the fusion of diverse geospatial data in desired reference levels" (NOAA 2021).

3 Coastal Design Evaluation

This section describes the wind-wave and vessel propeller wash analyses that were performed as part of the project. Erosive forces resulting from wind-generated waves and propeller wash were evaluated.

3.1 Wind-Generated Waves

Wind-generated wave effects were evaluated based on best practices from U.S. Army Corps of Engineers (USACE) and Palermo et al. (1998a, 1998b). A range of extreme wind speeds for various return intervals, including 1-, 2-, 10-, 20-, 50-, and 100-year return periods, were calculated based on the historical wind record dataset from the Bellingham International Airport meteorological station and provided by the National Climatic Data Center (NCEI 2021). The Bellingham International Airport station is located across Bellingham Bay, approximately 5 miles north-northwest of the Site. Data from 10 meters above the ground elevation were compiled into a single set for analysis using the methodology outlined in the USACE *Coastal Engineering Manual* (USACE 2006). Figure C-2 illustrates a wind rose of the combined dataset. The dominant wind direction at the airport is from the south.

The National Climatic Data Center historical wind gage data were compiled into eight directional bins based on the wind rose, each encompassing a 45° range starting from 22.5°N. For each directional bin, the annual maximum wind speed for each year from 1948 to 2021 (present) was identified. A statistical analysis of the maximum annual wind speed for each directional bin was performed by applying five candidate probability distribution functions (Fisher-Tippet Type I and Weibull distributions with exponent k varying from 0.75 to 2.0). These distributions were fitted to the maximum yearly wind speed in each directional bin, and the best fit distribution over the range of wind frequencies was identified. The best fit distribution was then used to estimate each return interval event wind speed in each directional bin. These design wind speeds were then used to predict the extreme wave heights and periods for those directional bins. Table C-2 summarizes the extreme wind speeds for each storm event.

Table C-2
Significant Wind Speeds for Various Wind Events, Bellingham International Airport

Direction	1-year (mph)	2-year (mph)	10-year (mph)	20-year (mph)	50-year (mph)	100-year (mph)
North	12.2	40.3	45.4	52.0	52.0	57.0
Northeast	20.7	33.0	49.7	55.6	63.0	68.2
East	12.8	17.6	36.6	46.6	61.1	72.8
Southeast	22.1	34.1	50.3	56.1	63.2	68.3
South	26.9	36.1	50.7	55.5	61.4	65.7
Southwest	9.5	24.2	44.2	51.4	60.2	66.5
West	14.4	18.3	33.8	41.9	53.7	63.2
Northwest	13.7	16.1	25.3	30.2	37.3	43.0

Three directional bins were identified along fetches that could produce wind-generated waves that would impact the Site: North (337.5 to 22.5°N), Northwest (292.5 to 315°N), and West (247.5 to 292.5°N). The estimated 100-year return interval wind speeds are 57.0 miles per hour (mph), 43.0 mph, and 63.2 mph for each directional bin, respectively. Fetch lengths were measured for each bin, as shown in Figure C-3.

The Automated Coastal Engineering System (ACES) developed by USACE (1992) was used to predict the return period wave height associated with each significant wind speed. The 100-year significant wind speed was selected as the appropriate wind speed used in design. Wave heights calculated by ACES ranged from 3.3 to 4.8 feet. Corresponding 100-year significant wave periods ranged from 3.4 to 4.1 seconds. Table C-3 summarizes the predicted 100-year wave heights affecting the Site for each of the evaluated wave bins.

Table C-3
100-Year Significant Wind-Generated Wave Heights for the Harris Avenue Shipyard

Wave Bin	Wind Speed (mph)	Wind-Generated Wave Height (feet)	Wave Period (seconds)
North	57.0	3.49	3.44
Northwest	43.0	3.24	3.37
West	63.2	4.83	4.09

3.2 Propeller Wash

The Site is understood to experience frequent nearshore vessel operations. As a vessel or boat operates, the propeller produces an underwater jet; this turbulent jet is known as propeller wash, or propwash. If this jet reaches the sediment mudline, it can contribute to erosion or resuspension of surficial sediment. Potential propeller wash effects of representative vessels that operate at the Site were evaluated in accordance with Appendix A of Palermo et al. (1998b) cap armor layer design guidance. A site-specific analysis of propeller wash was conducted for the proposed cover areas.

The propeller wash analysis consisted of the following components:

- Representative vessel type information was obtained from the site tenant.
- Representative vessel characteristics (e.g., draft, propeller type, dimensions) were obtained.
- Vessel operating information and assumptions (e.g., operating horsepower and vessel location and orientation) were defined based on initial discussions with the tenant to represent all known or expected vessel operations at the Site. A total of twelve propeller wash scenarios were defined.
- Site-specific conditions (e.g., bathymetry) were obtained.

- Based on the understood range of operational and site-specific conditions, the stable armor stone size necessary to withstand the erosive forces associated with propeller wash was computed for each scenario.

Propeller wash velocities from vessels are assumed to be localized and of short duration. The propeller wash from passing tugs and commercial vessels within Bellingham Bay will not likely affect the cover surfaces; however, the propeller from these vessels during a maneuvering operation (e.g., berthing with propellers, or tug assist) can cause significant erosion of bottom sediments if an appropriate armor stone is not in place to resist the propeller-induced bottom velocities. Anchor QEA consulted the Site tenant to determine representative vessels and vessel operations that frequently occur on site.

Two representative vessels were used in this analysis: the Ann Marie tugboat equipped with two engines totaling 4,100 horsepower (hp), and the Evergreen State, a large 310-foot-long commercial vessel with two engines totaling 2,500 hp. The design specifications for each vessel (including propeller type, horsepower, and propeller depth) were obtained through publicly available information and confirmed by the Site tenant. All vessels were understood to operate under a maximum of 50% of their total engines' hp at no closer than 200 feet from shore. To capture more frequent vessel operations, each vessel was also evaluated for 25% of their total engine hp.

Figure C-4 shows the orientations and operations along transects developed for the propeller wash analysis. The vessel operations that were evaluated include berthing and embarking maneuvers along three pier/dock locations, including a future use travel lift abutting the shoreline that will be dredged to an elevation of -5 feet MLLW. These orientations and operations were confirmed with the Site tenant during preliminary analysis. Four transects were identified based on the current proposed cleanup remedy and known vessel operations at the Site. Transect A-A′ is located along the West Dock, Transect B-B′ is located along the former marine railway and intersects the travel lift, Transect C-C′ is located along the Harris Avenue Pier, and Transect D-D′ is located parallel to shore, intersecting the pier where vessels typically dock. At Transects A, B, and C, vessel operations were simulated to be directing their propellers towards shore; at Transect D, vessel operations were simulated to represent likely tug propeller wash during tug-assisted docking procedures. At each transect, the appropriate vessel was analyzed based on understood vessel operations; both design vessels were evaluated at Transects A and C, while only the Ann Marie tugboat was evaluated at Transects B and D. For each scenario, vessels were evaluated at 25% and 50% of their total engine hp. It was assumed that vessels operating under 50% hp were done so in infrequent or emergency situations of short duration, while 25% hp was representative of more frequent daily operations.

Equation 6 from Appendix A of Palermo et al. (1998a) predicts the propeller velocity at any location below (z distance) and aft of (x distance) the vessel propeller (Equation C-1):

Equation C-1

$$V_x = 2.78 \times U_0 \times \frac{D_0}{x} \exp\left(-15.43 \left(\frac{z}{x}\right)^2\right)$$

where:

V_x	=	propeller wash velocity at location x and z (feet per second)
D_o	=	adjusted propeller diameter (function of propeller type and diameter)
x	=	horizontal distance aft of propeller (feet)
z	=	distance from axis of propeller (feet)
U_0	=	propeller wash jet velocity (fps) at the propeller (Equation 4 from Appendix A of Palermo et al. [1998b])

Bathymetric data for each vessel were compiled to apply water depths and shoreline orientations (distances and slopes) such that realistic scenarios were analyzed. Bed velocities were calculated by applying jet velocities to the water depths and local bathymetry data and determining the velocity of the jet where it met the mudline. Based on the bed velocities, required stone sizing could be determined using Palermo et al. (1998b) guidance Equation 5 (Equation C-2). It is important to note that, although vessels typically operate at some sailing speed, which acts to significantly reduce the duration and magnitude of the propeller wash acting on the river bottom, for purposes of this analysis, static vessels conditions were evaluated to provide a conservative assessment assuming vessels are performing slowly moving docking operations.

The velocities of the propeller jet dissipate with depth and distance; however, higher velocities can reach the bay floor. Vessel-generated propeller velocities at the seabed ranged from 1.6 to 9.8 feet per second (fps). The largest bed velocities calculated occurred at Transect B-B’ (9.8 fps) caused by the Ann Marie tug pointed directly toward shore.

3.3 Stable Armor Sizing

3.3.1 Propeller Wash

For propeller wash forces, based on the calculated bed velocities, required stone sizing was determined using Equation 5 from Palermo et al. (1998b) guidance (Equation C-2):

Equation C-2

$$D_{50} = \frac{{V_b}^2}{{C_3}^2 * g * A}$$

where:

D_{50}	=	median stone size (feet)
V_b	=	bed velocity (feet/second)
C_3	=	coefficient (0.55 for frequent, nonmoving vessels; 0.7 for infrequent attack)
g	=	gravitational constant (32.3 feet/square second)
A	=	ratio of unit weight of water to stone difference unit weight

For scenarios where vessels operated under 50% hp, a coefficient of 0.7 was used to calculate the stable D_{50} size, and a coefficient of 0.55 was used for vessels operating under 25% hp, based on the guidance of Maynord (2000):

> Blaauw et al. (1984) found C3 = 0.55 for no movement and C3 = 0.70 for small transport. Data from Maynord (1984) using equations 3-5 show that C3 = 0.55 provides good agreement with experimental results for no transport and should be used in harbor areas where repeated attack can be expected, and no movement can be allowed. For channel protection where infrequent attack can be expected, C3 = 0.6-0.7 should be used in design.

Model results of the propeller wash evaluation that carried out these equations can be found in Figures C-5a through C-5l. Table C-4 presents a summary of all erosion analyses performed and computed stable particle size for each type of erosive force.

Table C-4
Propeller Wash Analysis Stable Armor Stone Sizing

Transect	Vessel	Engine Horsepower (%)	Maximum Stable Stone Size (D_{50}; inches)
A-A’	Ann Marie Tugboat	50	6.3
A-A’	Ann Marie Tugboat	25	4
A-A’	Evergreen State	50	6
A-A’	Evergreen State	25	4
B-B’ (Travel Lift)	Ann Marie Tugboat	50	26
B-B’ (Travel Lift)	Ann Marie Tugboat	25	16

Transect	Vessel	Engine Horsepower (%)	Maximum Stable Stone Size (D_{50}; inches)
C-C′	Ann Marie Tugboat	50	29
C-C′	Ann Marie Tugboat	25	18
C-C′	Evergreen State	50	25
C-C′	Evergreen State	25	16
D-D′	Ann Marie Tugboat	50	3
D-D′	Ann Marie Tugboat	25	2

Note:
D_{50}: nominal rock size (diameter) of which 50% of the rocks are smaller

3.3.2 Wind Waves

For designed protection against wind-wave erosion, the rubble-mound revetment module with ACES (USACE 2004) was used to compute the median armor stone size (D_{50}) resistant to the predicted wind-generated wave heights based for cover material. The wind direction bin that produced the largest 100-year wave height and wave period was selected for use in the revetment module. Because the cover material is design to be placed at existing grades, a slope of 8H:1V was used in the computation. Table C-5 summarizes the minimum D_{50} stone sizes to resist motion caused by wind-generated wave erosive forces for each wind direction. The minimum D_{50} armor size should be 7 inches to provide erosion protection caused by wind waves.

Table C-5
100-year Significant Wave Height Stable Armor Sizing Summary

Wind Direction	100-year Wave Height (feet)	100-year Wave Period (seconds)	Stable Armor Stone Size (D_{50}; inches)	Stable Armor Thickness (inches)
North (337.5 to 22.5°N)	3.49	3.44	5	10
Northwest (292.5 to 337.5°N)	3.24	3.37	5	10
West (247.5 to 292.5°N)	4.83	4.09	7	14

Note:
D_{50}: nominal rock size (diameter) of which 50% of the rocks are smaller

3.3.3 Summary

Based on the results of the wind-wave and propeller wash stone sizing calculation, it was determined that vessel-generated propeller wash was the controlling erosive force in areas where vessels operate in the nearshore. To resist propeller wash forces, cover material placed within the footprint of the travel lift along the former marine railway should be robust enough to withstand erosive forces generated by the departing maneuvers of vessels being launched from the travel lift. Here, armor stone with a D_{50} of 18 inches is required to protect against propeller jet velocities. Within other underpier areas, including the West Dock area and beneath the Harris Avenue Pier where bathymetry is deeper, cobble-sized material with a D_{50} of 6 inches is suitable to protect against propeller wash forces. While undersized material may be considered adequate for protection of the isolation layer, instantaneous propeller jets and emergency maneuvers may mobilize material and require maintenance over time. Near the West Dock area, a cobble-sized material would be considered adequate for protection because water depths are great enough beneath the Harris Avenue Pier to allow significant dissipation of propeller jet velocities at the mudline.

Within the intertidal zone, propeller jet velocities dissipate significantly, resulting in wind-generated waves controlling erosion. Cover material placed in the shoreline should be sized with a D_{50} of 7 inches to appropriately withstand wind-generated waves for the 100-year storm.

3.4 Filter Design

The required filter layer was be computed based on the largest predicted median particle size (D_{50}) required for the armor layer in each area of the cap. This filter layer will be designed to prevent the loss of the finer grained material in the underlying chemical isolation layer. The design filter layer material gradation was be computed based on the Engineering Manual 1110 2 2300 equations, summarized in the ACES technical manual (USACE 2004). The standard geotechnical filter criteria presented by Palermo et al. (1998b) is be used to determine whether fine-grained underlying sediments or underlying cap material is susceptible to piping between void spaces of the overlying erosion protection armor layer. The minimum filter criteria suggest that five times the D_{85} (85% passing by weight sieve size) of the underlying material should be greater than the D_{15} (15% passing by weight sieve size) of the overlying material, as shown below:

Equation C-5

$$d_{15(Armor)} < 5d_{85(Base)}$$

where:

$d_{15(armor)}$ = The 15% passing sieve size of the overlying armor material by weight

$d_{85(\mathrm{filter})}$ = The 85% passing sieve size of the underlying material by weight

The filter material for each capping area must meet this criterion. If the filter criterion (above) is not met, an additional filter layer between the armor stone and the physical and/or chemical isolation layer of the cap will be required to prevent piping.

3.5 Sea Level Rise

To evaluating future environmental conditions, this section provides general guidance on the application of climate change, specifically sea level rise (SLR) to potential shoreline enhancements. The SLR guidance applies to changes in sea level relative to the Site but does not address changes in storm or precipitation frequency or intensity. Currently, the City of Bellingham is planning for more than 4 feet of SLR by 2100 (Owens 2020). This projection is in line with the most recent assessment for SLR detailed in a report prepared for the Washington Coastal Resiliency Project in 2018 providing an assessment of projected SLR for Washington State (Miller et al. 2018). The Washington Coastal Resiliency Project report provides updated projections for SLR under two pathways, similarly described in Owens 2020: Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. RCP 4.5 is a low estimate in which greenhouse gas estimates stabilize by mid-century and decrease thereafter. RCP 8.5 is a high scenario in which there is a continued increase in greenhouse gasses until the end of the twenty-first century (Mauger 2015). Based on the pathways, the highest range of SLR projections in Bellingham Bay range from 3 to 8 feet by 2100, consistent with the City of Bellingham’s current planning.

Implications of SLR are two-fold for the analysis presented in this appendix. First, propeller wash scenarios were evaluated under existing water levels with no project rise. Increasing sea levels may reduce propeller wash effects because deeper water depth would reduce the magnitude of jet velocities reaching the mudline; however, additional considerations should be made, and propeller wash may be re-evaluated to accommodate future SLR observations. Second, the wind-generated wave analysis was performed for current estimates for significant storm events and does not consider the impact that SLR and climate change may have on the frequency, intensity, or duration of similar storm events. The results of the armoring evaluations presented in this report should be applied to the top of the bank of the shoreline and include an appropriate allowance for SLR.

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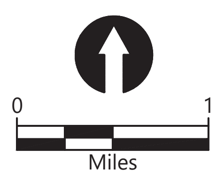
Figures

SOURCE: Aerial provided by Bing maps.
HORIZONTAL DATUM: (HARN) Washington State Plane North Zone, NAD83, U.S. Survey Feet



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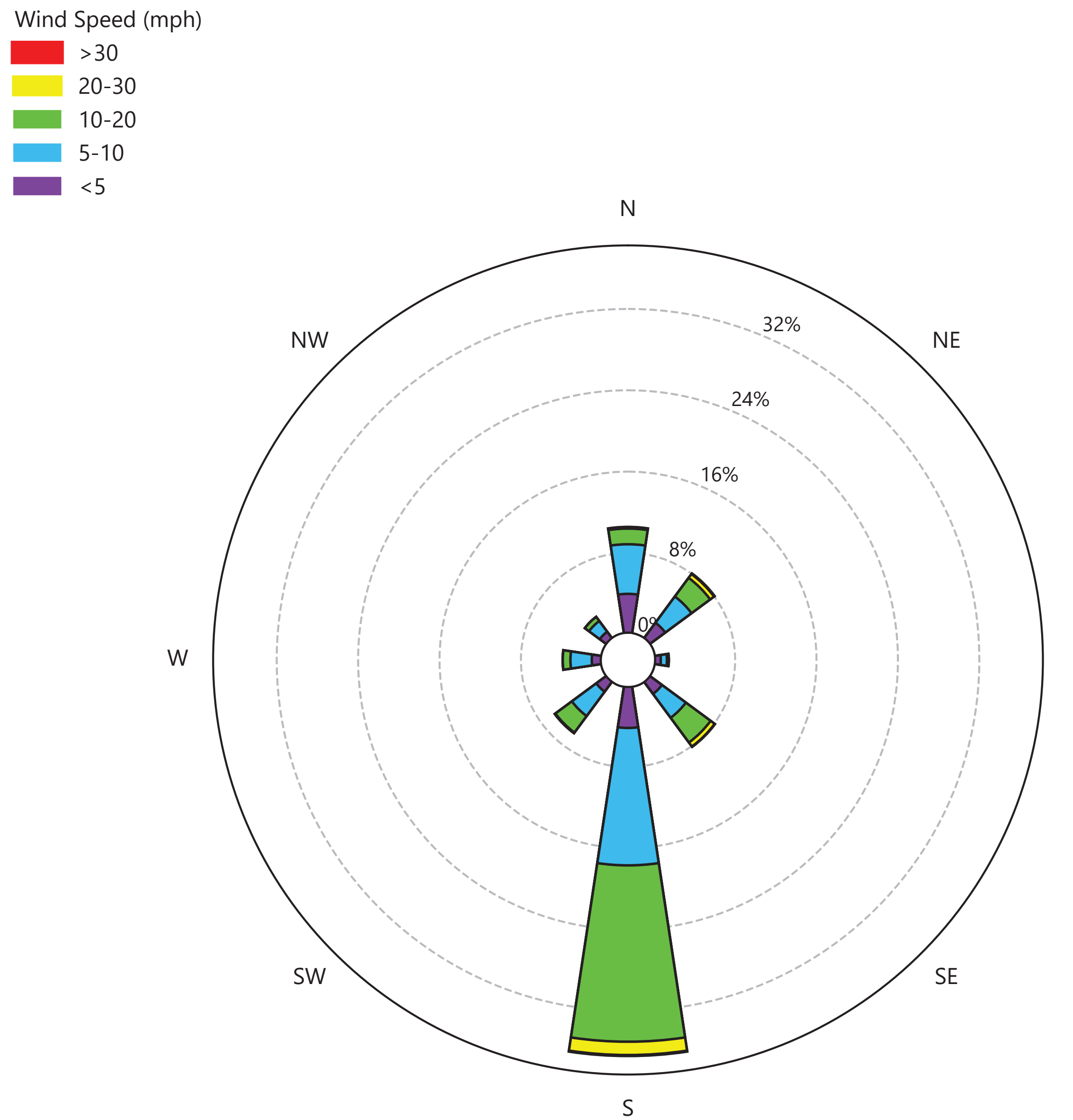
Filepath: K:\Projects\0007-Port of Bellingham\Harris Avenue Shipyard Cleanup\0007-RP-001 VICINITY MAP.dwg Figure 1

ANCHOR QEA

Figure C-1
Vicinity Map

Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes:
1. Hourly Wind Data Obtained from Bellingham, WA for Years 1948 through 2021
2. Calm and Variable Winds: 20.3%
3. Maximum Recorded Wind Speed: 67.8 mph
4. Wind data are presented as the "blowing from" direction.

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Figure C-2
Wind Rose for Bellingham, WA
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup

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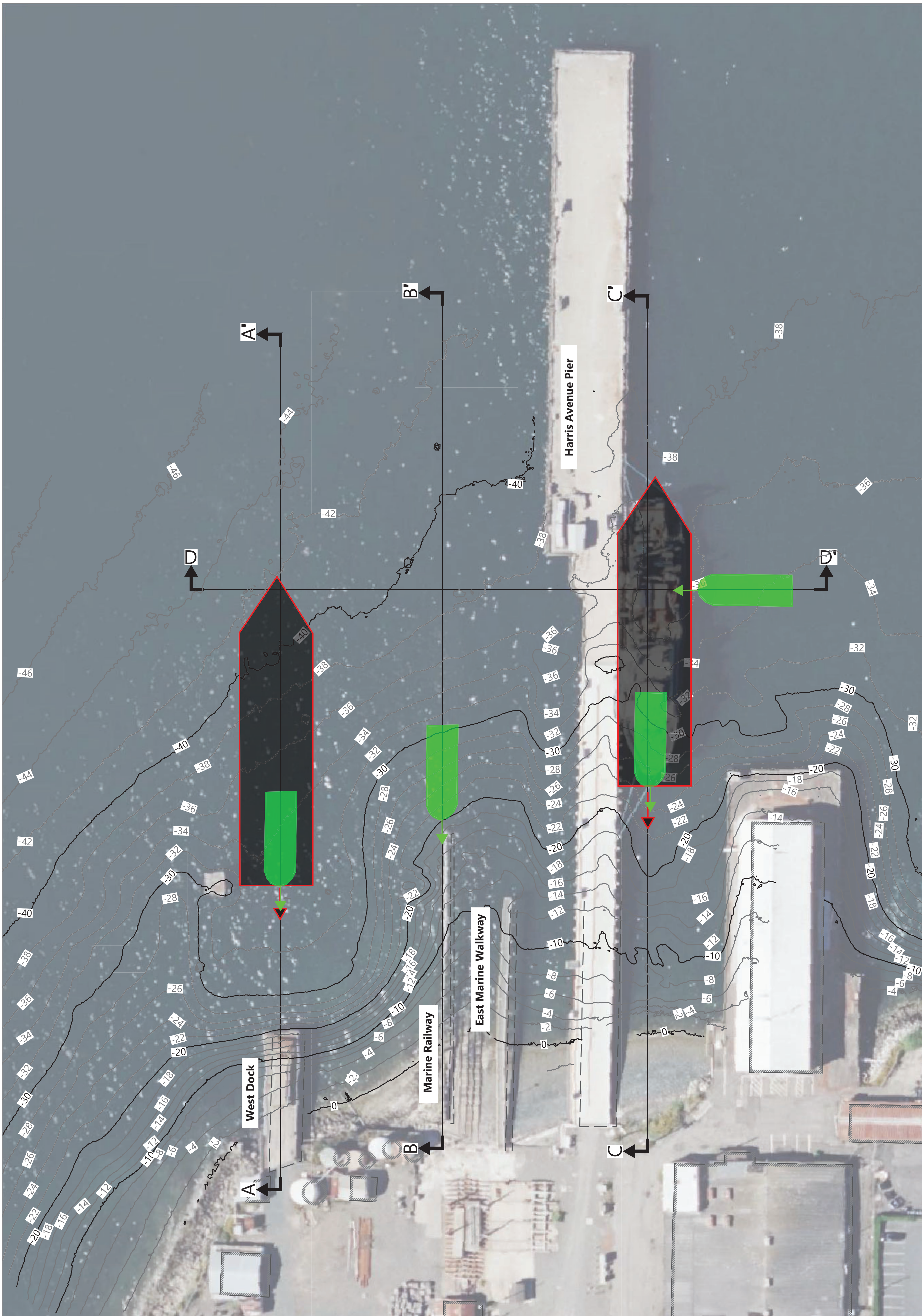
ANCHOR QEA

Figure C-3
Wind-Wave Fetch Distances
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



SOURCE: Aerial from Bing maps.
Bathymetric survey provided by Northwest Hydro Inc., dated August 29, 2022.
HORIZONTAL DATUM: (HARN) Washington State Plane North Zone, NAD83, U.S. Survey Feet
VERTICAL DATUM: MLLW

LEGEND:

-20 Existing Contours (2' & 10' Intervals)

A Cross Section Location and Designation

0 80
Feet

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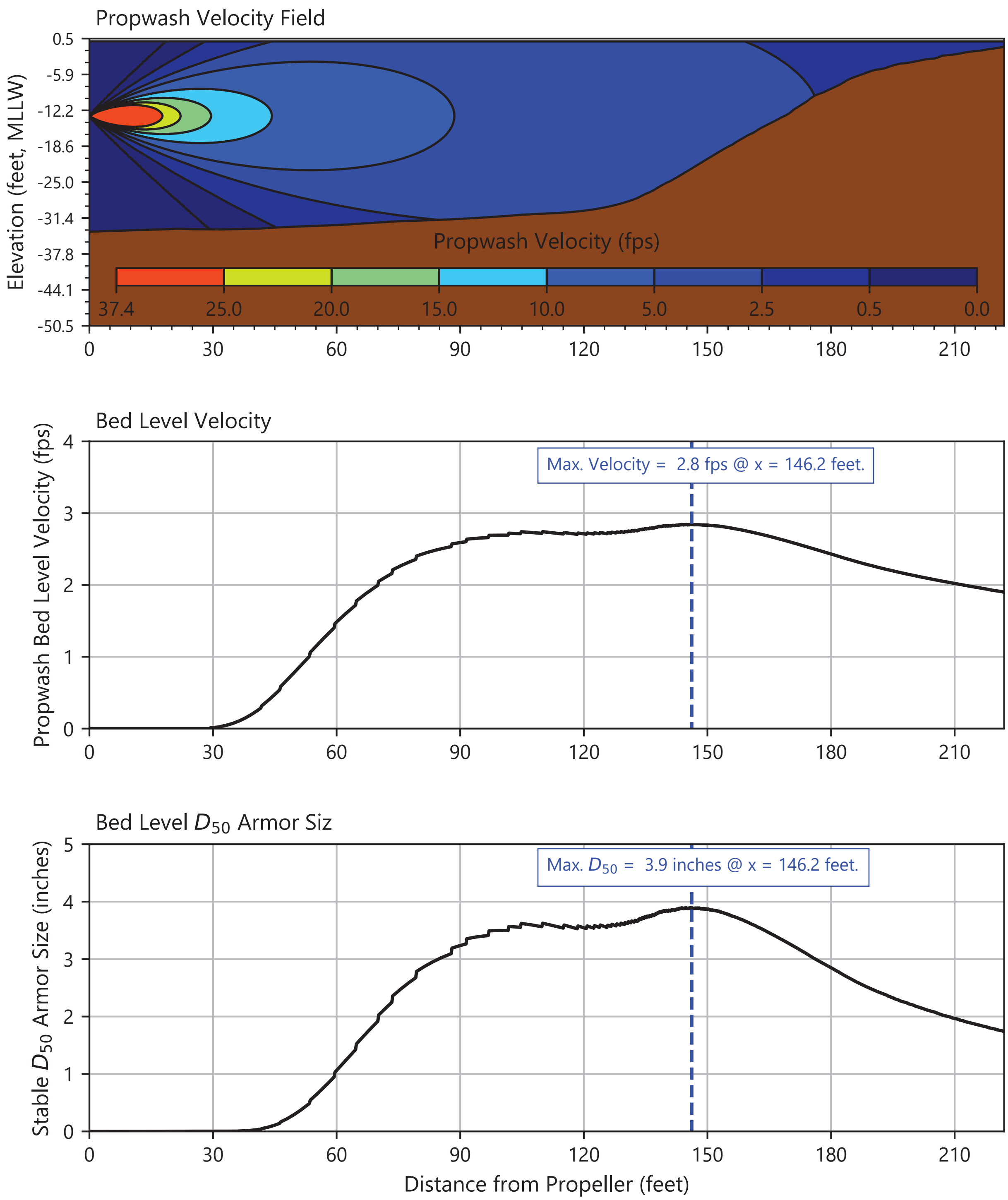
Filepath: K:\Projects\0007-Port of Bellingham\Harris Avenue Shipyard Cleanup\0007-RP-002 SITE BATHY FIGURE 4.dwg Figure 4

ANCHOR QEA

Figure C-4
Site Vessel Operations

Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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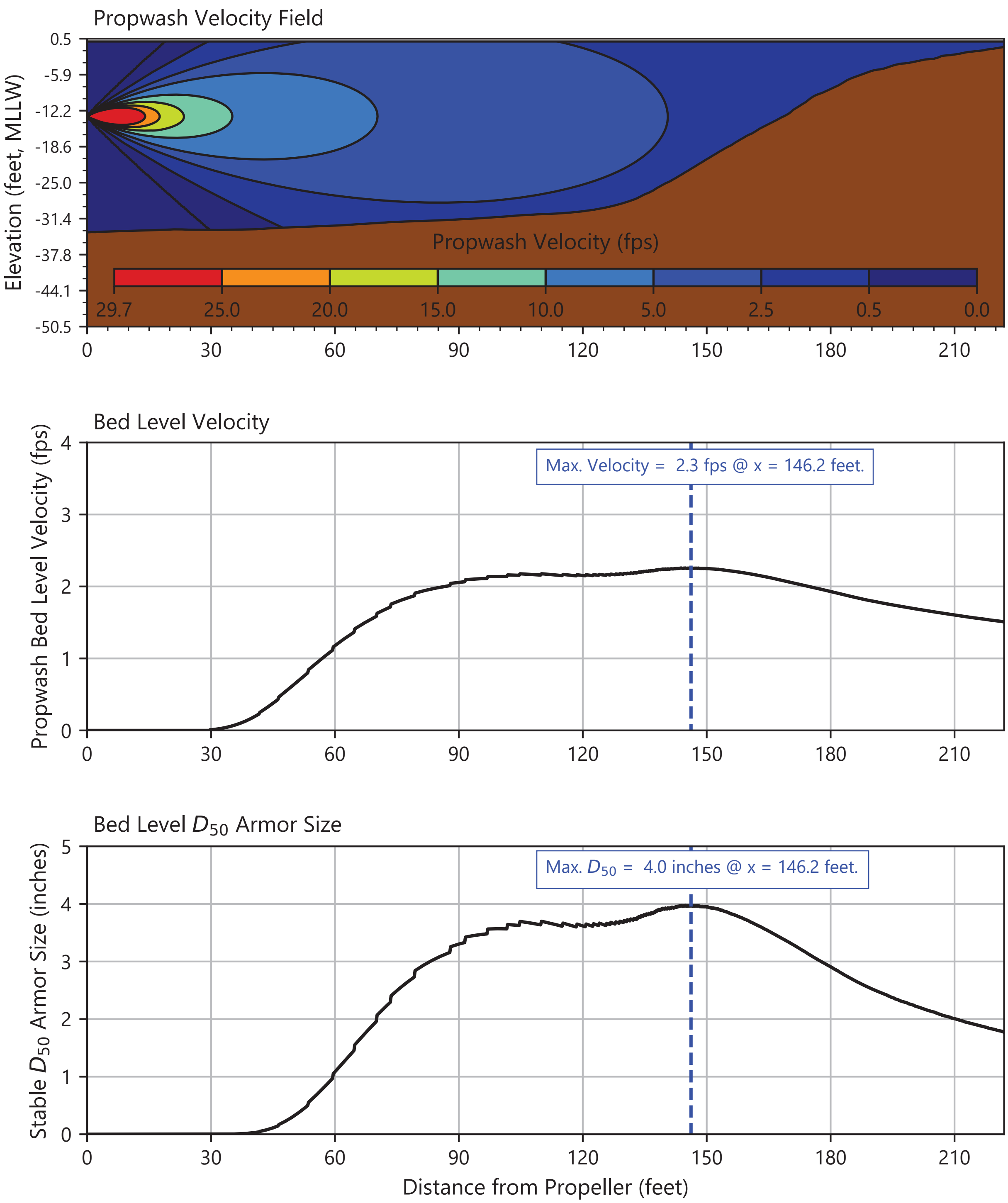
ANCHOR QEA

Figure C-5a
Ann Marie at 50% Applied Power at Transect: A-A' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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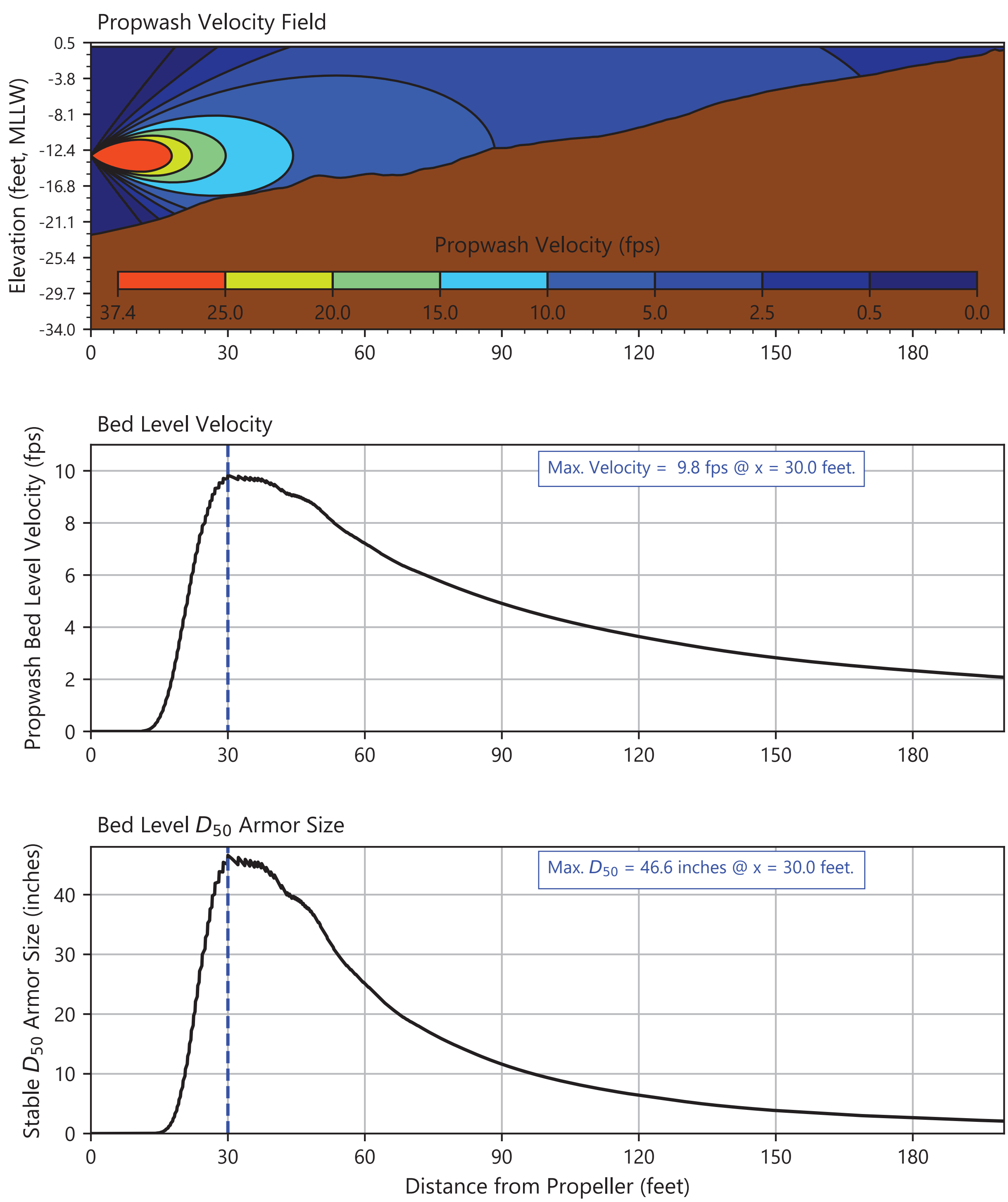
Figure C-5b
Ann Marie at 25% Applied Power at Transect: A-A' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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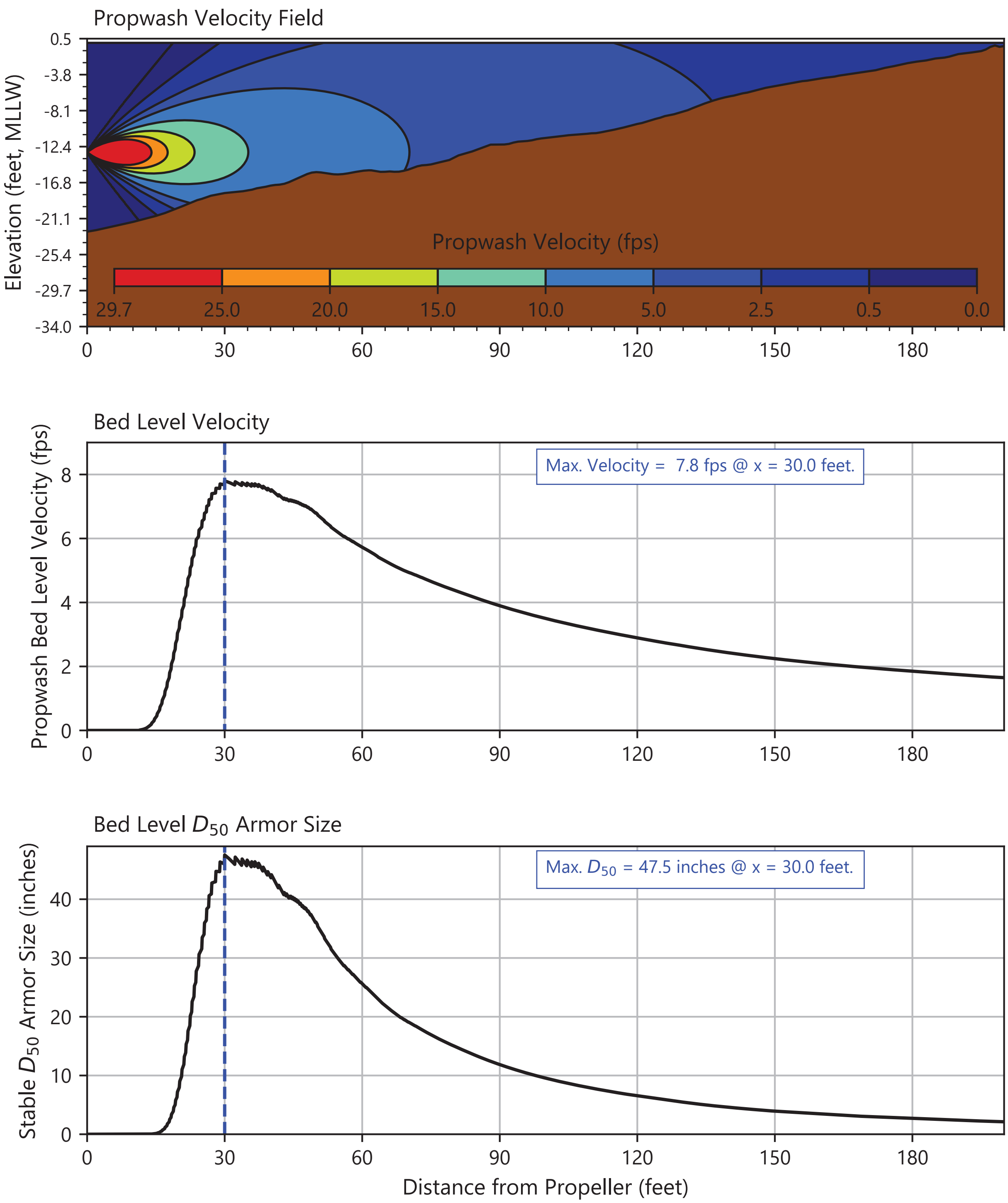
ANCHOR QEA

Figure C-5c
Ann Marie at 50% Applied Power at Transect: B-B' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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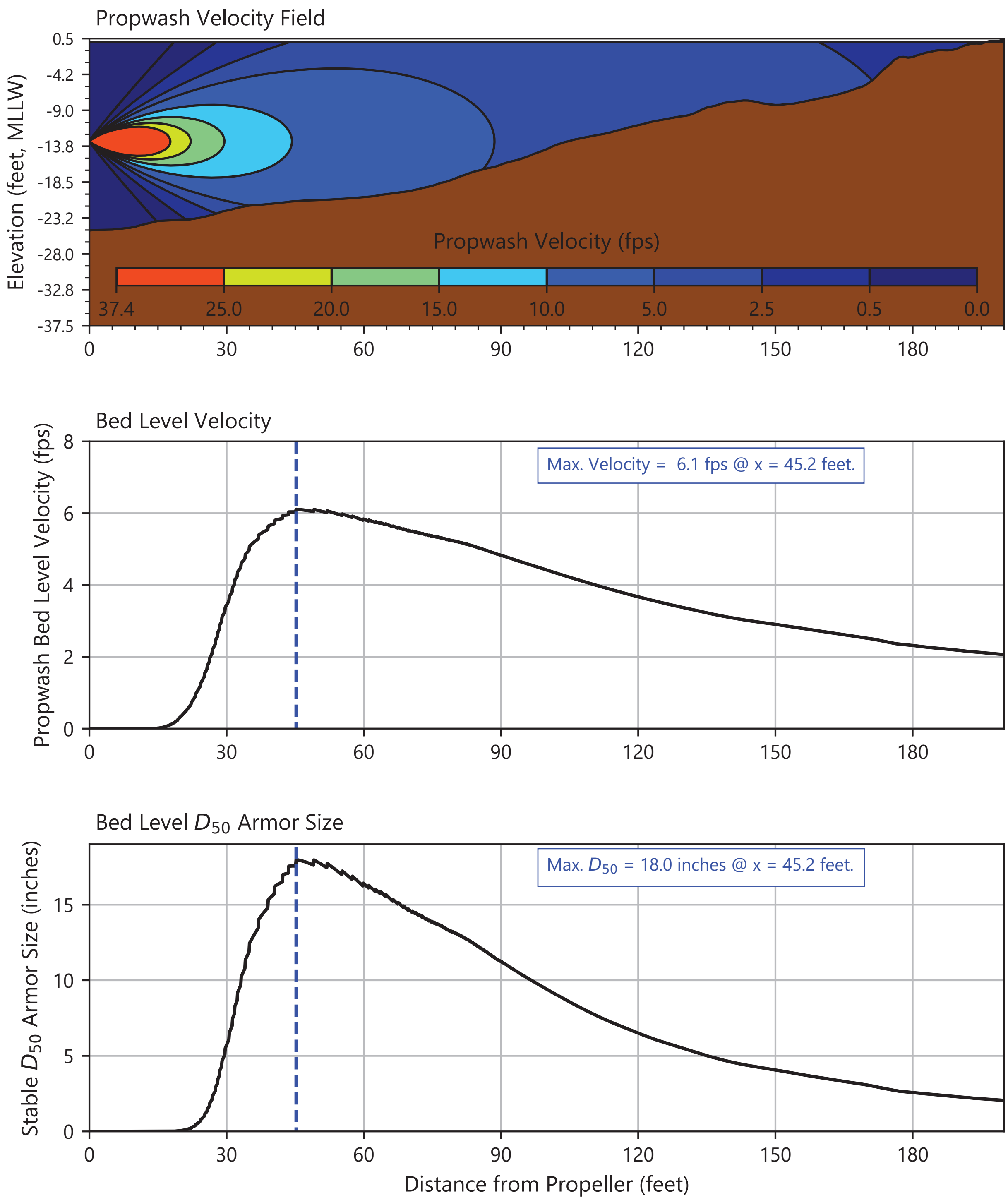
Figure C-5d
Ann Marie at 25% Applied Power at Transect: B-B' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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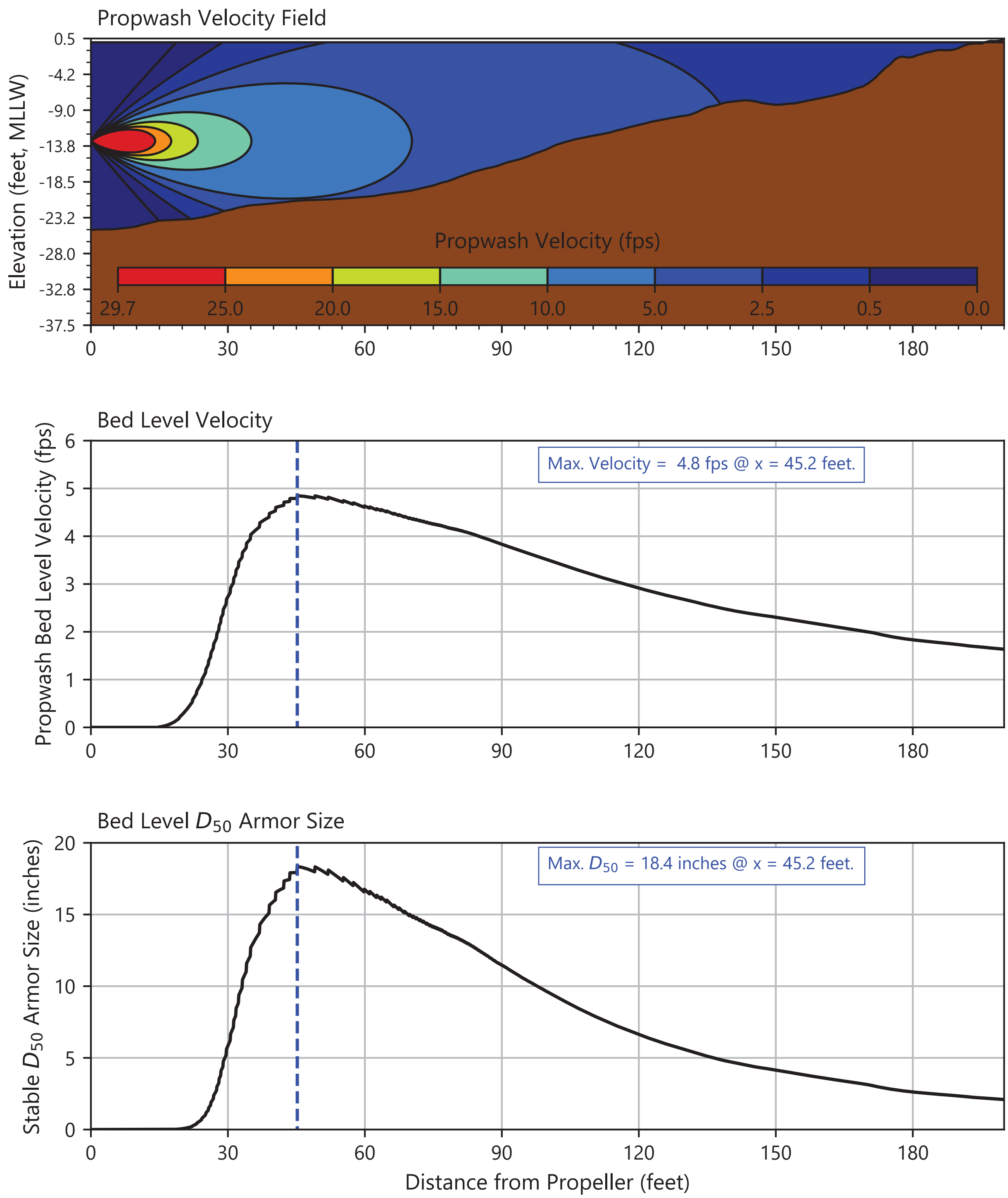
ANCHOR QEA

Figure C-5e
Ann Marie at 50% Applied Power at Transect: C-C' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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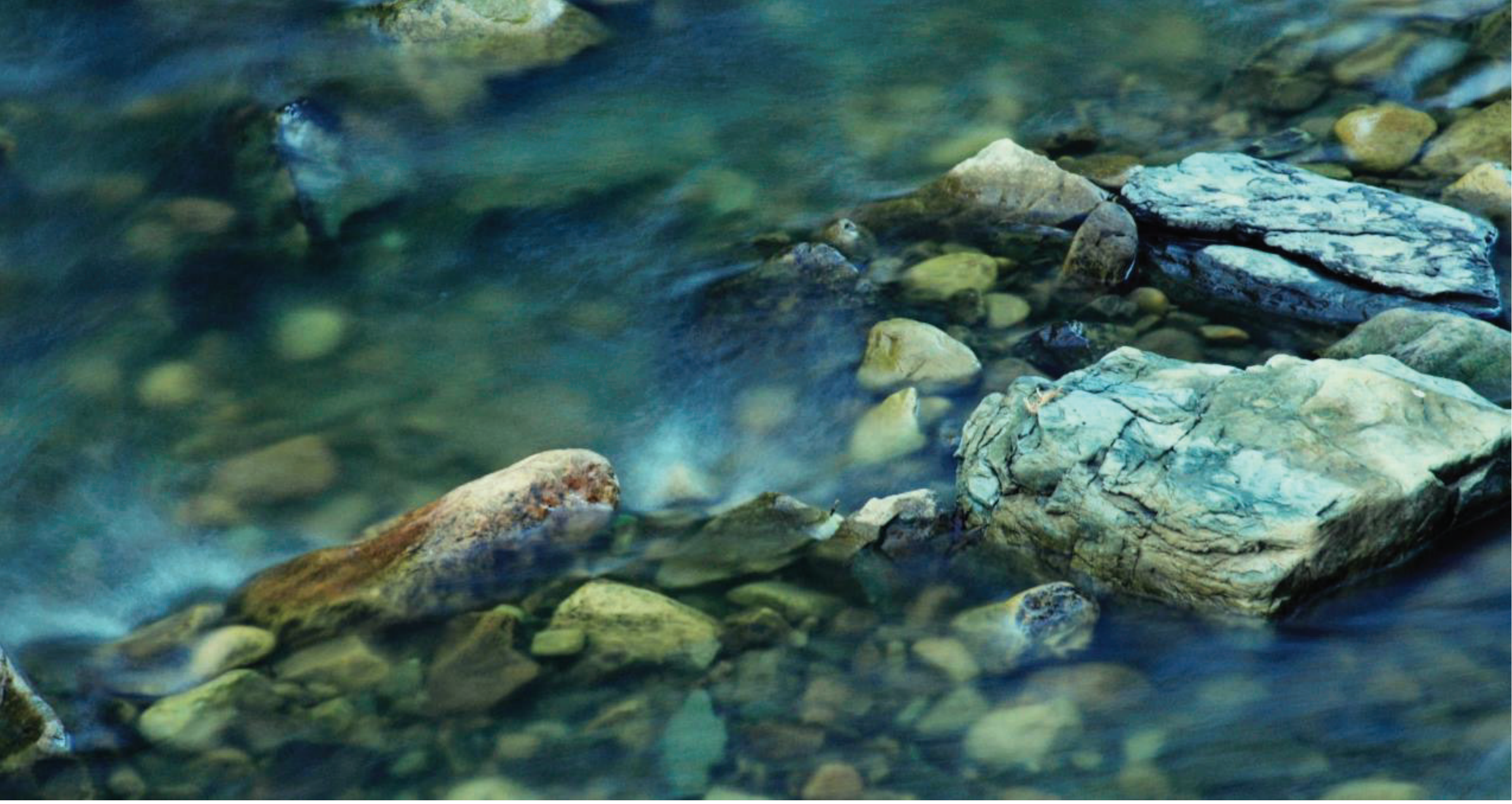
ANCHOR QEA

Figure C-5f
Ann Marie at 25% Applied Power at Transect: C-C' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



April 2024
Harris Avenue Shipyard Cleanup

Appendix C
Coastal Engineering and Propeller Wash Evaluation Summary

Prepared for Washington State Department of Ecology

April 2024
Harris Avenue Shipyard Cleanup

Appendix C
Coastal Engineering and Propeller Wash Evaluation Summary

Prepared for
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Project Number: 210007-02.01
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ABBREVIATIONS

ACES	Automated Coastal Engineering System
EDR	Engineering Design Report
fps	foot per second
hp	horsepower
MLLW	mean lower low water
mph	miles per hour
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
RCP	Representative Concentration Pathway
Site	Harris Avenue Shipyard Site
SLR	sea level rise
SMU	sediment management unit
USACE	U.S. Army Corps of Engineers

1 Introduction

The Coastal Engineering and Propeller Wash Evaluation Summary presents the design and evaluations for the Harris Avenue Shipyard Cleanup project in Bellingham, Washington. This report is an appendix to the *Sediment Engineering Design Report* (EDR; Anchor QEA 2024).

1.1 Site Description

The Harris Avenue Shipyard Site (Site) is located at 201 Harris Avenue within the Fairhaven district of Bellingham, Washington (Figure C-1). The Site is in an area designated as multi-use and consists of a commercial core; mixed use residential development; nearby single-family residential; marine industrial waterfront; ferry, bus, and train terminals; and intact historical buildings with a tourist district (City of Bellingham 2012). Portions of the upland and in-water areas have been used historically and recently for industrial purposes.

The Site consists of approximately 5 acres of upland and 5 acres of in-water area, totaling 10 acres, and is zoned by the City of Bellingham for water-dependent industrial use. The in-water portion of the Site includes two piers, a former marine railway and two supporting adjacent overwater walkways, and various mobile cranes. Industrial properties owned by the Port of Bellingham are present to the east and southeast of the Site. Properties to the east of the Site and their current uses include the former Arrowac Fisheries, Inc. warehouse on the uplands, and a parking lot. Farther to the east is the Bellingham Cruise Terminal, operated by the Port as the southern terminus for the Alaska State Ferry.

The upland potions of the shipyard are bordered on the north and west by Bellingham Bay and on the south by Marine Park and the BNSF Railway rail lines. Shoreline erosion has been observed along the northern portion of the Site.

1.2 Purpose

This appendix summarizes the coastal analyses performed to determine the stable armor sizing that will be appropriate to develop cover materials designed to withstand propeller wash and wind waves. Areas of concern identified for cover material placement include along the former marine railway (sediment management unit [SMU] 4a and SMU 4b), beneath the West Dock (SMU 3b), in an isolated area beneath the Harris Avenue Pier approximately 450 feet from shore (SMU 3a), and along the intertidal zone of the shoreline (SMU 2). The former marine railway is to be demolished and replaced with a vessel berthing structure, here referred to as the travel lift, consisting of two finger piers and travel lift equipment to transfer boats to and from the water.

1.3 Report Organization

This appendix is organized as follows:

- Section 1: Introduction
- Section 2: Site Conditions
- Section 3: Coastal Design Evaluations
- Section 4: References

2 Site Conditions

2.1 Current Site Tidal Levels

Tidal heights in the adjacent Bellingham Bay were obtained from the closest National Oceanic and Atmospheric Administration (NOAA) tidal station No. 9449211 located in Bellingham, Washington, approximately 1.8 miles north of the Site on the east side of Bellingham Bay. Table C-1 summarizes tidal datums relative to mean lower low water (MLLW) and North American Vertical Datum of 1988 (NAVD88) based on NOAA tidal station No. 9449211.

Table C-1
Tidal Datums at Bellingham Bay, Washington (NOAA Tidal Station No. 9449211)

Tidal Datum	Elevation (feet relative to MLLW)	Elevation (feet relative to NAVD88)
Highest observed water level	+10.42	+9.92
Mean higher high water	+8.51	+8.01
Mean high water	+7.79	+7.29
Mean sea level	+4.95	+4.45
Mean low water	+2.35	+1.85
Mean lower low water	+0.00	-0.50

Source: NOAA 2021

Based on NOAA's online vertical datum transformation tool, Vdatum,[1] the conversion between MLLW and NAVD88 at the Site is -0.50 foot, as shown in Table C-1. The evaluations in this appendix were performed under MLLW level conditions.

2.2 Floodplain Setting

The Harris Avenue Shipyard is located outside of the Federal Emergency Management Agency regulatory floodway.

[1] "VDatum is a free software tool being developed jointly by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS). VDatum is designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums - allowing users to convert their data from different horizontal/vertical references into a common system and enabling the fusion of diverse geospatial data in desired reference levels" (NOAA 2021).

3 Coastal Design Evaluation

This section describes the wind-wave and vessel propeller wash analyses that were performed as part of the project. Erosive forces resulting from wind-generated waves and propeller wash were evaluated.

3.1 Wind-Generated Waves

Wind-generated wave effects were evaluated based on best practices from U.S. Army Corps of Engineers (USACE) and Palermo et al. (1998a, 1998b). A range of extreme wind speeds for various return intervals, including 1-, 2-, 10-, 20-, 50-, and 100-year return periods, were calculated based on the historical wind record dataset from the Bellingham International Airport meteorological station and provided by the National Climatic Data Center (NCEI 2021). The Bellingham International Airport station is located across Bellingham Bay, approximately 5 miles north-northwest of the Site. Data from 10 meters above the ground elevation were compiled into a single set for analysis using the methodology outlined in the USACE *Coastal Engineering Manual* (USACE 2006). Figure C-2 illustrates a wind rose of the combined dataset. The dominant wind direction at the airport is from the south.

The National Climatic Data Center historical wind gage data were compiled into eight directional bins based on the wind rose, each encompassing a 45° range starting from 22.5°N. For each directional bin, the annual maximum wind speed for each year from 1948 to 2021 (present) was identified. A statistical analysis of the maximum annual wind speed for each directional bin was performed by applying five candidate probability distribution functions (Fisher-Tippet Type I and Weibull distributions with exponent k varying from 0.75 to 2.0). These distributions were fitted to the maximum yearly wind speed in each directional bin, and the best fit distribution over the range of wind frequencies was identified. The best fit distribution was then used to estimate each return interval event wind speed in each directional bin. These design wind speeds were then used to predict the extreme wave heights and periods for those directional bins. Table C-2 summarizes the extreme wind speeds for each storm event.

Table C-2
Significant Wind Speeds for Various Wind Events, Bellingham International Airport

Direction	1-year (mph)	2-year (mph)	10-year (mph)	20-year (mph)	50-year (mph)	100-year (mph)
North	12.2	40.3	45.4	52.0	52.0	57.0
Northeast	20.7	33.0	49.7	55.6	63.0	68.2
East	12.8	17.6	36.6	46.6	61.1	72.8
Southeast	22.1	34.1	50.3	56.1	63.2	68.3
South	26.9	36.1	50.7	55.5	61.4	65.7
Southwest	9.5	24.2	44.2	51.4	60.2	66.5
West	14.4	18.3	33.8	41.9	53.7	63.2
Northwest	13.7	16.1	25.3	30.2	37.3	43.0

Three directional bins were identified along fetches that could produce wind-generated waves that would impact the Site: North (337.5 to 22.5°N), Northwest (292.5 to 315°N), and West (247.5 to 292.5°N). The estimated 100-year return interval wind speeds are 57.0 miles per hour (mph), 43.0 mph, and 63.2 mph for each directional bin, respectively. Fetch lengths were measured for each bin, as shown in Figure C-3.

The Automated Coastal Engineering System (ACES) developed by USACE (1992) was used to predict the return period wave height associated with each significant wind speed. The 100-year significant wind speed was selected as the appropriate wind speed used in design. Wave heights calculated by ACES ranged from 3.3 to 4.8 feet. Corresponding 100-year significant wave periods ranged from 3.4 to 4.1 seconds. Table C-3 summarizes the predicted 100-year wave heights affecting the Site for each of the evaluated wave bins.

Table C-3
100-Year Significant Wind-Generated Wave Heights for the Harris Avenue Shipyard

Wave Bin	Wind Speed (mph)	Wind-Generated Wave Height (feet)	Wave Period (seconds)
North	57.0	3.49	3.44
Northwest	43.0	3.24	3.37
West	63.2	4.83	4.09

3.2 Propeller Wash

The Site is understood to experience frequent nearshore vessel operations. As a vessel or boat operates, the propeller produces an underwater jet; this turbulent jet is known as propeller wash, or propwash. If this jet reaches the sediment mudline, it can contribute to erosion or resuspension of surficial sediment. Potential propeller wash effects of representative vessels that operate at the Site were evaluated in accordance with Appendix A of Palermo et al. (1998b) cap armor layer design guidance. A site-specific analysis of propeller wash was conducted for the proposed cover areas.

The propeller wash analysis consisted of the following components:

- Representative vessel type information was obtained from the site tenant.
- Representative vessel characteristics (e.g., draft, propeller type, dimensions) were obtained.
- Vessel operating information and assumptions (e.g., operating horsepower and vessel location and orientation) were defined based on initial discussions with the tenant to represent all known or expected vessel operations at the Site. A total of twelve propeller wash scenarios were defined.
- Site-specific conditions (e.g., bathymetry) were obtained.

- Based on the understood range of operational and site-specific conditions, the stable armor stone size necessary to withstand the erosive forces associated with propeller wash was computed for each scenario.

Propeller wash velocities from vessels are assumed to be localized and of short duration. The propeller wash from passing tugs and commercial vessels within Bellingham Bay will not likely affect the cover surfaces; however, the propeller from these vessels during a maneuvering operation (e.g., berthing with propellers, or tug assist) can cause significant erosion of bottom sediments if an appropriate armor stone is not in place to resist the propeller-induced bottom velocities. Anchor QEA consulted the Site tenant to determine representative vessels and vessel operations that frequently occur on site.

Two representative vessels were used in this analysis: the Ann Marie tugboat equipped with two engines totaling 4,100 horsepower (hp), and the Evergreen State, a large 310-foot-long commercial vessel with two engines totaling 2,500 hp. The design specifications for each vessel (including propeller type, horsepower, and propeller depth) were obtained through publicly available information and confirmed by the Site tenant. All vessels were understood to operate under a maximum of 50% of their total engines' hp at no closer than 200 feet from shore. To capture more frequent vessel operations, each vessel was also evaluated for 25% of their total engine hp.

Figure C-4 shows the orientations and operations along transects developed for the propeller wash analysis. The vessel operations that were evaluated include berthing and embarking maneuvers along three pier/dock locations, including a future use travel lift abutting the shoreline that will be dredged to an elevation of -5 feet MLLW. These orientations and operations were confirmed with the Site tenant during preliminary analysis. Four transects were identified based on the current proposed cleanup remedy and known vessel operations at the Site. Transect A-A′ is located along the West Dock, Transect B-B′ is located along the former marine railway and intersects the travel lift, Transect C-C′ is located along the Harris Avenue Pier, and Transect D-D′ is located parallel to shore, intersecting the pier where vessels typically dock. At Transects A, B, and C, vessel operations were simulated to be directing their propellers towards shore; at Transect D, vessel operations were simulated to represent likely tug propeller wash during tug-assisted docking procedures. At each transect, the appropriate vessel was analyzed based on understood vessel operations; both design vessels were evaluated at Transects A and C, while only the Ann Marie tugboat was evaluated at Transects B and D. For each scenario, vessels were evaluated at 25% and 50% of their total engine hp. It was assumed that vessels operating under 50% hp were done so in infrequent or emergency situations of short duration, while 25% hp was representative of more frequent daily operations.

Equation 6 from Appendix A of Palermo et al. (1998a) predicts the propeller velocity at any location below (z distance) and aft of (x distance) the vessel propeller (Equation C-1):

Equation C-1

$$V_x = 2.78 \times U_0 \times \frac{D_0}{x} \exp\left(-15.43\left(\frac{z}{x}\right)^2\right)$$

where:

V_x	=	propeller wash velocity at location x and z (feet per second)
D_o	=	adjusted propeller diameter (function of propeller type and diameter)
x	=	horizontal distance aft of propeller (feet)
z	=	distance from axis of propeller (feet)
U_0	=	propeller wash jet velocity (fps) at the propeller (Equation 4 from Appendix A of Palermo et al. [1998b])

Bathymetric data for each vessel were compiled to apply water depths and shoreline orientations (distances and slopes) such that realistic scenarios were analyzed. Bed velocities were calculated by applying jet velocities to the water depths and local bathymetry data and determining the velocity of the jet where it met the mudline. Based on the bed velocities, required stone sizing could be determined using Palermo et al. (1998b) guidance Equation 5 (Equation C-2). It is important to note that, although vessels typically operate at some sailing speed, which acts to significantly reduce the duration and magnitude of the propeller wash acting on the river bottom, for purposes of this analysis, static vessels conditions were evaluated to provide a conservative assessment assuming vessels are performing slowly moving docking operations.

The velocities of the propeller jet dissipate with depth and distance; however, higher velocities can reach the bay floor. Vessel-generated propeller velocities at the seabed ranged from 1.6 to 9.8 feet per second (fps). The largest bed velocities calculated occurred at Transect B-B' (9.8 fps) caused by the Ann Marie tug pointed directly toward shore.

3.3 Stable Armor Sizing

3.3.1 Propeller Wash

For propeller wash forces, based on the calculated bed velocities, required stone sizing was determined using Equation 5 from Palermo et al. (1998b) guidance (Equation C-2):

Equation C-2

$$D_{50} = \frac{{V_b}^2}{{C_3}^2 * g * A}$$

where:

D_{50} = median stone size (feet)

V_b = bed velocity (feet/second)

C_3 = coefficient (0.55 for frequent, nonmoving vessels; 0.7 for infrequent attack)

g = gravitational constant (32.3 feet/square second)

A = ratio of unit weight of water to stone difference unit weight

For scenarios where vessels operated under 50% hp, a coefficient of 0.7 was used to calculate the stable D_{50} size, and a coefficient of 0.55 was used for vessels operating under 25% hp, based on the guidance of Maynord (2000):

> Blaauw et al. (1984) found C3 = 0.55 for no movement and C3 = 0.70 for small transport. Data from Maynord (1984) using equations 3-5 show that C3 = 0.55 provides good agreement with experimental results for no transport and should be used in harbor areas where repeated attack can be expected, and no movement can be allowed. For channel protection where infrequent attack can be expected, C3 = 0.6-0.7 should be used in design.

Model results of the propeller wash evaluation that carried out these equations can be found in Figures C-5a through C-5l. Table C-4 presents a summary of all erosion analyses performed and computed stable particle size for each type of erosive force.

Table C-4
Propeller Wash Analysis Stable Armor Stone Sizing

Transect	Vessel	Engine Horsepower (%)	Maximum Stable Stone Size (D_{50}; inches)
A-A′	Ann Marie Tugboat	50	6.3
A-A′	Ann Marie Tugboat	25	4
A-A′	Evergreen State	50	6
A-A′	Evergreen State	25	4
B-B′ (Travel Lift)	Ann Marie Tugboat	50	26
B-B′ (Travel Lift)	Ann Marie Tugboat	25	16

Transect	Vessel	Engine Horsepower (%)	Maximum Stable Stone Size (D_{50}; inches)
C-C′	Ann Marie Tugboat	50	29
C-C′	Ann Marie Tugboat	25	18
C-C′	Evergreen State	50	25
C-C′	Evergreen State	25	16
D-D′	Ann Marie Tugboat	50	3
D-D′	Ann Marie Tugboat	25	2

Note:
D_{50}: nominal rock size (diameter) of which 50% of the rocks are smaller

3.3.2 Wind Waves

For designed protection against wind-wave erosion, the rubble-mound revetment module with ACES (USACE 2004) was used to compute the median armor stone size (D_{50}) resistant to the predicted wind-generated wave heights based for cover material. The wind direction bin that produced the largest 100-year wave height and wave period was selected for use in the revetment module. Because the cover material is design to be placed at existing grades, a slope of 8H:1V was used in the computation. Table C-5 summarizes the minimum D_{50} stone sizes to resist motion caused by wind-generated wave erosive forces for each wind direction. The minimum D_{50} armor size should be 7 inches to provide erosion protection caused by wind waves.

Table C-5
100-year Significant Wave Height Stable Armor Sizing Summary

Wind Direction	100-year Wave Height (feet)	100-year Wave Period (seconds)	Stable Armor Stone Size (D_{50}; inches)	Stable Armor Thickness (inches)
North (337.5 to 22.5°N)	3.49	3.44	5	10
Northwest (292.5 to 337.5°N)	3.24	3.37	5	10
West (247.5 to 292.5°N)	4.83	4.09	7	14

Note:
D_{50}: nominal rock size (diameter) of which 50% of the rocks are smaller

3.3.3 Summary

Based on the results of the wind-wave and propeller wash stone sizing calculation, it was determined that vessel-generated propeller wash was the controlling erosive force in areas where vessels operate in the nearshore. To resist propeller wash forces, cover material placed within the footprint of the travel lift along the former marine railway should be robust enough to withstand erosive forces generated by the departing maneuvers of vessels being launched from the travel lift. Here, armor stone with a D_{50} of 18 inches is required to protect against propeller jet velocities. Within other underpier areas, including the West Dock area and beneath the Harris Avenue Pier where bathymetry is deeper, cobble-sized material with a D_{50} of 6 inches is suitable to protect against propeller wash forces. While undersized material may be considered adequate for protection of the isolation layer, instantaneous propeller jets and emergency maneuvers may mobilize material and require maintenance over time. Near the West Dock area, a cobble-sized material would be considered adequate for protection because water depths are great enough beneath the Harris Avenue Pier to allow significant dissipation of propeller jet velocities at the mudline.

Within the intertidal zone, propeller jet velocities dissipate significantly, resulting in wind-generated waves controlling erosion. Cover material placed in the shoreline should be sized with a D_{50} of 7 inches to appropriately withstand wind-generated waves for the 100-year storm.

3.4 Filter Design

The required filter layer was be computed based on the largest predicted median particle size (D_{50}) required for the armor layer in each area of the cap. This filter layer will be designed to prevent the loss of the finer grained material in the underlying chemical isolation layer. The design filter layer material gradation was be computed based on the Engineering Manual 1110 2 2300 equations, summarized in the ACES technical manual (USACE 2004). The standard geotechnical filter criteria presented by Palermo et al. (1998b) is be used to determine whether fine-grained underlying sediments or underlying cap material is susceptible to piping between void spaces of the overlying erosion protection armor layer. The minimum filter criteria suggest that five times the D_{85} (85% passing by weight sieve size) of the underlying material should be greater than the D_{15} (15% passing by weight sieve size) of the overlying material, as shown below:

Equation C-5

$$d_{15(Armor)} < 5d_{85(Base)}$$

where:

$d_{15(armor)}$ = The 15% passing sieve size of the overlying armor material by weight
$d_{85(\text{filter})}$ = The 85% passing sieve size of the underlying material by weight

The filter material for each capping area must meet this criterion. If the filter criterion (above) is not met, an additional filter layer between the armor stone and the physical and/or chemical isolation layer of the cap will be required to prevent piping.

3.5 Sea Level Rise

To evaluating future environmental conditions, this section provides general guidance on the application of climate change, specifically sea level rise (SLR) to potential shoreline enhancements. The SLR guidance applies to changes in sea level relative to the Site but does not address changes in storm or precipitation frequency or intensity. Currently, the City of Bellingham is planning for more than 4 feet of SLR by 2100 (Owens 2020). This projection is in line with the most recent assessment for SLR detailed in a report prepared for the Washington Coastal Resiliency Project in 2018 providing an assessment of projected SLR for Washington State (Miller et al. 2018). The Washington Coastal Resiliency Project report provides updated projections for SLR under two pathways, similarly described in Owens 2020: Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. RCP 4.5 is a low estimate in which greenhouse gas estimates stabilize by mid-century and decrease thereafter. RCP 8.5 is a high scenario in which there is a continued increase in greenhouse gasses until the end of the twenty-first century (Mauger 2015). Based on the pathways, the highest range of SLR projections in Bellingham Bay range from 3 to 8 feet by 2100, consistent with the City of Bellingham's current planning.

Implications of SLR are two-fold for the analysis presented in this appendix. First, propeller wash scenarios were evaluated under existing water levels with no project rise. Increasing sea levels may reduce propeller wash effects because deeper water depth would reduce the magnitude of jet velocities reaching the mudline; however, additional considerations should be made, and propeller wash may be re-evaluated to accommodate future SLR observations. Second, the wind-generated wave analysis was performed for current estimates for significant storm events and does not consider the impact that SLR and climate change may have on the frequency, intensity, or duration of similar storm events. The results of the armoring evaluations presented in this report should be applied to the top of the bank of the shoreline and include an appropriate allowance for SLR.

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Figures

SOURCE: Aerial provided by Bing maps.
HORIZONTAL DATUM: (HARN) Washington State Plane North Zone, NAD83, U.S. Survey Feet

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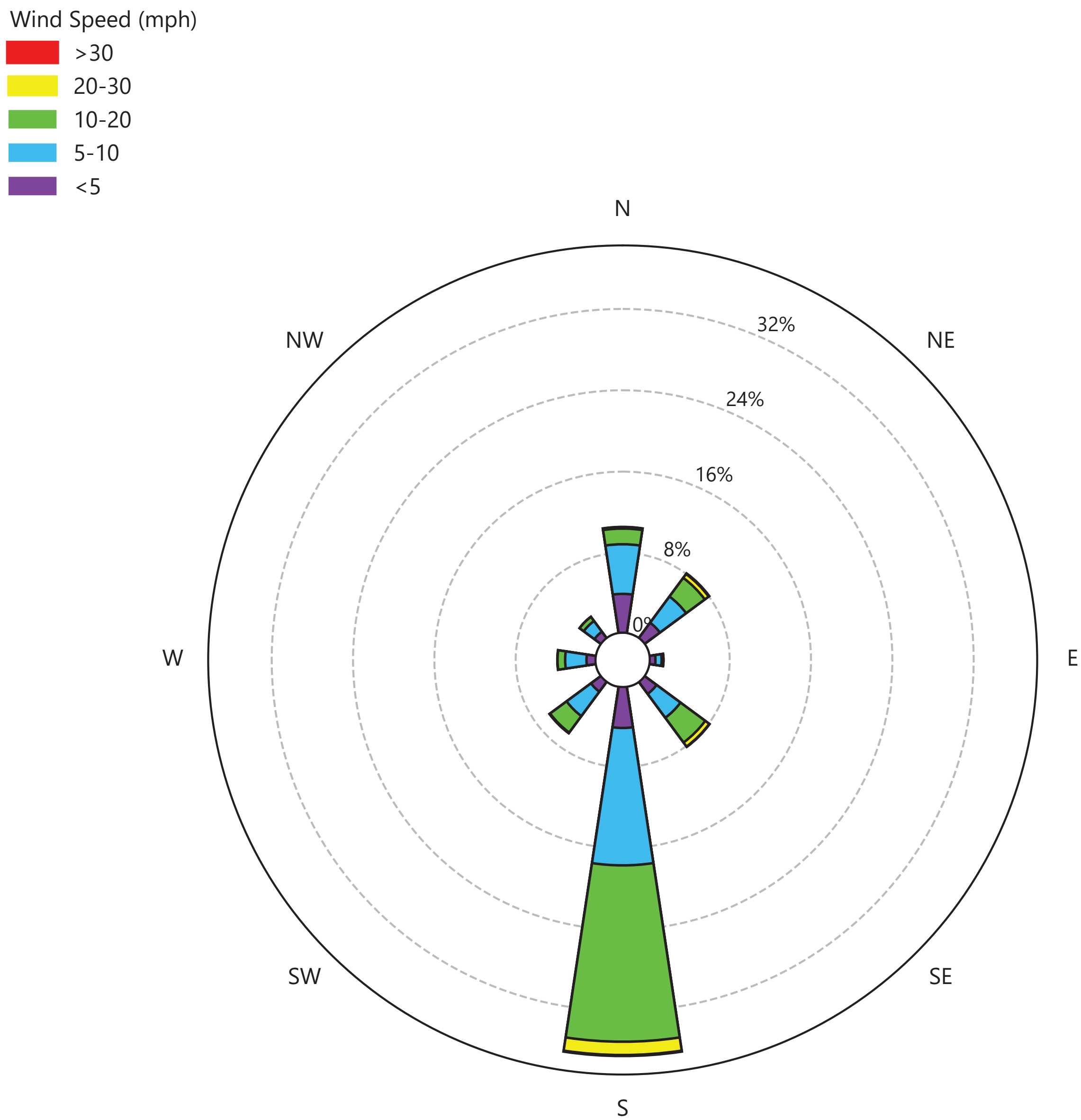
Figure C-1
Vicinity Map

Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes:
1. Hourly Wind Data Obtained from Bellingham, WA for Years 1948 through 2021
2. Calm and Variable Winds: 20.3%
3. Maximum Recorded Wind Speed: 67.8 mph
4. Wind data are presented as the "blowing from" direction.

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Figure C-2
Wind Rose for Bellingham, WA
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup

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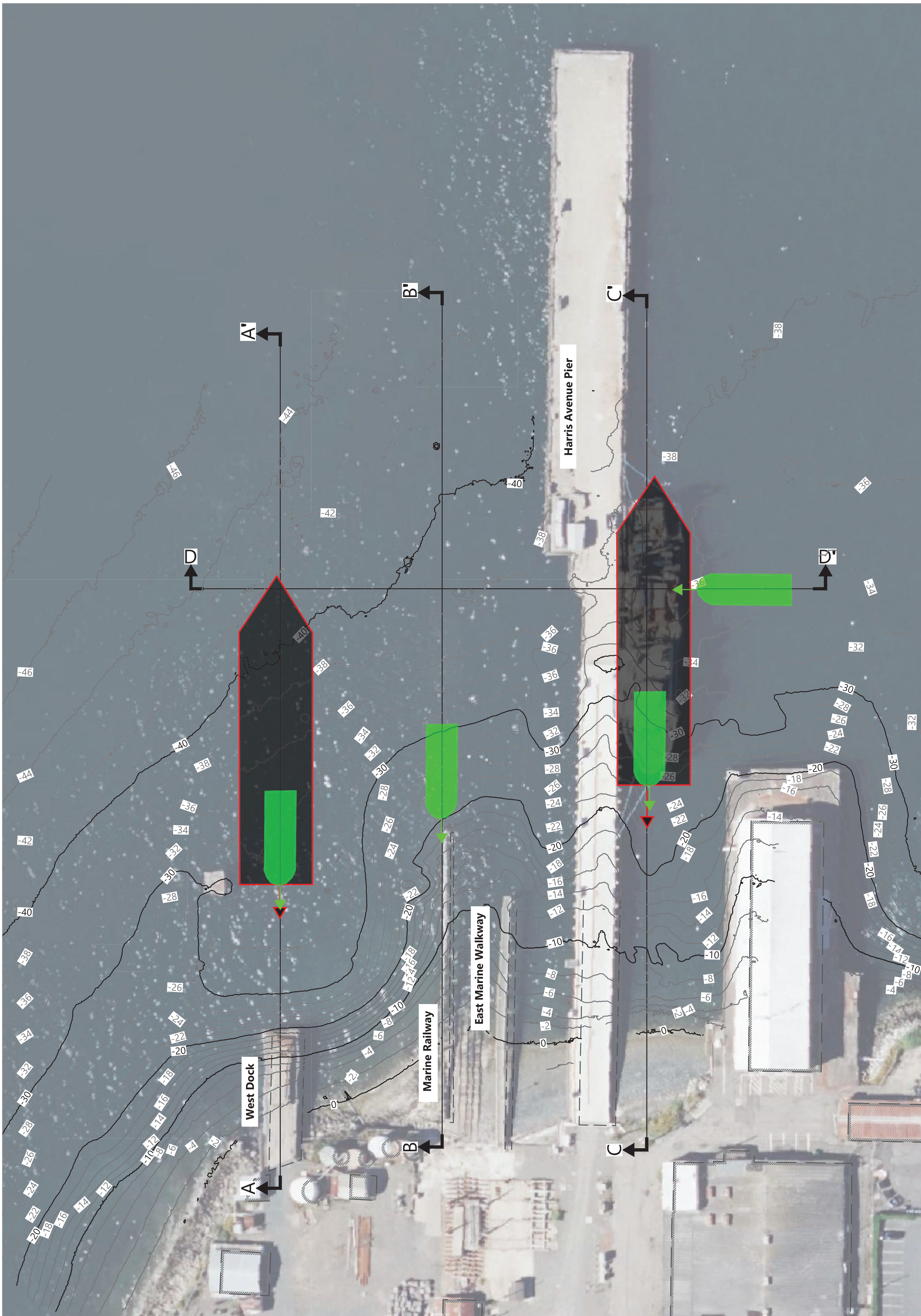
ANCHOR QEA

Figure C-3
Wind-Wave Fetch Distances
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



SOURCE: Aerial from Bing maps.
Bathymetric survey provided by Northwest Hydro Inc., dated August 29, 2022.
HORIZONTAL DATUM: (HARN) Washington State Plane North Zone, NAD83, U.S. Survey Feet
VERTICAL DATUM: MLLW

LEGEND:

-20 Existing Contours (2' & 10' Intervals)

A Cross Section Location and Designation

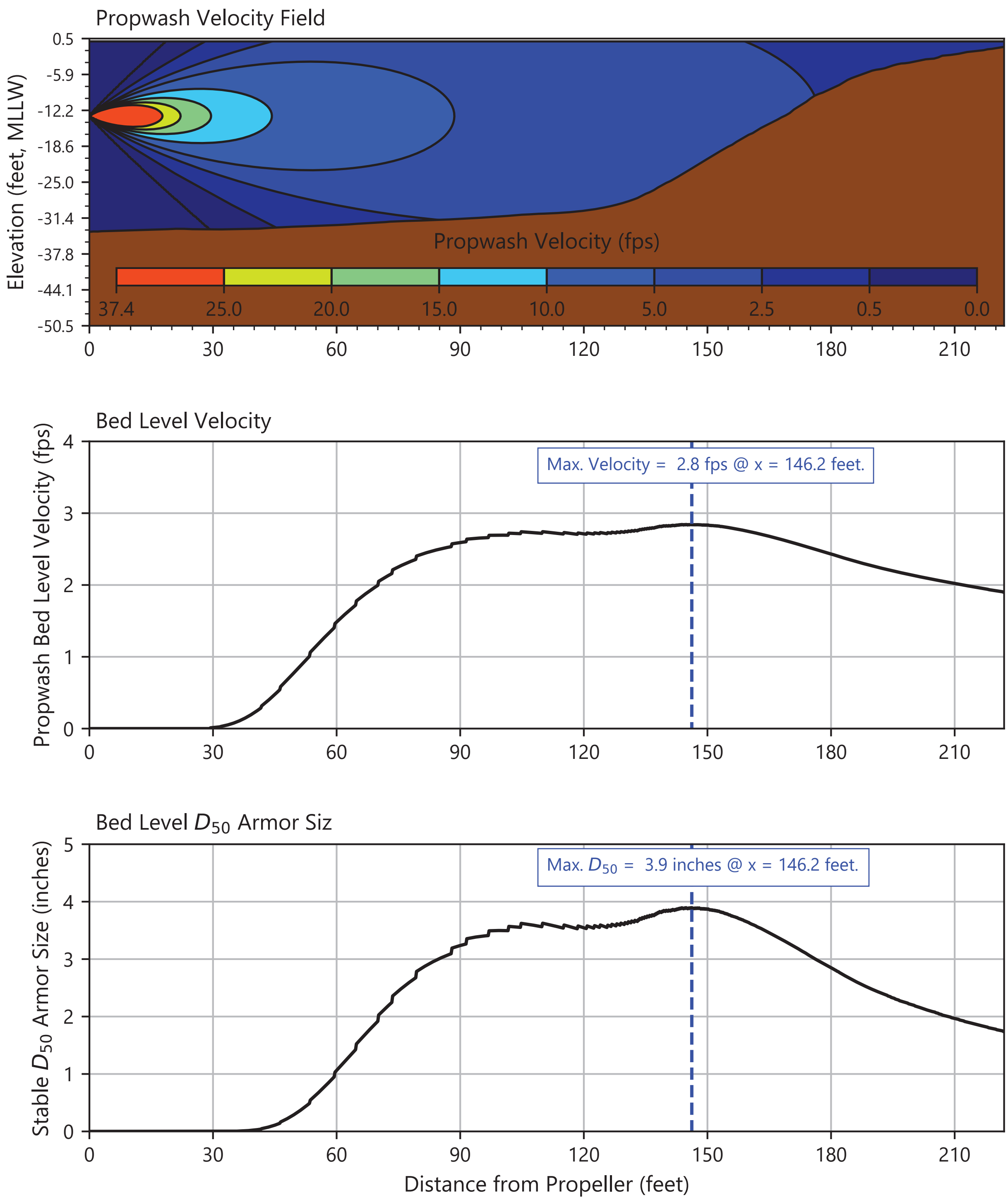
0 80 Feet

Publish Date: 2022/12/16 8:05 AM | User: jfoster
Filepath: K:\Projects\0007-Port of Bellingham\Harris Avenue Shipyard Cleanup\0007-RP-002 SITE BATHY FIGURE 4.dwg Figure 4

ANCHOR QEA

Figure C-4
Site Vessel Operations

Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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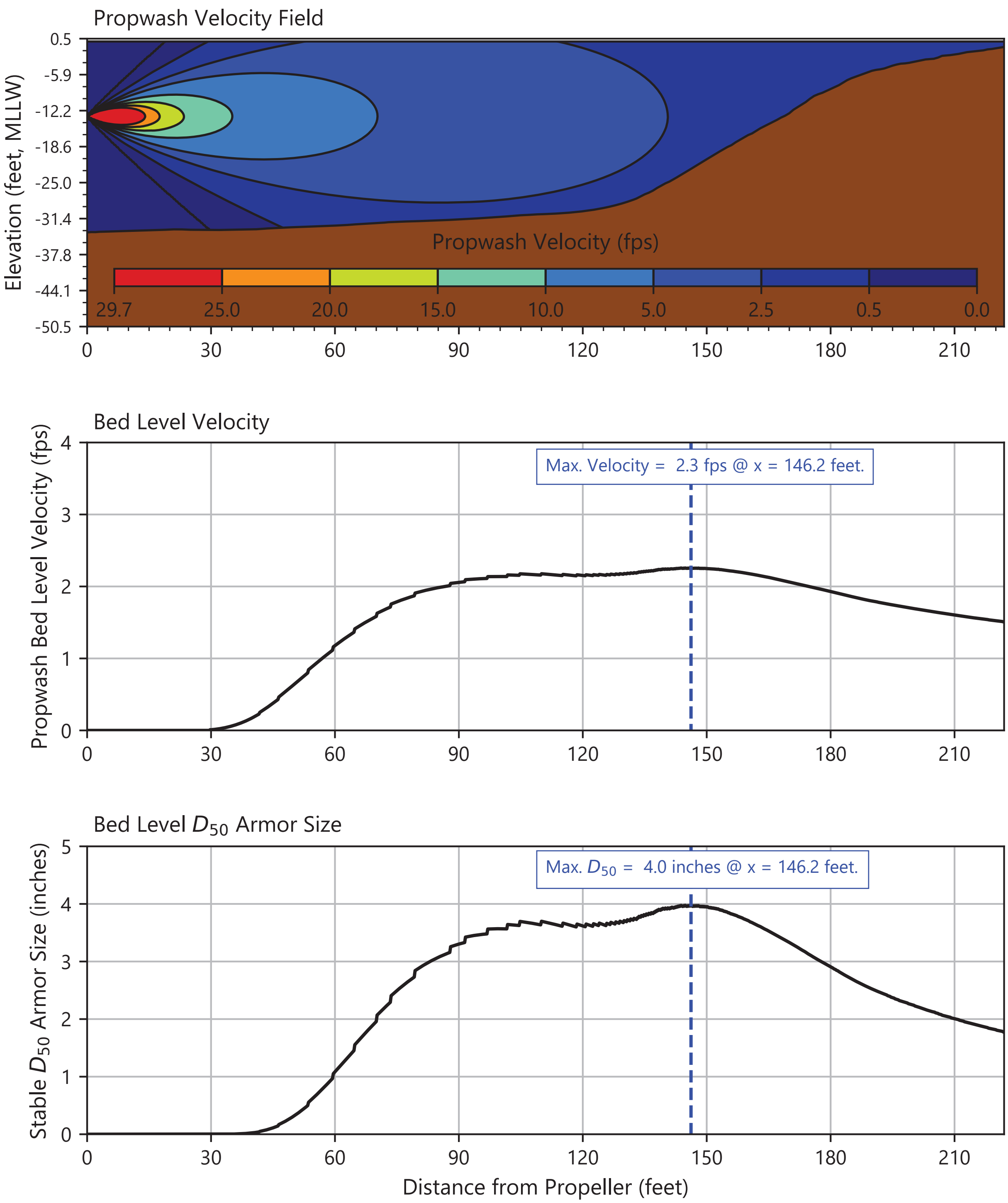
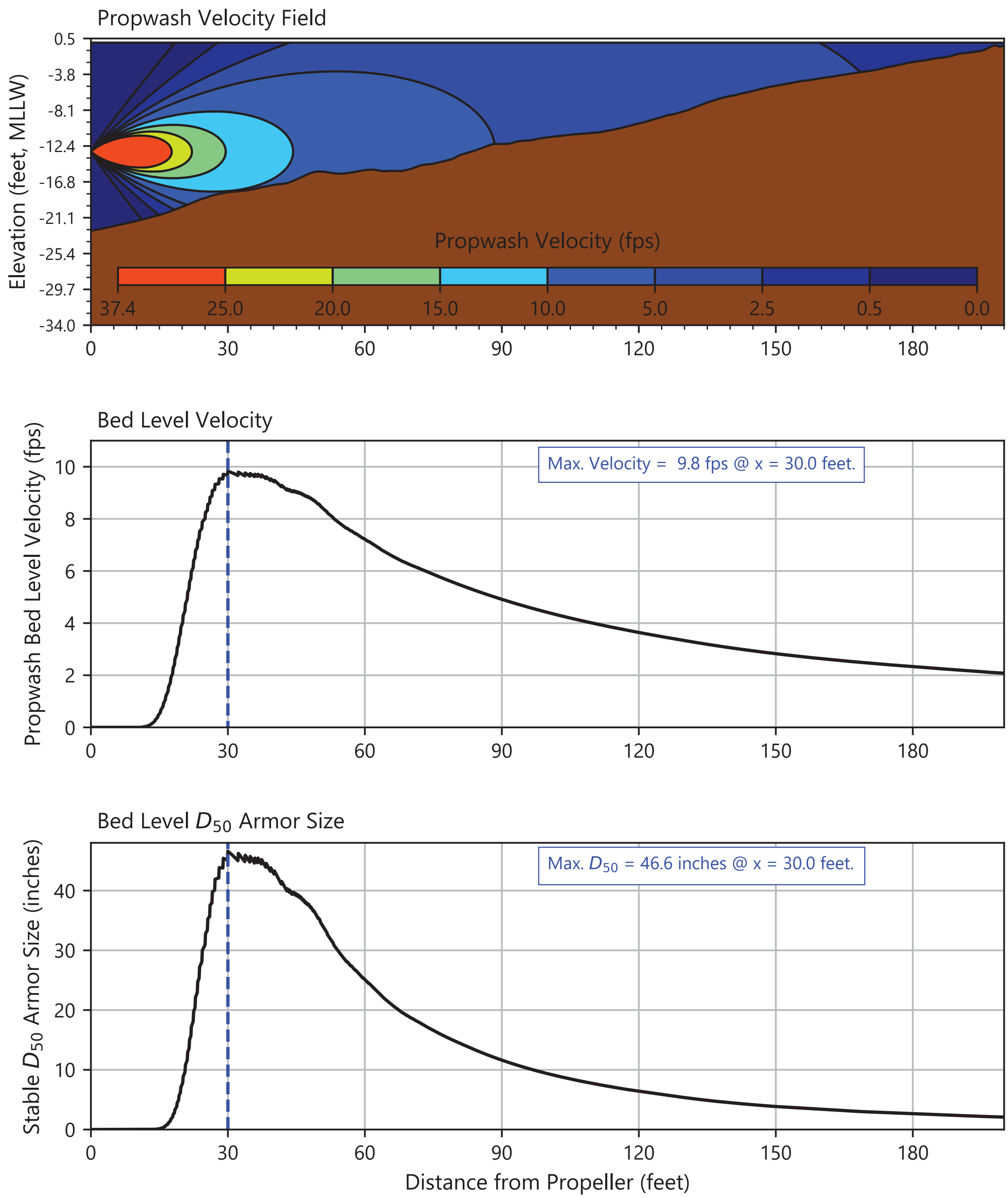
Figure C-5a
Ann Marie at 50% Applied Power at Transect: A-A' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

Figure C-5b
Ann Marie at 25% Applied Power at Transect: A-A' at MLLW



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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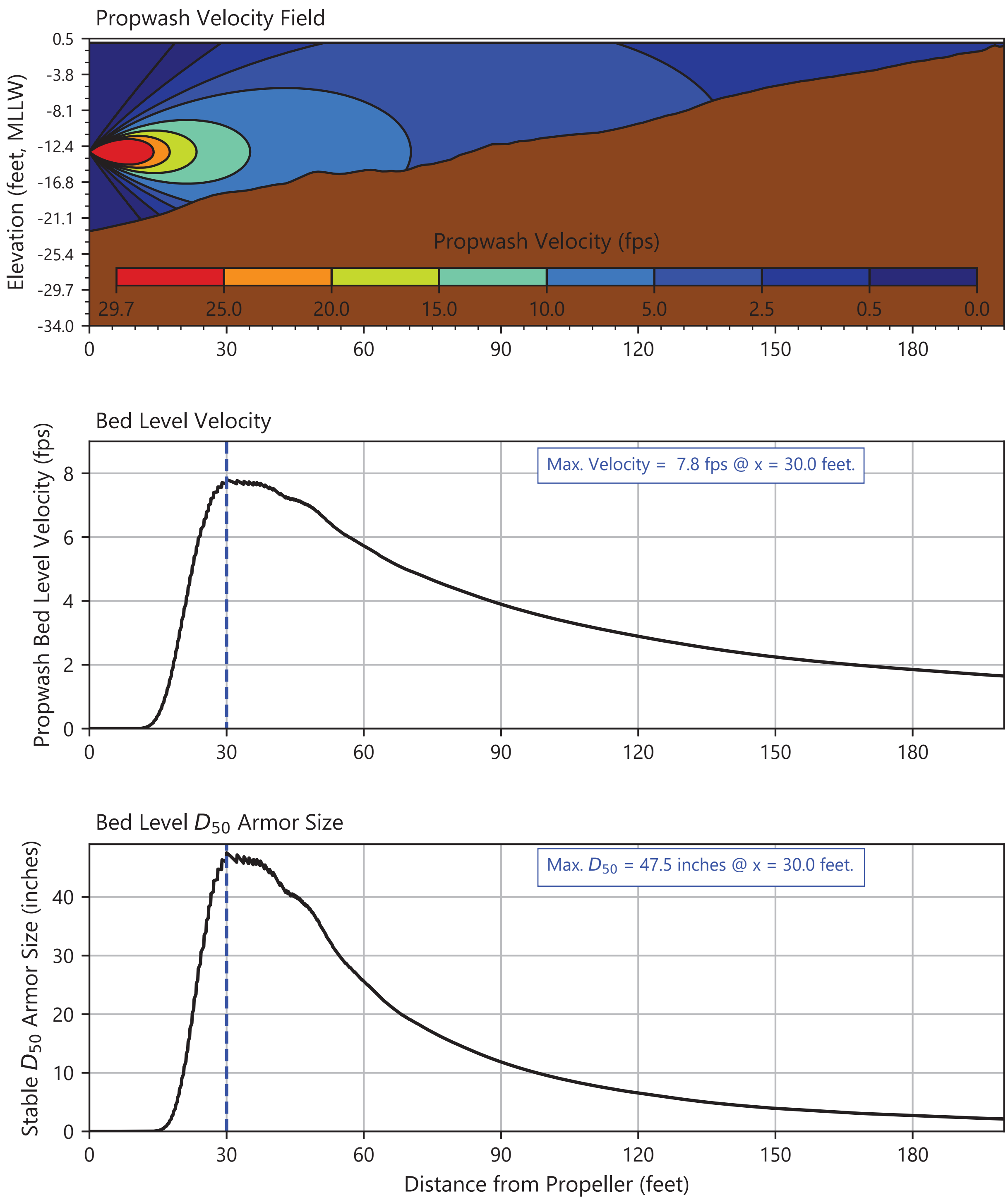
Figure C-5c
Ann Marie at 50% Applied Power at Transect: B-B' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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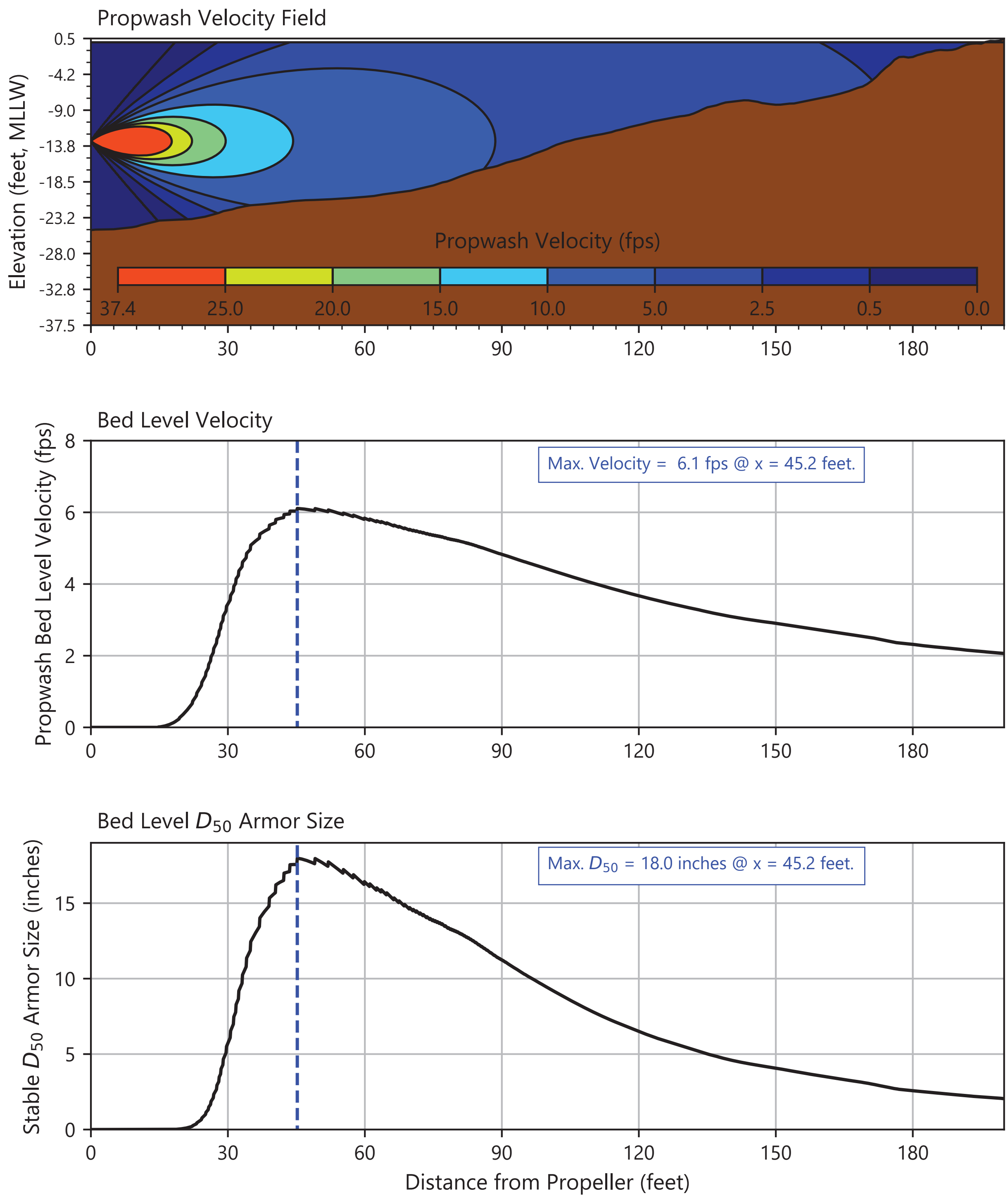
ANCHOR QEA

Figure C-5d

Ann Marie at 25% Applied Power at Transect: B-B' at MLLW

Coastal Engineering and Propeller Wash Evaluation Summary

Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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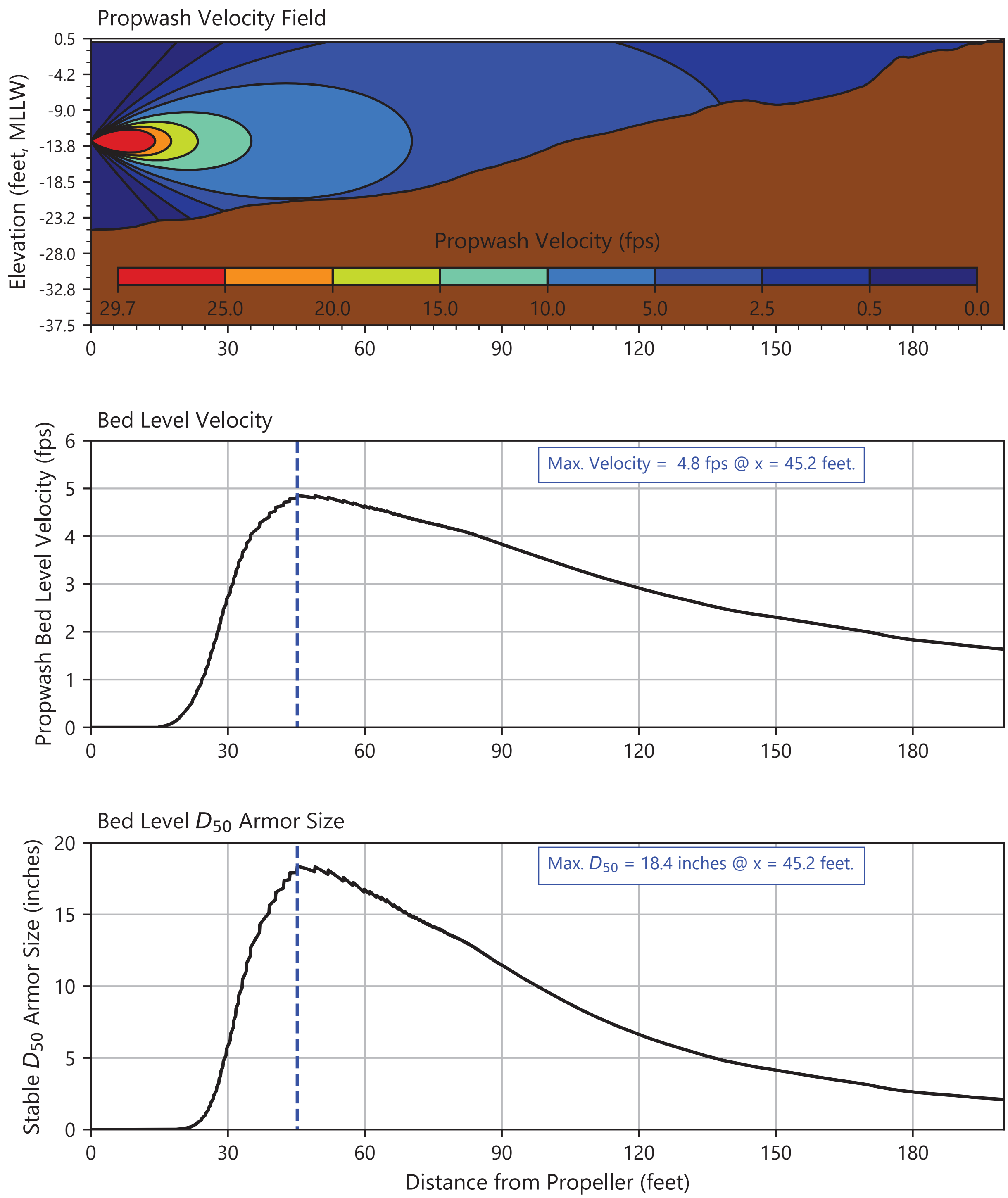
Figure C-5e
Ann Marie at 50% Applied Power at Transect: C-C' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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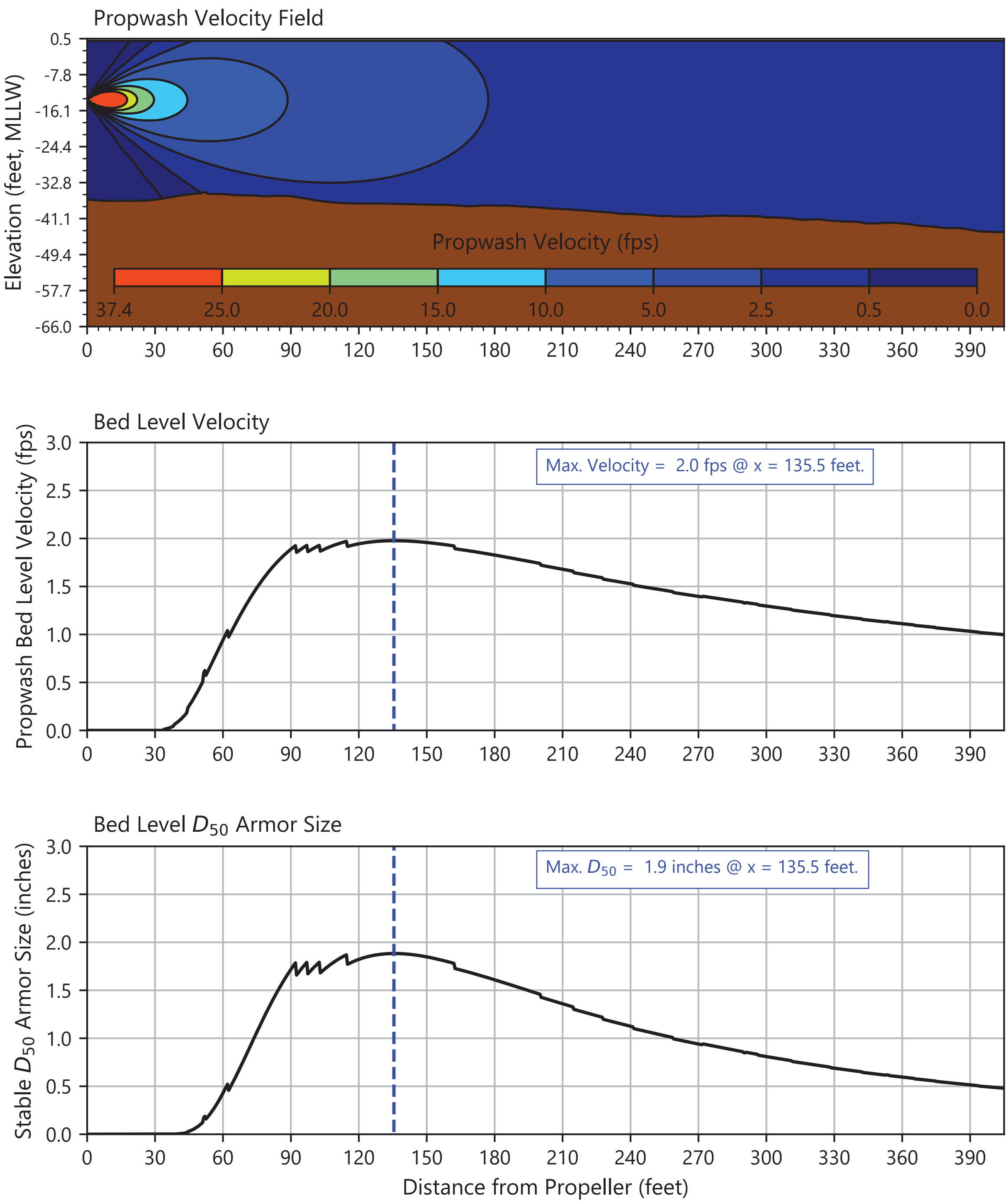
ANCHOR QEA

Figure C-5f
Ann Marie at 25% Applied Power at Transect: C-C' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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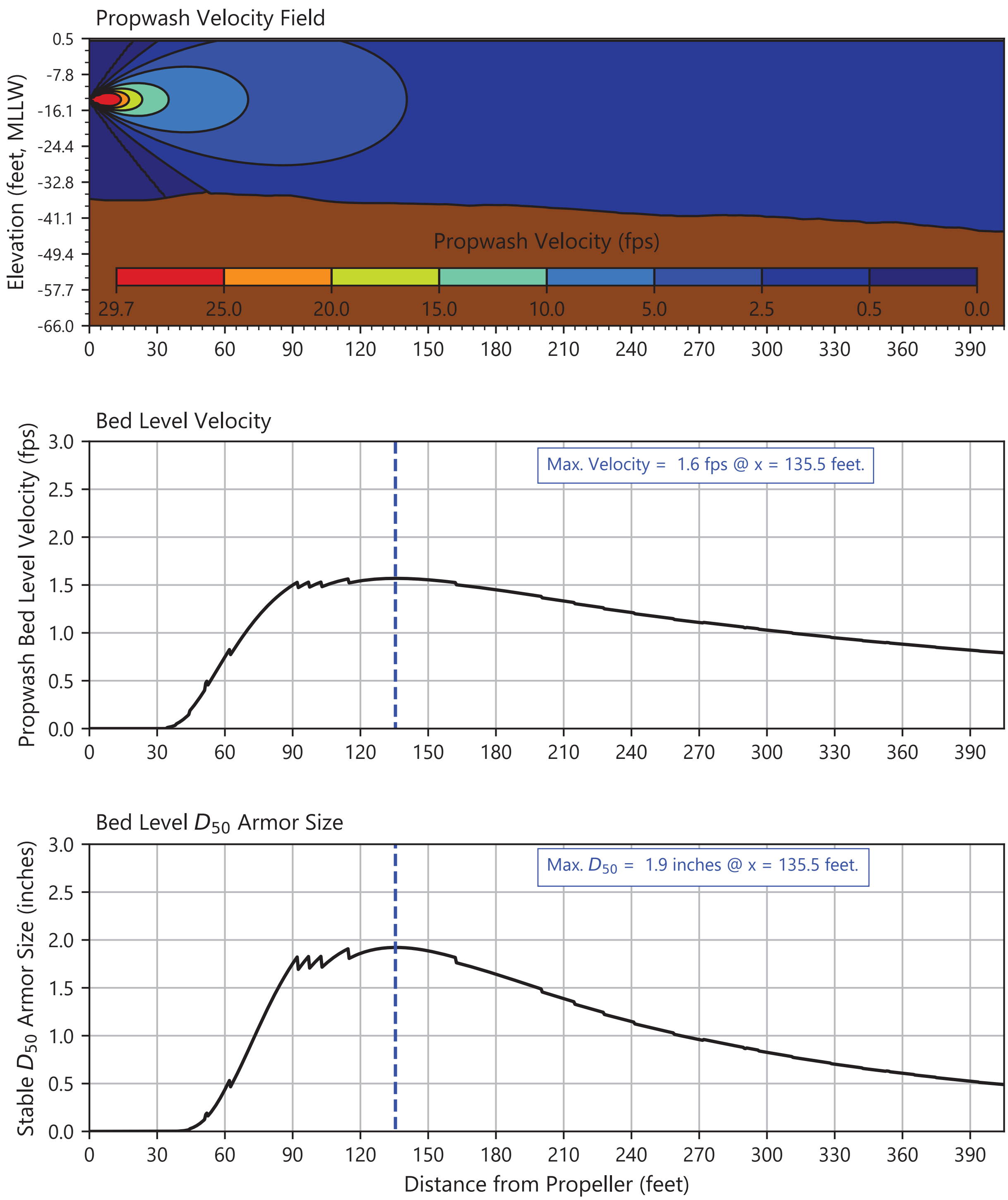
Figure C-5g
Ann Marie at 50% Applied Power at Transect: D-D' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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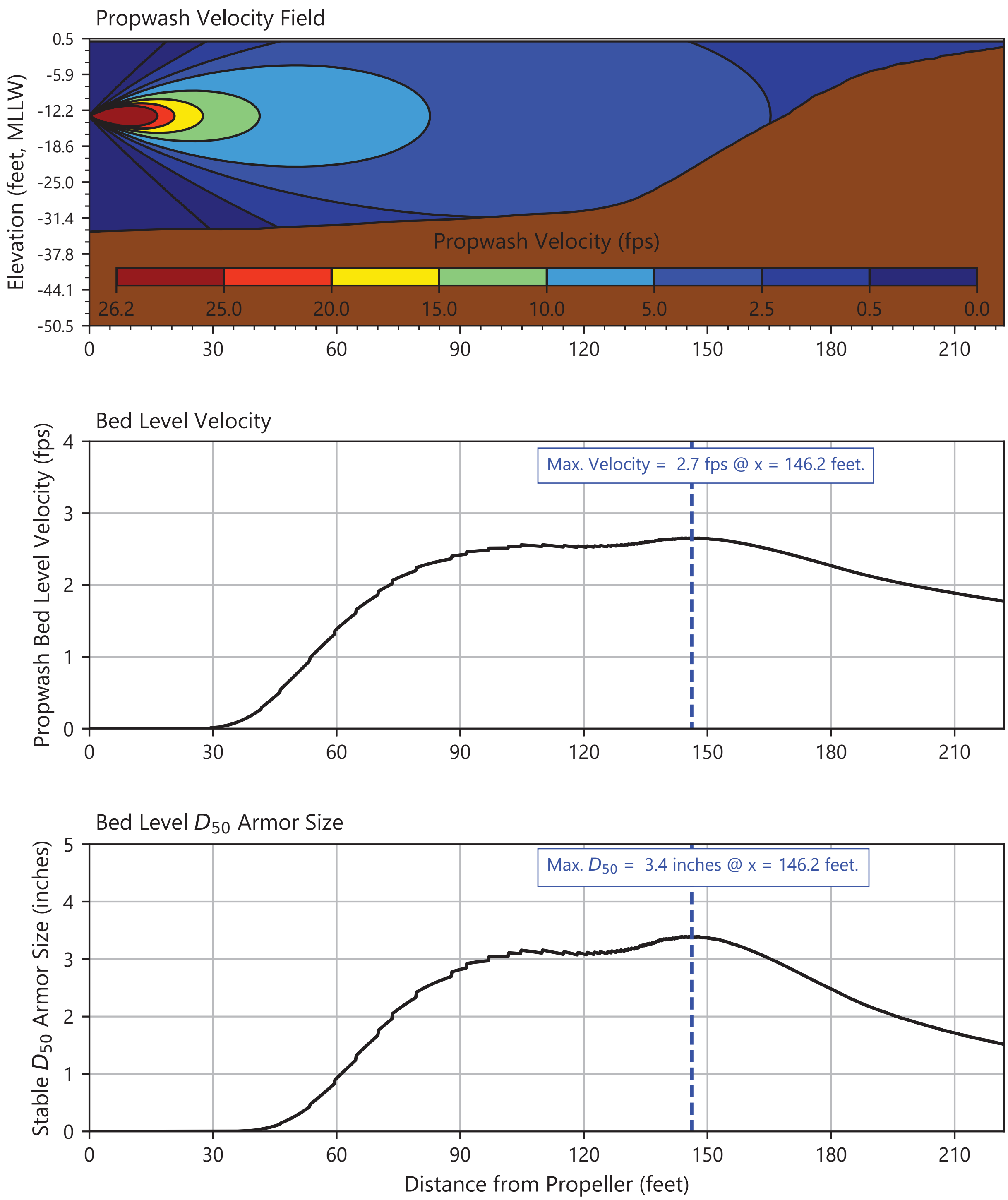
ANCHOR QEA

Figure C-5h

Ann Marie at 25% Applied Power at Transect: D-D' at MLLW

Coastal Engineering and Propeller Wash Evaluation Summary

Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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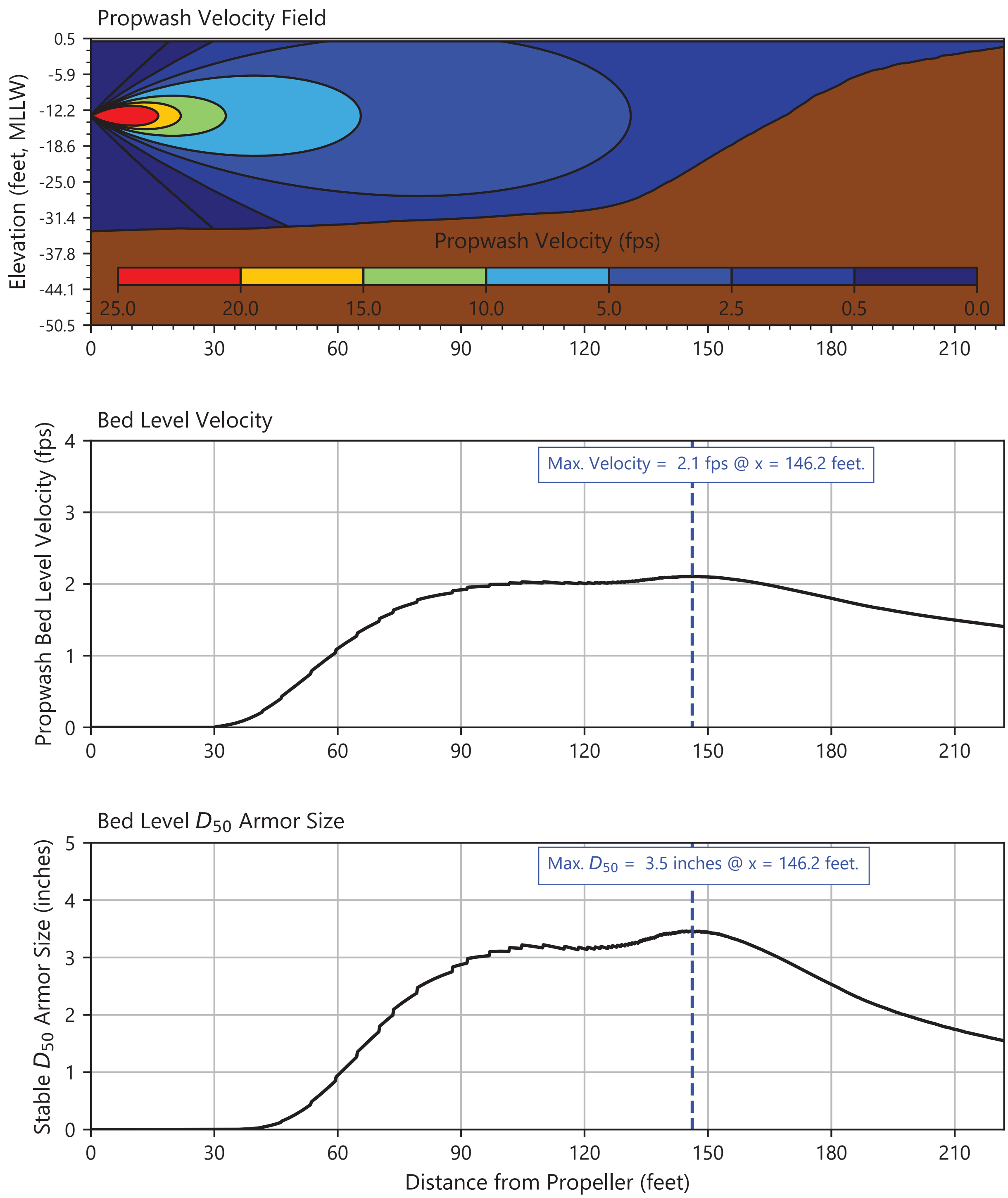
ANCHOR QEA

Figure C-5i
Evergreen State at 50% Applied Power at Transect: A-A' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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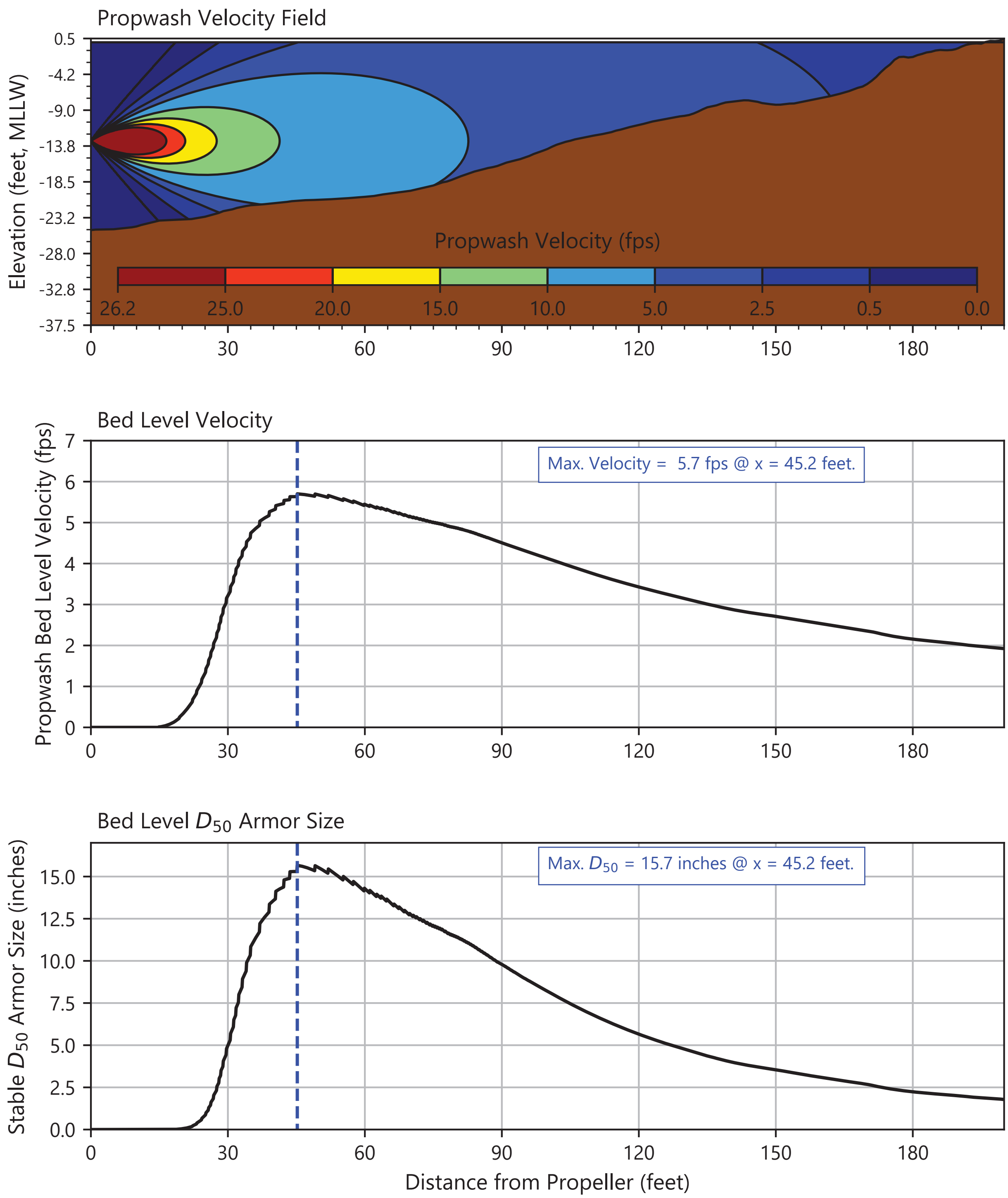
Figure C-5j
Evergreen State at 25% Applied Power at Transect: A-A' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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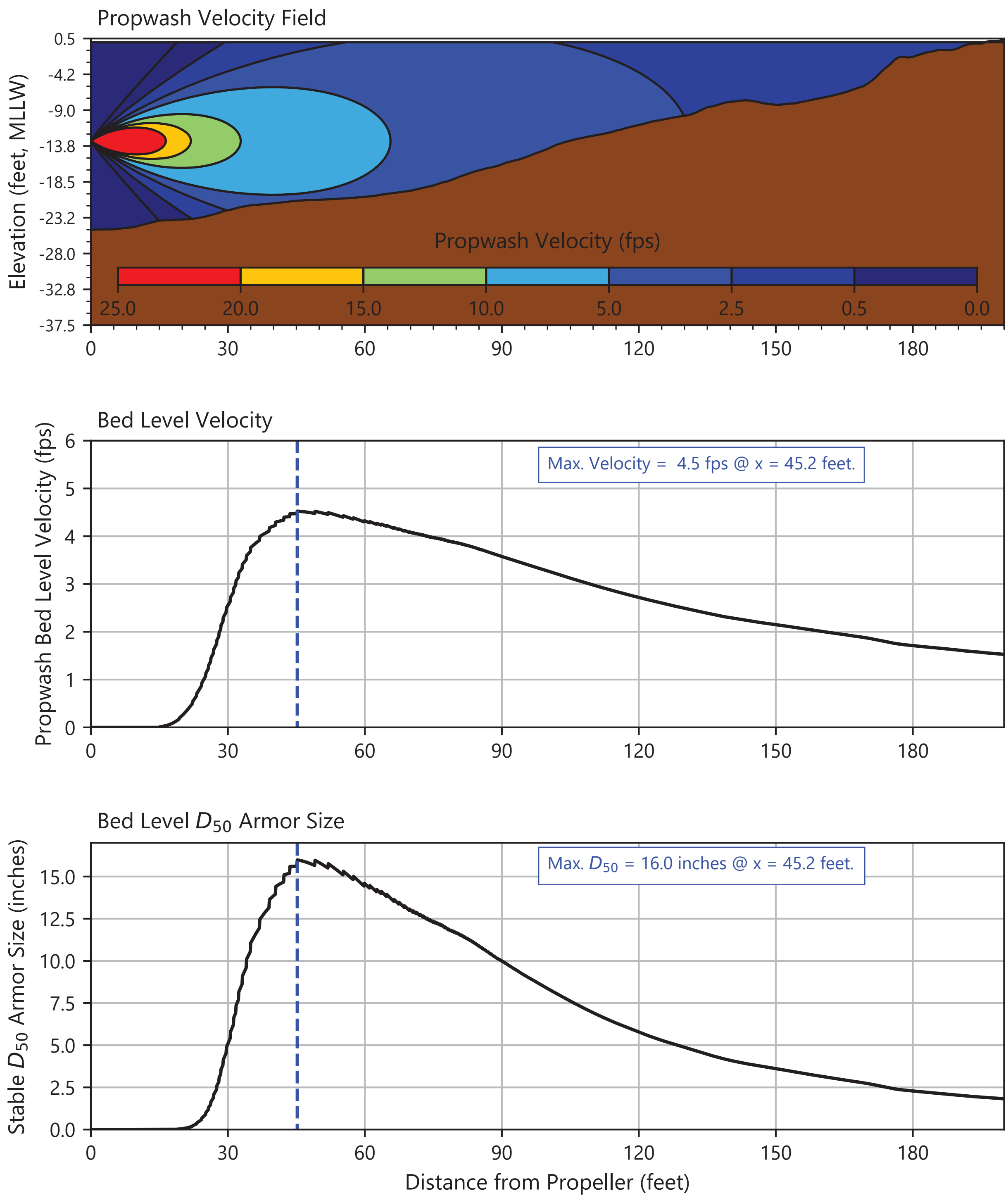
ANCHOR QEA

Figure C-5k
Evergreen State at 50% Applied Power at Transect: C-C' at MLLW
Coastal Engineering and Propeller Wash Evaluation Summary
Harris Avenue Shipyard Cleanup



Notes: The propwash analysis is based on the Maynord 2000 capping methodology.

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ANCHOR QEA

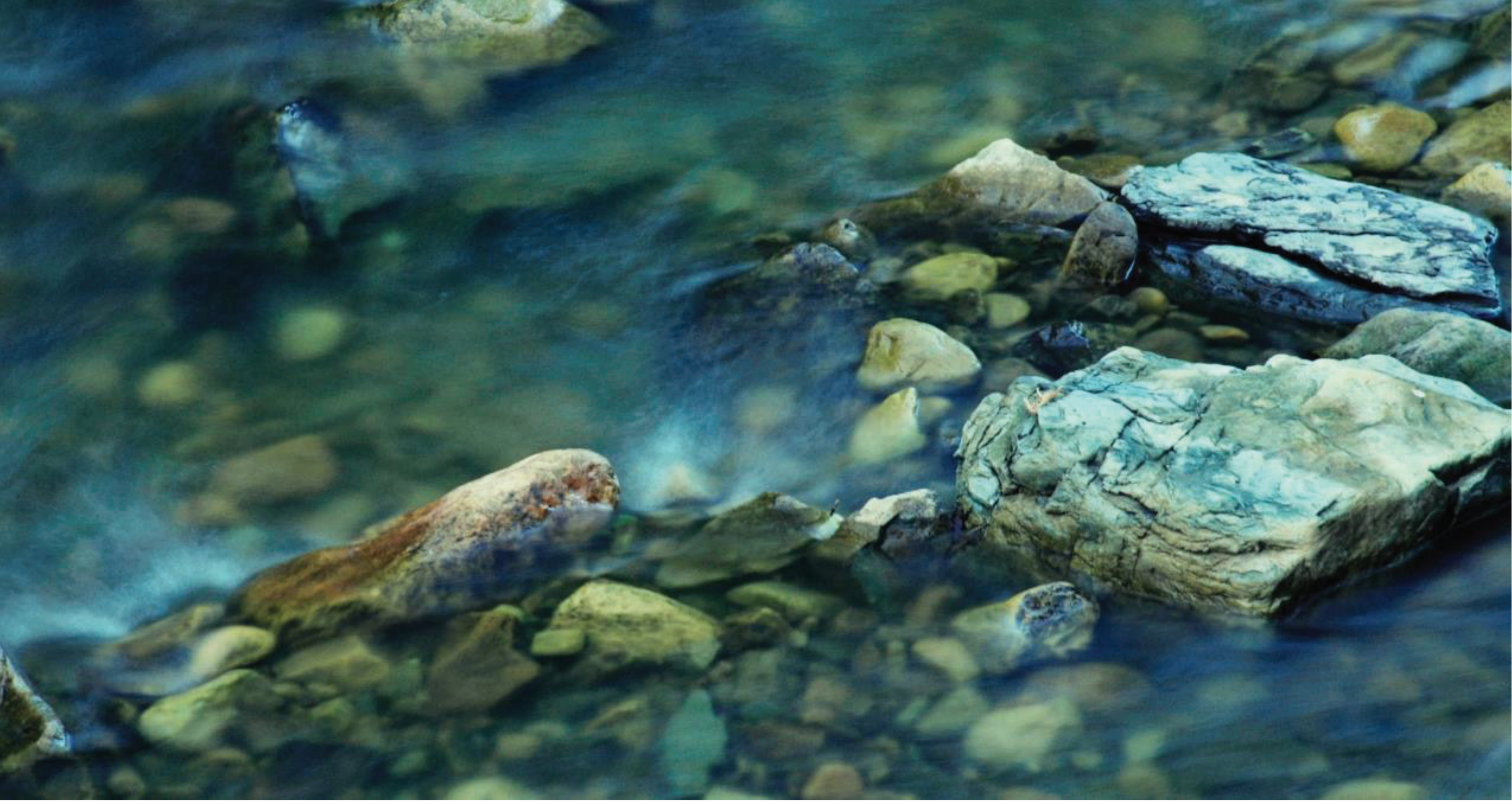
Figure C-5l

Evergreen State at 25% Applied Power at Transect: C-C' at MLLW

Coastal Engineering and Propeller Wash Evaluation Summary

Harris Avenue Shipyard Cleanup

Appendix D
Dredge Residuals Analysis



April 2024
Harris Avenue Shipyard Cleanup

Appendix D
Dredge Residuals Analysis

Prepared for Washington State Department of Ecology

April 2024
Harris Avenue Shipyard Cleanup

Appendix D
Dredge Residuals Analysis

Prepared for
Washington State Department of Ecology
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Bellingham, Washington 98225

Prepared by
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20 Bellwether Way, Suite 101
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Prepared on behalf of
Port of Bellingham
1801 Roeder Avenue
Bellingham, Washington 98227

Project Number: 210007-02.01
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ABBREVIATIONS

cm	centimeter
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
DU	dredging unit
EDR	Engineering Design Report
ft^2	square foot
gm/cm^3	grams per cubic centimeter
IDW	inverse distance weighting
µg/kg	micrograms per kilogram
mg/kg	milligrams per kilogram
MLLW	mean lower low water
RMC	residual management cover
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
Site	Harris Avenue Shipyard Site
SWAC	surface-weighted average concentration
TEQ	toxicity equivalence
USACE	U.S. Army Corps of Engineers

1 Introduction

The engineering design for the Harris Avenue Shipyard Site (Site) includes the application of best management practices to address dredging residuals. This report is an appendix to the *Sediment Engineering Design Report* (EDR; Anchor QEA 2023). The evaluation presented in this appendix has been incorporated into the design of the cleanup action as described in the EDR.

The generation of dredge residuals is inherent to the dredging process, whatever the method (USACE 2008a, 2008b; Patmont and Palermo 2007; Bridges et al. 2010). These residuals result from the loose sediment that re-deposits on the surface during each dredging pass. Best management practices include use of appropriate dredging methods and equipment, use of appropriate dredge pass thicknesses, use of cleanup pass dredging as appropriate, and placement of clean cover material to mix with the dredging residuals. These actions collectively minimize the resulting quantity and concentration of contaminants remaining in the completed dredge area.

As described in the Cleanup Action Plan (Ecology 2021), post-dredging residual sediment contamination for the Site will include the use of best management practices, including the placement of clean sand cover. The evaluation presented herein provides an estimate of concentrations of the following contaminants of concern (COCs) in the substrate's biologically active zone (upper 12 centimeters [cm] of the sediment bed in Bellingham Bay) after the required dredging and the placement of residual management cover (RMC):

- Arsenic
- Cadmium
- Carcinogenic polycyclic aromatic hydrocarbons (cPAHs)
- Total polychlorinated biphenyls (PCBs)

The residual concentrations were then compared to the sediment cleanup levels (Table 1 of the EDR) on an area-weighted basis (i.e., surface-weighted averaged concentration [SWAC]) to determine the effectiveness of the RMC.

2 Methodology

The resulting post-dredge and post-placement chemical concentrations within the Site were determined using guidance provided by the U.S. Army Corps of Engineers (USACE) (USACE 2008a). The approach taken is the mass-balance method for determining final concentration of the remaining material as a mixed layer of cover material and residual material. This methodology has been utilized for many sediment cleanup projects (e.g., on the Grasse River, Hudson River, Fox River, and for the Lower Willamette Group in Portland Harbor).

Multiple, detailed site investigations have been conducted at the Site to support development of the Remedial Investigation and Feasibility Study (a summary of these investigations is included in Section 2 of the *Harris Avenue Shipyard Cleanup Pre-Remedial Design Investigation Work Plan* [Anchor QEA 2021]). Surface sediment and sediment cores collected as part of these investigations and that were considered during this evaluation are listed in Table D-1. The post-dredge and post-placement chemical concentrations were calculated twice, as described in the following scenarios:

- **Scenario 1 – Calculated Surface Average.** In this scenario, analytical results for the COCs from all surface sediment samples (i.e., samples with intervals from 0 to 12 cm) within each dredging unit (DU) were averaged to determine an average surface sediment concentration for the DU. If only a single surface sediment sample was located within the DU, that sample's result was used directly, with the following exceptions:
  - In DU3, there were no surface samples located there. In this case, the closest five surface samples located adjacent to DU3 were averaged together.
  - Across both DU4 and DU5, there was only one station that included a surface sample. In this case, analytical results from this sample were applied to both DUs, equally.
- **Scenario 2 – Inverse Distance Weighting (IDW).** In this scenario, all analytical results for the COCs from all surface sediment samples were plotted in GIS, and an IDW interpolated surface was generated across the project site (see Figures D-1 through D-4 for arsenic, cadmium, total cPAH toxicity equivalence [TEQ], and total PCBs, respectively). Then, an average surface sediment concentration was generated for each DU from the IDW surface.

For both scenarios, after the surface concentrations were calculated for each DU, a depth-averaged concentration representative of the dredge depth within each DU was generated. This was completed by using analytical results from sediment core intervals that were located below the surface depth but typically greater than or equal to the required dredge depth. In some cases, core intervals did extend below the required dredge depth, but those typically did not extend below the allowable overdredge depth (Section 7.1.2 of the EDR). In DUs with multiple cores, similar core intervals were averaged together (i.e., sample results from core interval 1 to 2 feet were averaged, and sample results from core interval 2 to 3 feet were averaged). These results were then used with the surface sediment concentration to determine a depth-averaged concentration.

Exceptions to this approach were as follows:

- Across both DU4 and DU5, there were only two stations that included subsurface samples. In this case, these chemical concentrations were applied to both DUs, equally.
- In DU6, core samples located within its boundary did not extend to the proposed dredge depth; the deepest core was only 3 feet below the mudline. In this case, a core located in DU7, that was in close proximity to DU6 and extended deeper than the proposed dredge depth, was used as a surrogate for chemical concentrations below 3 feet in DU6.

Analytical results for each COC were treated as follows:

- **Arsenic and cadmium.** Detected values were used as reported. If values were U-qualified (i.e., non-detect), half the method detection limit was used. In some cases, half the reporting limit was used if the method detection limit was not included in the historical database.
- **cPAHs.** The cPAH TEQ was calculated based on methods identified in Ecology 2015. Applicable polycyclic aromatic hydrocarbon (PAH) compound results were multiplied by their associated toxicity equivalency factors and summed. Detected values were used as reported. If an individual PAH compound was U-qualified, half the method detection limit was used in the TEQ calculation. If the method detection limit was not included in the historical database, half of the reporting limit was used. In some cases, only benzo(b+j+k)fluoranthene was reported; in these cases, it was treated as benzo(b)fluoranthene plus benzo(k)fluoranthene.
- **Total PCBs.** Total PCBs were derived from Aroclor data. Specifically, only Aroclors 1254 and 1260 were used in the calculation because those two Aroclors were the predominant Aroclors detected at the Site. Detected values were used as reported. If either Aroclor was U-qualified, half the method detection limit was used in the summation. If both Aroclors were U-qualified, half of the higher method detection limit of the two Aroclors was used as the result value. In some cases, half the reporting limit was used if the method detection limit was not included in the historical database.

Required dredge depths (i.e., neatline elevations) for the Site were determined based on factors such as the nature and extent of contamination and anticipated vessel operation depths (Section 7.1.1 of the EDR). Required dredge depths for each DU are consistent with the proposed dredge depths in the EDR. In the case of DU4 and DU5, where an elevation dredge cut of -7 feet mean lower low water (MLLW) is proposed, a dredge depth of 7 feet is used in this analysis. In this analysis, it is also assumed that the RMC volume will be placed at a thickness of 6 inches in all DUs, with the exception of DU5 and DU6 (marine railway footprint) where RMC will be placed at a thickness of 1 foot, consistent with the minimum RMC placement thickness proposed in the EDR.

Table D-1
Surface and Subsurface Samples Included in Dredge Residual Analysis

DU/No Action Area	Surface Samples		Subsurface Samples	
	Location	Year	Location	Year
1	HAS-SC-11	2015	HAS-SC-07	2015
	HS-08SS	2022	HAS-SC-08	2015
	HS-09SS	2022	HAS-SC-09	2015
	HAS-SC-07	2015	HAS-SC-11	2015
	HAS-SC-08	2015	HAS-SC-12	2015
	HG-44	2000	HAS-SC-22	2015
	HS-10SS	2022	HS-08SC	2022
	HS-11SS	2022		
2	HAS-IASMU-1.1	2018	HAS-IASMU-1.1	2018
	HAS-IASMU-1.2	2018	HAS-IASMU-1.3	2018
	HAS-IASMU-1.3	2018	HAS-IASMU-1.4	2018
	HAS-IASMU-1.4	2018	HAS-IASMU-1.6	2018
	HAS-IASMU-1.6	2018	HAS-IASMU-1.9	2018
	HAS-IASMU-1.7	2018	HAS-IASMU-1.10	2018
	HAS-IASMU-1.8	2018	HAS-IASMU-1.13	2018
	HAS-IASMU-1.9	2018	HS-01SG	2022
	HAS-IASMU-1.10	2018	HS-02SG	2022
	HAS-IASMU-1.11	2018	HS-03SG	2022
	HAS-IASMU-1.12	2018	HS-04SG	2022
	HAS-IASMU-1.13	2018	HS-05SG	2022
	HS-01SG	2022	HS-06SG	2022
	HS-02SG	2022		
	HS-03SG	2022		
	HS-04SG	2022		
	HS-05SG	2022		
	HS-06SG	2022		
3	HG-42	2000	HS-09SC	2022
	HG-44	2000		
	HAS-SC-05	2015		
	HAS-SC-09	2015		
	HS-11SS	2022		
4	HAS-HA-03	2011	HAS-HD-14	2015
			HV53S2	2000

DU/No Action Area	Surface Samples		Subsurface Samples	
	Location	Year	Location	Year
5	HAS-HA-03	2011	HAS-HD-14	2015
			HV53S2	2000
6	HAS-SG-04	2011	HAS-SC-17	2015
	HAS-SG-06	2013	HAS-HV-4	1998
			HV-50-S2	2000
7	HAS-HG-3	1998	HAS-HV-3	1998
	HAS-HG-4	1998	HAS-HV-4	1998
	HAS-HG-7	1998	HAS-HV-6	1998
	HAS-HG-11	1998	HAS-HV-8	1998
	HAS-HG-12	1998	HV-38-S2	2000
	HAS-HV-3	1998	HV-39-S2	2000
	HAS-HV-4	1998	HV51S2A	2000
	HAS-HV-6	1998	HV52S2	2000
	HAS-HV-8	1998	HV-54-S2	2000
	HG-36	2000	HAS-SC-05	2015
	HG-37	2000	HAS-SC-06	2015
	HG-38	2000	HS-07SC	2022
	HG-39	2000		
	HG-42	2000		
	HAS-SG-07	2013		
	HAS-SC-04	2015		
	HAS-SC-05	2015		
8	HAS-HA-03	2011	HV-54-S2	2000
	HAS-HA-04	2011		
No Action Area 1, northwest of DU1	HAS-SC-24	2015		
	HAS-SC-25	2015		
	HS-13SS	2022		
	HS-14SS	2022		
No Action Area 2, south of DU2	Used Typical Chemical Concentrations of Cover Material in Table D-3.			
No Action Area 3, under stub pier southeast of DU8	HG-40	2000		
No Action Area 4, eelgrass protection area	HAS-SG-03	2011		
	HG-41	2000		

2.1 Model Parameterization

Analysis of dredging residuals requires estimation of the quantity and quality residuals generated during each dredging pass. Primary factors affecting the dredge residuals calculations include the following:

- In situ chemical concentration of the target dredge material
- In situ bulk density of the target dredge material
- Dredge cut thickness
- Presence or absence of debris content or hard-bottom conditions (affecting potential bucket loss)

The effectiveness of the residuals management strategy depends on the following factors:

- Target post-remedy surface concentration
- Thickness of the final production or cleanup pass dredge cut
- Thickness of cover material
- Bulk density of cover material
- Chemical concentration of cover material

Table D-2 contains descriptions of the input parameters for the dredging residuals analysis, including the source of each parameter, and the value assumed for this evaluation.

Table D-2
Dredge Residual Calculation Parameter Input Values

Parameter	Source	Input Value or Range
In situ dry density of target dredge material	Estimated based on visual description of density from field loggers and *Foundation and Earth Structures: Design Manual 7.1* (NAVFAC 1986)	1.40 gm/cm^3
Required dredge cut thickness	Existing site data and preliminary dredge plan	1 foot for interim action areas 3 feet for other areas
Residual loss	Figure 1 of Patmont and Palermo (2007)	5% (Typical range 3.5% to 7.5%)
Target chemical concentration (required site-wide SWAC)	Target concentrations based on cleanup levels as defined in the Cleanup Action Plan (Ecology 2021)	≤13 mg/kg for arsenic ≤0.8 mg/kg for cadmium ≤140 µg/kg for cPAH TEQ ≤33 µg/kg for Total PCBs
Thickness of production dredge passes	Existing site data and preliminary dredge plan	1 foot for interim action areas 3 feet for other areas
Thickness of post-dredge sand cover material	Expected value based on past experience with similar projects	minimum of 6 inches
Bulk density of post-dredge cap material	Assumed value for loose, pluviated sand	1.47 gm/cm^3
Chemical concentration of cover material	Estimated based on Washington State Natural Background and past experience with common borrow source material	See Table D-3

2.2 Residuals Calculations

The post-remedy surface concentrations were estimated for each DU and across the Site. It is assumed that the chemical concentrations in the cover materials are as shown in Table D-3. These concentrations are intended to represent naturally occurring chemical concentrations that may be present in quarry sands used for residuals management.

Table D-3
Typical Chemical Concentrations of Cover Material

Material	Cover Material Concentration
Arsenic (mg/kg)	7 (Puget Sound soil natural background)
Cadmium (mg/kg)	1.0 (Puget Sound soil natural background) 0.6 (preliminary target concentration)
cPAH TEQ (µg/kg)	9 (past experience with common borrow source materials for Whatcom Waterway Project)
Total PCBs (µg/kg)	3.5 (typical detection limit)

Equation D-1 represents the formulation for a one-pass production dredge scenario used for the analysis.

Equation D-1

$$C_T = \frac{C_S \cdot S \cdot \rho_S + C_R \cdot R \cdot \rho_R}{S \cdot \rho_S + R \cdot \rho_R}$$

where:

C_T = targeted/resulting chemical concentration
S = sand thickness (6 inches)
R = thickness of dredge residual (percentage of production pass)
C = in situ chemical concentration
ρ = in situ dry density
(subscripts denote layers; S = residual cover material; R = residual sediment)

The area for each DU and no action area used in the surface-weighted average concentration is provided in Table D-4.

Table D-4
Surface Area of All Evaluated DUs and No Action Areas

DU/No Action Area	Surface Area (ft^2)
1	31,056
2	55,679
3	8,995
4	7,456
5	2,801
6	5,650
7	123,438
8	3,510
No Action Area 1, northwest of DU1	16,377
No Action Area 2, south of DU2	14,839
No Action Area 3, under stub pier southeast of DU8	4,221
No Action Area 4, eelgrass protection area	7,773

2.3 Target Contaminant Levels

The post-remedy surface concentrations were then compared to sediment cleanup levels established in the Cleanup Action Plan (Ecology 2021), which are 13 milligrams per kilogram (mg/kg) for arsenic, 0.8 mg/kg for cadmium, 140 micrograms per kilogram (µg/kg) for cPAH TEQ and 33 µg/kg for total PCBs (Table 1 of the EDR).

These cleanup levels were developed by considering the following pathways:

- Protection of benthic species in site sediments
- Protection of human health via direct contact by site workers and incidental ingestion of intertidal sediment
- Protection of human health via direct contact during net fishing and incidental ingestion of subtidal sediment
- Protection of humans and higher trophic levels species via the consumption of seafood.

3 Discussion and Results

The resulting post-remedy surface concentrations for arsenic, cadmium, cPAH TEQ, and total PCBs for the two scenarios described in Section 2 are summarized in Table D-5 and Table D-6. The results show that none of the site-wide SWACs established for arsenic, cadmium, cPAHs, or total PCBs are expected to be exceeded. Evaluating the results on a DU-by-DU basis, the following was found:

- **Arsenic.** None of the DUs to be remediated are expected to exceed the 13 mg/kg seafood consumption SWAC. None of the DUs or no action areas are expected to exceed the point-by-point benthic protection cleanup level (57 mg/kg).
- **Cadmium.** None of the DUs for either scenario analyzed are expected to exceed the 0.8 mg/kg seafood consumption SWAC if the cover material does not exceed a target concentration of 0.6 mg/kg. If the cover material contains cadmium in concentrations equivalent to Puget Sound soil natural background levels (1.0 mg/kg), then the seafood consumption SWAC will be exceeded. However, the expected cadmium concentrations are anticipated to be below northern Puget Sound background sediment concentrations.
- **cPAHs.** Only one of the DUs (DU6) for either scenario analyzed is expected to exceed the 140 µg/kg seafood consumption SWAC. This result is likely driven by elevated subsurface concentrations of cPAHs in a single core.
- **Total PCBs.** Similar to cPAHs, only one of the DUs (DU6) for either scenario analyzed is expected to exceed the 33 µg/kg seafood consumption SWAC, which is likely driven by elevated subsurface concentrations of total PCBs in a single core. None of the DUs or no action areas are expected to exceed the point-by-point benthic protection cleanup level (130 µg/kg).

Table D-7 provides a comparison of the resulting concentrations following dredging and dredge residuals management (i.e., placement of clean cover) to the initial (i.e., calculated or interpolated) surface concentration.

The above results demonstrate that the placement of a 6-inch layer of RMC in DUs 1, 2, 3, 6, and 7 and a 1-foot layer of RMC in DUs 4 and 5 will result in final surface concentrations that comply with the site-specific cleanup levels for arsenic, cadmium, cPAHs, and total PCBs.

Table D-5
Residuals Management Evaluation for Site – SWAC (Scenario 1 – Calculated Surface Average)

DU/No Action Area	Surface-Weighted Average Concentration at 5% Generated Residuals			
	Arsenic (mg/kg)	Cadmium (mg/kg)	cPAH TEQ (µg/kg)	Total PCBs (µg/kg)
1	7.17	0.89/0.58	40.04	6.41
2	6.72	1.01/0.65	73.89	20.36
3	10.08	0.97/0.66	39.21	9.89
4	12.98	0.80/0.56	94.58	6.18
5	10.74	0.88/0.58	62.49	4.14
6	6.21	1.03/0.70	178.34	62.23
7	8.71	0.88/0.57	38.25	26.19
8	12.56	0.31/0.31	122.36	12.55
No Action Area 1, northwest of DU1	7.04	1.06/1.06	168.46	44.10
No Action Area 2, south of DU2	7.00	1.00/0.60	9.00	3.50
No Action Area 3, under stub pier southeast of DU8	20.00	0.25/0.25	9.50	19.10
No Action Area 4, eelgrass protection area	15.50	0.29/0.29	870.40	98.00
Post-Remediation Site-Wide SWAC	**8.49**	**0.89/0.60**	**79.66**	**23.86**

Note:
The calculation used cover material with two different cadmium concentrations: 1 mg/kg and 0.6 mg/kg, as described in Table D-2. The first number in the table above is the resulting SWAC if the cover material cadmium concentration was assumed to be 1 mg/kg, and the second number is the resulting SWAC if the cover material cadmium concentration was assumed to be 0.6 mg/kg.

Table D-6
Residuals Management Evaluation for Site – SWAC (Scenario 2 – Inverse Distance Weighting)

DU/No Action Area	Surface-Weighted Average Concentration at 5% Generated Residuals			
	Arsenic (mg/kg)	Cadmium (mg/kg)	cPAH TEQ (µg/kg)	Total PCBs (µg/kg)
1	7.28	0.90/0.59	67.99	5.86
2	6.83	1.01/0.65	82.25	22.88
3	9.22	0.96/0.65	38.73	12.49
4	12.45	0.82/0.58	108.88	12.96
5	10.37	0.88/0.58	72.70	8.52
6	6.15	1.05/0.73	178.13	76.41
7	8.04	0.87/0.56	36.20	18.09
8	18.97	0.41/0.41	105.24	22.46
No Action Area 1, northwest of DU1	5.09	1.00/1.00	400.94	45.00
No Action Area 2, south of DU2	7.00	1.00/0.60	9.00	3.50
No Action Area 3, under stub pier southeast of DU8	18.26	0.64/0.64	151.74	44.02
No Action Area 4, eelgrass protection area	16.35	0.69/0.69	427.79	63.43
Post-Remediation Site-Wide SWAC	**8.15**	**0.91/0.62**	**87.17**	**20.94**

Note:
The calculation used cover material with two different cadmium concentrations: 1 mg/kg and 0.6 mg/kg, as described in Table D-2. The first number in the table above is the resulting SWAC if the cover material cadmium concentration was assumed to be 1 mg/kg, and the second number is the resulting SWAC if the cover material cadmium concentration was assumed to be 0.6 mg/kg.

Table D-7
SWAC Before and After for Scenarios 1 and 2

DU	Arsenic (mg/kg)				Cadmium (mg/kg)				cPAH TEQ (µg/kg)				Total PCBs (µg/kg)			
	Scenario 1 Initial	Scenario 1 Final	Scenario 2 Initial	Scenario 2 Final	Scenario 1 Initial	Scenario 1 Final	Scenario 2 Initial	Scenario 2 Final	Scenario 1 Initial	Scenario 1 Final	Scenario 2 Initial	Scenario 2 Final	Scenario 1 Initial	Scenario 1 Final	Scenario 2 Initial	Scenario 2 Final
1	7.36	7.17	9.50	7.28	0.91	0.89/0.58	1.10	0.90/0.59	449.97	40.04	991.41	67.99	65.34	6.41	54.73	5.86
2	6.18	6.72	9.57	6.83	1.34	1.01/0.65	1.22	1.01/0.65	611.38	73.89	855.75	82.25	147.97	20.36	221.46	22.88
3	48.20	10.08	38.46	9.22	1.12	0.97/0.66	0.99	0.96/0.65	341.00	39.21	335.57	38.73	73.98	9.89	103.29	12.49
4	50.00	12.98	36.55	12.45	0.50	0.80/0.56	0.70	0.82/0.58	76.60	94.58	435.65	108.88	1.95	6.18	172.12	12.96
5	50.00	10.74	35.07	10.37	0.50	0.88/0.58	0.63	0.88/0.58	76.60	62.49	487.05	72.70	1.95	4.14	177.83	8.52
6	17.00	6.21	14.88	6.15	0.10	1.03/0.70	0.71	1.05/0.73	771.80	178.34	763.80	178.13	120.00	62.23	649.36	76.41
7	43.33	8.71	30.32	8.04	1.29	0.88/0.57	1.17	0.87/0.56	483.67	38.25	443.95	36.20	368.32	26.19	211.29	18.09
8	21.00	12.56	48.62	18.97	0.50	0.31/0.31	0.95	0.41/0.41	324.70	122.36	250.99	105.24	24.30	12.55	66.93	22.46
No Action Area 1, northwest of DU1	7.04	7.04	5.09	5.09	1.06	1.06	1.00	1.00	168.46	168.46	400.94	400.94	44.10	44.10	45.00	45.00
No Action Area 2, south of DU2	7.00	7.00	7.00	7.00	1.00/0.60	1.00/0.60	1.00/0.60	1.00/0.60	9.00	9.00	9.00	9.00	3.50	3.50	3.50	3.50
No Action Area 3, under stub pier southeast of DU8	20.00	20.00	18.26	18.26	0.25	0.25	0.64	0.64	9.50	9.50	151.74	151.74	19.10	19.10	44.02	44.02
No Action Area 4, eelgrass protection area	15.50	15.50	16.35	16.35	0.29	0.29	0.69	0.69	870.40	870.40	427.79	427.79	98.00	98.00	63.43	63.43
Post-Remediation Site-Wide SWAC	**26.48**	**8.49**	**21.06**	**8.15**	**1.12/1.10**	**0.89/0.60**	**1.09/1.07**	**0.91/0.62**	**449.85**	**79.66**	**556.18**	**87.17**	**208.65**	**23.86**	**171.02**	**20.94**

Notes:
Initial: current surface (0 to 12 cm) concentration
Final: expected surface (0 to 12 cm) concentration after dredging and cover material placement

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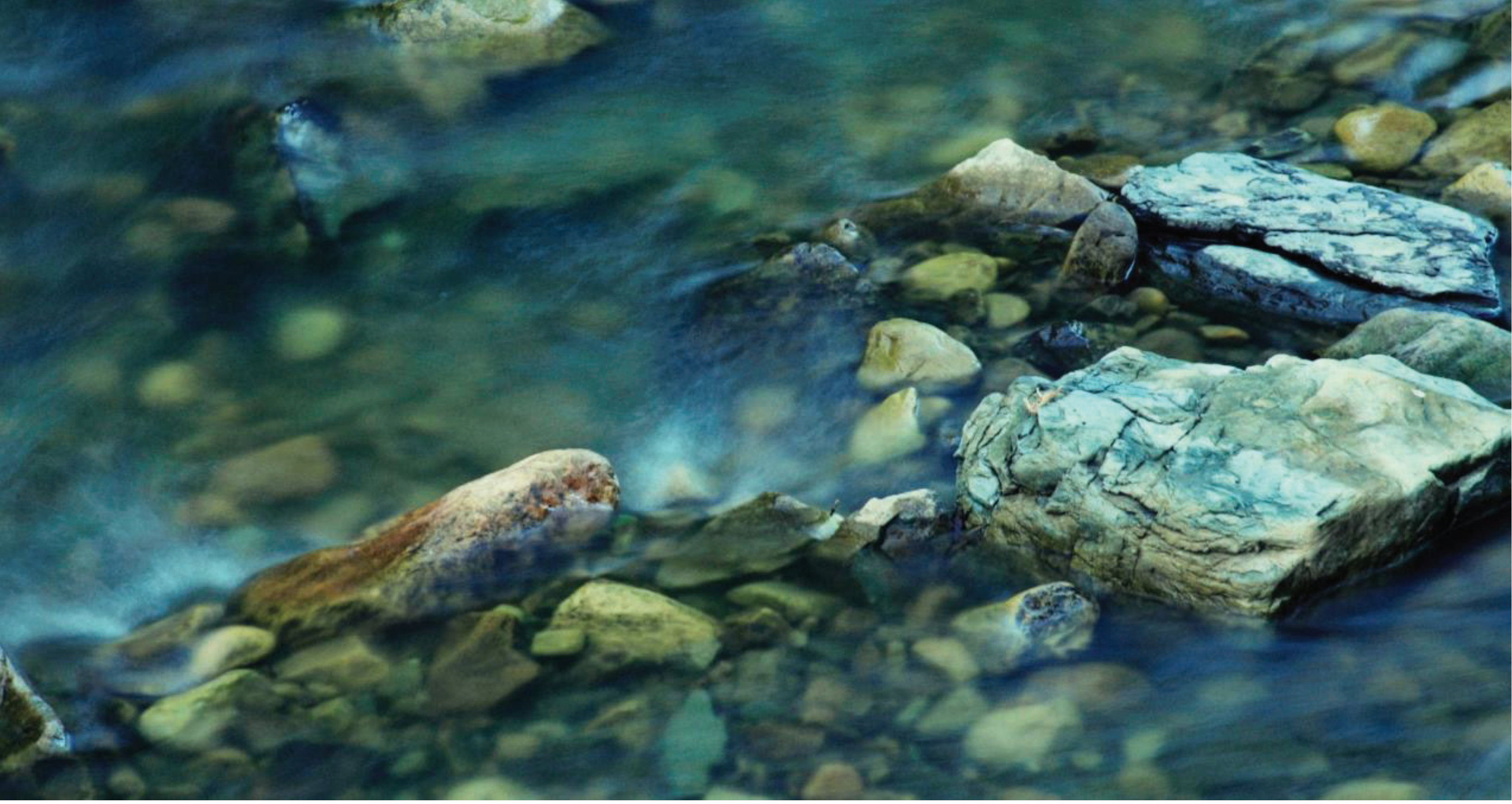
Figures

Appendix E
Proposed Best Management Practices



April 2024
Harris Avenue Shipyard Cleanup

Appendix E
Proposed Best Management Practices

Prepared for Washington State Department of Ecology

April 2024
Harris Avenue Shipyard Cleanup

Appendix E
Proposed Best Management Practices

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ABBREVIATIONS

BMP	best management practice
dB	decibel
Ecology	Washington State Department of Ecology
HPA	Hydraulic Project Approval
OHW	ordinary high water
SEL	sound exposure level
Site	Harris Avenue Shipyard Site
SPCC	Spill, Prevention, Control, and Countermeasure
USACE	U.S. Army Corps of Engineers
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources

Proposed Best Management Practices

The following best management practices (BMPs) will be employed during implementation of the in-water cleanup project for the Harris Avenue Shipyard Site (Site).

BMPs are management practices that are determined to be effective, practical, and sustainable means of achieving an environmental performance objective (e.g., compliance with water quality criteria) during Site cleanup. BMPs will be used to meet these performance objectives during construction and to limit potential adverse construction impacts. Final BMPs will be updated where necessary to incorporate additional BMPs if defined during final permits or substantive requirements.

1. Notifications

- The Washington Department of Fish and Wildlife (WDFW) Area Habitat Biologist, the U.S. Army Corps of Engineers (USACE) regulatory lead, the Washington State Department of Ecology (Ecology) regulatory lead, and the City of Bellingham regulatory lead for the project shall be notified of the project start date.
- If at any time, as a result of project activities, fish are observed in distress, a fish kill occurs, or water quality problems develop (including equipment leaks or spills), the Washington Military Department's Emergency Management Division shall be immediately contacted at 1-800-258-5990.

2. In-Water Work Timing

- In-water work will be performed consistent with the joint regulatory agency-approved fish protection work windows for the project as determined during the permitting approvals for the project.

3. Water Quality

- Turbidity and other water quality parameters will be monitored to ensure construction activities are in compliance with Washington State Surface Water Quality Standards (173-201A WAC) and in accordance with the final Water Quality Monitoring Plan (to be developed as part of the Final Sediment Engineering Design Report).
- Appropriate BMPs will be employed to minimize sediment loss and turbidity generation during dredging. BMPs include, but are not limited to, the following:
  - Removing large debris where practicable prior to dredging in known debris areas
  - Avoiding overfilling of the dredge bucket
  - Eliminating multiple bites while the bucket is on the seafloor
  - No stockpiling of dredged material below the ordinary high water line and mean higher high water line
  - No seafloor leveling

- Depending on the results of the water quality monitoring program, enhanced BMPs may also be implemented to further control turbidity. Enhanced BMPs may include, but are not limited to, the following:
  - Slowing the velocity (i.e., increasing the cycle time) of the ascending loaded clamshell bucket through the water column
  - Pausing the dredge bucket near the bottom while descending and near the water line while ascending
  - Placing filter material over the barge scuppers to clear return water
  - Using surface or near-surface silt curtains during dredging operations
- All barges transporting contaminated dredge materials will be certified as sealed (watertight) and seaworthy by a marine inspector prior to barge use.
- Barges will be managed such that the dredged sediment load does not exceed the capacity of the barge. The load will be placed in the barge to maintain an even keel and avoid listing.
- Haul barges will be loaded evenly to maintain barge stability.
- Haul barges will be filled to less than 90% capacity to reduce the potential for spillage or overflow.
- Once the barge is loaded and stabilized, it will be inspected for sediment adhered to the outside of the barge that could fall off the barge during transport. Contractor personnel will conduct a visual inspection around the entire barge deck area to remove such sediment before moving the barge out of the Site.
- All barges handling dredged materials within the Site shall have hay bales and/or filter fabric placed over the barge scuppers to help filter suspended sediment from the barge effluent.
- Barges leaving the Site will be sealed such that no discharge of water or suspended sediment occurs in the receiving waters.
- No petroleum products or other deleterious materials shall enter surface waters.
- Project activities shall not degrade water quality to the detriment of fish life.

4. Barge Operations

- Construction barges shall be restricted to tide elevations adequate to prevent grounding of the barge.
- Barge anchors shall not be placed in contaminated sediments unless specified by Ecology.
- Whenever feasible, the barge location shall be fixed through the use of methods that do not disturb contaminated sediments (e.g., mooring dolphins, docks, piers, upland structures, and anchoring in non-contaminated areas). Where these methods are not feasible, spuds may be used. The use of walking spuds shall not be permitted.
- Live boating shall be held to an absolute minimum.
- Motorized vessel operation shall be restricted to tidal elevations adequate to prevent prop scour disturbance to the contaminated sediments.

- Minimal propulsion power shall be used when maneuvering barges or other vessels to prevent prop scour disturbance to the contaminated sediments.

5. Dredging, Residuals Management Cover, and Backfill Placement

- Mechanical dredging equipment shall be used for the dredging activities.
- Slope dredging will be initiated at the top of the slope and then proceed in the down-slope direction.
- For placement of backfill materials and residual cover layers, the following measures will be observed:
  - The placement of material will generally occur starting at lower elevations and working to higher elevations.
  - Set volume, tonnage, lead line measurements, and bathymetry information or similar will be used to confirm adequate coverage during and following material placement.
  - Imported materials will be pre-approved by Ecology and consist of clean, granular material free of roots, organic material, contaminants, and all other deleterious material.

6. Spill Prevention

- The dredging contractor will inspect fuel hoses, oil or fuel transfer valves, and fittings on a regular basis for drips or leaks in order to prevent spills into the surface water.
- The use of vegetable oil-based hydraulic fluids will be specified for hydraulic lines and systems of all compatible equipment associated with in-water work to minimize the potential impacts of leaking hydraulic fluids on the aquatic environment.
- The contractor will contain all visible floating oils with booms, dikes, oil-absorbent pads, or other appropriate means and remove from the water prior to discharge into state waters.
- The contractor will immediately contain all visible oils on land using dikes, straw bales, or other appropriate means and remove using sand, ground clay, sawdust, or other absorbent material, and properly dispose.
- The contractor will temporarily store waste materials in drums or other leak-proof containers after cleanup and during transport to disposal.
- The contractor will dispose waste materials off property at an approved and permitted disposal facility and obtain certificates of disposal.
- Dredge vessel personnel will be trained in hazardous material handling and spill response and will be equipped with appropriate response tools, including absorbent oil booms. If a spill occurs, spill cleanup and containment efforts will begin immediately and will take precedence over normal work.
- The National Response Center (1-800-424-8802), the Washington Emergency Management Division (1-800-258-5990 OR 1-800-OILS-911), and U.S. Coast Guard (206-217-6002) will be notified immediately if a spill occurs.

- The contractor shall be responsible for the preparation of a Spill, Prevention, Control, and Countermeasure (SPCC) Plan to be used for the duration of the project. The SPCC Plan shall be submitted to the Project Engineer prior to the commencement of any construction activities. A copy of the SPCC Plan, and any updates, will be maintained at the work site by the contractor and will include the following:
  - The SPCC Plan shall identify construction planning elements and recognize potential spill sources at the work site. The SPCC Plan shall outline responsive actions in the event of a spill or release and shall describe notification and reporting procedures. The SPCC Plan shall outline contractor management elements such as personnel responsibilities, project site security, site inspections, and training.
  - The SPCC Plan will outline what measures shall be taken by the contractor to prevent the release or spread of hazardous materials, either found on site and encountered during construction but not identified in contract documents, or any hazardous materials that the contractor stores, uses, or generates on the construction site during construction activities. These items include, but are not limited to, gasoline, oils, and chemicals. Hazardous materials are defined in Revised Code of Washington 70.105.010 under "hazardous substance."
  - The contractor shall maintain at the job site the applicable equipment and material designated in the SPCC Plan.

7. Shoreline Dredging and Modifications

- Excavators operated from the shoreline and used to dredge or otherwise modify the shoreline shall only be operated from above ordinary high water (OHW).
- Shoreline excavation shall be conducted in the dry to the extent possible.
- Each pass of the excavator bucket shall be complete.
- Under no circumstances shall excavated materials be stockpiled below the OHW line.
- Track excavators used for shoreline excavations shall be routinely inspected and repaired as necessary to prevent the introduction of hydraulic fluid and petroleum products into waters of the state.
- Manmade shoreline debris shall be appropriately recycled for reuse or shall be disposed of at appropriate upland sites.

8. Sediment Offloading to the ASB CDF

The following BMPs will be applied during offloading of sediment to the aerated stabilization basin confined disposal facility (ASB CDF):

- Offloading will be conducted using the purpose-built facilities established for that purpose as part of the Whatcom Waterway cleanup project. Those facilities provide appropriate engineering controls (e.g., enclosed pipelines and spill aprons) for containment of sediment and entrained waters during transloading from the haul barges to the ASB CDF.

- Transloading equipment shall be operated to prevent dredged material spillage when transferring materials between the haul barge and the ASB CDF. Enclosed pipelines and spill aprons will direct any sediment or water spillage back into the ASB CDF or into the haul barges and not into Whatcom Waterway.
- For transfers by dredge bucket, the bucket swing path from the haul barge to the ASB CDF will not be allowed to occur over open water. The contractor will need to swing the offloading bucket over either the derrick barge and spill apron or a "spanning" barge and spill apron to capture any spillage from the offloading bucket.
- Visual monitoring will be performed by the contractor to determine if the transport of dry dredged/excavated materials creates a dust concern, and, if so, dust suppression controls will be employed (e.g., covering the haul trucks or containers).
- When wet materials are transported over land, haul trucks or rail car containers will be lined or sealed to reduce the chance of sediment or water release during transport.

9. Sediment Offloading to Other Upland Areas

The following BMPs will be applied to any sediment offloading facilities used to transfer contaminated sediment or debris:

- Proposed offloading facilities must be of adequate structural capacity for use for offloading and staging. The maximum structural capacity of these facilities cannot be exceeded by the contractor.
- If upland stockpiles are used, these stockpiles will have full perimeter containment to prevent uncontrolled runoff of water that has been in contact with contaminated sediment or debris.
- The contractor will be required to collect, test, and treat effluent water from transport haul barge and stockpiling operations per local regulations prior to discharge into receiving waters.
- The contractor's off-site offload facility will use applicable erosion and sedimentation controls, such as filter fence barriers and/or lined ecology block walls, to prevent stockpiled materials from entering adjacent receiving waters.
- Catch basins within the offloading area will be sealed and all water will be collected and stored on site for treatment and/or off-site disposal.
- The offloading facility will include active measures (e.g., wheel/truck wash) to prevent vehicles from tracking contaminated sediment off site. Trucks will be inspected before they leave the temporary upland stockpile area.
- Trucks or rail cars will not be overloaded (i.e., appropriate freeboard will be maintained) to prevent loss due to spilling during transport.
- Truck loading areas will be swept frequently to reduce the probability of truck tires tracking contaminated materials outside of the loading areas.

- The trucks, truck loading area, and the access route will be visually inspected to confirm there is no loss of material from the trucks prior to releasing the truck from the temporary upland stockpile to public roads.
- Equipment will be fueled in a designated area that separates fueling operations and protects the environment from accidental spills during fueling.
- The contractor will maintain a spill kit on site in the event that a leak develops from their equipment. In the event of a spill, all other work will stop until the contractor has adequately cleaned the spill.

10. Material Handling and Disposal

- If required, staging facilities installed for management of dredged materials are intended only for temporary use during the project. After the project is completed, these temporary facilities shall be completely removed unless otherwise approved in writing by Ecology.
- Contaminated sediments dredged from the Site shall be disposed of at either the ASB CDF or an alternative Ecology-approved Subtitle D landfill facility.

11. Pile Removal, Handling, and Disposal

The following pile removal BMPs adapted from U.S. Environmental Protection Agency guidance (USEPA 2007) and Washington Department of Natural Resources (WDNR) (WDNR 2007) will also be employed for pile removal:

- The removal of the creosote-treated piles shall be consistent with conditions issued as part of the Derelict Creosote Pile Removal Project Hydraulic Project Approval (HPA), issued to the WDNR Northwest Region (Control Number 106389 – 3, Issued August 8, 2007).
- The contractor will initially vibrate piles to break the friction bond between piles and soil.
- To help minimize turbidity, the contractor will engage the vibrator to the minimum extent required to initiate vertical pile movement, and will disengage the vibrator once piles have been mobilized and are moving upward.
- The piles will be removed in a single, slow, and continuous motion to the extent possible.
- Upon removal from the substrate, piles will be moved expeditiously from the water to a barge and then offloaded for disposal or recycling if possible.
- Piles shall be removed slowly and in a direction that is an extension of the longitudinal centerline of each pile to minimize the disturbance of the bed and the suspension of contaminated sediments into the water column.
- Extracted piles shall be placed immediately in a containment basin constructed on the barge or adjacent upland to capture and contain the extracted piles, adhering sediments, and water.
- The extracted piles shall not be shaken, hosed off, left hanging to drip, or made subject to any other action intended to clean or remove adhering material from the pile.

- Holes in the bed resulting from the extraction of the piles shall be covered with clean cap materials consistent with the project design.
- Every attempt will be made to completely remove the piling in its entirety; however, pile cut-off will be an acceptable alternative where vibratory extraction or pulling is not feasible, as described below. In addition, if a pile is broken or breaks during vibratory extraction, the contractor will employ the following methods:
  - A chain will be used if practicable to attempt to entirely remove the broken pile.
  - If the entire pile cannot be removed, the pile will be cut at the mudline.
  - Pile cut-off will be an acceptable alternative in areas (e.g., shoreline area) where removal of the existing piles may result in adverse impact to slope stability.
- If a pile cannot be removed or breaks off at or near the existing substrate, then the pile shall be cut off using a pneumatic underwater or a clamshell bucket as close to the bed as possible without disturbing the bed and a maximum of 12 inches above the bed. Areas where piles are cut off will be capped with Ecology-approved materials to contain the remaining contamination associated with the piles.
- Cut-off pile stubs shall be captured whenever feasible, removed, and deposited in the containment basin constructed on the barge or adjacent upland.
- Sawdust from cutting pile stubs shall be captured whenever feasible, removed, and deposited in the containment basin constructed on the barge or adjacent upland.
- A floating surface boom shall be installed around the pile extraction site to capture floating pile debris. Floating pile debris shall be removed and deposited in a containment basin constructed on the barge or adjacent upland.
- The floating surface boom shall be equipped with absorbent pads to contain any oil sheens. The absorbent pads shall be removed and deposited in the containment basin constructed on the barge or adjacent upland.
- A containment basin shall be constructed on the barge deck or adjacent upland to receive the piles, pile stubs, water, sawdust, and any sediment.
- The containment basin shall be constructed of durable plastic sheeting with sidewalls supported by hay bales or support structure.
- To the extent possible, pile extraction shall be conducted during periods when the water currents are low.
- The piles, pile stubs, sawdust, and absorbent pads from the floating surface boom shall be removed and disposed of in accordance with applicable federal and state regulations.
- The water captured in the containment basin shall be removed and disposed of in accordance with applicable federal and state regulations.
- The containment basin shall be removed and disposed of in accordance with applicable federal and state regulations.

- Extracted piles within the containment basin or disposal container shall be cut to size as required by container and disposal contractors. All sawdust and cuttings shall be contained within the containment basin or disposal container.
- The cut-up piles, sediments, sawdust, water, absorbent pads from the floating surface boom, and plastic from the containment basin shall be packed into a disposal container and transported to an approved upland disposal site.

The use of a boom and the other measures listed above to contain and properly dispose of debris shall also be employed during removal of creosote-treated wooden bulkhead or dock structures. Specific removal methods for these structures will be appropriate to the structure and location (e.g., a backhoe or clamshell may be used rather than a vibratory hammer or chain to remove sections of treated wood from a dock or bulkhead).

12. Replacement Infrastructure

- Sound attenuation methods are required for the driving or proofing of steel piles with an impact hammer below the OHW line. For impact driving of steel piles that exceed the following criteria, a bubble curtain or other WDFW-approved sound attenuation device shall be used. The specific criteria include sound pressure levels of the following:
  - Greater than or equal to 206 decibels (dB) (one microPascal squared per second) peak
  - Greater than or equal to 187 dB (one microPascal squared per second) accumulated sound exposure level (SEL) for fish greater than or equal to 2 grams
  - Greater than or equal to 183 dB (one microPascal squared per second) SEL for fish less than 2 grams
- A bubble curtain shall be installed and properly functioning around the pile during all impact driving operations. The bubble curtain shall distribute air bubbles around 100% of the perimeter of the piles over the full length of the pile in the water column.
- New steel piling, dolphins, and fender piles shall be coated with a rubbing surface, rubbing strip, or rubber energy absorption fenders.

13. Steel Sheetpile Bulkheads

- The new steel sheetpile bulkheads will be installed to the extent possible with a vibratory hammer. If an impact hammer is required to drive or proof the new steel sheetpile bulkhead, then a bubble curtain shall be installed and properly functioning around the sheetpile bulkhead.
- Wet concrete used to construct a concrete cap on top of the steel sheetpile bulkhead shall be prevented from entering waters of the state. Forms shall be constructed to prevent leaching of wet concrete. Impervious materials shall be placed over any exposed concrete not lined with the forms that will come in contact with state waters. Forms and impervious materials shall remain in place until the concrete is cured.

- The contractor will be required to collect and manage soil cuttings generated during drilled tie-back anchor installation such that no cuttings are allowed to discharge to Bellingham Bay during drilling operations.

14. Decontamination of Construction Equipment

- At the completion of the dredging work and prior to any clean material placement, the dredging buckets will be pressure-washed over the last haul barge and the wash water will be managed for off-site disposal consistent with the barge dewatering effluents. Similarly, the dredged material haul barges will be decontaminated prior to any other use.
- Decontamination of the dredge, excavation equipment (where applicable), and haul barges will be conducted at the completion of the Site remedial activities. The haul barges will be swept and pressure-washed (including all portions of the barge where sediment is visually present) such that no sediment or dredge return water is released to Bellingham Bay. The remaining sediment and water inside the barge will be collected and treated in accordance with state and federal requirements prior to being discharged.

15. Barge Operations

- Barges shall be restricted to tide elevations adequate to prevent grounding of the barge.
- Barge anchors shall not be placed in contaminated sediments unless approved by Ecology.
- Whenever feasible, the barge location shall be fixed through the use of methods that do not disturb contaminated sediments (e.g., mooring dolphins, docks, piers, upland structures, and anchoring in non-contaminated areas). Where these methods are not feasible, spuds may be used. The use of walking spuds shall not be permitted.
- Live boating shall be held to an absolute minimum.
- Motorized vessel operation shall be restricted to tidal elevations adequate to prevent propeller scour disturbance to the contaminated sediments.
- Minimal propulsion power shall be used when maneuvering barges or other vessels to prevent propeller scour disturbance to the contaminated sediments.

16. Eelgrass Protection

- The existing eelgrass habitat in the southeastern corner of the Site will be protected. This area will be buoy-marked prior to initiating in-water construction activities.

17. Cultural and Historic Resources

- If any previously unknown historic, cultural, or archaeological remains and artifacts are discovered during construction, the Port of Bellingham will immediately notify the District Engineer of what was found and, to the maximum extent practicable, avoid construction activities that may affect the remains and artifacts until the required coordination has been completed. The USACE District Engineer will initiate the federal, tribal, and state coordination required to determine if the items or remains warrant a recovery effort or if the Site is eligible for listing in the National Register of Historic Places.

- Work will immediately stop and notification will be provided to the USACE District Engineer within 24 hours if, during the course of conducting authorized work, human burials, cultural resources, or historic properties, as identified by the National Historic Preservation Act, are discovered.

References

USEPA (U.S. Environmental Protection Agency), 2007. Best Management Practices for Pile Removal & Disposal (White Paper). March 2007.

WDNR (Washington Department of Natural Resources), 2007. Puget Sound Initiative—Derelict Creosote Piling Removal Best Management Practices For Pile Removal & Disposal. Washington Department of Natural Resources. Control Number 106389 – 3, Issued August 2007.

Appendix F
Project Schedule

Harris Avenue Shipyard Cleanup Project
Draft Overall Project Schedule - Years 2024 to 2027

		2024												2025											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Agreed Order Amendment [1]																								
	AO Amendment (schedule revision and sediment disposal at ASB)																								
In-Water	**In-Water EDR**																								
	Ecology Review Period																								
	Final EDR (schedule pending AO revisions)																								
	Ecology Approval of Final EDR [2]																								
	In-Water Permitting																								
	Draft In-Water Permits (schedule pending AO revisions)																								
	Ecology Review Period																								
	Final In-Water Permits (schedule pending AO revisions)																								
	USACE/Ecology Permit Timeline																								
	In-Water Remediation Design																								
	30% Design (internal review only)																								
	60% Design (internal review only)																								
	90% Design (schedule pending AO revisions)																								
	Ecology Review Period																								
	Response to Comments (schedule pending AO revisions)																								
	100% Design (schedule pending AO revisions)																								
Bidding and Construction	**Bidding and Construction**																								
	In-Water Remediation																								
	Bidding and Contract Award																								
	Construction													X	X						X	X	X	X	X

Upland Remediation Elements
In-Water Remediation Elements
Ecology Review or Approval Periods
Timeline Requirement per Agreed Order (described in corresponding parenthetical)

X: In-Water Work Window: approximately Aug 1 to Feb 15
d: Days

Harris Avenue Shipyard Cleanup Project
Draft Overall Project Schedule - Years 2024 to 2027

		2026												2027											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Agreed Order Amendment [1]																								
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Bidding and Construction	**Bidding and Construction**																								
Bidding and Construction	**In-Water Remediation**																								
Bidding and Construction	Bidding and Contract Award																								
Bidding and Construction	Construction	X	X						X	X	X	X	X	X	X						X	X	X	X	X

Upland Remediation Elements
In-Water Remediation Elements
Ecology Review or Approval Periods
Timeline Requirement per Agreed Order (described in corresponding parenthetical)

X: In-Water Work Window: approximately Aug 1 to Feb 15
d: Days