APPENDIX P

Mill A Scour Study

Vessel Propeller Wash Scour Analysis

Project:	Vessel Propeller Wash Scour Analysis, Port of Everett, South Terminal		
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Approved by:	Shane Phillips	**Checked by:**	Shane Phillips
Subject:	Vessel Propeller Wash Scour Analysis		

Introduction

This report presents the results of a vessel prop wash scour assessment performed to identify the depth of scour that is projected to be caused by ships and tugs at the Former Weyerhaeuser Mill A Site, which encompasses Pacific Terminal, Pier 1 South, and South Terminal at the Port of Everett as shown in Figure 1. The assessment evaluates scour due to deep-draft vessel and tug propulsion systems associated with maneuvering and berthing at the at these locations. The results of the engineering analysis will be used to support characterization of the site as part of the remediation investigation (RI).

General Assumptions

The following general assumptions are be used throughout the analysis:

- Environmental factors such as winds, waves, currents, or ship-induced wakes are assumed to be negligible contributors to the scour and are, therefore, not included in the analysis.
- Vessel maneuvering operations are based on a combination of information including maneuvering operations using AIS data and port descriptions, along with industry guidance.

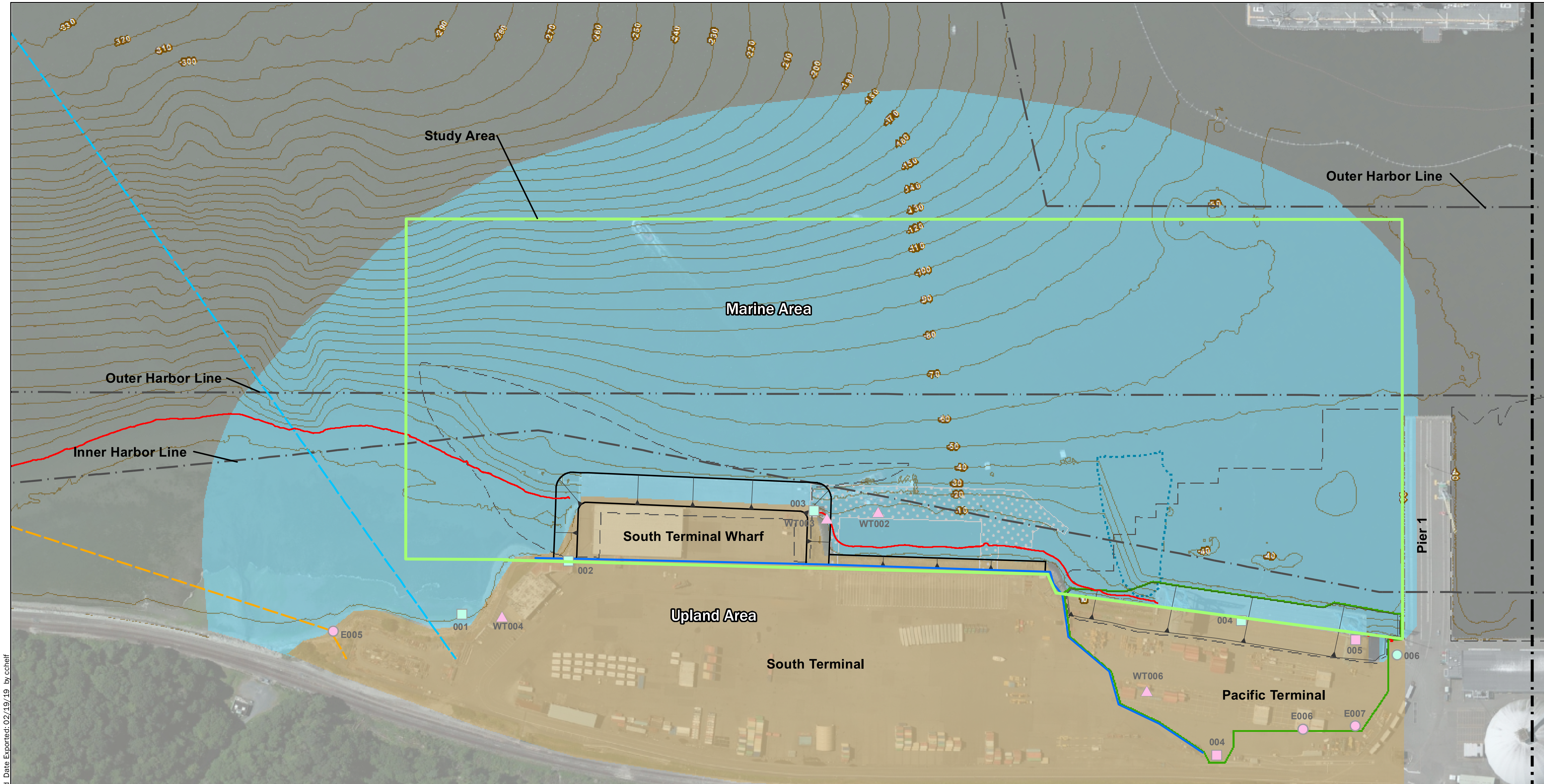
Study Area

Terminal Areas

The study area is located at the Port of Everett (Port), in Everett, Washington. The limits of the study area encompass three Port terminal areas (Figure 1) within the area undergoing investigation as part of the RI for the former Mill A Site (GeoEngineers, 2017) (Figure 2). The three Port terminal areas within the study area are the following:

- Pacific Terminal;
- Pier 1 South; and
- South Terminal.

Figure 1. Terminal Areas in Study Area (Source: GeoEngineers, 2017)



Legend

- Marine Remedial Investigation Area (Marine Area)
- Upland Remedial Investigation Area (Upland Area)
- Construction Berm Fill
- Historical Pier
- Interim Action Dredge Area
- Dredged Area
- Nearshore Confined Disposal (NCD) Facility
- -3 Feet Mean Low Low Water (MLLW) Elevation Contour Line
- Bulkhead
- Historical Industrial Outfall
- Former Combined Sewer Outfall (CSO)
- Former Stormwater Outfall
- Current CSO
- Current Stormwater Outfall
- Current Kimberly-Clark/City of Everett/ City of Marysville Outfall 100 (approximate)
- Historic Kimberly-Clark/Weyerhaeuser Outfall SW001 (approximate)

300 0 300

Feet

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and contentof electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Data Source: Base aerial from Bing Maps, 2011.
Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

C:\Users\cchelf\Desktop\0676020005_F02_StudyArea.mxd Date Exported: 02/19/19 by cchelf

Scour Analysis

Weyerhaeuser Mill A Former
Everett, Washington

GEOENGINEERS

Figure 2

Bathymetry

The bathymetry in the study area is based on the following two surveys:

- Pacific Geomatics Services, Inc. (PGS) bathymetric survey performed September 8-11, 2013.
- Tetra Tech (TT) bathymetric survey performed February 21-22, 2017.

The survey completed in September 2013 encompasses the entire study area. The 2017 survey was specifically completed to document the change in bathymetry resulting from the completion of an interim action performed at the southwest end of the Pacific Terminal. The survey data collected in 2017 was used to update the survey performed in 2013 in the specific area of the interim action. The combined surveys are presented in Figure 2.

Tides

Tidal datum elevations at the study area used for the scour study are based on those at NOAA Station 9447569, Everett, Washington and are presented in Table 1. Note that these elevations are based on the 1983-2001 tidal epoch. The vertical datum for the analysis is Mean Lower Low Water (MLLW). The assumed water level for analysis is 0.0 feet MLLW.

Table 1. Tidal Datum Elevation Information, NOAA Station 9447659 Everett, 1983-2001 Tidal Epoch (Source: NOAA, 2013)

Tidal Datum	Elevation (fee. MLLW)
Highest Astronomical Tide (HAT)	+13.22
Mean Higher High Water (MHHW)	+11.09
Mean High Water (MHW)	+10.22
Mean Tide Level (MTL)	+6.51
Mean Sea Level (MSL)	+6.48
National Geodetic Vertical Datum of 1929 (NGVD29)	+5.72
Mean Low Water (MLW)	+2.80
North American Vertical Datum of 1988 (NAVD88)	+2.04
Mean Lower Low Water (MLLW)	0.00
Lowest Astronomical Tide (LAT)	-4.28

Sediment Characteristics

The characterization of the existing sediment in the study area is based on surface and subsurface sediment sampling performed as part of the RI. Numerous surface sediment samples and subsurface sediment cores have been collected and logged as part of the investigation to characterize contaminant concentrations and sediment stratigraphy (GeoEngineers, 2017).

Based on observations of surface and subsurface sediment performed as part of the RI, the existing sediment in the terminal areas are comprised of the following:

- Pacific Terminal and Southwest of Pier 1 Shoreward of the Outer Harbor Line (Figure 2) – Surface sediment in this area is predominantly comprised of recent deposits that range from silt to fine to medium sand with occasional wood debris (bark, sawdust, chips, chunks, and twigs) and shell fragments overlying native deposits comprised of silt to fine to medium sand with occasional shell fragments. On the southwest end of the Pacific Terminal, where an interim action was performed in 2017 (Figure 3), dredging removed the recent deposits and exposed the native fine to medium sand at the surface.

- Area Between the Pacific Terminal and South Terminal Shoreward of the Outer Harbor Line – Surface sediment in the navigational portion of this area (i.e., between the mooring dolphins and outer harbor line) is predominantly comprised of recent deposits consisting of silt to silty fine sand with wood debris (bark, sawdust, chips and chunks) and trace shell fragments. The native sediment underlying surface sediment is comprised of silty fine to medium sand with occasional wood debris and shell fragments.
- South Terminal Shoreward of the Outer Harbor Line – Surface sediment in this area is predominantly comprised of recent deposits of silty fine sand with traces of or occasional wood debris (bark chips, chunks, twigs and lumber) and shell fragments overlying native silty fine sand to course sand with trace wood debris and shell fragments.
- Study Area Waterward of the Outer Harbor Line – Surface sediment in this area is predominantly comprised of recent deposits ranging from silt to silty fine sand with traces of or occasional wood debris (bark sawdust, chips, chunks, twigs and lumber) and shell fragments overlying native fine sand to medium sand with trace to occasional shell fragments.

Generalized cross-sections depicting the sediment stratigraphy in the study area are provided in Appendix 1. The cross-sections were used to map the sediment properties over the extent of the study area.

Grain Sizes

Grain size distributions were provided by GeoEngineers (2017), from which median grain sizes were estimated. Except for a coarse sample near the offshore end of Pier 1, median grain sizes range from 0.036 to 0.23 mm (-0.67 to 4.80 phi).

Stratigraphy and Bulk Sediment Characteristics

Sediment stratigraphy over six cross-sections – A-A', B-B', C-C', D-D', E-E', and F-F' – was developed by GeoEngineers (2016) as depicted in Appendix 1. In general, the cross-sections include up to four types of material:

1. Sediment Deposit (<10% Wood)
2. Mixed Deposit (>10%, <50% Wood)
3. Wood Debris (>50% Wood)
4. Native Silt and Sand

Bulk sediment characteristics developed by GeoEngineers (Chin, 2019) are listed in Table 2. For all four sediment types, the cohesion was assumed to be negligible (Chin, 2019).

Table 2. Bulk Sediment Characteristics

Sediment Type	Specific Gravity of the Sediment Solids G_s	Unit Weight (lbs./foot^3)	Friction Angle (deg.)
Sediment Deposit (<10% Wood)	2.65	115	32
Mixed Deposit (>10%, <50% Wood)	1.85	80	28
Wood Debris (>50% Wood)	1.40	70	28
Native Silt and Sand	2.65	115	32

Terminal and Vessel Information

Introduction

The study area encompasses a zone identified to have contaminated sediment where vessel and tug maneuvering occurs to berth and moor deep-draft vessels on the southwest side of Pier 1 and at the Pacific Terminal and the South Terminal (Figure 2). The existing configurations of the three terminal areas are shown on Figures 1 and 2 and are based on the following sources:

- Remedial Investigation / Feasibility Study Work Plan (GeoEngineers, 2014);
- Information available from the Port of Everett (2018a, 2018b, 2018c, 2018d, and 2018e); and,
- The list of vessels provided by the Port of Everett (2018f) (see Appendix 2).

The configurations and uses of the terminals and a description of the deep-draft vessels and tugs that use the terminal areas are discussed below. A list of deep-draft vessels based on input from the Port of Everett (2018f) and vessel tracking information provided by Astra Paging, Ltd. (2018) can be found in Appendix 2.

Terminal Information

Pacific Terminal

The Pacific Terminal wharf is 650 feet long and runs parallel to the shoreline. The depth of the berth at the Pacific Terminal is -40 feet MLLW. This facility is typically used for container ships, general cargo (break bulk) vessels, and bulk carriers (Port of Everett, 2018b).

Pier 1

The Pier 1 wharf is located at the northern boundary of the study area, is 600 feet long, and runs perpendicular to the shoreline. The depth on the berth on southwest side of Pier 1 (i.e., Pier 1 South) within the study area is -40 feet MLLW. The facility is typically used for Ro/Ro vessels and barges (Port of Everett, 2018a). Although ships and barges berth on northeast portion of Pier 1, the scour analysis is not being performed for the northeast portion of Pier 1 because the northeast portion of Pier 1 is not in the study area.

South Terminal

The South Terminal wharf (Berth 1) is 700 feet in length and is located at the southwestern end of the Port’s terminal areas. The depth of the South Terminal berth is -36 to -38 feet MLLW. Uses of the South Terminal wharf have included general cargo ships and barges that do not include a crane for offloading, with the exception of a heavy lift pod located on the north corner of the South Terminal wharf utilized by the Port’s mobile harbor crane. The South Terminal wharf is currently undergoing upgrades to allow the use of shore-side cranes for vessel offloading.

The South Terminal also includes mooring dolphins that extend approximately 800 feet north from the northwest corner of the South Terminal wharf (Figure 1). The mooring dolphins are used by Ro/Ro vessels to moor and offload at the South Terminal wharf.

The South Terminal wharf is currently undergoing upgrades to allow the use of shore-side cranes for vessel offloading. Future dredging is anticipated to allow larger vessels to access the terminal.

Vessel Information

Pacific Terminal

Deep-draft vessels using the Pacific Terminal primarily include container vessels of the class operated by Westwood Shipping Lines, such as the Bardu. The Bardu is 685 feet in length and has a beam (width) of 98 feet and a maximum draft of 38 feet of water (Appendix 2). Barges are also a primary user of the Pacific Terminal. Tug boats used to assist the maneuvering of deep-draft vessels and for maneuvering barges to the Pacific Terminal include tractor type tugs like the Bo Brusco or conventional tugs like the Spartan. However, the preference is for use of tractor-type tugs to maneuver vessels and barges to the Pacific Terminal.

Deep-draft vessels that use the Pacific Terminal less frequently include general cargo (break bulk) vessels similar in size to the Donaugracht, operated by Spliethoff. The Donaugracht is 515 feet in length and has a beam of 75 feet and a typical draft of 34 feet of water. Tug boats used to assist the maneuvering of general cargo vessels to the Pacific Terminal include tractor-type tugs like the Bo Brusco or conventional tugs like the Skagit.

Vessels that are anticipated to use the Pacific Terminal in the future include larger Handy Max vessels, as well as the existing container and break-bulk vessels and barges. Tug boats anticipated to be used in the future at the Pacific Terminal are predominantly tractor type tugs.

Pier 1 South

Pier 1 South is primarily used by Ro-Ro vessels and barges that are maneuvered by tug boats. Deep-draft vessels using Pier 1 South primarily include Ro-Ro vessels of the class of the Madame Butterfly. The Ro-Ro vessel Madame Butterfly is 649 feet in length and has a beam (width) of 106 feet and a maximum draft of 38 feet of water. Tug boats used to assist the maneuvering of vessels and for maneuvering barges to Pier 1 South include tractor type tugs like the Bo Brusco or conventional type tugs like the Spartan. As stated above, the preference is for use of tractor type tugs to maneuver vessels and barges to Pier 1 South.

Vessel and barge use in the future at Pier 1 are anticipated to be similar to the present. Tug boats anticipated to be used in the future at Pier 1 South are predominantly tractor-type tugs.

South Terminal

Vessels using the South Terminal primarily include break bulk vessels and bulk carriers that do not need a dock-side crane for unloading. The vessels are similar in size to the POS Oceania, operated by Fukujin Kisen. The POS Oceania vessel is 556 feet in length and has a beam of 89 feet and a maximum draft of 32 feet of water. Tug boats used to assist the maneuvering of vessels to the South Terminal include tractor type tugs like the Bo Brusco or conventional type tugs like the Spartan. However, the preference is for use of tractor type tugs to maneuver vessels and barges to the South Terminal.

Vessels that use the South Terminal less frequently include Ro-Ro vessels of the same class using Pier 1 South. Tug boats used to assist in maneuvering the Ro-Ro vessels to the South Terminal include tractor type tugs like the Bo Brusco or conventional type tugs like the Spartan.

Vessels that are anticipated to use the South Terminal in the future include container vessels of the class used by Westwood Shipping Lines described above and larger Post-Panamax container vessels up to 1,050 feet in length with a 6,000 twenty-foot equivalent units (TEUs) capacity. Tug boats anticipated to be used in the future at the Pacific Terminal are predominantly tractor-type tugs.

Vessel Tracking Data

General

For the purposes of the scour assessment, the movement of vessels into, within, and out of the study area are based on Automatic Identification System (AIS) vessel tracking data provided by Astra Paging Ltd. (aishub.net). AIS is a tracking system used by marine vessel traffic services (VTS) to monitor and record maritime vessel activities. The data is for the period between January 1, 2016 to December 31, 2017 and includes the following parameters spaced an average of 30 seconds apart:

- Date and time
- Maritime Mobil Service Identity (MMSI) and International Maritime Organization (IMO) numbers for each vessel
- Vessel's name
- Vessel's call sign
- Coordinates in latitude and longitude
- Heading of the vessel's hull in degrees
- Course over ground in degrees
- Speed over ground in knots
- Vessel's type according to AIS specification (http://catb.org/gpsd/AIVDM.html#_type_5_static_and_voyage_related_data).
- Vessel length
- Vessel beam (width)
- Vessel draft at the time of the position record
- Destination port the vessel is sailing to as manually entered by the vessel Master
- Estimated time of arrival as manually entered by the Master

The AIS data was analyzed to evaluate vessel movements within the study area and terminal locations. Appendix 3 provides details regarding the sorting of the vessel tracking data by vessel type and location. The AIS data analysis as described in Appendix 3 and below identifies the areas of vessel, barge, and tug movements and associated main engine and bow thruster usage based on the data collected in 2016 and 2017.

AIS Vessel Type

The AIS vessel tracking system includes a numerical designation for each vessel type based on an AIS-specific vessel type description. The AIS data for the Port identifies vessel and tug types that utilize the terminals in the study area (Table 3). The scour analysis includes cargo vessels (AIS types 70-74 and 79), which consist of container ships, bulk carriers, and general cargo vessels that utilize the terminals being evaluated. The scour analysis also includes “tugs” (AIS type 52), “towing vessels” (AIS types 31 and 32) (see Table 3). Although “tugs” and “towing” vessels are generally tug boats, the AIS vessel tracking system makes the following distinctions in terms of function (BOEM, 2018; Raymond, 2016):

- The type 31, “towing” classification refers to vessels towing ahead of or alongside, but not astern, of larger vessels.
- The type 32, “towing” classification refers to vessels that are towing astern of larger vessels, regardless of whether the length of the tow exceeds 656 feet (200 m) or the breadth of the larger vessel exceeds 82 feet (25 m).
- The type 52, “tug” classification refers to light boats, fleet boats, or similar work boats.

Vessel types 31 and 32 are generally exerting high engine thrust to assist the maneuvering of larger vessels. Vessels of type 52 are generally traveling alone, and for that reason, are usually not having to exert high engine thrust. The vessel types to be evaluated as part of the scour assessment based on the AIS data analysis in Appendix 3 are listed in Table 3.

Table 3. AIS Vessel Types to Be Evaluated

Code	AIS Vessel Type
	CARGO VESSELS:
70	Cargo - all ships of this type
71	Cargo - Hazardous Category A
72	Cargo - Hazardous Category B
73	Cargo - Hazardous Category C
74	Cargo - Hazardous Category D
79	Cargo - No additional information
	TUGS AND TOWING VESSELS:
31	Towing
32	Towing: length exceeds 200m or breadth exceeds 25m
52	Tug

Vessels for Scour Analysis

Based on the AIS data (Appendix 3) and information on vessels that utilize the terminals from the Port (Appendix 2), vessels to be used in the scour analysis are listed in Table 4. Photographs of the selected vessels appear in Appendix 2.

Table 4. Hull and Propulsion System Characteristics of Vessels to Be Used in the Scour Analysis

Vessel Name	Bardu	Madame Butterfly	Pos Oceania	Bo Brusco
Vessel Type	Container Ship	Ro / Ro Carrier	Bulk Carrier / Cargo	Tug
MMSI	538005316	563892000	538004706	367642530
Location	Pacific Terminal	Pacific Terminal	South Terminal	All 3 Terminals
Length (feet)	685	649	556	78
Beam (feet)	98	106	89	29
Max. Draft (feet)	38	38	32	9
Main Propeller Diameter (feet)	18.7 (not ducted)	19.8 (not ducted)	17.3 (not ducted)	7.9 (ducted)
Main Propeller Power	21,660 kW 29,047 hp	13,554 kW 18,176 hp	16,160 kW 21,671 hp	3,529 kW 4,732 hp
Applied Main Power	15% at berth 28% off berth	15% at berth 28% off berth	15% at berth 28% off berth	100%
Bow Thruster Diameter (feet)	6.6 (ducted)	6.6 (ducted)	6.1 (ducted)	Not applicable
Bow Thruster Power	1,282 kW 1,719 hp	1,500 kW 2,012 hp	1,030 kW 1,381 hp	Not applicable
Applied Thruster Power	100%	100%	100%	Not applicable

Vessel Operations

Overview

Deep-draft vessels enter the study area from the west to approach the Pacific Terminal, Pier 1 South, and the South Terminal. Other deep-draft vessels including lumber ships up to Handymax size traverse the study area to moor at Pier 1 North and Pier 3 north of the study area.

Tugs typically engage inbound, deep-draft vessels in the western portion of the study area. Vessel propeller wash is not believed to be a major contributor to scour from inbound vessels except when the ship is getting aligned with the berth it is using. Tugs typically disengage from outbound, deep-draft vessels in the western portion of the study area upon maneuvering away from the terminal mooring area.

Handymax vessels and Westwood Shipping’s “N” class (≤ 656-foot) vessels (i.e.: Olympia, Victoria, Rainier) typically use their bow thrusters and a single tug during berthing operations. Westwood Shipping’s larger vessels (>679-foot) may need one or two tugs to berth, depending on which terminal is being used. Ro/Ro vessels typically need two tugs to berth. During tug operations, water has the potential to be forced down where the tug’s propeller wash is deflected off the larger vessel's hull. Vessels at the port do not use anchors. As deep-draft vessels leave the berth, they turn on their main engine propellers to maneuver away from the terminals with the assistance of tugs.

Deep-draft vessel maneuvering patterns during arrival and departure at each terminal are depicted in Appendix 4, with narrative descriptions below. The vessel maneuvering patterns depicted in Appendix 4 were used with the AIS data to develop the assumed vessel positions used in the propeller wash evaluation.

Pier 1 South

Deep-draft vessels approaching Pier 1 South typically come in from the west or northwest, engaging with tugs on the vessel's port side. The vessel is rotated counterclockwise, lining up the starboard side of the vessel with the southwest side of Pier 1. Initial contact of the vessel with Pier 1 is near the stern of the vessel. Bow thrusters or a tug are then used to maneuver the vessel's forward section to the pier. Port staff members stated that tugs are sometimes used to keep Ro/Ro vessels from hard impacts to the dock in higher wind conditions.

During departure, the vessel rotates clockwise about its stern until facing either southwest or west. Once the vessel passes opposite the south end of Pacific Terminal, the tugs disengage from the vessel.

Pacific Terminal

Ships coming into the Pacific Terminal utilize several different approaches depending on ship size, wind direction and strength, tide, and pilot preference. However, deep-draft vessels approaching Pacific Terminal typically come in from the west or northwest, turning clockwise until the bow faces the southwest. Once the vessel is opposite the South Terminal, tugs engage with the vessel. Westwood Shipping's "N" class (≤ 656-foot) vessels use only one tug near the stern. Other ships, including the Westwood Shipping's larger vessels may use two tugs during arrival. After engagement with the tugs, the vessel is backed into the berth along its port side. Initial contact with the Pacific Terminal wharf is near the stern of the vessel. Bow thrusters or a tug are then used to maneuver the vessel's forward section to the wharf.

During departure, Westwood Shipping's vessels, including its larger ships, typically use only one tug near the stern. Other vessels use two tugs. During departure, the vessel is rotated clockwise about its stern until facing west or west-southwest. Once the vessel passes opposite the south end of Pacific Terminal, the tugs disengage from the vessel.

South Terminal

Starboard Side Berthing

Vessels that berth on the starboard side at the South Terminal approach the berth from the west or northwest and then rotate counterclockwise so that the bow begins to face east-northeast. Tugs then engage with the vessel and further rotate the vessel so that it is parallel to the wharf. Then the vessel is maneuvered into the South Terminal wharf. Starboard side berthing is typically used for Ro/Ro carriers.

During departure, tugs rotate the vessel counterclockwise about its stern until the vessel is facing the west or northwest. Once the vessel has been aligned to its outbound heading, the tugs disengage from the vessel, and the vessel engages its main engine propeller.

Port Side Berthing

Vessels that berth on the port side approach the berth from the west or northwest. After the vessel passes opposite the south end of Pacific Terminal, a single tug engages the rear half of the vessel. The deep draft vessel is gradually rotated clockwise so that the bow is facing the southwest. Initial contact with the South Terminal occurs on the forward half of the vessel, with the tug maneuvering the vessel's rear half to the wharf.

Upon departure, the vessel is rotated clockwise about its stern until facing the west or northwest. Once the vessel passes opposite the south end of Pacific Terminal, the single tug disengages from the vessel.

Propeller Wash Evaluation

Methods

Water velocities due to propeller wash were evaluated using FLOW-3D model, version 11.2 (Flow Science, Inc, 2016) and version 12.0 (Flow Science, Inc, 2019). FLOW-3D is a computational fluid dynamics (CFD) package that resolves the velocity field in three dimensions based on discharges from propeller jets or other sources into the model domain, bathymetry, user- prescribed parameters, and other site characteristics.

Input discharges from propeller jets were developed based on the initial velocities at the main propellers and bow thrusters. These, in turn, were estimated for each vessel (see Table 4) based on the propeller size, the propeller power, the percentages of applied power, the vessel draft, the assumed vessel positions, and empirical formulae published by PIANC (2015):

Main Propulsion:

$$V_o = C_3 \left[(f\, P_D) / (\rho_w\, D_p^2) \right]^{0.33}$$

Thrusters:

$$V_o = 1.15 \left[P_{thruster} / (\rho_w\, D_{thruster}^2) \right]^{0.33}$$

Where:

V_o = Initial water velocity at propeller in m/s

C_3 = 1.48 for non-ducted propellers or 1.17 for ducted propellers

f = Fraction of applied power (0.15 if 15%, 0.28 if 28%, etc.)

P_D = Main propeller power in watts

D_p = Main propeller diameter in meters

ρ_w = Density of sea water in kg/m^3 (1025 kg/m^3 = 64 lbs/foot^3)

$P_{thruster}$ = Thruster power in watts

$D_{thruster}$ = Thruster propeller diameter in meters

Propeller power for the various model scenarios were assumed using PIANC (2015) guidance on applied vessel power during port navigation and berthing operations. The assumed applied power and resulting velocities at the main propellers and bow thrusters are listed in Table 5.

Assumptions

Propwash evaluations using FLOW-3D assume the following:

- As noted earlier, waves and tidal currents at Pacific Terminal, Pier 1 South, and South Terminal are not included in the analysis.
- All simulations are modeled assuming water elevations at Mean Lower Low Water (MLLW).
- The presence of the vessel hulls does not affect the velocity fields in the outflow zones of the propellers.
- The main axes of the cargo vessels' main propellers and bow thrusters are horizontal.

- The bottom grade elevations are equal to the existing bathymetry (see Figure 2), not the scoured bathymetry.
- Due to a lack of detailed vessel drawings, the following assumptions were made regarding vessel geometry (based on review of typical vessels) where necessary:
    - Propeller centerline depth is determined assuming that the lower tip of the propeller is located at vessel keel level.
    - Thruster centerline depth is assumed to be 80% of vessel max draft.

FLOW-3D Model Settings

The following parameters were applied globally to all model simulations:

- Acceleration due to gravity: -9.806 m/s^2 (32.17 ft/s^2)
- Density of Water: 1025 kg/m^3 (64.0 lbs/ft^3)
- Water Temperature: 20 degrees Celsius (68 degrees Fahrenheit)
- Viscosity of Water: 0.001 kg/m/s (6.72E-4 lb/ft/s)
- Atmospheric pressure: 1 atm

Scenarios

Propwash modeling scenarios are presented in Appendix 5 that were developed based on input from GeoEngineers and the Port and vessel operations at the study area. It should be noted that while the area affected by propwash includes Pier 1 South, Flow-3D simulations are limited to vessels berthing at Pacific Terminal and South Terminal. A summary of all modeled scenarios and the corresponding initial water velocity V_o at the propeller/thruster are provided in Table 5.

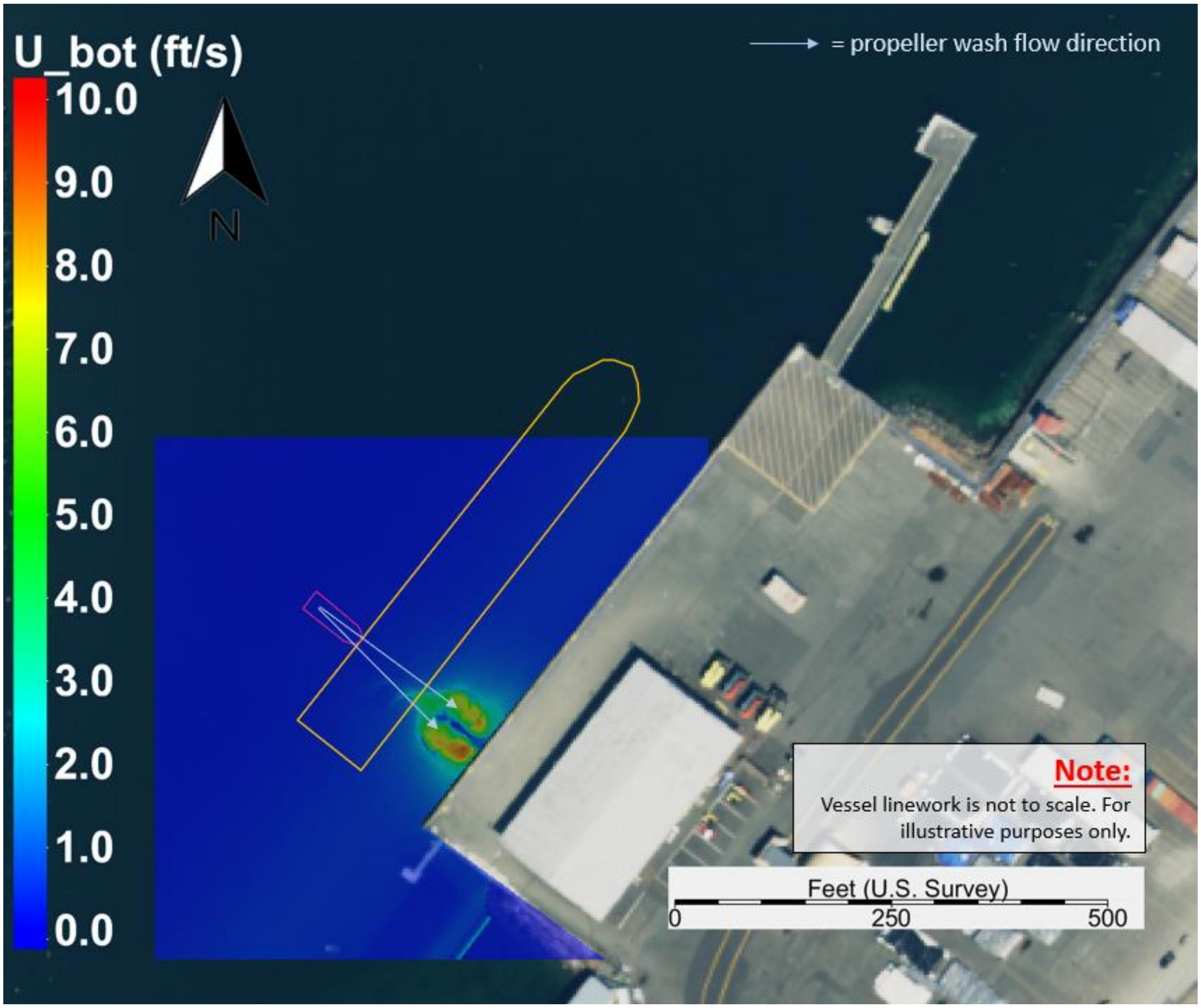
Simulated Velocities Due to Propeller Wash

Using the inputs summarized in Tables 4 and 5, water velocities due to propeller jets were estimated using the Flow-3D model, with velocities near the existing seabed being the primary output of interest. All simulations were performed at MLLW. Sensitivity testing was completed to assess how the bottom velocities vary for scenarios in which the vessel is approaching the terminals as well as departing the terminals by varying the distance of vessels from the berth. All model simulations were run until steady state was achieved to allow the propeller wash jet to fully develop. Bottom velocities were extracted from the model at steady state for use in scour calculations. Figure 3 shows an example of simulated bottom velocities for the Bo Brusco at the South Terminal as it pulls the POS Oceania vessel off the berth. Simulated bottom velocities for all scenarios in Table 5 (including sensitivity simulations) can be found in Appendix 6.

Table 5. Model Scenarios Summary with Corresponding Flow Velocities at Propeller/Thruster

Terminal	Scenario	Vessel	Scenario Description	% of Power Applied	Flow Velocity at Propeller
Pacific Terminal	1	Bardu	Main Propeller at Berth	15%	22.0 ft/s
	2	Bardu	Main Propeller off Berth	28%	27.0 ft/s
	3	Bardu	Thruster Directed Towards Berth	100%	25.1 ft/s
	4	Bardu	Thruster Directed Away from Berth	100%	25.1 ft/s
	5	Bo Brusco (Acting on Bardu)	Propellers Directed Towards Berth	100%	31.6 ft/s
	6	Bo Brusco (Acting on Bardu)	Propellers Directed Away from Berth	100%	31.6 ft/s
South Terminal	7	Madame Butterfly	Main Propeller at Berth	15%	18.1 ft/s
	8	Madame Butterfly	Thruster Directed Towards Berth	100%	26.5 ft/s
	9	Madame Butterfly	Thruster Directed Away from Berth	100%	26.5 ft/s
	10	Bo Brusco (Acting on Madame Butterfly)	Propellers Directed Towards Berth	100%	31.6 ft/s
	11	Bo Brusco (Acting on Madame Butterfly)	Propellers Directed Away from Berth	100%	31.6 ft/s
	12	POS Oceania	Main Propeller at Berth	15%	21.0 ft/s
	13	POS Oceania	Main Propeller off Berth	28%	25.8 ft/s
	14	POS Oceania	Thruster Directed Towards Berth	100%	24.5 ft/s
	15	POS Oceania	Thruster Directed Away from Berth	100%	24.5 ft/s
	16	Bo Brusco (Acting on POS Oceania)	Propellers Directed Towards Berth	100%	31.6 ft/s
	17	Bo Brusco (Acting on POS Oceania)	Propellers Directed Away from Berth	100%	31.6 ft/s

Figure 3. Simulated Bottom Velocities – Bo Brusco at South Terminal as it pulls the POS Oceania off the Berth.



Scour Evaluation

After estimating the bottom velocities associated with the fully developed jet for each Flow-3D simulation, the bottom velocity results were used as input for estimating the maximum scour for each simulation.

Methodology

Maximum estimated scour was calculated based on the empirical method developed by Roelse (2014), which is similar to the methods presented in PIANC (2015), but accounts for the natural slope of the existing bathymetry. Current PIANC guidance for estimating scour assumes a perfectly flat bottom and does not account for the effect of sloping bottoms, as are present in the existing bathymetry at the Port of Everett Terminals (see Figure 2 contours). The following assumptions were also made in applying the methodology developed by Roelse (2014):

- Scour is estimated for steady-state flow velocity conditions, taken from Flow-3D simulations. This assumes the flow conditions in the model occur long enough (or repeatedly occur enough) for maximum equilibrium scour to occur.
- Resettlement of any scoured material due to propeller wash is ignored in the methodology.
- No additional sources or sedimentation are included in the methodology.

The method presented by Roelse (2014) also accounts for pile effects. However, since the areas under the terminal wharfs are armored (see Appendix 5) and are not the focus of this analysis, scour estimates in this analysis neglect the effects of the piles on the propeller wash jet. All scour estimates assume non-cohesive sediment (per Chin, 2019). Equations 1 through 6 provide a complete background of the scour calculation methodology:

$$h_{sem} / D_o = 0.3 \, (Fr_{slope,max}^2 - Fr_{slope,crit}^2)^{0.5} \qquad \text{Equation (1)}$$

where h_{sem} is the estimated scour due to the maximum bottom velocities produced by the propeller wash, $F_{slope,max}$ is the densimetric slope Froude number due to the maximum bottom velocities, and $F_{slope,crit}$ is the critical densimetric slope Froude number required for scour to occur. $F_{slope,max}$ and $F_{slope,crit}$ are defined as follows (Roelse, 2014):

$$Fr_{slope} = U_{slope} / (g \, \Delta \, d_{50})^{1/2} \qquad \text{Equation (2)}$$

$$Fr_{slope,crit}^2 = U_{slope,crit}^2 / (g \, \Delta \, d_{50}) \approx (\Psi_{cr} / 0.055) \cdot [\, 2 / (m_h \, \beta_{Iz,crit}) \,] \qquad \text{Equation (3)}$$

where U_{slope} is the bottom velocity on the slope/bottom. In this analysis U_{slope} is the bottom velocity from Flow-3D simulations at steady state conditions (see Appendix 6), g is the acceleration due to gravity, d_{50} is the median sediment size of the scoured material, $\beta_{Iz,crit}$ is the critical Izbash coefficient (range from 2.5 to 3 per Roelse, 2014), Ψ_{cr} is the critical shields parameter as defined below, and m_h is the slope stability factor as defined below:

$$\Psi_{cr} = A \, D^{*B} \qquad \text{Equation (4)}$$

$$m_h = \tan \varphi_s \, / \, [\cos \theta_u \sin \alpha + (\cos^2 \alpha \, \tan^2 \varphi_s - \sin^2 \theta_u \sin^2 \alpha)^{1/2}] \qquad \text{Equation (5)}$$

The parameters φ_s , θ_u, and α are the angle of repose (typically 40 to 42 degrees), the angle of flow with respect to the slope, and the slope angle, respectively. The parameter D* is the non-dimensional grain size, defined as:

$$D^* = d_{50} \, (g \, \Delta / v^2)^{1/3} \qquad \text{with } \Delta = G_s - 1 \qquad \text{Equation (6)}$$

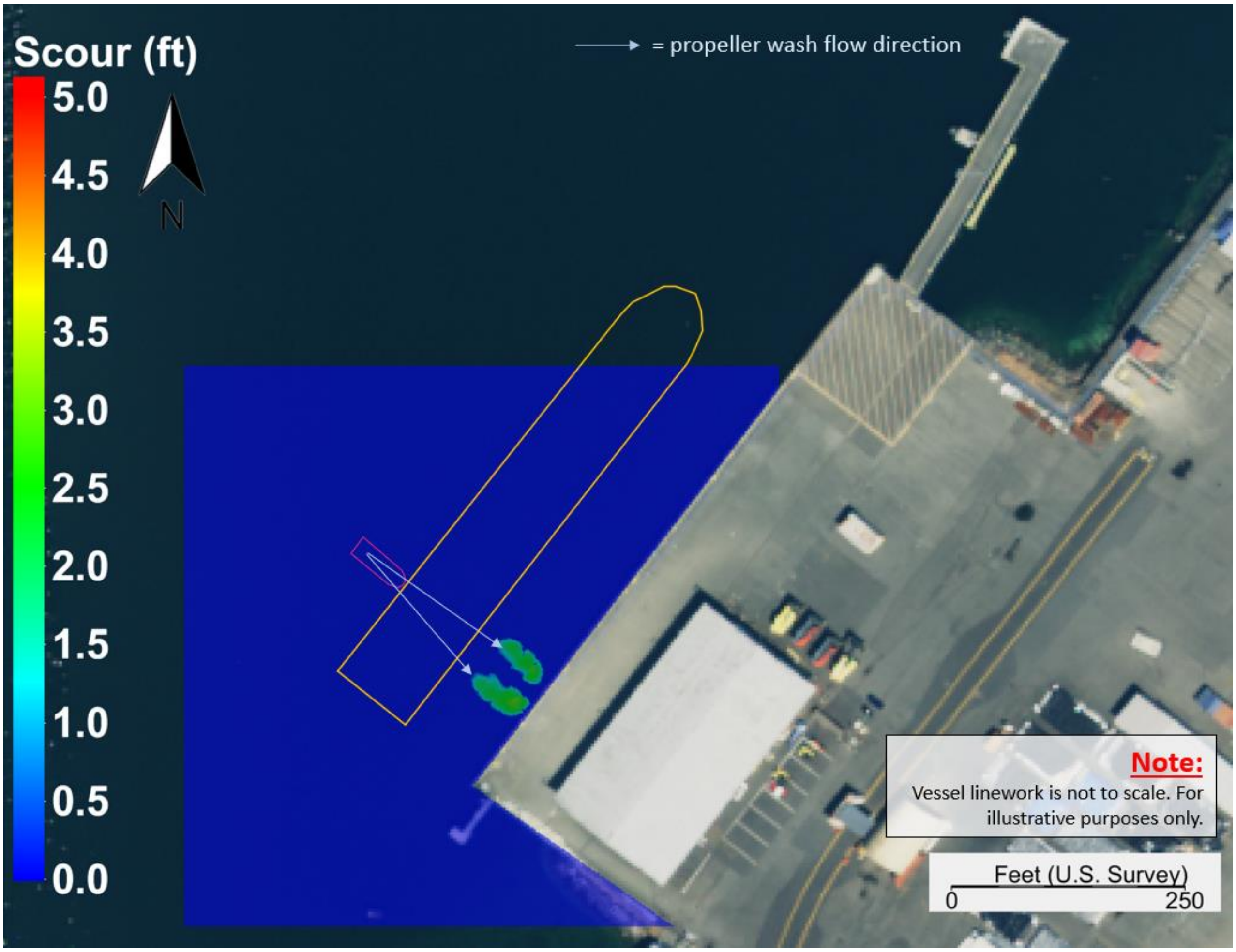
where v is the kinematic viscosity for water, and G_s is the specific gravity of the sediment solids (see Table 2). The values of A and B, which depend on the non-dimensional grain size D*, are listed in Table 6.

Table 6: Roelse (2014) Constants

Range of D*	A	B
1 < D* < 4	0.24	-1
4 < D* < 10	0.14	-0.64
10 < D* < 20	0.04	-0.1
20 < D* < 150	0.013	0.29
D* > 150	0.055	0

The calculation methodology outlined in Equations 1-6 was applied at all grid cells over the entire domain of each Flow-3D simulation. Values for the specific gravity and internal friction angle of the sediments were determined from data provided by GeoEngineers (See Table 2 and Appendix 1), which were interpolated to the plan-view locations of the Flow-3D grid points for each simulation. An example of the estimated scour for the Bo Brusco at the South Terminal as it pulls the POS Oceania vessel off the Berth is shown in Figure 4. Note that the estimated scour shown in Figure 4 corresponds to the estimated bottom velocities shown in Figure 3. Figures of estimated scour for each simulated scenario are provided in Appendix 6.

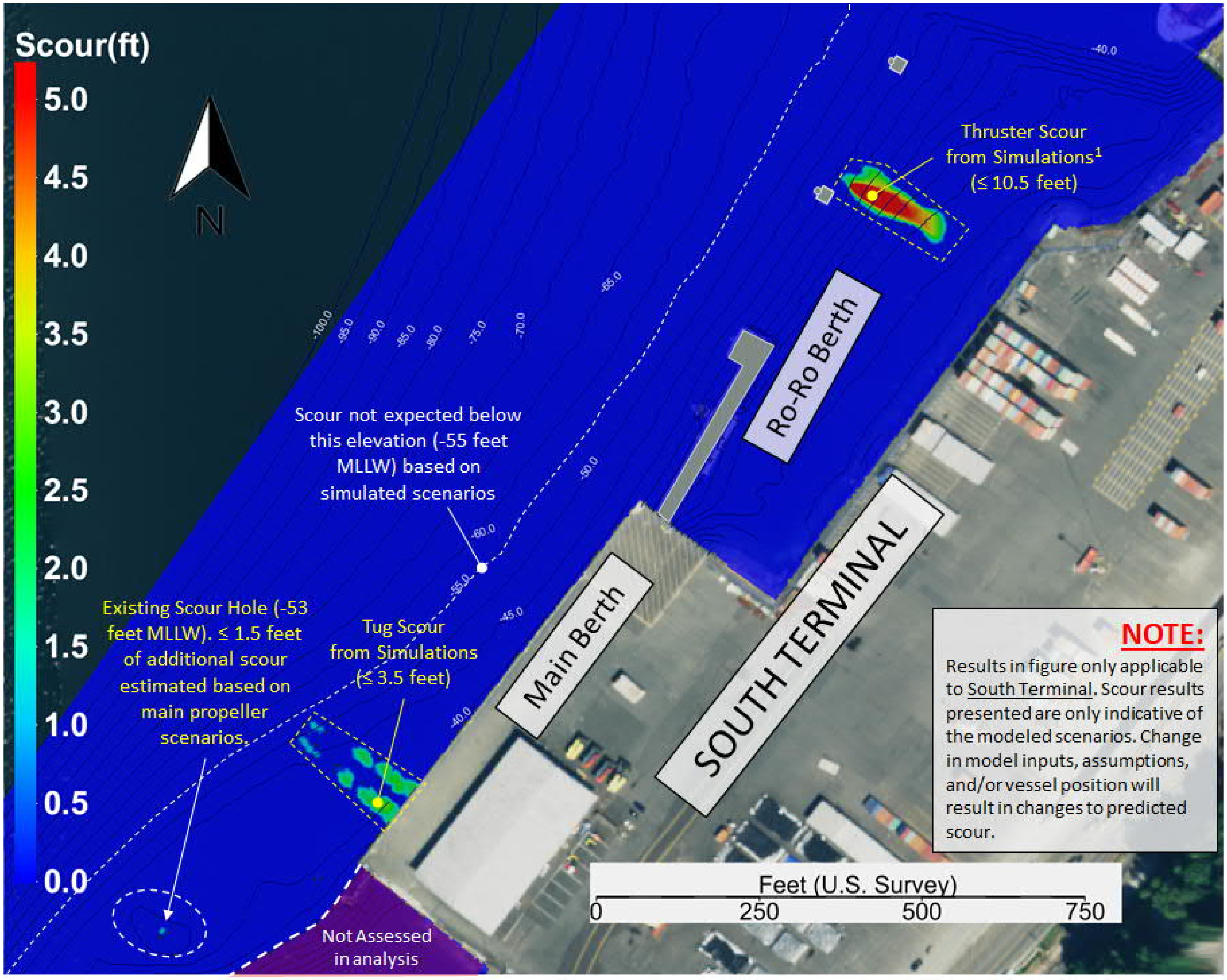
Figure 4. Example Estimated Scour – Bo Brusco at South Terminal as it pulls the POS Oceania off the Berth.



Scour Assessment

In order to assess scour for the Pacific and South Terminals, the maximum estimated scour for all model scenarios at each terminal were combined and compared to previously completed vessel tracking AIS analysis results at each terminal (AIS data range: 01/01/2016 to 12/31/2017, see Appendix 3 for additional AIS figures). Figures 5 and 7 show the maximum estimated scour for all simulated propeller wash scenarios at the South and Pacific Terminals, respectively. Figures 6 and 8 show the corresponding AIS traffic for both cargo vessels (Container, Bulk, Ro-Ro, Break-Bulk, etc.) and tug vessels (while towing/pushing on a vessel) for the South and Pacific Terminals, respectively.

Figure 5. Estimated Scour for All Propeller Wash Simulations at South Terminal.[1]



[1] Note that scour thruster is outside the limits of the color bar. Maximum scour due to thrusters in Figure 5 is ≤ 10.5 feet.

Figure 6. AIS Vessel Tracking Data for Cargo and Tugs (while towing/pushing vessel) at South Terminal

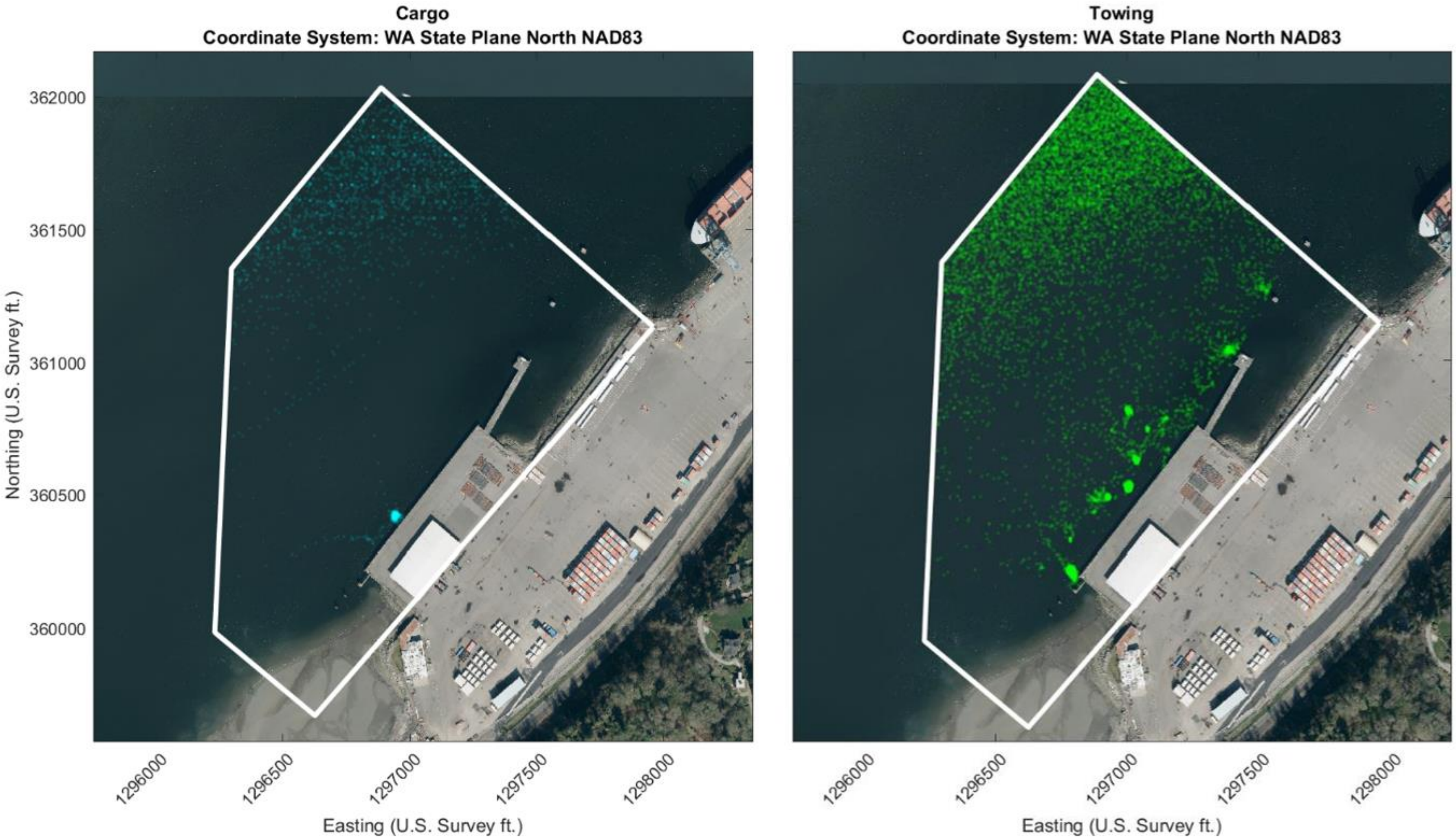


Figure 7. Estimated Scour for All Propeller Wash Simulations at Pacific Terminal.

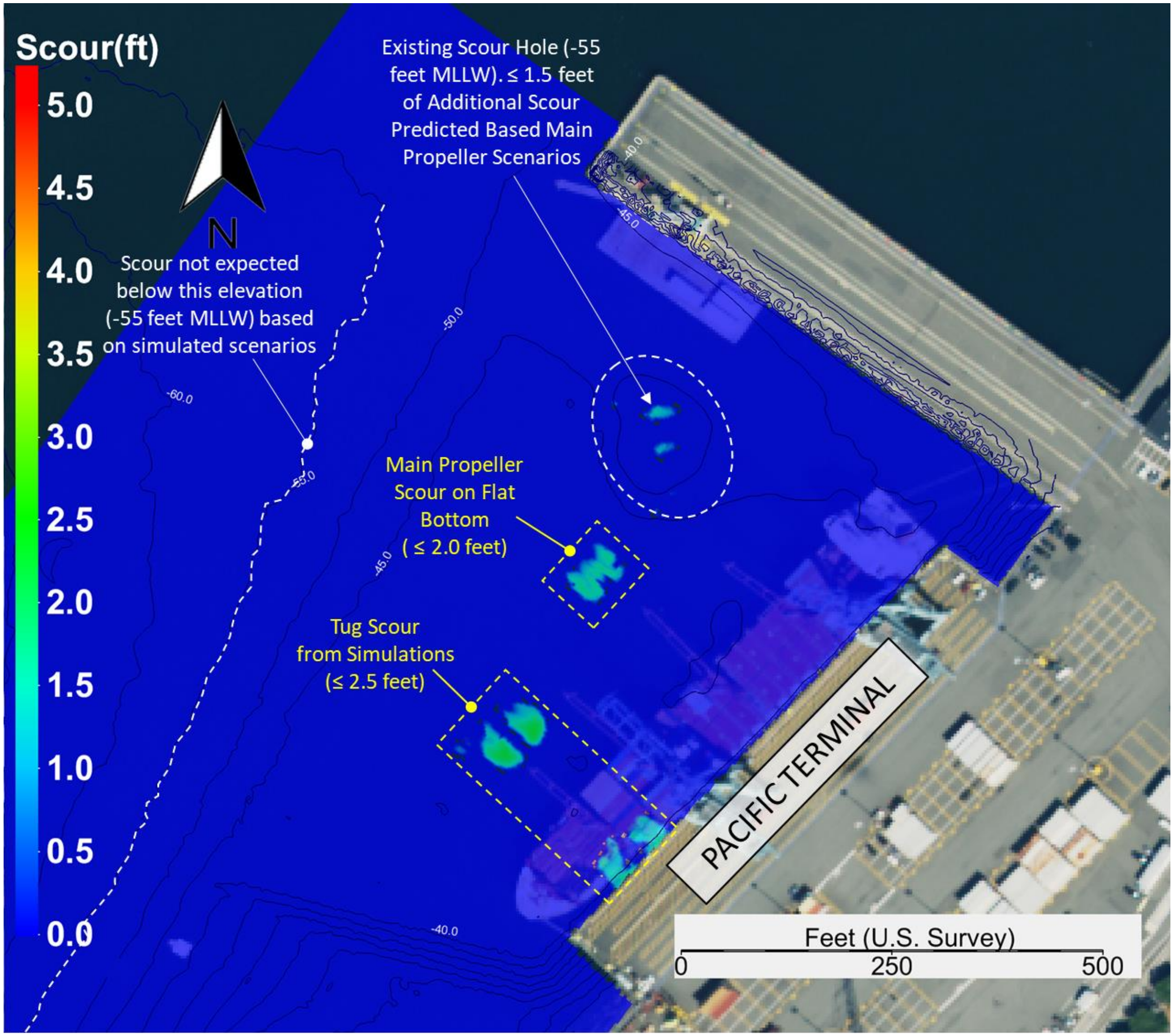
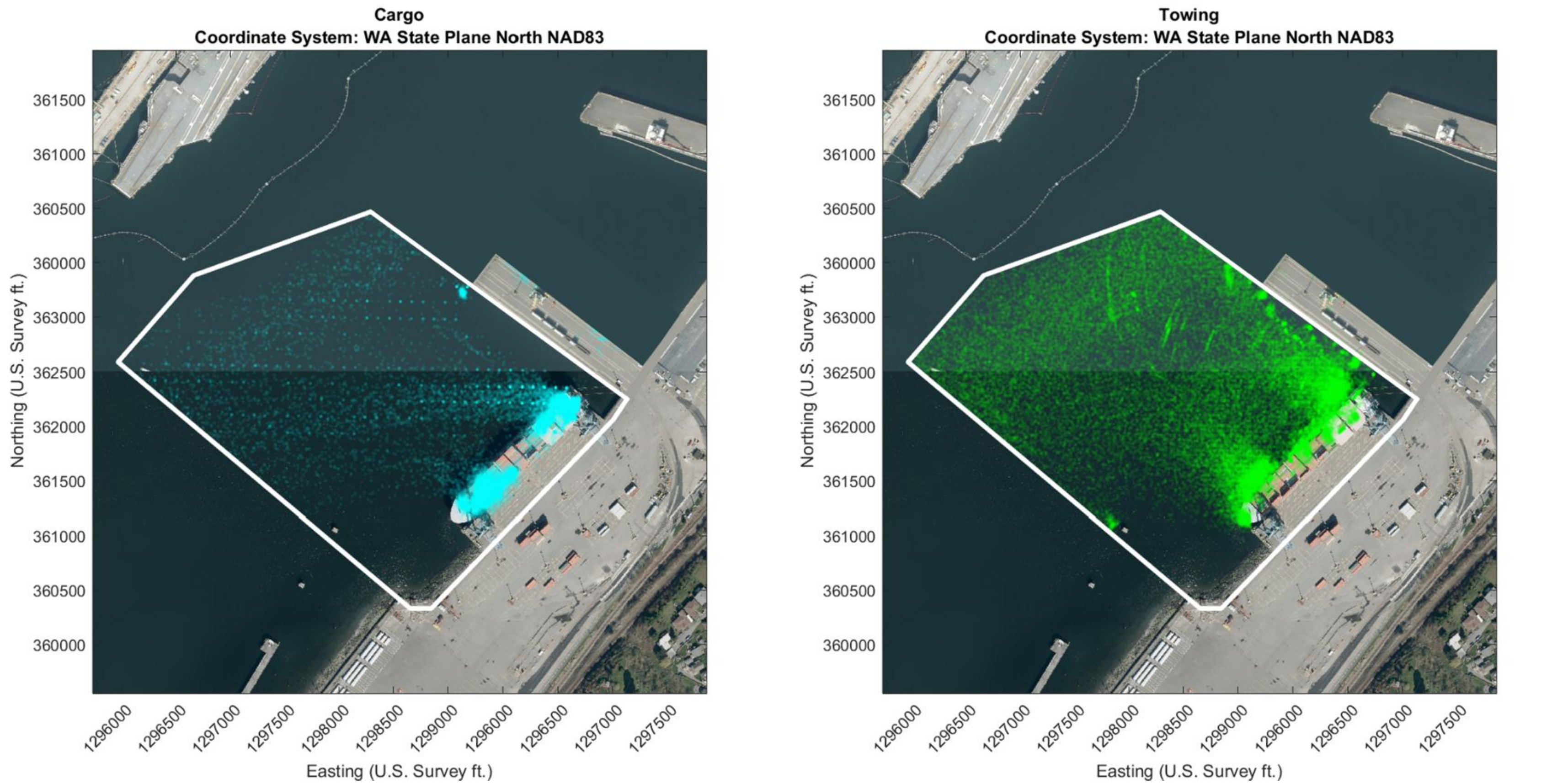


Figure 8. AIS Vessel Tracking Data for Cargo and Tugs (while towing/pushing vessel) at Pacific Terminal



South Terminal

Estimated scour results at South Terminal suggest the primary scour risks are associated with propeller wash from tug operations along the South Terminal Main Berth and propeller wash from thruster use at the South Terminal Ro-Ro Berth, with scour from main propulsion playing a minor role. Potential scour was found to be associated with maneuvering and/or pulling vessels off the Berth, with little or no scour estimated during operations when a vessel is being pushed towards the berth. This difference in estimated scour for arrival versus departing operations is due to the natural, sloping bathymetry present at South Terminal (see Figure 2), which reduces propeller wash interaction with the existing bottom when the jet is directed away from the berth. Estimated scour due to main propeller operations was generally 1.5 feet or less, including an existing, -53 foot MLLW depression roughly 5 feet below the surrounding bathymetry (see Figure 5). The -53 foot MLLW depression is believed to be the result of previous scour.

AIS analysis of tug operations at the South Terminal Main Berth and Ro-Ro Berth show considerable variation in tug position when acting on arriving or departing vessels. Estimated scour due to tug operations at the South Terminal Main Berth were estimated to be equal to or less than 3.5 feet. Although model simulations and scour analysis of the Bo-Brusco tug pulling the Madame Butterfly vessel off the Ro-Ro Berth resulted in little to no estimated scour, AIS analysis results (Figure 6) clearly show tug activity in close proximity to the Ro-Ro Berth and dolphins (closer proximity to berth/dolphins than simulated in model). It is therefore recommended that the estimated tug scour at the South Terminal Main Berth (≤ 3.5 feet) be applied in the region associated with these closer-than-simulated tug operations at the South Terminal Ro-Ro Berth. Sensitivity testing of tug distance relative to the berth suggests that tug scour is not expected below an existing bathymetry elevation of -55.0 ft MLLW.

In the 2-year dataset (2016-2017) of AIS vessel tracking data, there is limited data available for cargo vessels (includes container, Bulk/Break-Bulk, Ro-Ro, etc.) at the South Terminal to help guide the scour risk assessment. Estimated scour from cargo vessels was associated with propeller wash from thruster operations, with estimated scour less than or equal to 10.5 feet. This scour is the result of high thruster jet velocities and the unprotected slopes directly shoreward of the South Terminal Ro-Ro Berth. The slopes under the South Terminal Main Berth are protected from thruster scour with by an armor rock blanket, which are not assessed in this analysis. Due to the lack of AIS data available for cargo vessels to aid in defining scour risk areas for thruster operations at the Ro-Ro Berth, it is assumed that the thruster scour footprint show in Figure 5 could shift along the berth length plus or minus one eighth (+/- 80 feet) of the length of the Madame Butterfly due to variation in operations – this assumption is likely conservative but could be confirmed with further AIS data and analysis.

Combining the results and analysis from Figure 5 and Figure 6, a map was developed indicating where scour could over the vessel maneuvering areas at South Terminal, shown in Figure 9 and summarized in Table 7. Any change to the vessels used for this analysis, the assumptions, operations, and input parameters used in this work will affect the estimated scour results and the recommended scour risk zones for the South Terminal.

Figure 9. Scour Risk Zones at South Terminal Based on Propeller Wash and Scour Analysis.

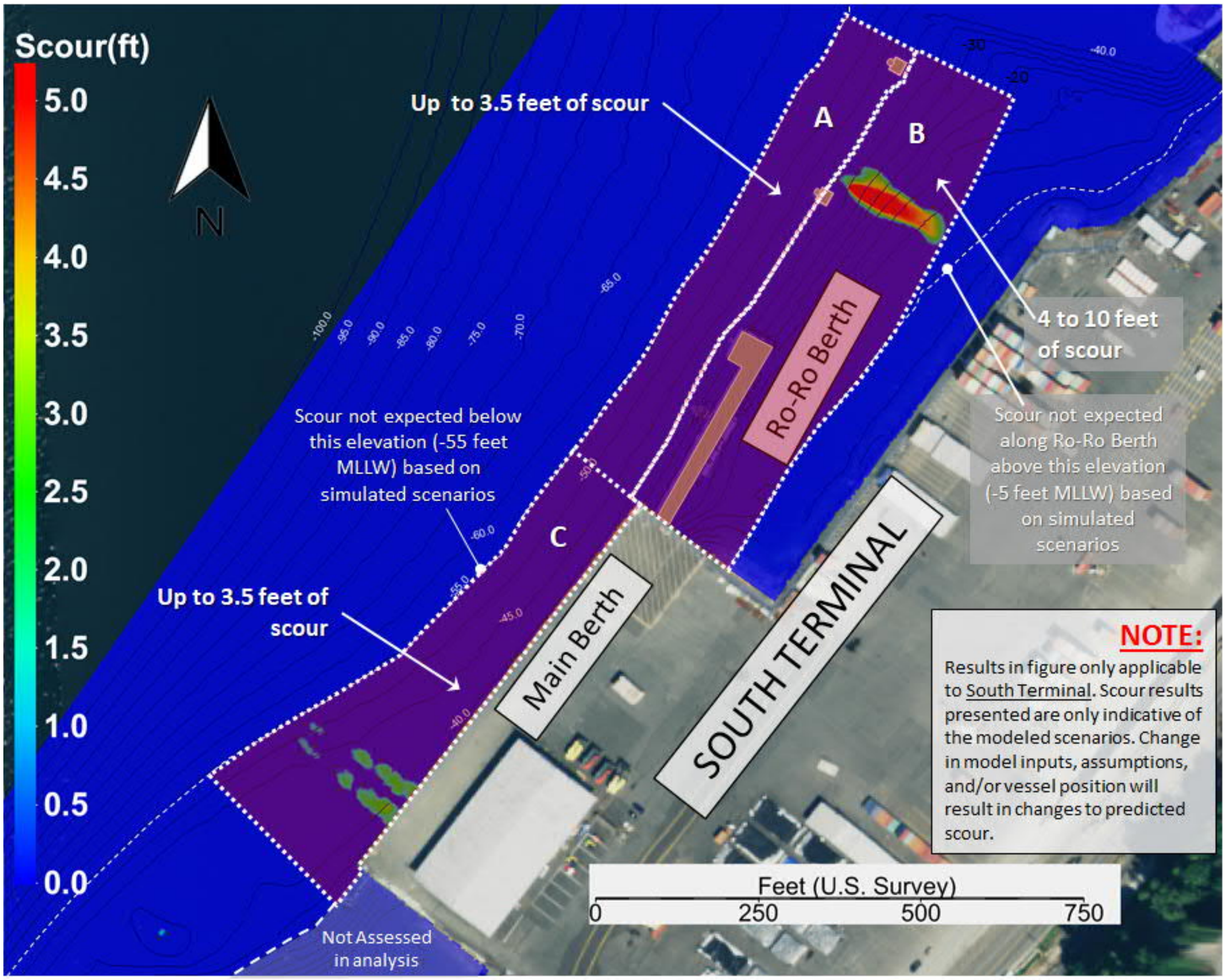


Table 7. Scour Risk Zones at South Terminal Based on Propeller Wash and Scour Analysis

Scour Risk Zone	Source of Scour Risk	Estimated Scour in Zone
A	Tugs	Up to 3.5 feet
B	Thrusters	4 to 10 feet
C	Tugs and main propeller	Up to 3.5 feet

Pacific Terminal

Estimated scour results at Pacific Terminal suggest the primary scour risks are associated with propeller wash from tug operations and main propeller operations. Unlike South Terminal, where the existing bathymetry increases in depth with distance from the terminal berths, the bathymetry at Pacific terminal is mostly flat, with depths typically near -42 feet MLLW. Scour is estimated to occur during both arrival and departure operations of vessels due to the flat bottom. At Pacific Terminal, little to no scour of the existing bathymetry due to thruster operations was estimated. An existing depression in bathymetry is also present at Pacific Terminal, similar to South Terminal, and is believed to be a result of previous scour.

Estimated scour due to tug operations at the Pacific Terminal were estimated to be equal to or less than 2.5 feet. Due to the widespread nature of tug operations at Pacific Terminal, the majority of the Terminal area is likely to be subject to scour due to tug operations (see Figure 10 and Table 8).

AIS analysis of cargo vessel operations at the Pacific Terminal show well defined paths of activity over the 2-year period of the AIS dataset (2016-2017). In particular, there appears to be a well-defined departure path for cargo vessels calling Pacific Terminal along a heading of 260 to 270 degrees. Estimated scour due to main propeller operations over the flat bottom at the Pacific Terminal (elevation approx. -42.0 ft. MLLW) were estimated to be equal to or less than 2.0 feet. Main propeller wash simulations over the existing depression (believed to be an existing scour hole) resulted in less than 1.5 feet of additional scour being estimated, which suggests the depression is starting to approach but is not at the equilibrium scour depth for main propeller operations. Scour over the existing depression at Pacific Terminal due to tug operation was not evaluated.

Combining the results and analysis from Figure 7 and Figure 8, a map was developed to indicate where scour could over the vessel maneuvering areas at Pacific Terminal, shown in Figure 10 and summarized in Table 8. Any change to the vessels used for this analysis, the assumptions, operations, and input parameters used in this work will affect the estimated scour results and the recommended scour risk zones for Pacific Terminal.

Figure 10. Scour Risk Zones at Pacific Terminal Based on Propeller Wash and Scour Analysis.

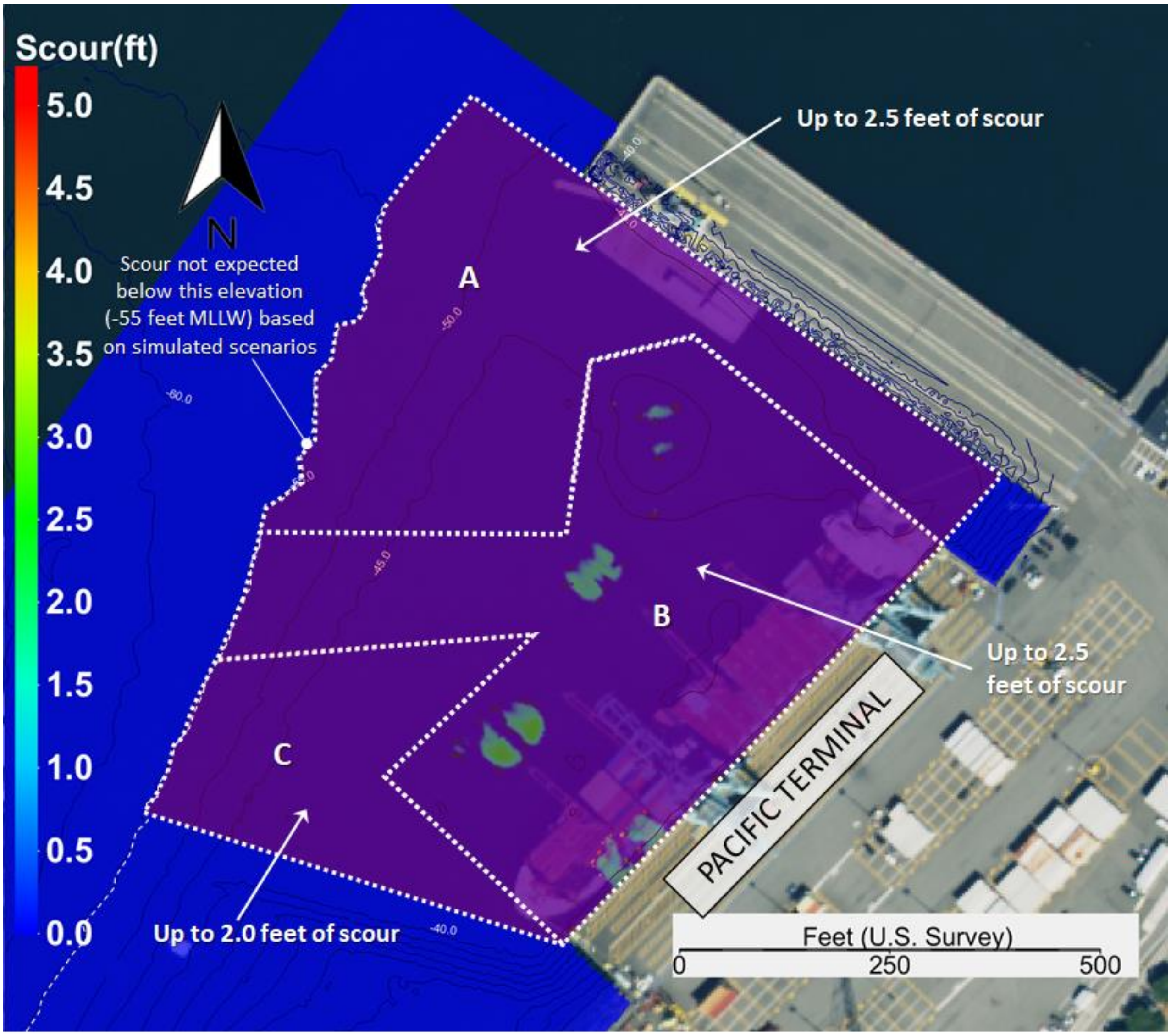


Table 8. Scour Risk Zones at Pacific Terminal Based on Propeller Wash and Scour Analysis

Scour Risk Zone	Source of Scour Risk	Estimated Scour in Zone
A	Tugs and main propeller	Up to 2.5 feet
B	Main propeller	Up to 2.5 feet
C	Tugs	Up to 2.0 feet

Conclusions

A propeller wash scour assessment was performed to identify potential scour depths projected to be caused by ships and tugs at the Pacific Terminal and South Terminal at the Port of Everett (Former Weyerhaeuser Mill A Site). Analysis of AIS vessel tracking data was conducted to gain an understanding of the operations at the terminals using data from a 2-year period (2016-2017). Propeller wash velocities and associated bottom velocities were modeled using 28 Flow-3D CFD model simulations. Applied propeller power for each simulation was assumed following guidance outlined in PIANC (2015) and was used to develop initial jet velocities for input in the Flow-3D model. Using the resulting bottom velocities from Flow-3D, estimates for potential scour of each simulation were developed by applying an empirical methodology for estimating scour which accounts for variations in bottom slope described by Roelse (2014). These potential scour estimates were combined with the results of the AIS vessel tracking analysis to develop a map showing zones of low, medium, and high likelihood of scour and their corresponding potential scour depths.

Nineteen simulations were performed to evaluate scour from ship and tug operations at the South Terminal based on cargo and Ro-Ro ship use. Scour is estimated to occur to depths of -55 feet MLLW at the South Terminal (see Figure 9) based on cargo and Ro-Ro ship use. Zones of potential scour were identified based on AIS data for 2016 and 2017 that occur within 200 feet from the berth at the South Terminal. Vessel traffic recorded in the AIS data show areas of tug operation which translate to medium to high likelihood of scour (see Figure 9 and Table 7). Potential scour depths associated with tug propeller wash scour are up to 3.5 feet at the South Terminal. Potential scour depths associated with thruster propeller wash scour are up to 10.5 feet. A simulation of main propeller wash at the location of an existing depression/scour hole (-53 feet MLLW) indicates that additional scour of up to 1.5 feet could occur from main propeller wash.

Vessel traffic at Pacific Terminal recorded in the AIS data show significant and widespread operations of both tug and cargo vessels. The resulting potential scour at the Pacific Terminal is therefore estimated over this area (see Figure 10 and Table 8). Nine simulations were performed to evaluate scour from ship and tug operations at the Pacific Terminal based on cargo ship use. Scour is estimated to occur to depths of -55 feet MLLW. Potential scour depths associated with tug propeller wash scour are up to 2.5 feet. Potential scour depths associated with main propeller wash scour are up to 2.0 feet at Pacific Terminal. Simulations at Pacific Terminal estimated negligible scour due to thruster propeller operations. Simulation of main propeller wash at an existing, -55 foot MLLW depression/scour hole estimated additional scour up to 1.5 feet could occur from main propeller wash.

All results in this analysis are valid for the chosen vessels, the existing bathymetry, vessel operations based on 2-years of AIS data, the range of vessels and berthing/mooring areas developed in the basis of analysis, and the stated assumptions included in this analysis. Changes in future use by changes in the sizes of vessels, locations of the vessels on the berth, or operational methods from the historic conditions may change the estimated potential scour results presented in this document or result in a scour risk outside the areas identified in this study (limited to historical and current vessel use).

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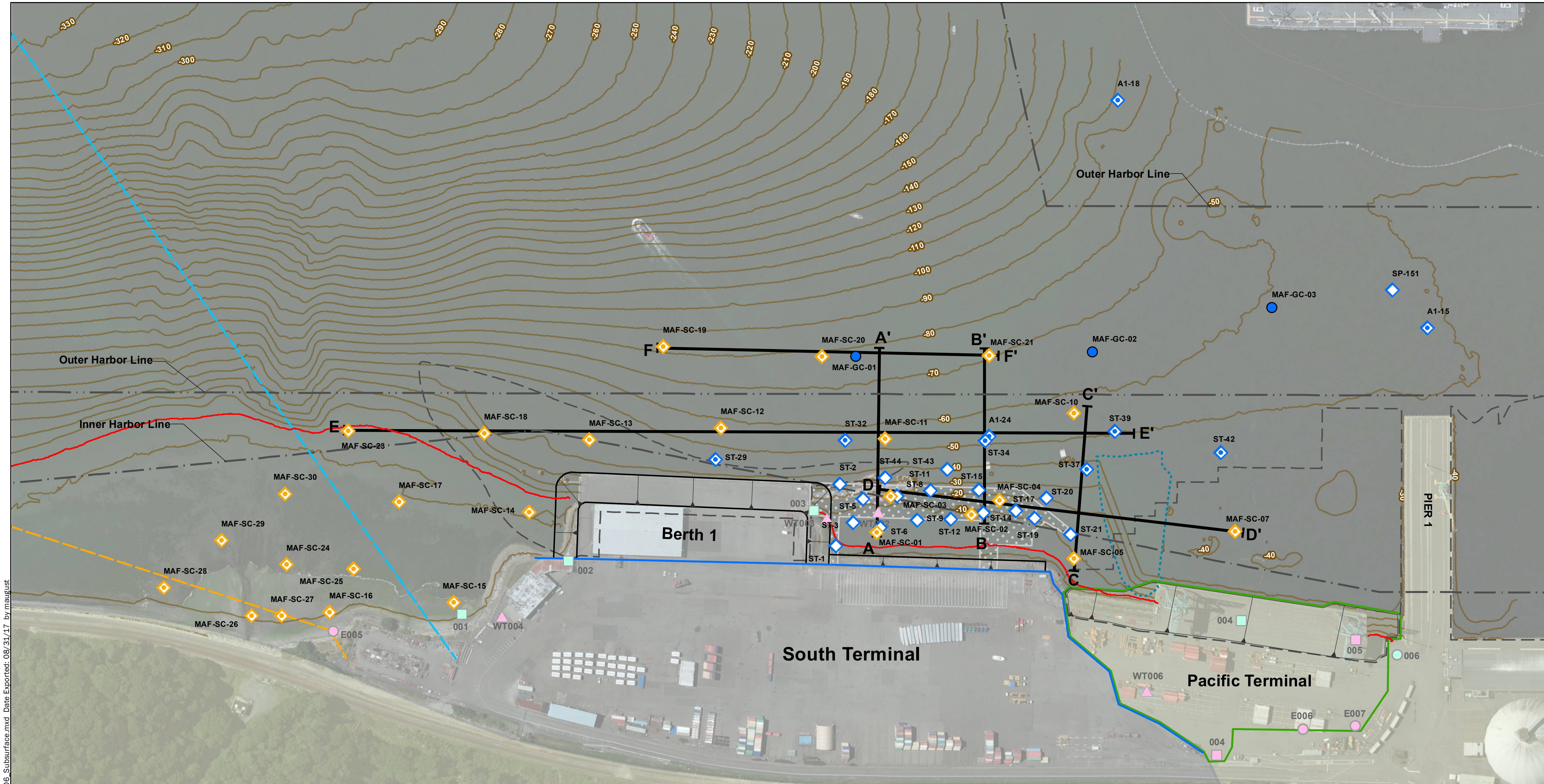
Appendix 1: Summary of Sediment Stratigraphy



300 0 300
Feet

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and contentof electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Data Source: Base aerial from Bing Maps, 2011.
Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet

Legend

Remedial Investigation (RI) Subsurface Sediment Investigation
- Sediment Core/Subsurface Sediment Sample Location With Co-Located Surface Sediment Sample (See Figure 4)
- Sediment Location for Isotope Analysis

Previous Subsurface Sediment Investigation
- Sediment Core/Subsurface Sample Location Only
- Sediment Core/Subsurface Sediment Sample Location With Co-Located Surface Sediment Sample (See Figure 4)

- Construction Berm Fill
- Historical Pier
- Interim Action Dredge Area
- Dredged Area
- Nearshore Confined Disposal (NCD) Facility
- -3 Feet Mean Low Low Water (MLLW) Elevation Contour Line
- Bulkhead
- Cross Section

- Historical Industrial Outfall
- Former Combined Sewer Outfall (CSO)
- Former Stormwater Outfall
- Current CSO
- Current Stormwater Outfall
- Current Kimberly-Clark/City of Everett/ City of Marysville Outfall 100 (approximate)
- Historic Kimberly-Clark/Weyerhaeuser Outfall SW001 (approximate)

Sediment Core/Subsurface Sediment Investigation Locations

Weyerhaeuser Mill A Former
Everett, Washington

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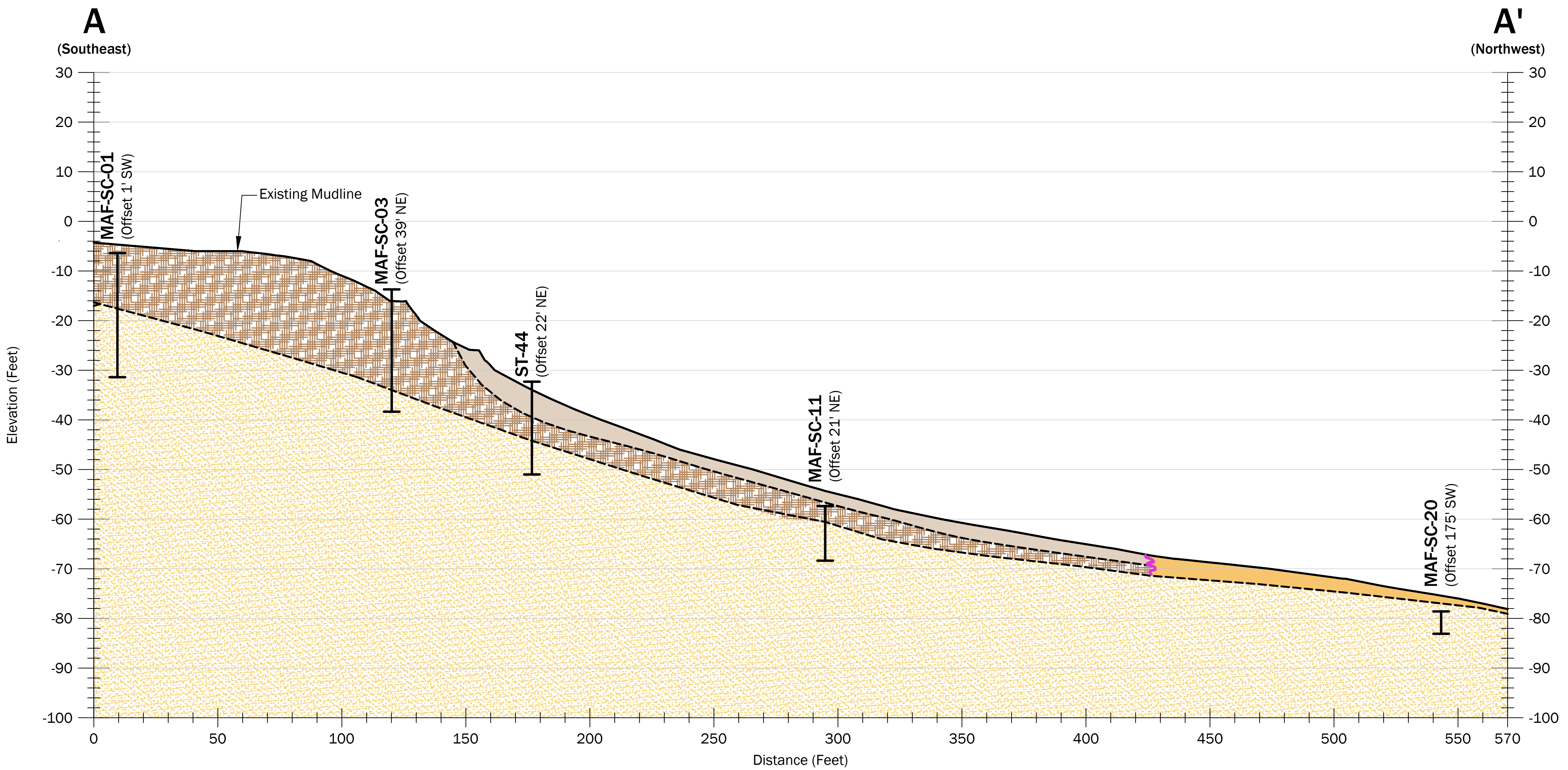
Figure 6



Legend

Existing Bathymetric Ground Surface

Inferred Sediment Contact

Location and Characteristics of Transition Not Observed

Wood Debris (>50% Wood)

Mixed Deposit (>10%, <50% Wood)

Sediment Deposit (≤10% Wood)

Native Silt and Sand

50 0 50
Horizontal Scale in Feet

25 0 25
Vertical Scale in Feet
Vertical Exaggeration: 2X

Notes:

1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Cores shown at actual mudline and bottom depth elevations.
3. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Marine Area Cross-Section A-A'

Weyerhaeuser Mill A Former
Everett, Washington

GeoEngineers

Figure 8

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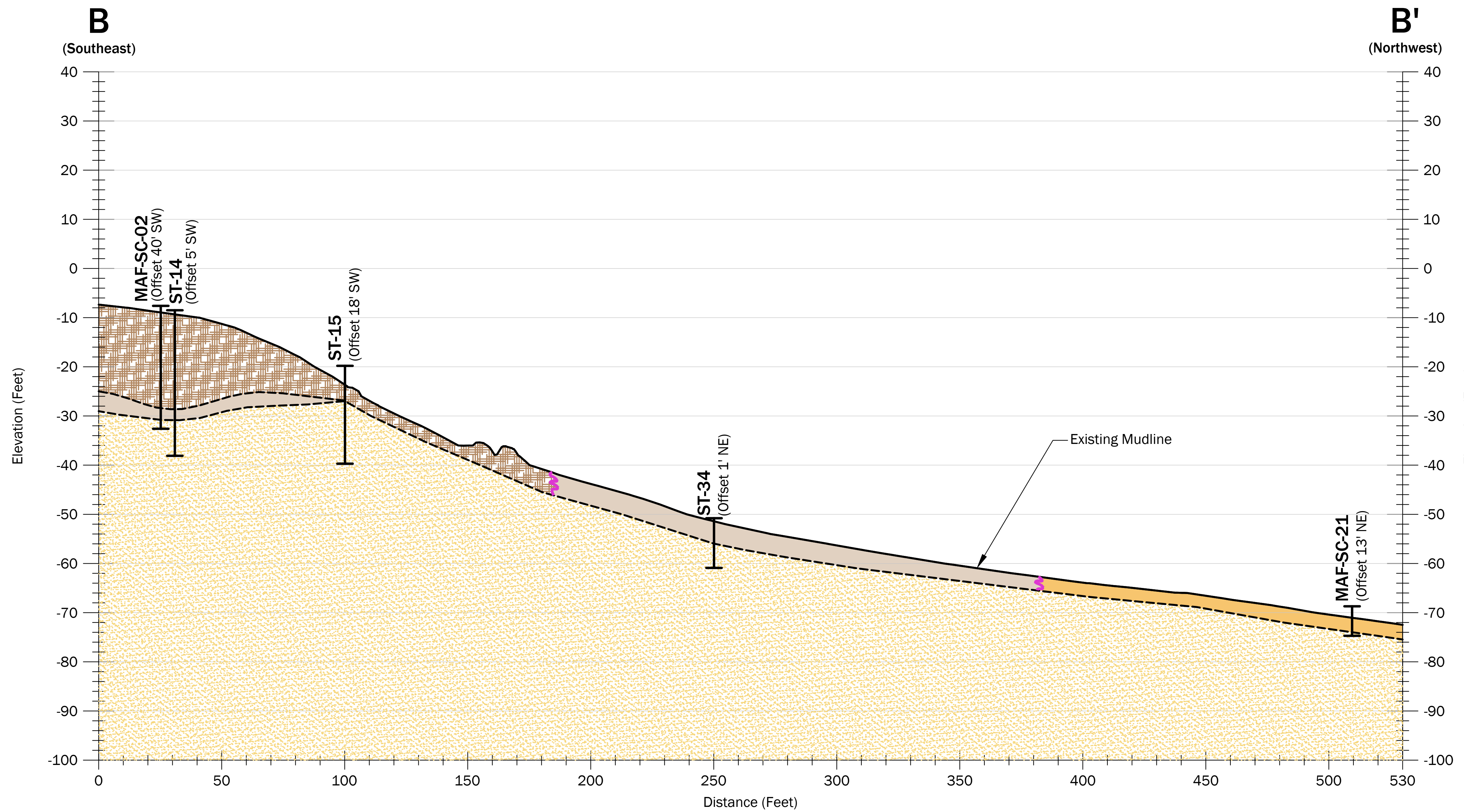

Notes:
1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
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50 0 50
Horizontal Scale in Feet
25 0 25
Vertical Scale in Feet
Vertical Exaggeration: 2X

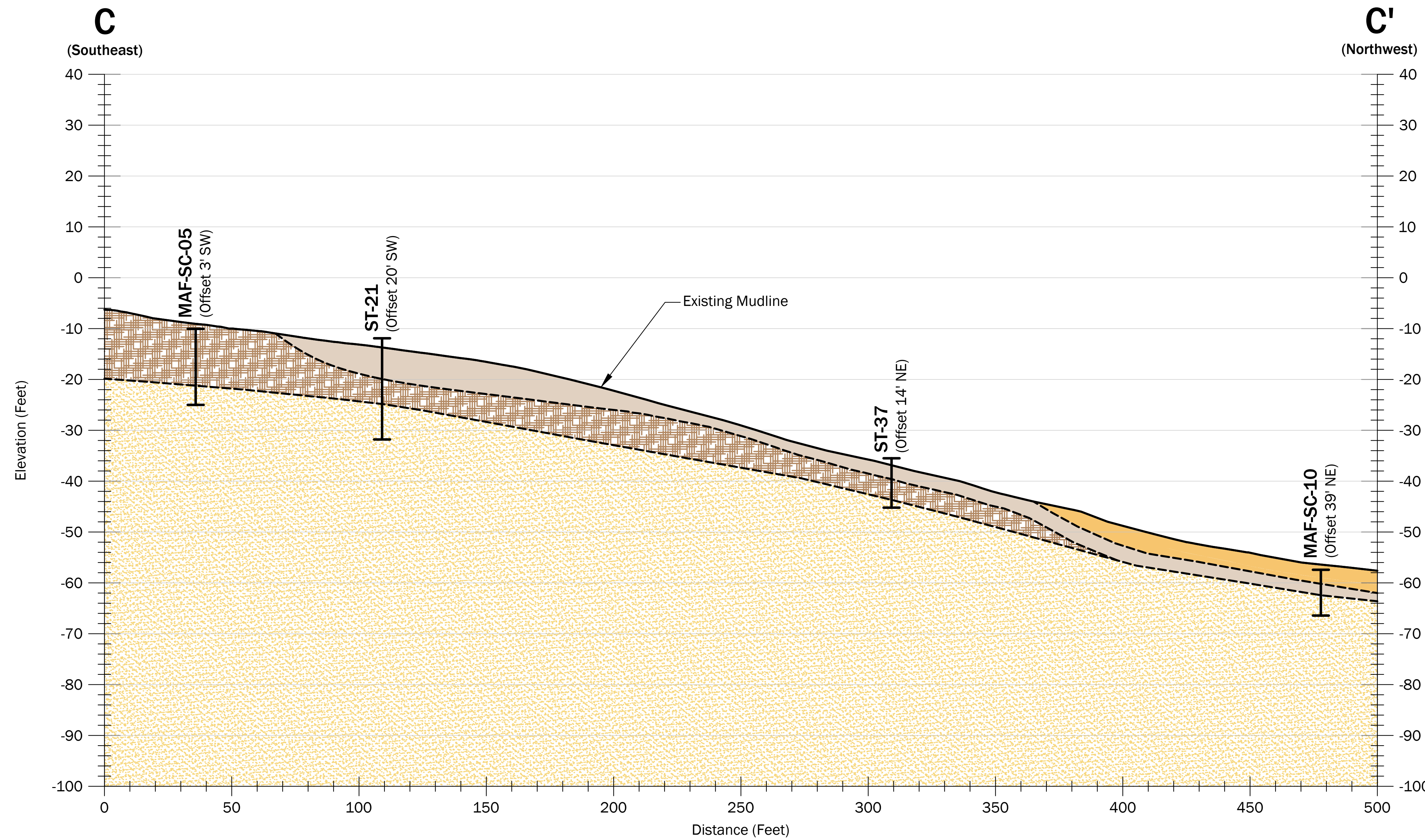
Legend
- Existing Bathymetric Ground Surface
- Inferred Sediment Contact
- Location and Characteristics of Transition Not Observed
- Wood Debris (>50% Wood)
- Mixed Deposit (>10%, <50% Wood)
- Sediment Deposit (≤10% Wood)
- Native Silt and Sand

Marine Area Cross-Section B-B'

Weyerhaeuser Mill A Former
Everett, Washington

GeoEngineers

Figure 9



Notes:
1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Cores shown at actual mudline and bottom depth elevations.
3. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

50 0 50
Horizontal Scale in Feet

25 0 25
Vertical Scale in Feet
Vertical Exaggeration: 2X

Legend

Existing Bathymetric Ground Surface
Inferred Sediment Contact
Wood Debris (>50% Wood)
Mixed Deposit (>10%, <50% Wood)
Sediment Deposit (≤10% Wood)
Native Silt and Sand

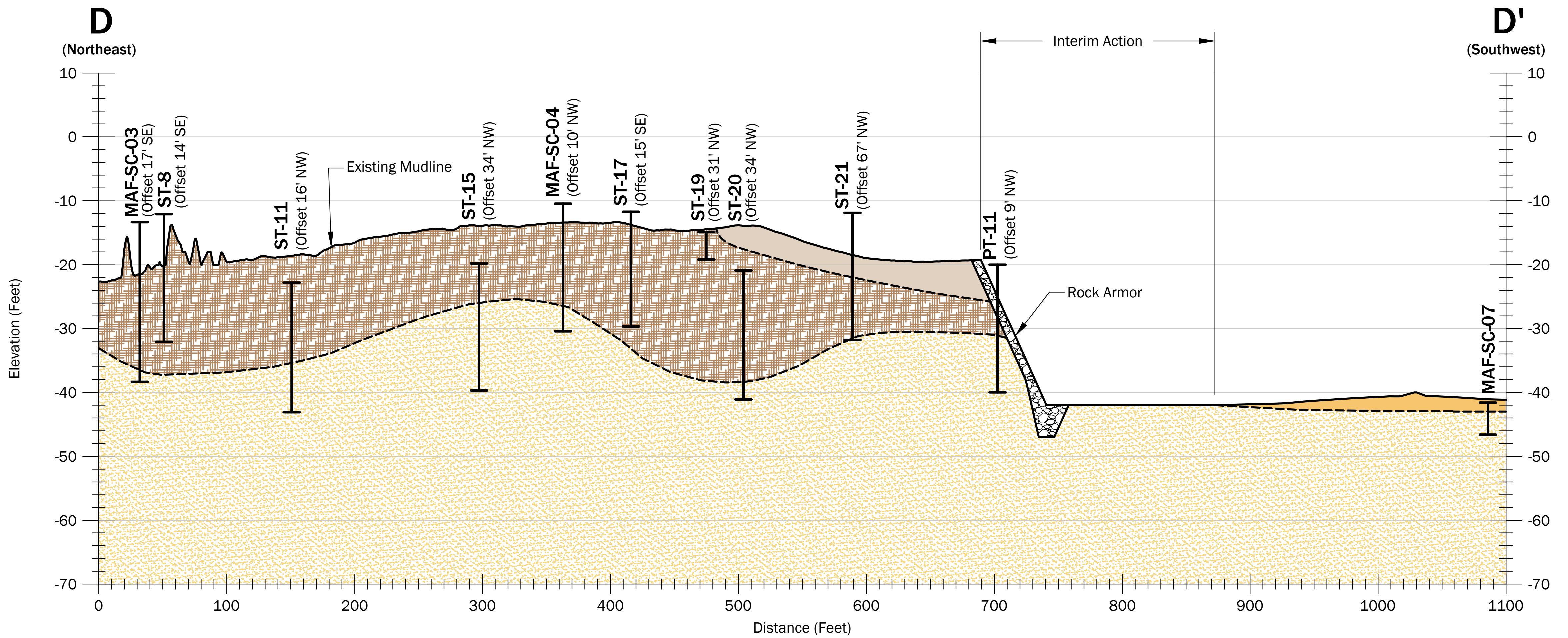
Marine Area Cross-Section C-C'

Weyerhaeuser Mill A Former
Everett, Washington

GeoEngineers

Figure 10

P:\0\0676020\05\CAD\Task 1900 Wood Native Cross-sections\067020-05_F0X_Cross-Sections.dwg TAB:AA Date Exported: 12/13/16 - 14:53 by tmichaud



Notes:

1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Cores shown at actual mudline and bottom depth elevations.
3. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

100 0 100
Horizontal Scale in Feet

20 0 20
Vertical Scale in Feet
Vertical Exaggeration: 5X

Legend

- Existing Bathymetric Ground Surface
- Inferred Sediment Contact
- Wood Debris (≥50% Wood)
- Mixed Deposit (>10%, <50% Wood)
- Sediment Deposit (≤10% Wood)
- Native Silt and Sand

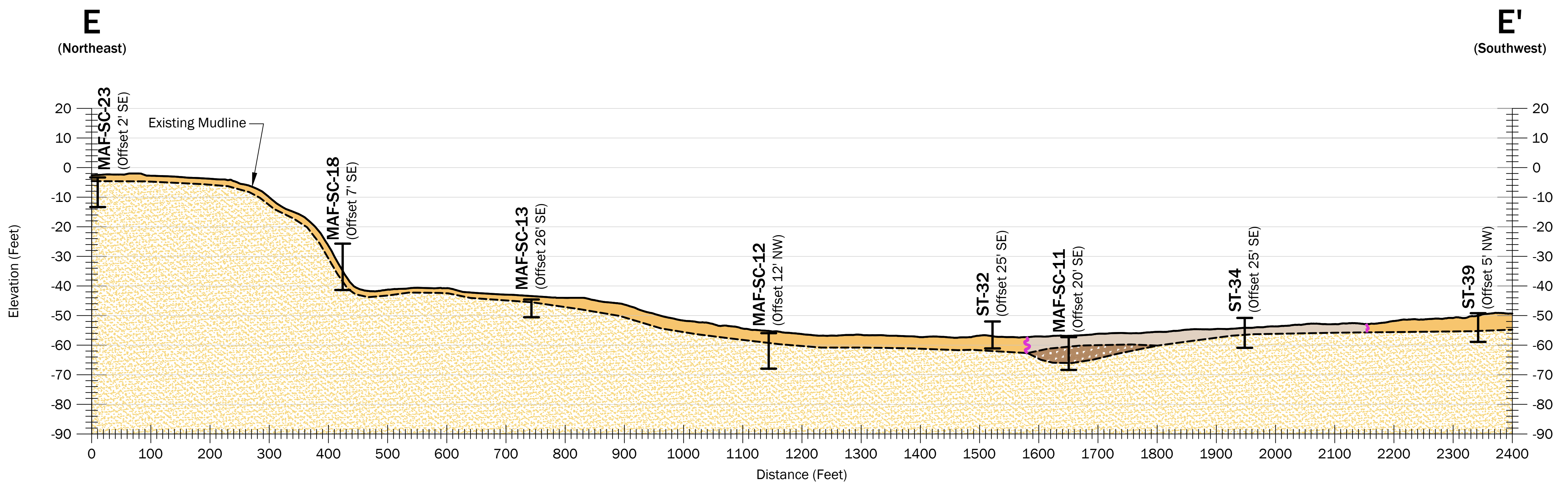
Marine Area Cross-Section D-D'

Weyerhaeuser Mill A Former
Everett, Washington

GeoEngineers

Figure 11

P:\0\0676020\05\CAD\Task 1900 Wood Native Cross-sections\067020-05_F0X_Cross-Sections.dwg TAB:FF Date Exported: 12/13/16 - 14:51 by tmichaud



Notes:

1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Cores shown at actual mudline and bottom depth elevations.
3. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

200 0 200
Horizontal Scale in Feet

40 0 40
Vertical Scale in Feet
Vertical Exaggeration: 5X

Legend

- Existing Bathymetric Ground Surface
- Inferred Sediment Contact
- Location and Characteristics of Transition Not Observed
- Wood Debris (>50% Wood)
- Mixed Deposit (>10%, <50% Wood)
- Sediment Deposit (≤10% Wood)
- Native Silt and Sand

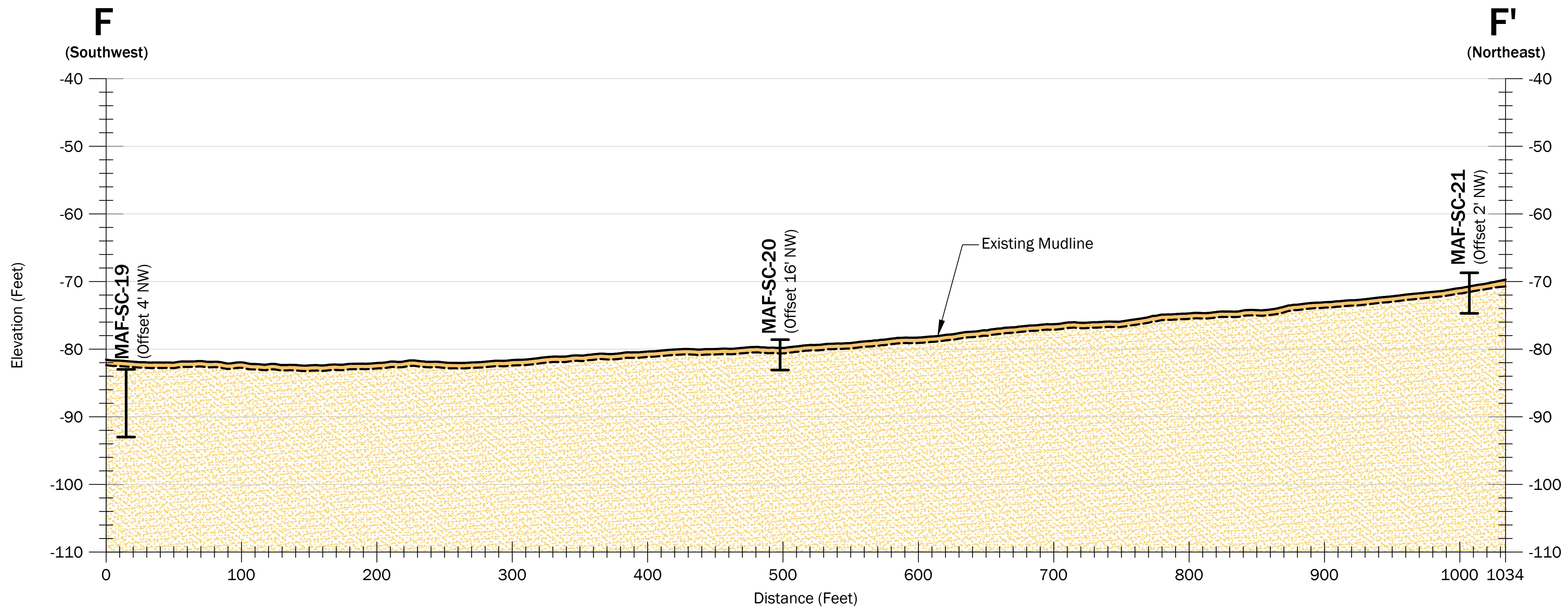
Marine Area Cross-Section E-E'

Weyerhaeuser Mill A Former
Everett, Washington

GeoEngineers

Figure 12

P:\0\0676020\05\CAD\Task 1900 Wood Native Cross-sections\067020-05_FOX_Cross-Sections.dwg TAB:EE Date Exported: 12/13/16 - 14:52 by tmichaud



Legend

- Existing Bathymetric Ground Surface
- Inferred Sediment Contact
- Wood Debris (≥50% Wood)
- Mixed Deposit (>10%, <50% Wood)
- Sediment Deposit (≤10% Wood)
- Native Silt and Sand

Horizontal Scale in Feet (100 – 0 – 100)

Vertical Scale in Feet (20 – 0 – 20)
Vertical Exaggeration: 5X

Notes:
1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Cores shown at actual mudline and bottom depth elevations.
3. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Marine Area Cross-Section F-F'

Weyerhaeuser Mill A Former
Everett, Washington

GeoEngineers

Figure 13

P:\0\0676020\05\CAD\Task 1900 Wood Native Cross-sections\067020-05_F0X_Cross-Sections.dwg TAB:DD Date Exported: 12/13/16 - 14:52 by tmichaud

Appendix 2: Vessels

Table 2-1: List of Deep-Draft Vessels Provided by the Port of Everett

Vessel Name	Vessel Type	Length (ft.)	Beam (ft.)	Terminal Location
Westwood Shipping Lines:				
"N" Class Vessels:				
Westwood Rainier	Container	656	102	Pier 1 South
Westwood Victoria	Container	656	102	Pier 1 South
Westwood Columbia	Container	656	102	Pier 1 South
Westwood Olympia	Container	656	102	Pier 1 South
Other Vessels:				
Westwood Robson	Container	685	99	(Not avail.)
Westwood Pacific	Container	604	98	Pier 1 South, Pacific Term.
Westwood Frasier	Container	689	98	Pier 1 (north side)
Hammonia Berolina	Container	686	98	Pier 1 South
Bardu	Container	685	98	Pier 1 South, Pacific Term.
Westerland	Container	679	105	Pacific Term.
Ballenita	Container	685	98	(Not avail.)
Eastern Car Liner:				
Asian Naga	General Cargo	407	66	Pacific Term.
Cosmic Ace	General Cargo	390	69	(Not avail.)
POS Oceania	Bulk carrier	556	89	Pacific Term., South Term.
Millennium Leader	General Cargo	417	69	Pacific Term.
ISS Sprit	Bulk carrier	564	92	(Not avail.)
AEC Diligence	Bulk carrier	564	92	Pier 1 (north side)
Genius Starr VII	General Cargo	394	70	(Not avail.)
Ocean Seagull	General Cargo	394	70	(Not avail.)
AAL:				
AAL Singapore	General Cargo	636	96	(Not avail.)
AAL Melbourne	General Cargo	636	95	(Not avail.)
AAL Sydney	General Cargo	636	95	(Not avail.)
AAL Newcastle	General Cargo	636	96	(Not avail.)
Swire:				
Siangtan	Container	653	92	Pier 1 South, Pacific Term.
Shengking	Container	656	92	Pier 1 South, Pacific Term.

Source: Port of Everett (2018e).

Table 2-1 (continued): List of Deep-Draft Vessels Provided by the Port of Everett

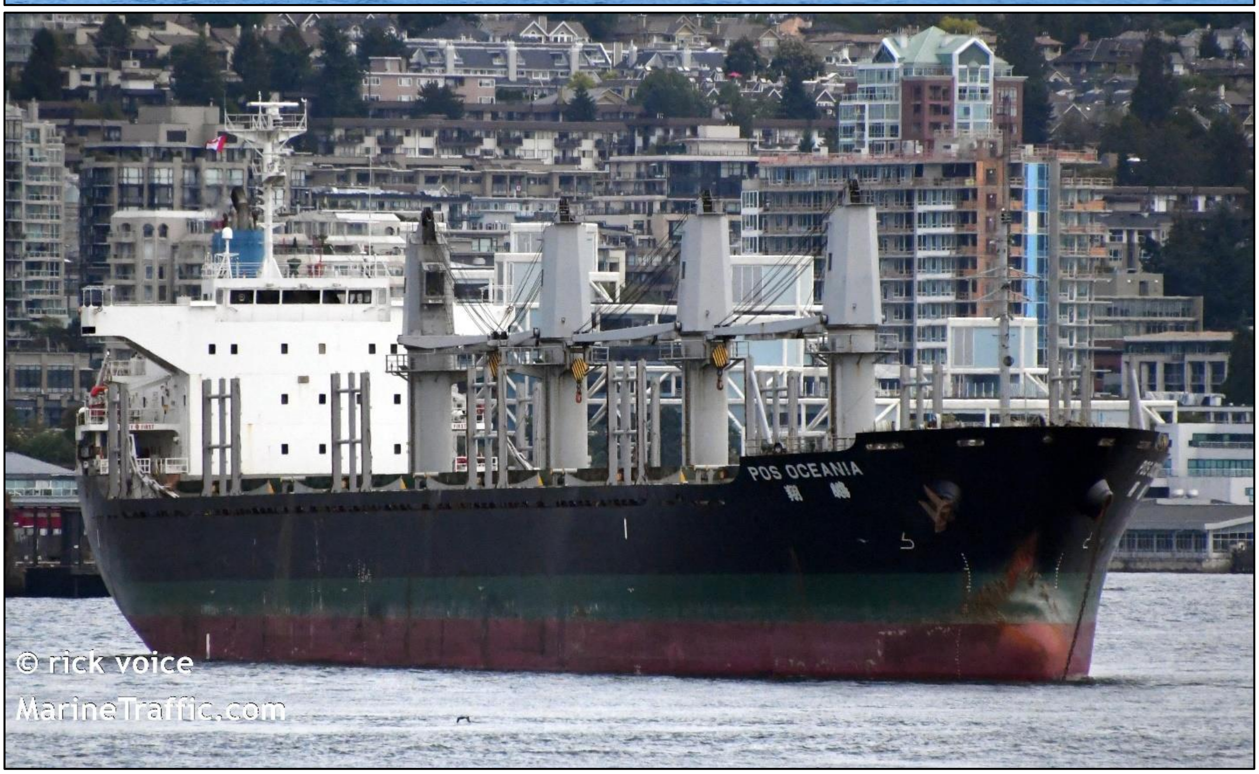
Vessel Name	Vessel Type	Length (feet)	Beam (feet)	Terminal Location
Roll On / Roll Off (Ro/Ro):				
Kaijin	Ro/Ro	638	94	Pier 1, South Term.
Madame Butterfly	Ro/Ro	649	106	Pier 1, South Term.
Morning Glory	Ro/Ro	636	102	Pier 1, South Term.
Morning Miracle	Ro/Ro	600	103	Pier 1, South Term.
Hoegh Triton	Ro/Ro	656	105	Pier 1, South Term.
Tijuca	Ro/Ro	760	107	Pier 1, South Term.
Grand Mark	Ro/Ro	654	106	Pier 1, South Term.
Grand Mercury	Ro/Ro	655	106	Pier 1, South Term.
Lord Vishnu	Ro/Ro	590	106	Pier 1, South Term.
Chang Tai Hong	Ro/Ro	577	102	Pier 1, South Term.
Grand Pace	Ro/Ro	588	106	Pier 1, South Term.
Grand Race	Ro/Ro	588	106	Pier 1, South Term.
Morning Melody	Ro/Ro	591	105	Pier 1, South Term.
Turand	Ro/Ro	653	106	Pier 1, South Term.
Ryujin	Ro/Ro	591	106	Pier 1, South Term.
Auto Atlas	Ro/Ro	655	106	Pier 1, South Term.
Miscellaneous Vessels:				
Black Forest	Bulk Carrier	581	92	Pier 1 (n. side)
Port Alice	Bulk Carrier	576	96	(Not avail.)
Shikoku Island	Bulk Carrier	581	95	Terminals north of Pier 1
Orient Becrux	Bulk Carrier	580	94	(Not avail.)
Yangtze Eternal	Bulk Carrier	591	92	Pacific Term.
Donaugracht	General Cargo	515	75	Pacific Term.
Impression Bay	Bulk Carrier	591	98	Terminals north of Pier 1
Avacha	General Cargo	400	59	(Not avail.)
BBC Rushmore	General Cargo	413	73	(Not avail.)
BBC Sapphire	General Cargo	503	77	(Not avail.)
BBC Vesuvius	General Cargo	413	73	(Not avail.)
BBC Denmark	General Cargo	331	56	(Not avail.)
Thorco Legacy	General Cargo	432	75	(Not avail.)
Star Juventus	General Cargo	650	102	(Not avail.)

Source: Port of Everett (2018e).

Bardu – Container Ship

Madame Butterfly – Ro / Ro Carrier

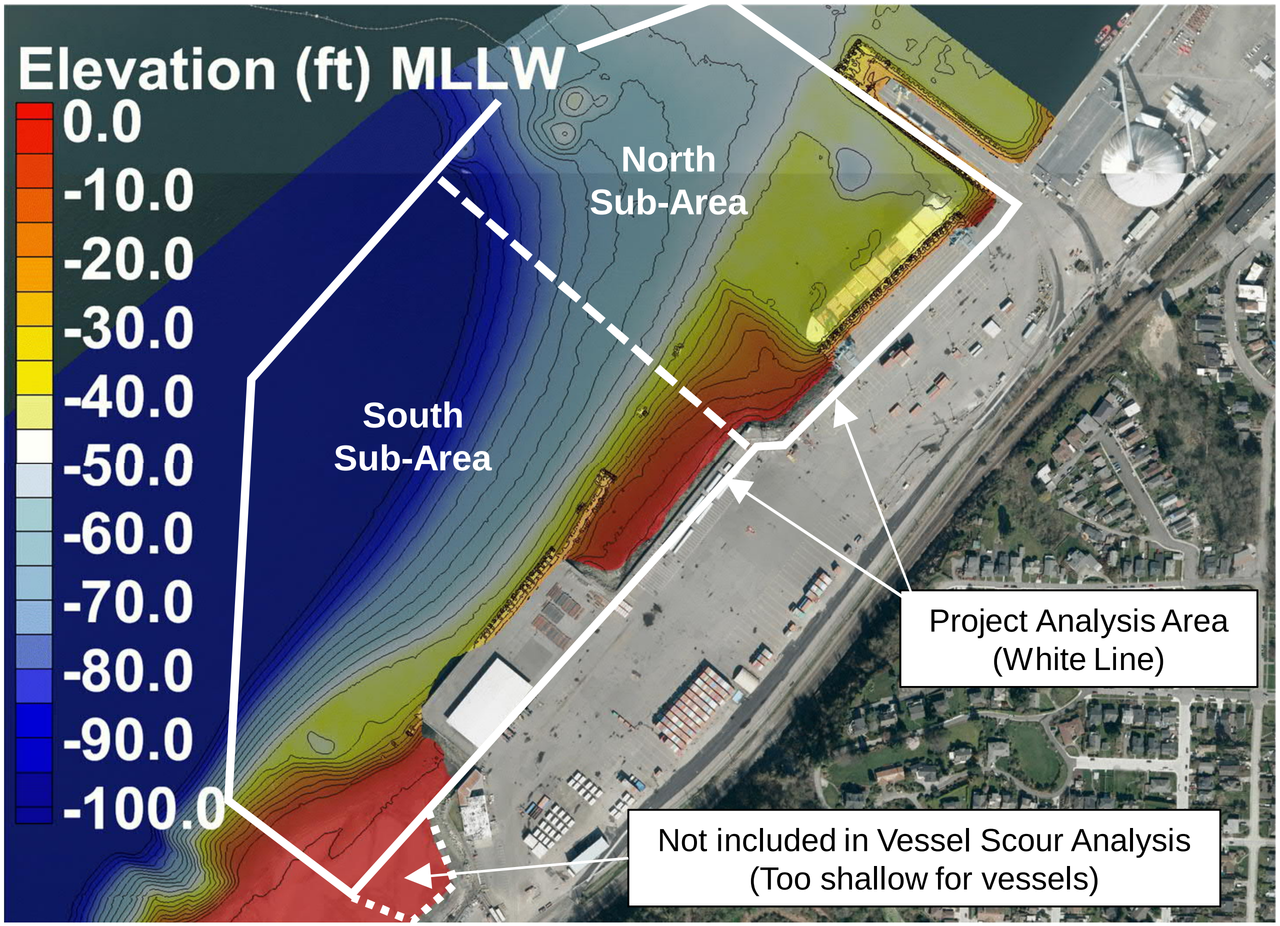
POS Oceania – Bulk Carrier / Cargo Vessel



Bo Brusco – Tractor Tug

Appendix 3: AIS Vessel Tracking Analysis

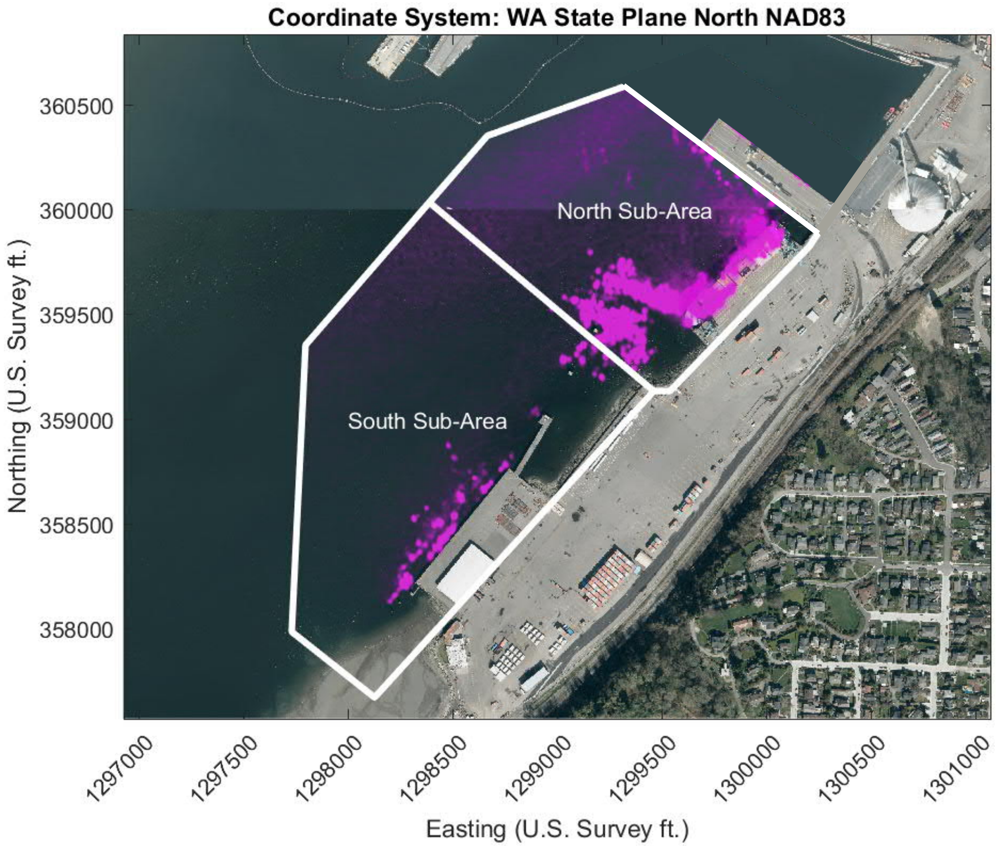
Define AIS Data Analysis Area



- Scour analysis area includes area of surface and sub-surface sediment contamination
- Analysis area is further divided into North and South sub-areas
- North Sub-Area
  - Pacific Terminal
  - Pier 1
- South Sub-Area
  - South Terminal

Received AIS Data in Project Area – All Vessels

Source of Data: AstraPaging (2 years of data requested)



Legend

- Low density of AIS pings (less active areas)
- Medium density of AIS pings (more active areas)
- High density of AIS pings (most active areas)

Each AIS "ping" records the vessels position at an instant in time

Types of Vessels

Occurrences by Vessel type in AIS data

AISTYPE	Ping_Count	Description
52	378954	'Tug'
31	321327	'Towing'
70	199034	Cargo - all ships of this type'
32	147399	'Towing: length exceeds 200m or breadth exceeds 25m'
35	74209	'Military ops'
33	53638	'Dredging or underwater ops'
71	31401	'Cargo - Hazardous category A'
79	27039	Cargo - No additional information'
0	16611	'Not available (default)'
57	10774	'Spare - Local Vessel'
74	10517	'Cargo - Hazardous category D'
90	5960	'Other Type - all ships of this type'
73	1585	'Cargo - Hazardous category C'
9	1142	'Reserved for future use'
37	854	'Pleasure Craft'
50	769	'Pilot Vessel'
38	647	'Reserved'
72	601	'Cargo - Hazardous category B'
1	229	'Reserved for future use'
30	197	'Fishing'
56	151	'Spare - Local Vessel'
99	91	'Other Type - no additional information'
39	82	'Reserved'
20	60	'Wing in ground (WIG) - all ships of this type'
89	50	'Tanker - No additional information'
60	40	'Passenger - all ships of this type'
55	19	'Law Enforcement'
36	11	'Sailing'

Data Filtering

- All occurrences shaded GREEN were used in analysis. All categories in RED were removed from the dataset.
- All Cargo categories were grouped into a single category
- Only 1 Pilot vessel found WASHTUCNA YT801 (used for Navy operations) – removed from data
- Only 1 Tanker vessel found OCEAN RELIANCE – removed from data
- 4 Vessel categories after filtering

Vessel Type	AISTYPE Code	Description[1,2]
Tug	52	Light boats, fleet boats, or similar workboats
Towing	31	Towing ahead or alongside, but, not astern
Towing (Length > 200m **or** Breadth > 25m)	32	Towing astern, regardless whether the length of the tow exceeds 200 m or breadth exceeds 25 m
Cargo	70 - 79	Cargo, all ships of this type Cargo, Hazardous category A – D Cargo, Reserved for future use

1. *USCG definitions used for Tugs, Towing, and Towing* (Length > 200m **or** Breadth > 25m)
2. AIVDM/AIVDO definitions for Cargo and Tankers

Types of Vessels Analyzed

Cargo

North Sub-Area

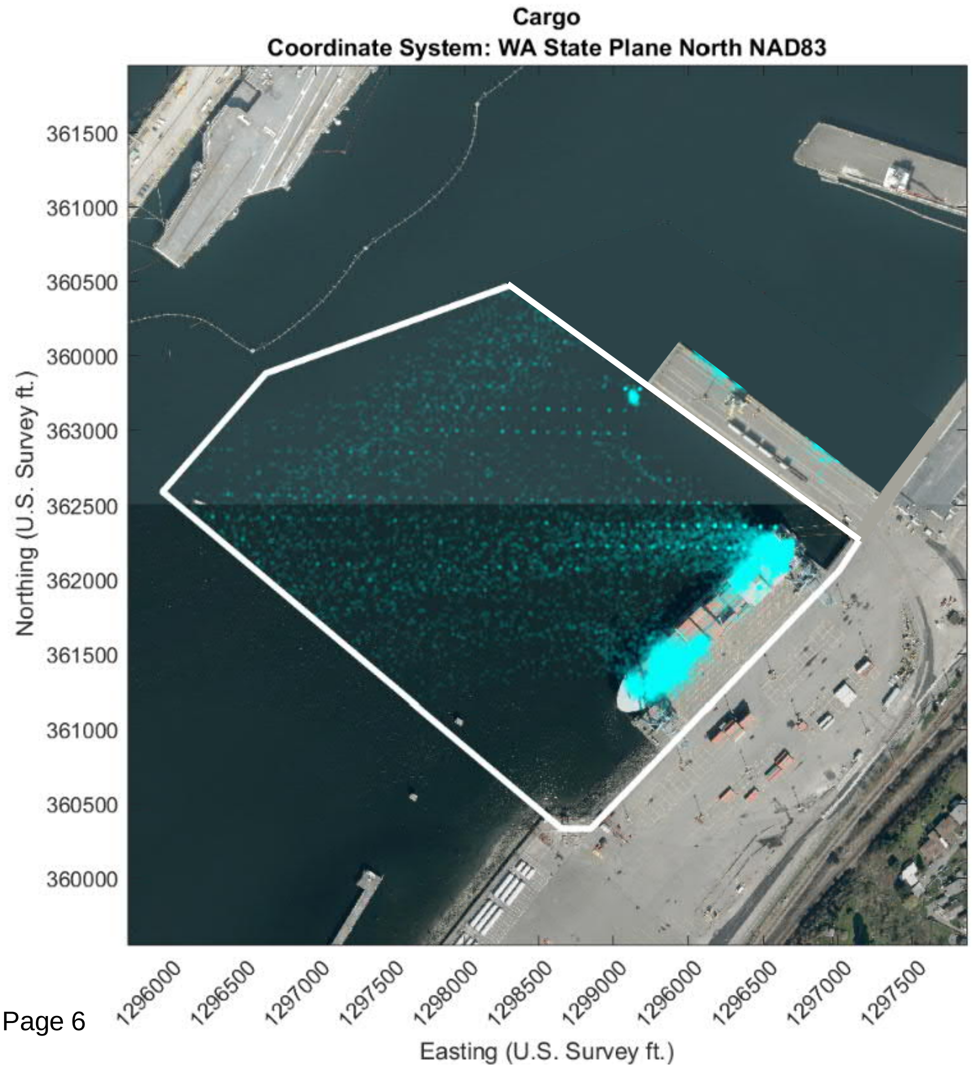
Pacific Terminal
Pier 1

North Sub-Area

Cargo

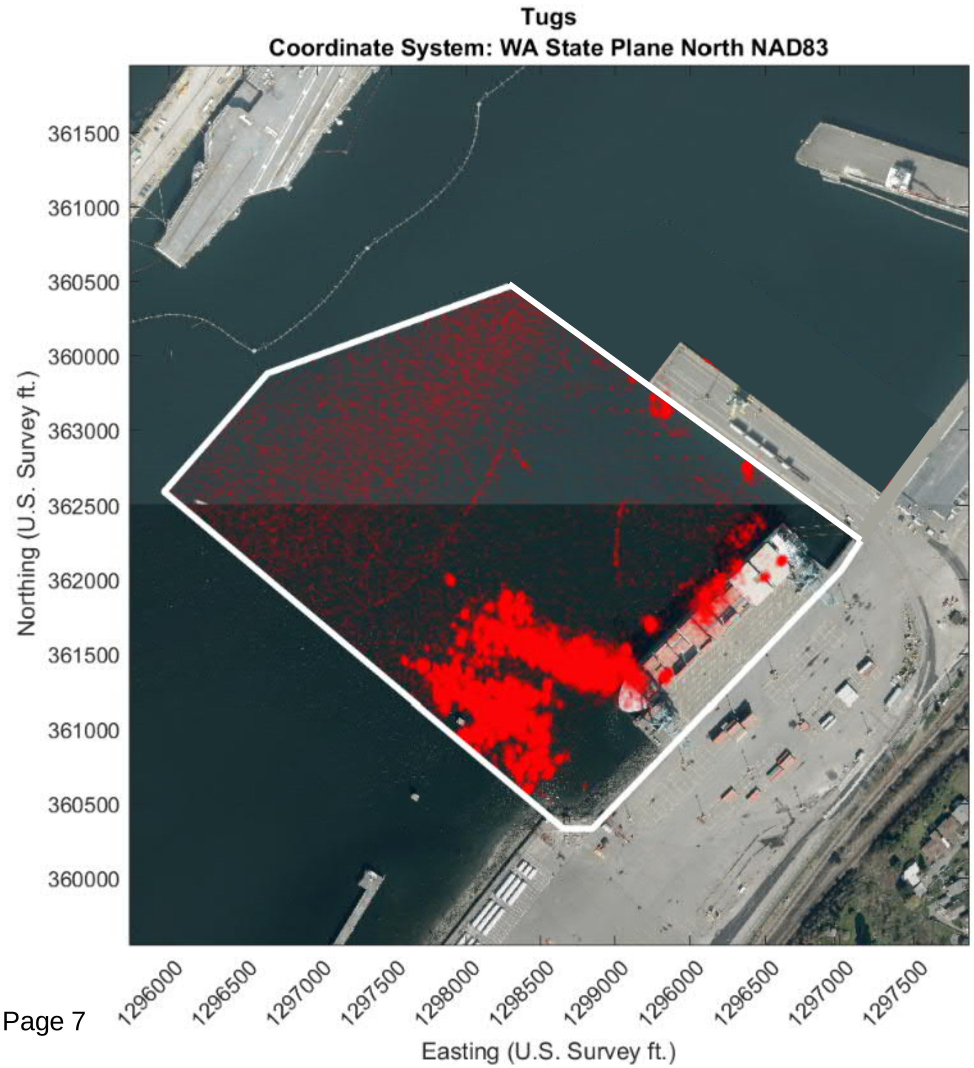
For reference:

Vessel Type	AISTYPE Code	Description[1,2]
Tug	52	Light boats, fleet boats, or similar workboats
Towing	31	Towing ahead or alongside, but, not astern
Towing (Length > 200m **or** Breadth > 25m)	32	Towing astern, regardless whether the length of the tow exceeds 200 m or breadth exceeds 25 m
Cargo	70 - 79	Cargo, all ships of this type Cargo, Hazardous category A – D Cargo, Reserved for future use



North Sub-Area

Tugs



For reference:

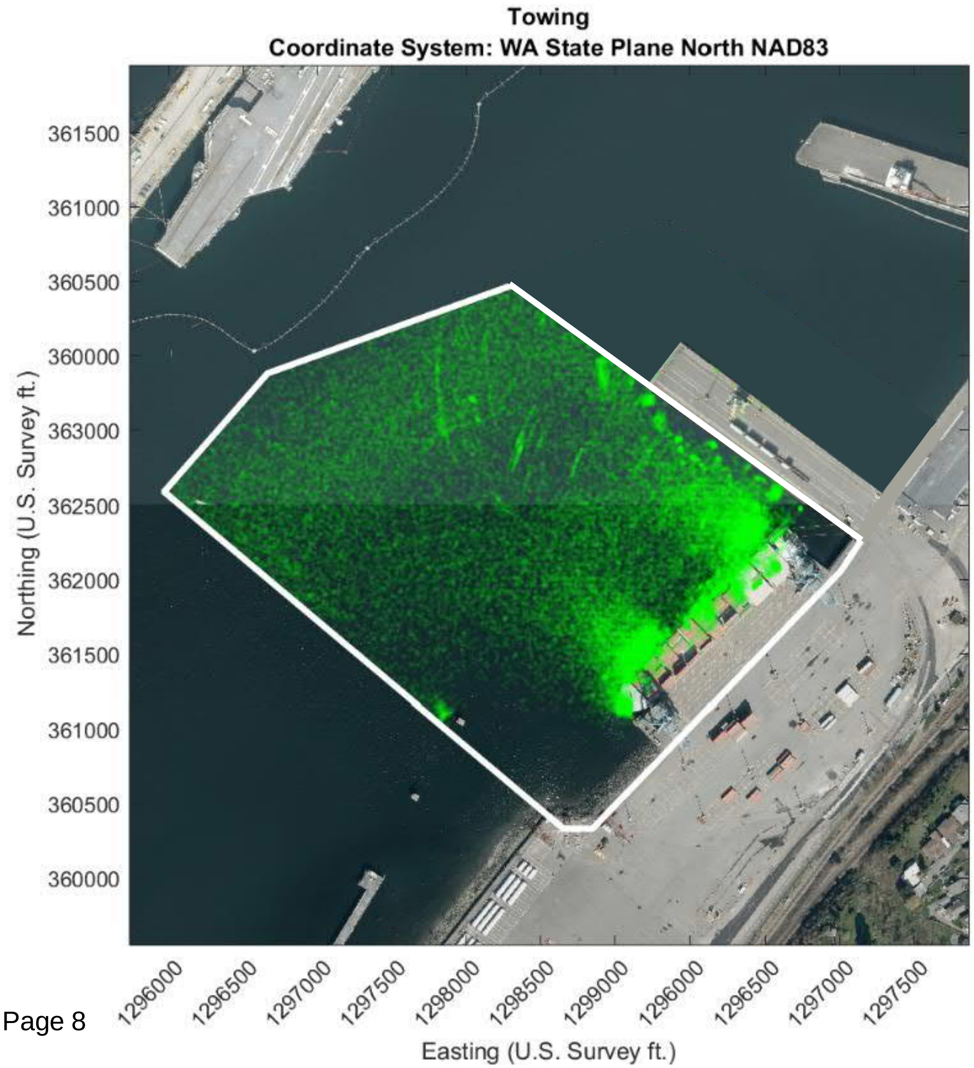
Vessel Type	AISTYPE Code	Description[1,2]
Tug	52	Light boats, fleet boats, or similar workboats
Towing	31	Towing ahead or alongside, but, not astern
Towing (Length > 200m **or** Breadth > 25m)	32	Towing astern, regardless whether the length of the tow exceeds 200 m or breadth exceeds 25 m
Cargo	70 - 79	Cargo, all ships of this type Cargo, Hazardous category A – D Cargo, Reserved for future use

North Sub-Area

Towing

For reference:

Vessel Type	AISTYPE Code	Description[1,2]
Tug	52	Light boats, fleet boats, or similar workboats
Towing	31	Towing ahead or alongside, but, not astern
Towing (Length > 200m **or** Breadth > 25m)	32	Towing astern, regardless whether the length of the tow exceeds 200 m or breadth exceeds 25 m
Cargo	70 - 79	Cargo, all ships of this type Cargo, Hazardous category A – D Cargo, Reserved for future use



South Sub-Area

South Terminal

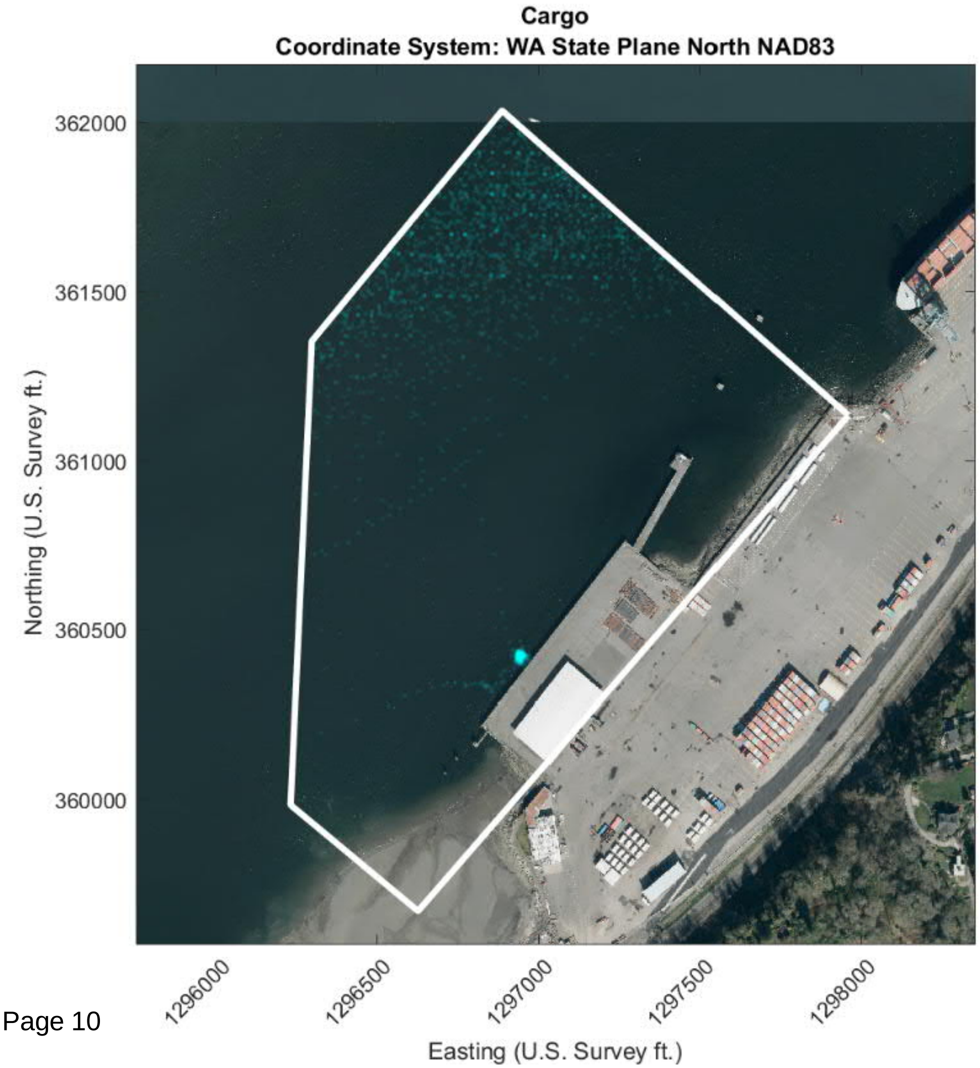
South Sub-Area

Cargo

- Limited cargo use at South Terminal during period of AIS data

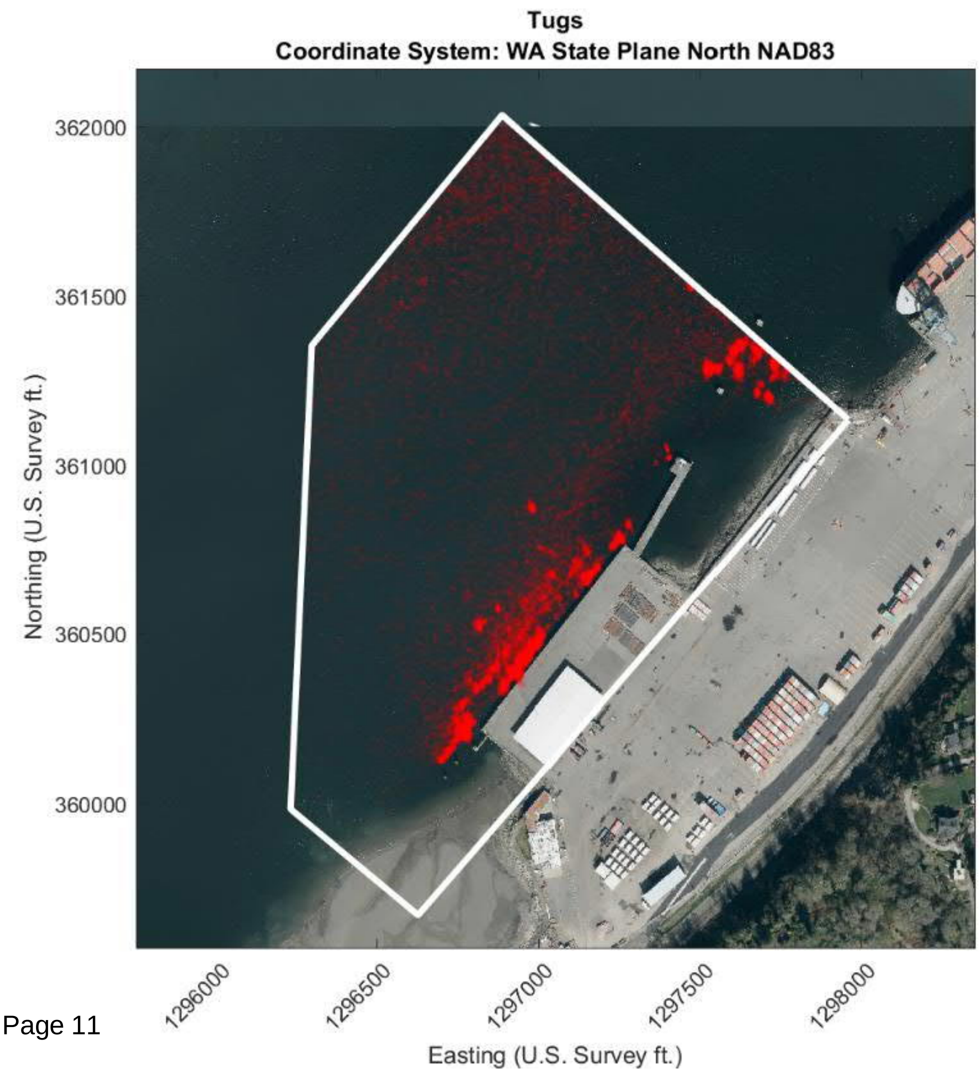
For reference:

Vessel Type	AISTYPE Code	Description[1,2]
Tug	52	Light boats, fleet boats, or similar workboats
Towing	31	Towing ahead or alongside, but, not astern
Towing (Length > 200m **or** Breadth > 25m)	32	Towing astern, regardless whether the length of the tow exceeds 200 m or breadth exceeds 25 m
Cargo	70 - 79	Cargo, all ships of this type Cargo, Hazardous category A – D Cargo, Reserved for future use



South Sub-Area

Tugs

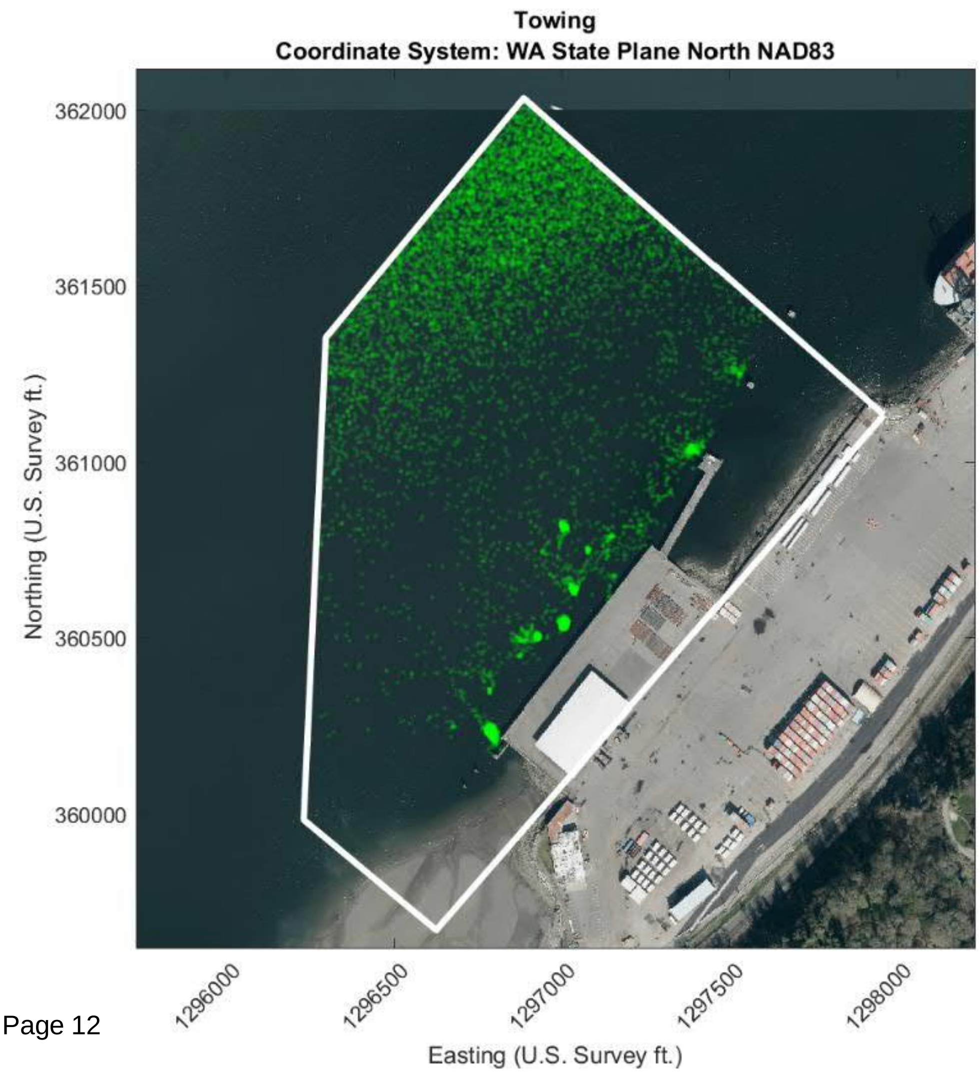


For reference:

Vessel Type	AISTYPE Code	Description[1,2]
Tug	52	Light boats, fleet boats, or similar workboats
Towing	31	Towing ahead or alongside, but, not astern
Towing (Length > 200m **or** Breadth > 25m)	32	Towing astern, regardless whether the length of the tow exceeds 200 m or breadth exceeds 25 m
Cargo	70 - 79	Cargo, all ships of this type Cargo, Hazardous category A – D Cargo, Reserved for future use

South Sub-Area

Towing



For reference:

Vessel Type	AISTYPE Code	Description[1,2]
Tug	52	Light boats, fleet boats, or similar workboats
Towing	31	Towing ahead or alongside, but, not astern
Towing (Length > 200m **or** Breadth > 25m)	32	Towing astern, regardless whether the length of the tow exceeds 200 m or breadth exceeds 25 m
Cargo	70 - 79	Cargo, all ships of this type Cargo, Hazardous category A – D Cargo, Reserved for future use

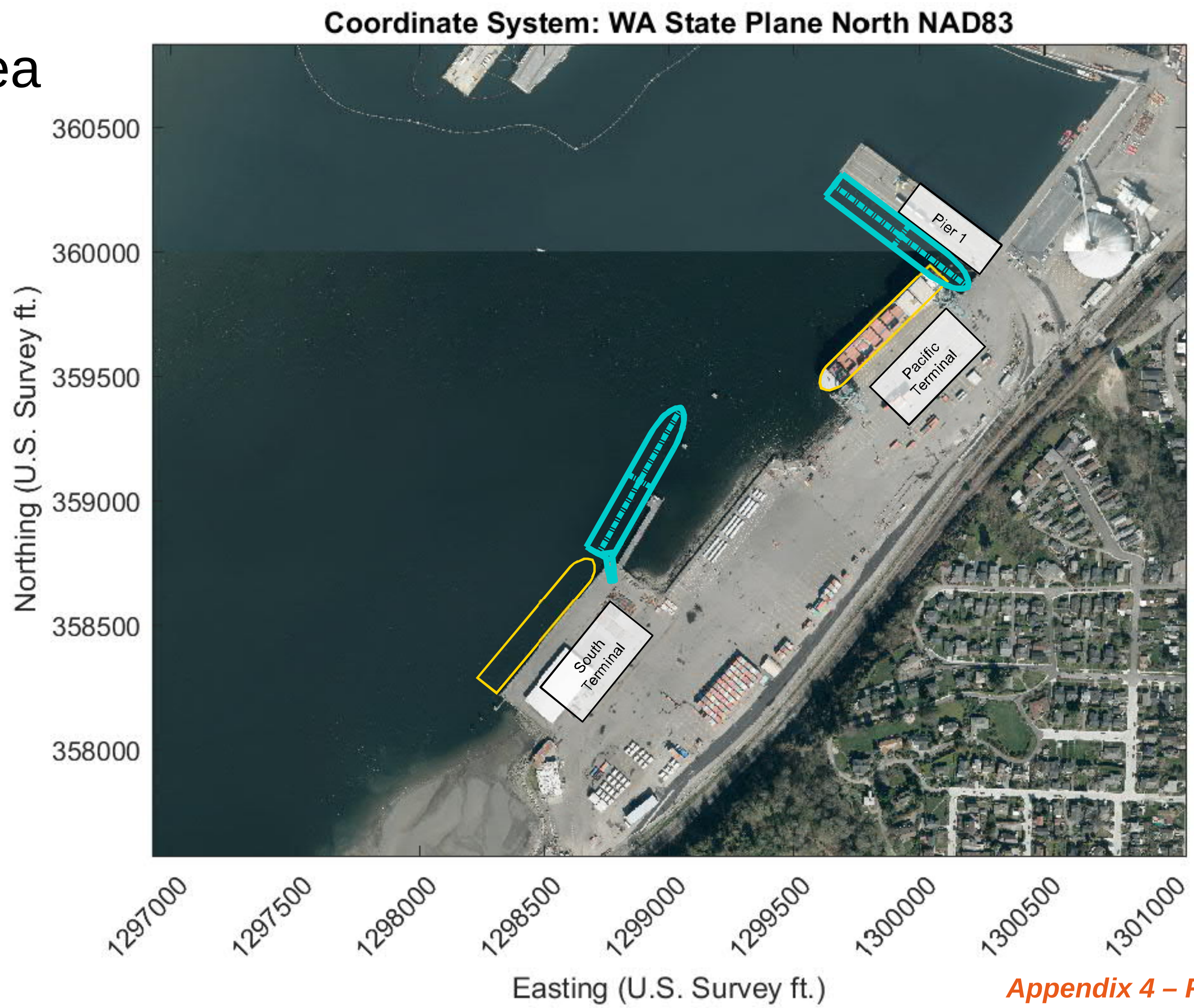
Appendix 4: Vessel Maneuvering and Berthing

Berths in Study Area

Pier 1
- Barges, container ships, and Ro-Ro vessels

Pacific Terminal
- Cargo
- Westwood shipping
- Ro-Ro potentially

South Terminal
- Ro-Ro historically
- Bulk cargo



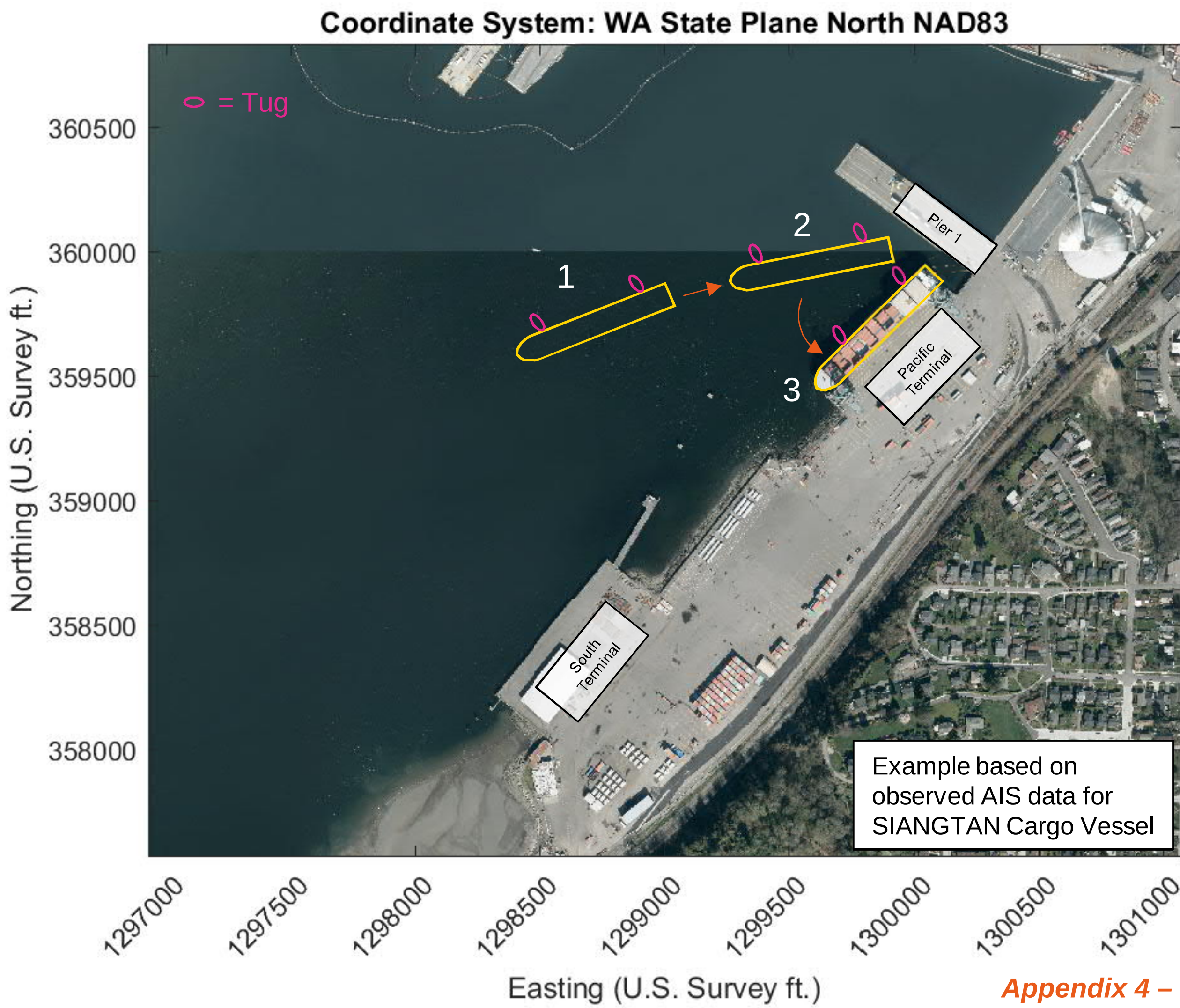
Appendix 4 – Figure 1

Pacific Terminal

Cargo - Arriving

Operations

- Westwood shipping lines (every Tuesday)
- N-class vessels use 1 tug in, 1 tug out
- Larger vessels use 2 tugs in, 1 tug out
- Bow thrusters during approach and departure
- Main engine once rotated to face West
- Tractor tug (Bo Brusco) preferred by many captains



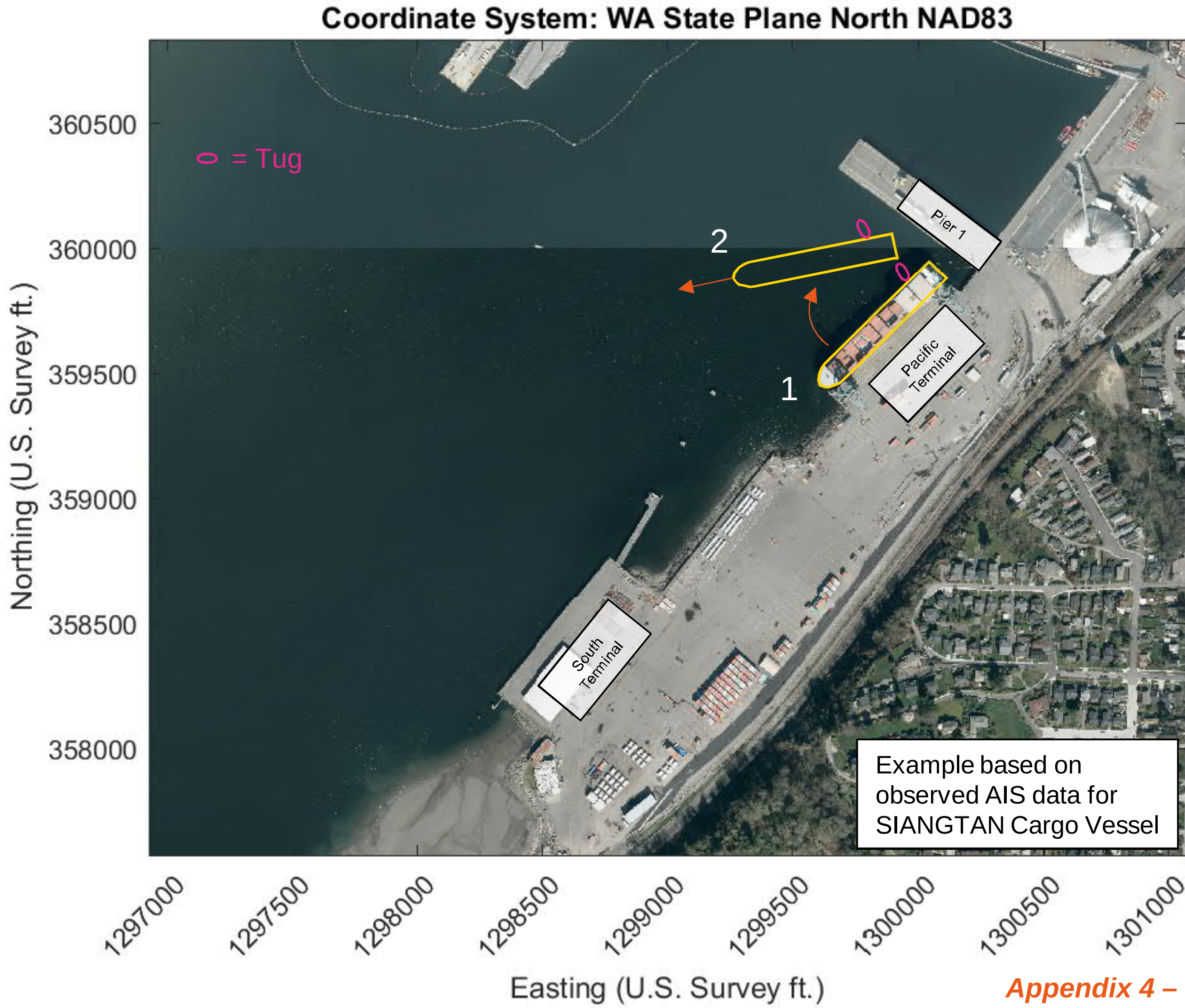
Appendix 4 – Figure 2

Pacific Terminal

Cargo - Departing

Operations

- Westwood shipping lines (every Tuesday)
- N-class vessels use 1 tug in, 1 tug out
- Larger vessels use 2 tugs in, 1 tug out
- Bow thrusters during approach and departure
- Main engine once rotated to face West
- Tractor tug (Bo Brusco) preferred by many captains



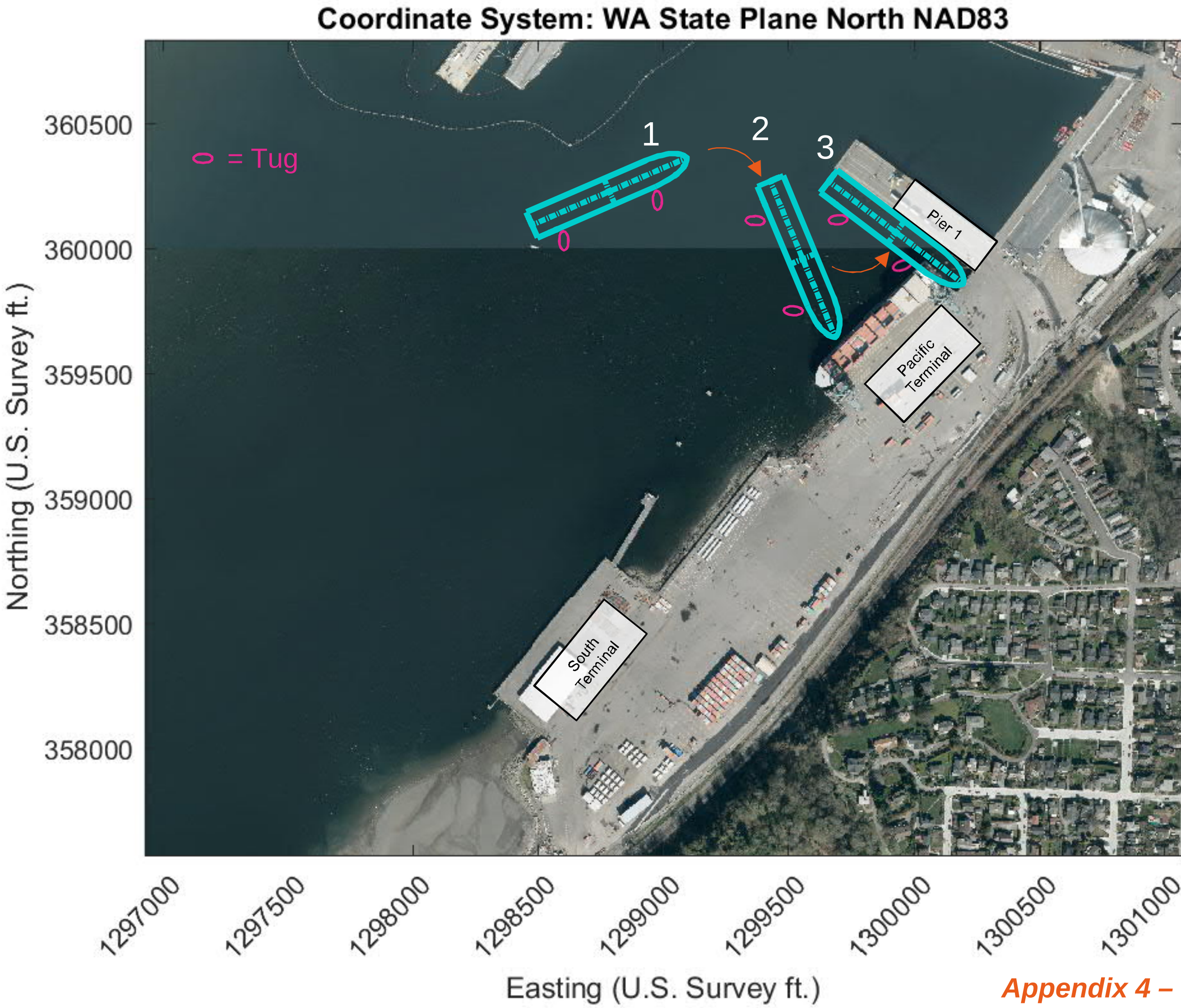
Appendix 4 – Figure 3

Pier 1

Cargo - Arriving

Operations

- Primarily barges, also Container Ships (i.e. Westwood Shipping Line vessels)
- Bow thrusters can blast water "upslope"
- Vessel bow typically facing shoreline
- Tug assisted in and out



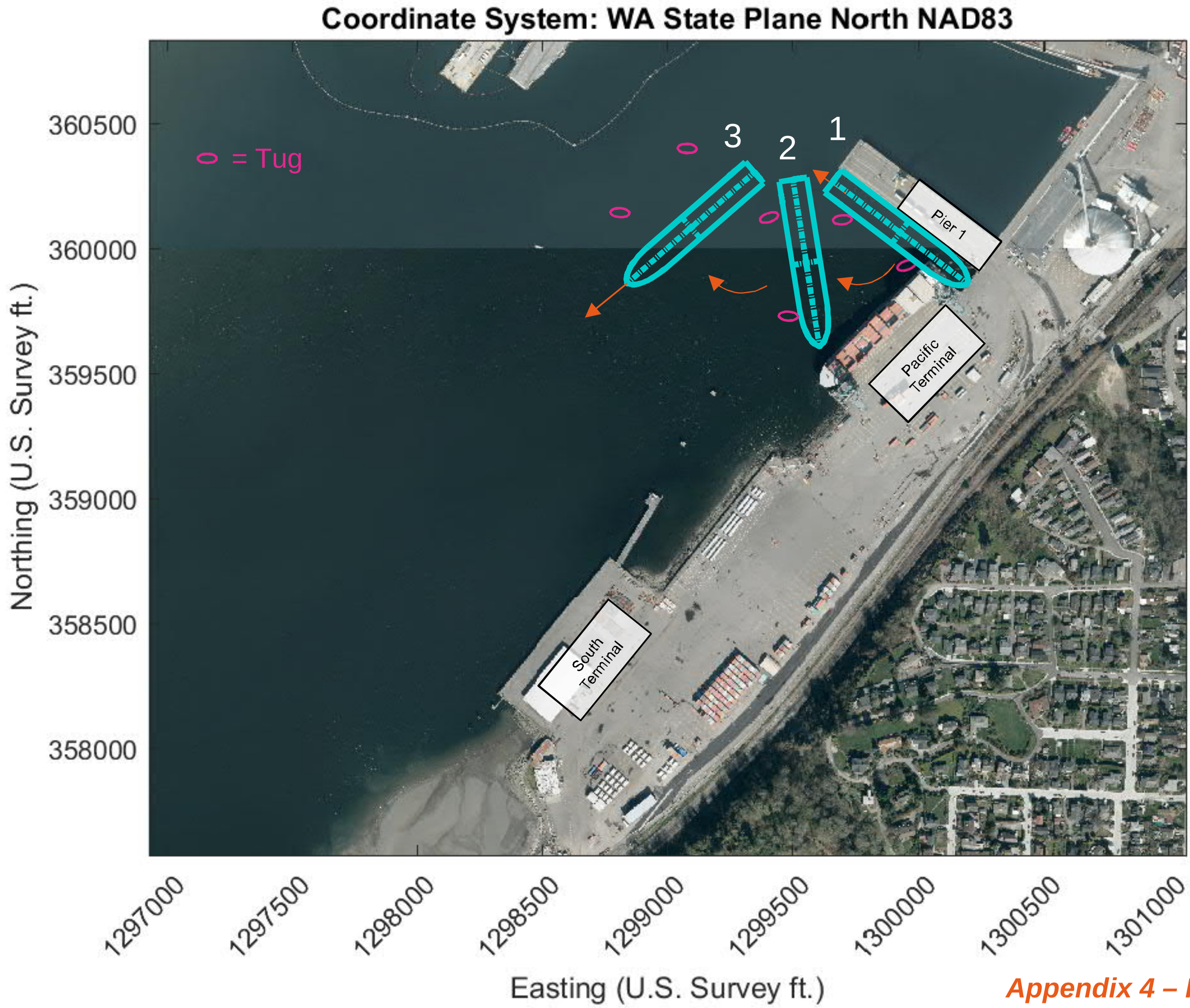
Appendix 4 – Figure 4

Pier 1

Cargo - Departing

Operations

- Primarily barges, also Container Ships (i.e. Westwood Shipping Line vessels)
- Bow thrusters can blast water "upslope"
- Vessel bow typically facing shoreline
- Tug assisted in and out



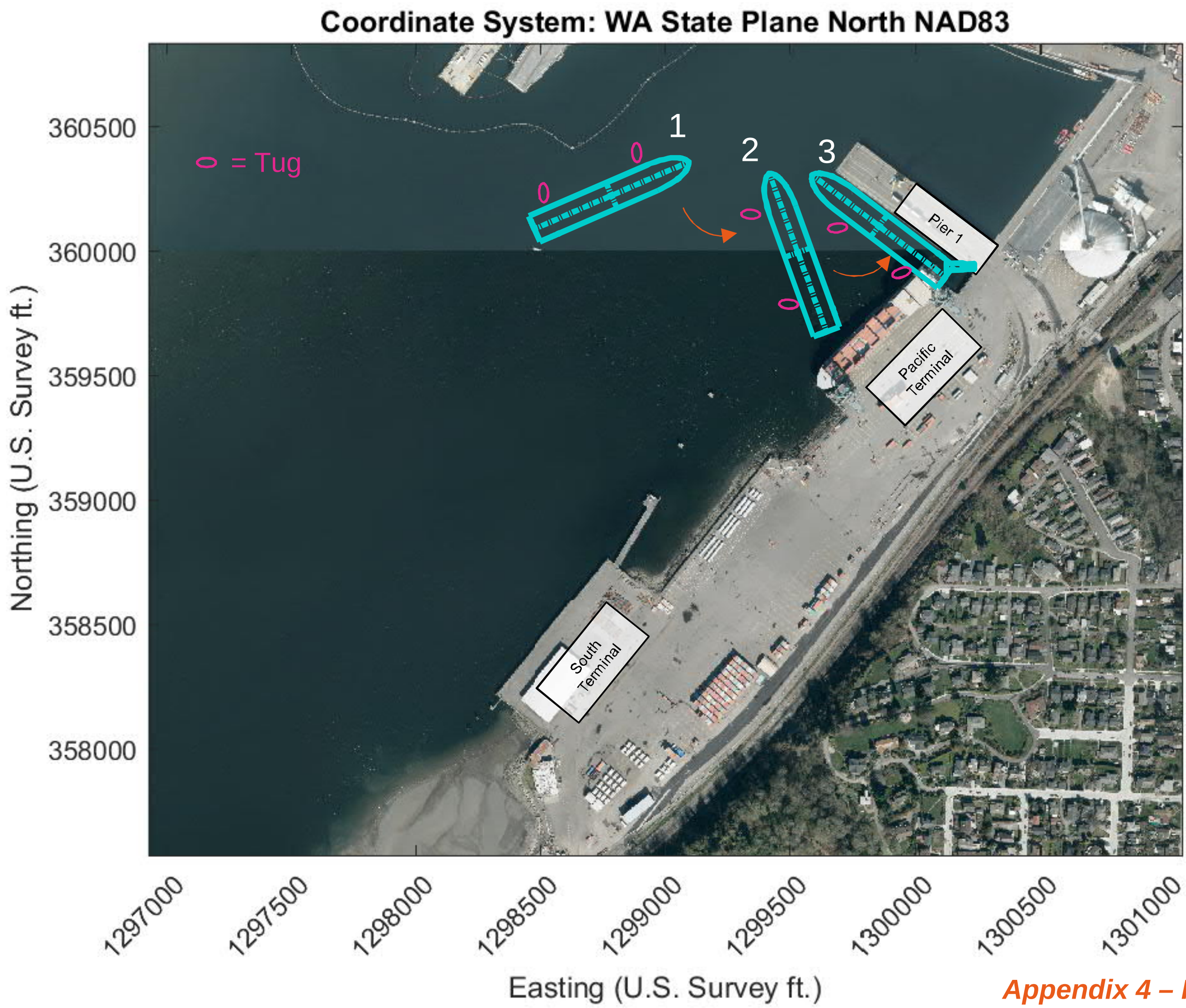
Appendix 4 – Figure 5

Pier 1

Ro-Ro - Arriving

Operations

- Example vessels: *VCOR* & *Glovis*
- Bow thrusters can blast water “upslope”
- Vessel bow typically facing away from shoreline
- Tug assisted in and out



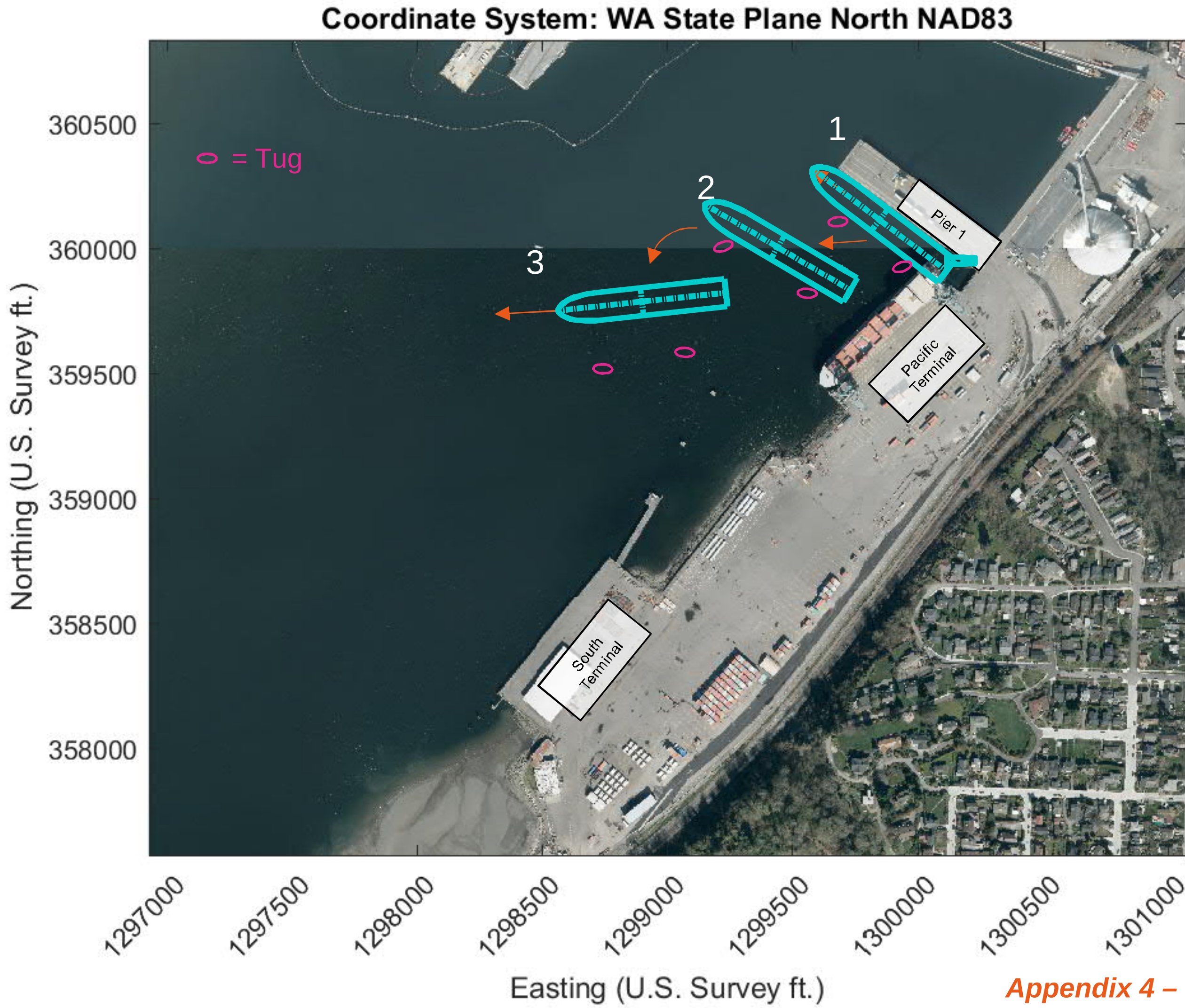
Appendix 4 – Figure 6

Pier 1

Ro-Ro - Departing

Operations

- Example vessels: *VCOR* & *Glovis*
- Bow thrusters can blast water "upslope"
- Vessel bow typically facing away from shoreline
- Tug assisted in and out



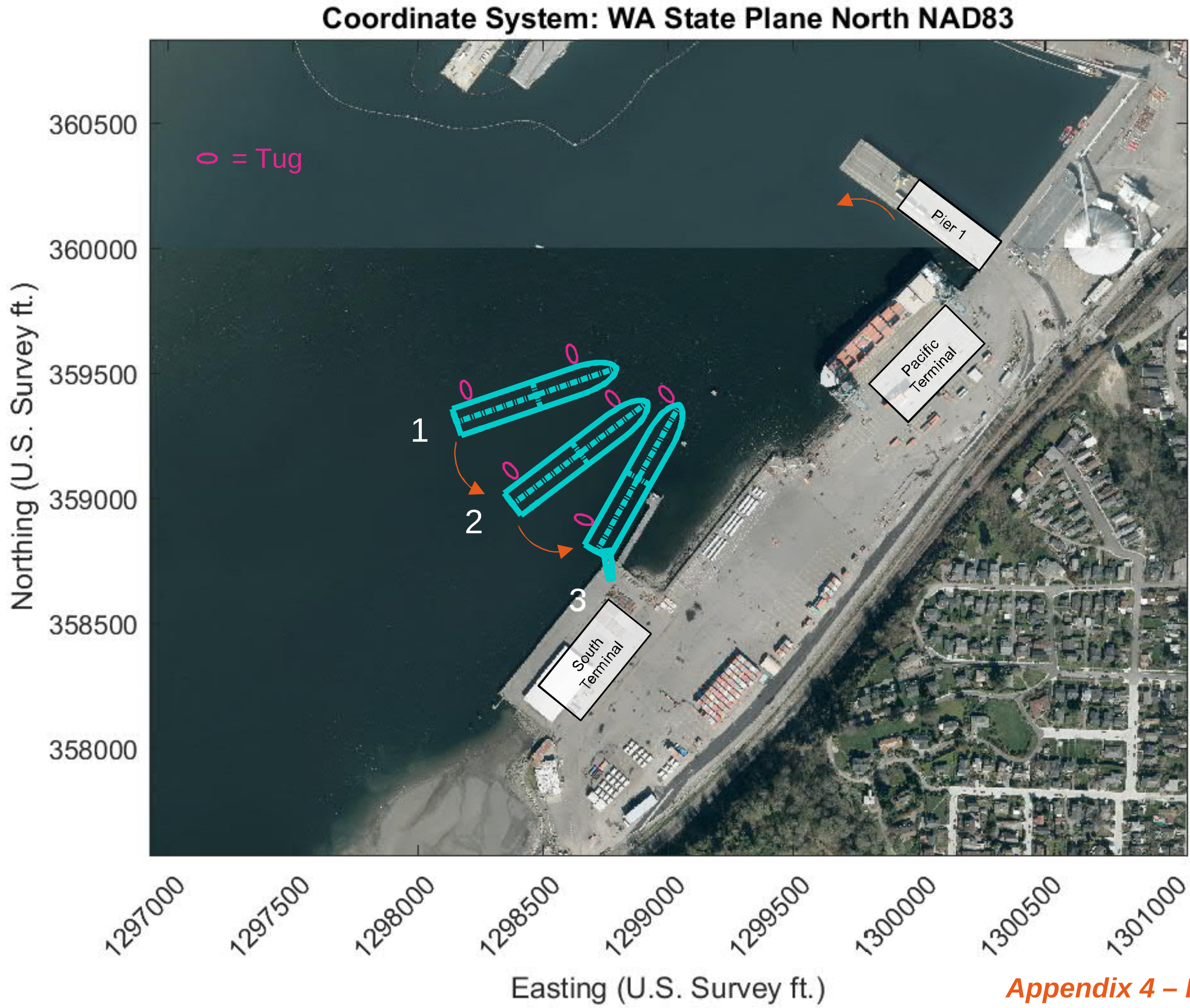
Appendix 4 – Figure 7

South Terminal

Ro-Ro - Arriving

Operations

- Ro-Ro previously used South Terminal (currently using Pier 1)
- Tug-assisted in and out



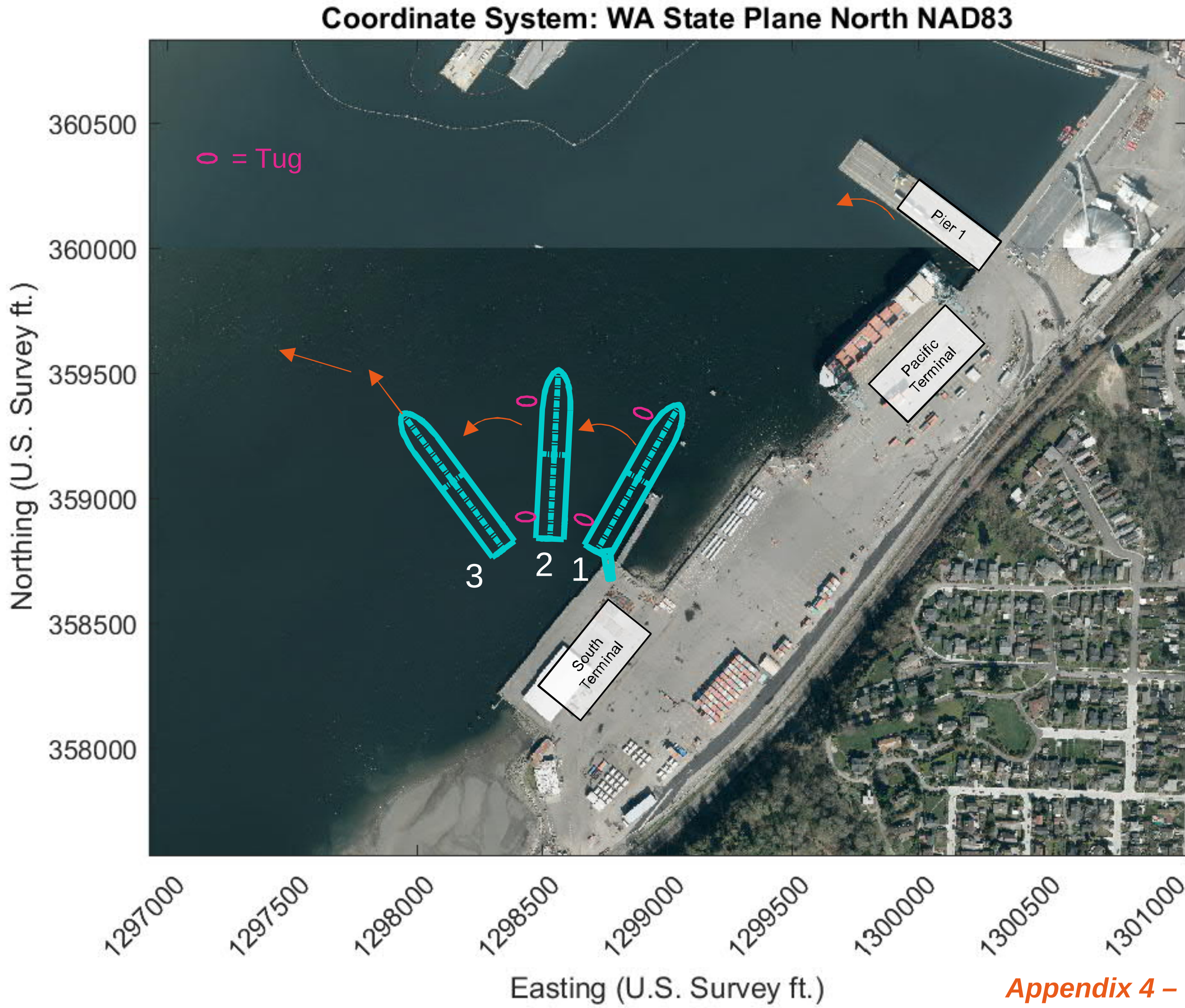
Appendix 4 – Figure 8

South Terminal

Ro-Ro - Departing

Operations

- Ro-Ro previously used South Terminal (currently using Pier 1)
- Tug-assisted in and out



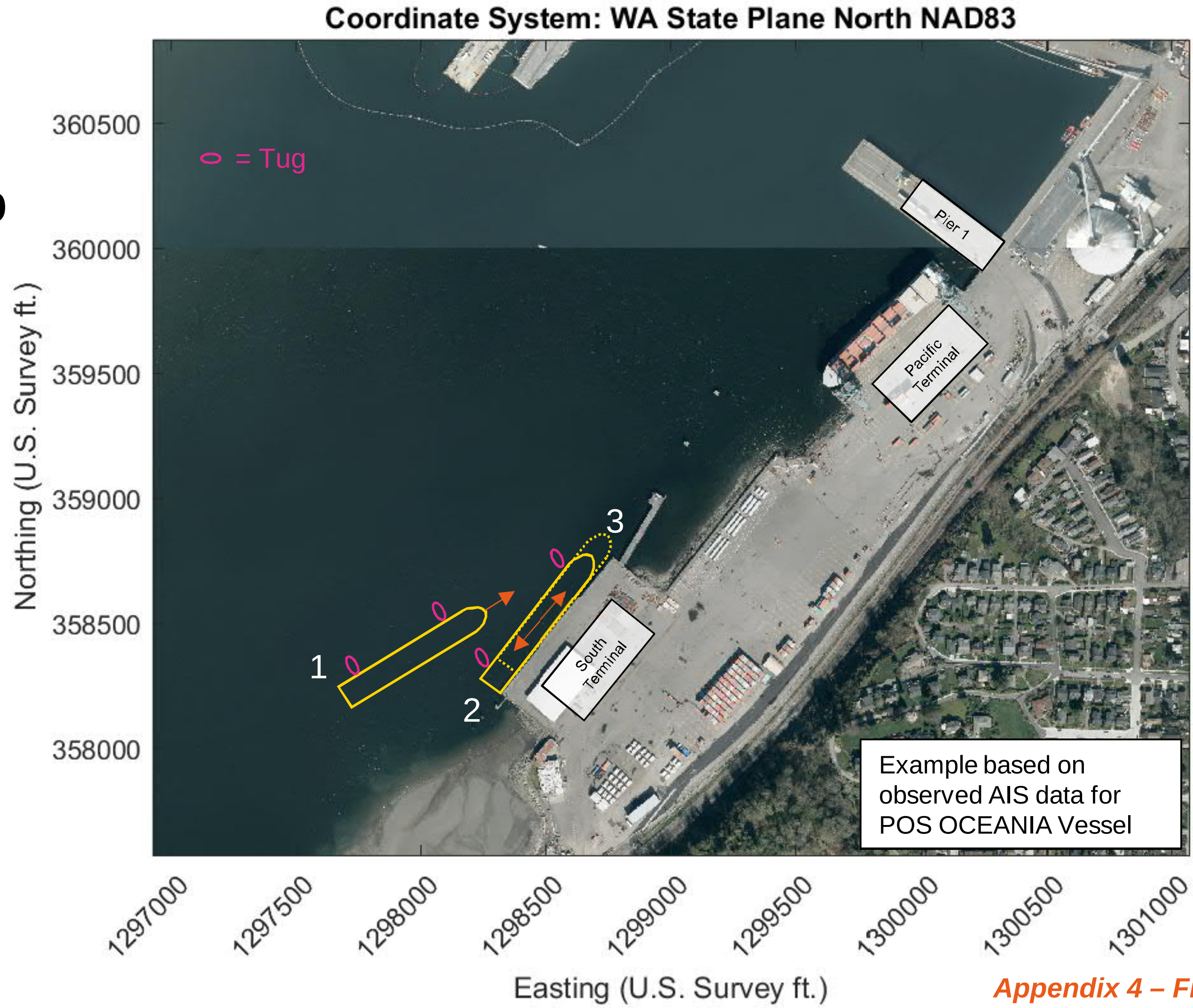
Appendix 4 – Figure 9

South Terminal

Cargo – Arriving to Starboard

Operations

- Max vessel size ~850 ft.
- Handy Max vessels typically 400 – 550 ft.
- Typical draft 30 ft.
- Some vessels dock starboard side to berth, others port



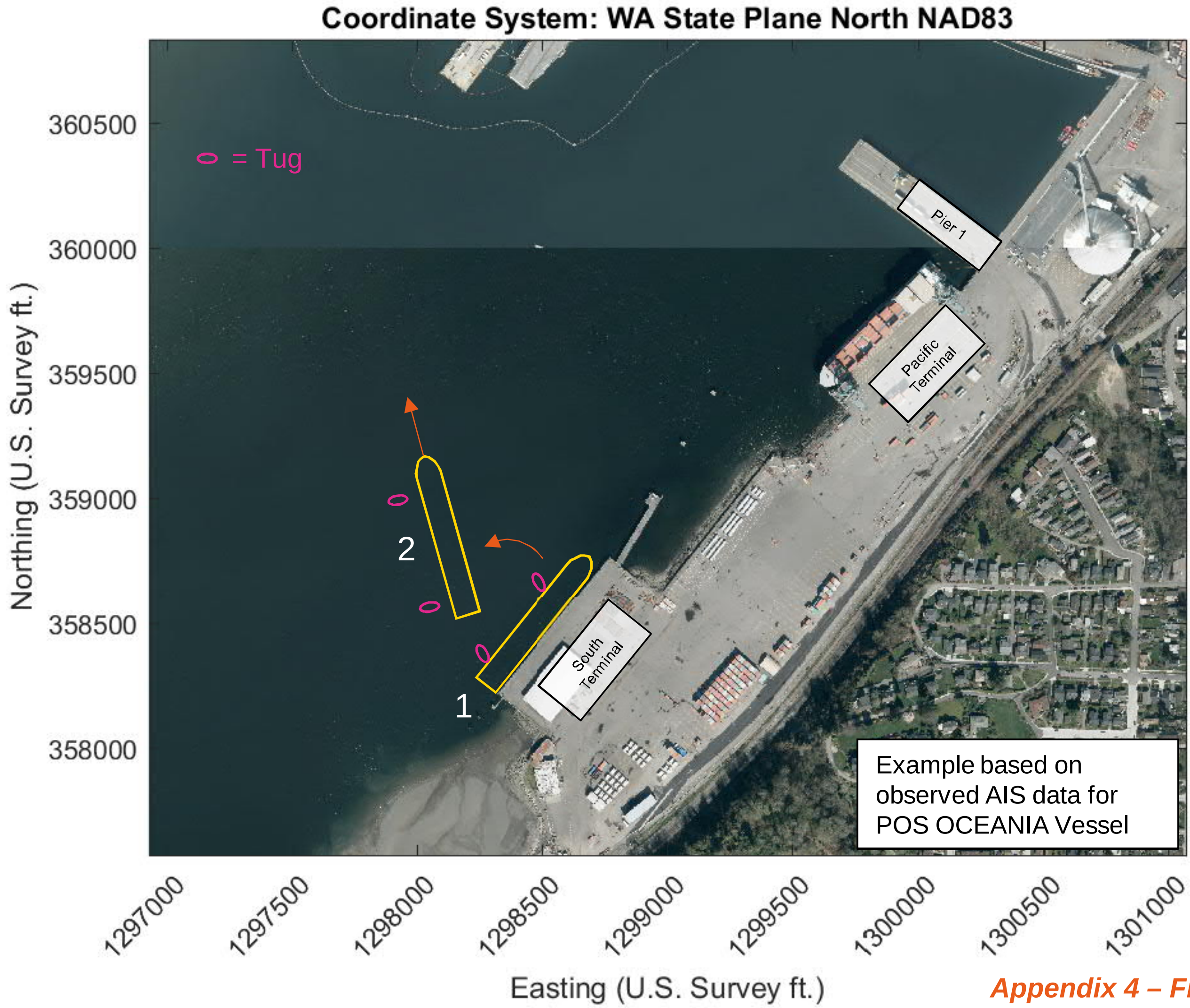
Appendix 4 – Figure 10

South Terminal

Cargo – Departing to Starboard

Operations

- Max vessel size ~850 ft.
- Handy Max vessels typically 400 – 550 ft.
- Typical draft 30 ft.
- Some vessels dock starboard side to berth, others port



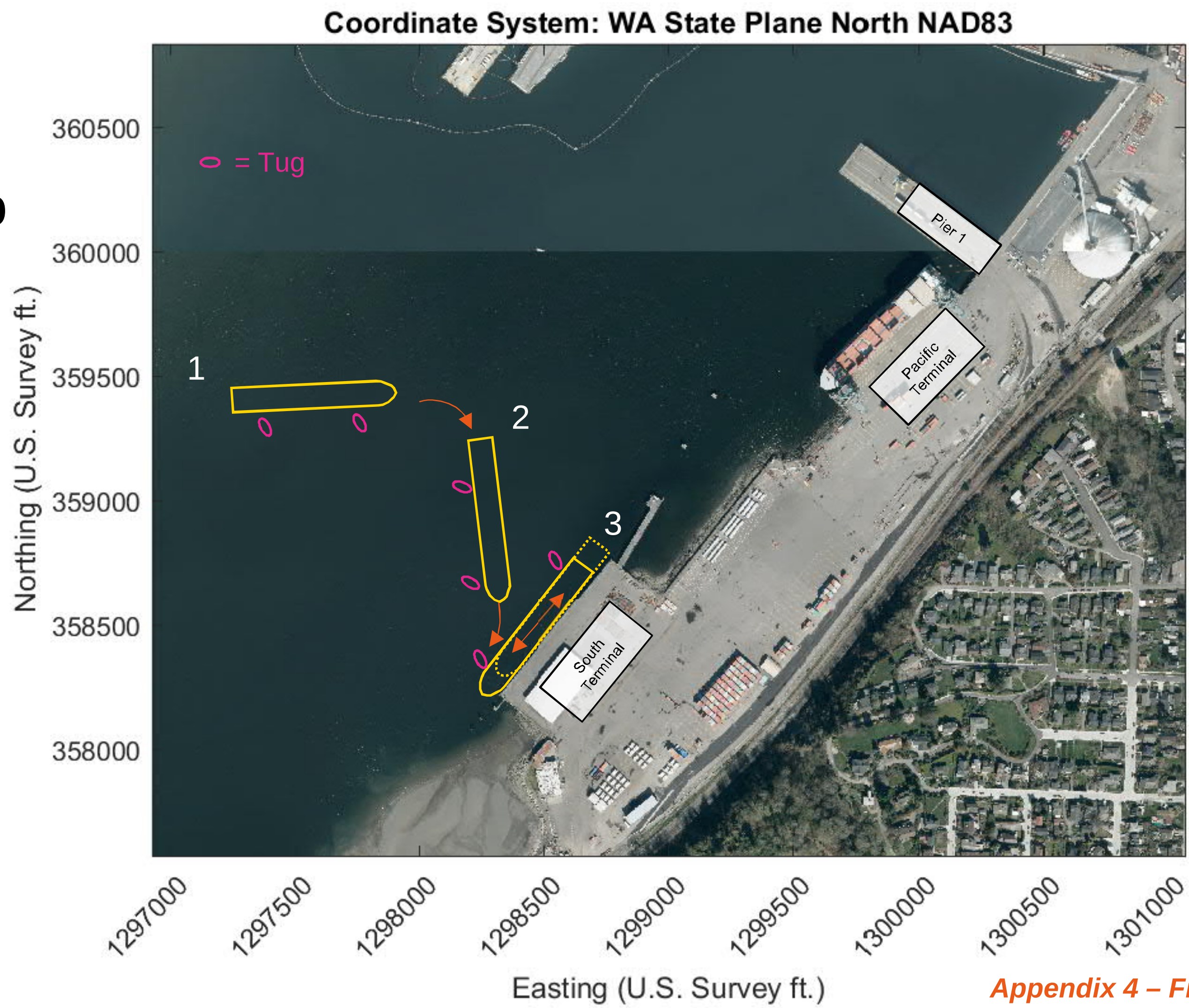
Appendix 4 – Figure 11

South Terminal

Cargo – Arriving to Port

Operations

- Max vessel size ~850 ft.
- Handy Max vessels typically 400 – 550 ft.
- Typical draft 30 ft.
- Some vessels dock starboard side to berth, others port



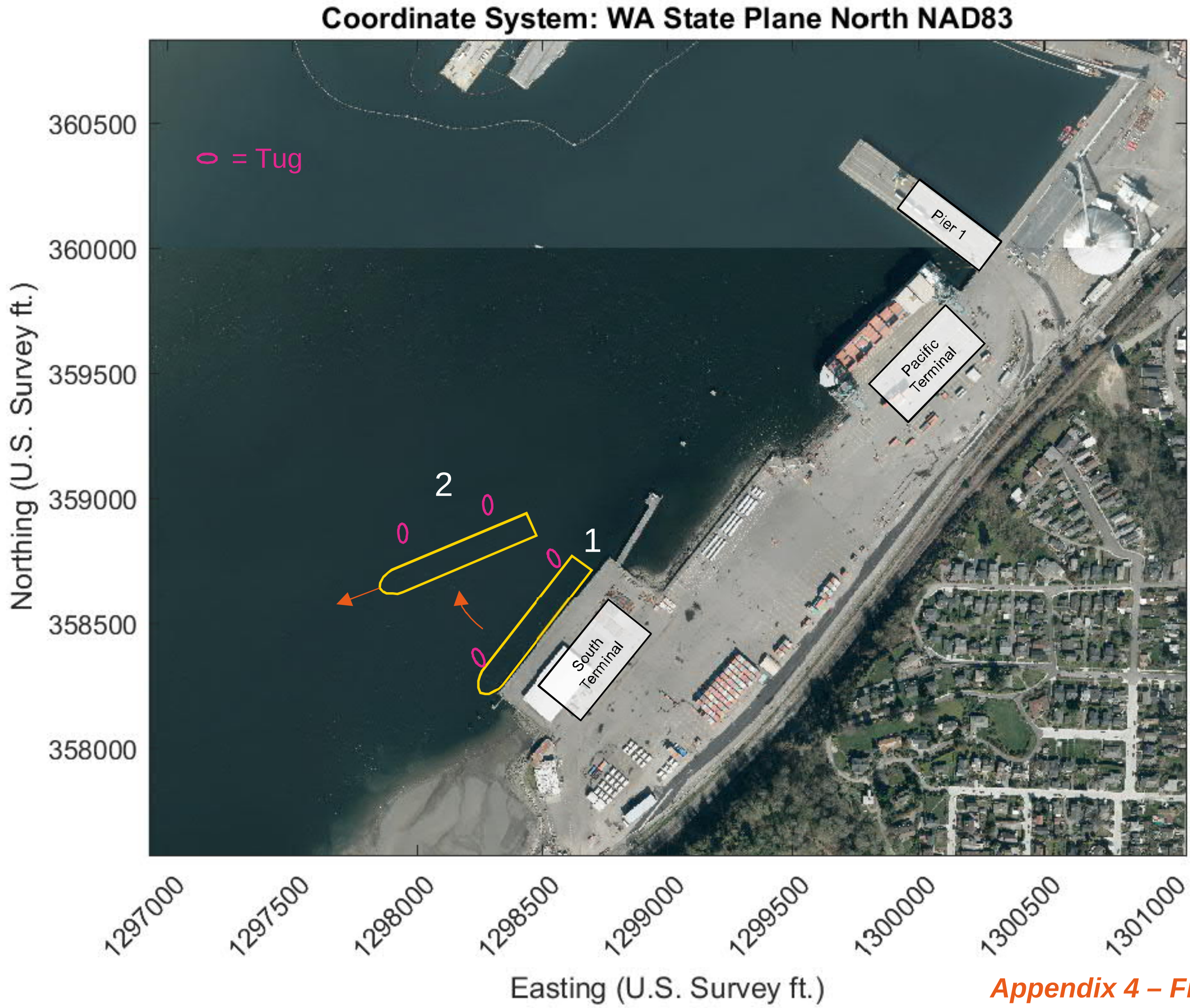
Appendix 4 – Figure 12

South Terminal

Cargo – Departing to Port

Operations

- Max vessel size ~850 ft.
- Handy Max vessels typically 400 – 550 ft.
- Typical draft 30 ft.
- Some vessels dock starboard side to berth, others port



Appendix 4 – Figure 13

Appendix 5: Propwash Modeling Scenarios

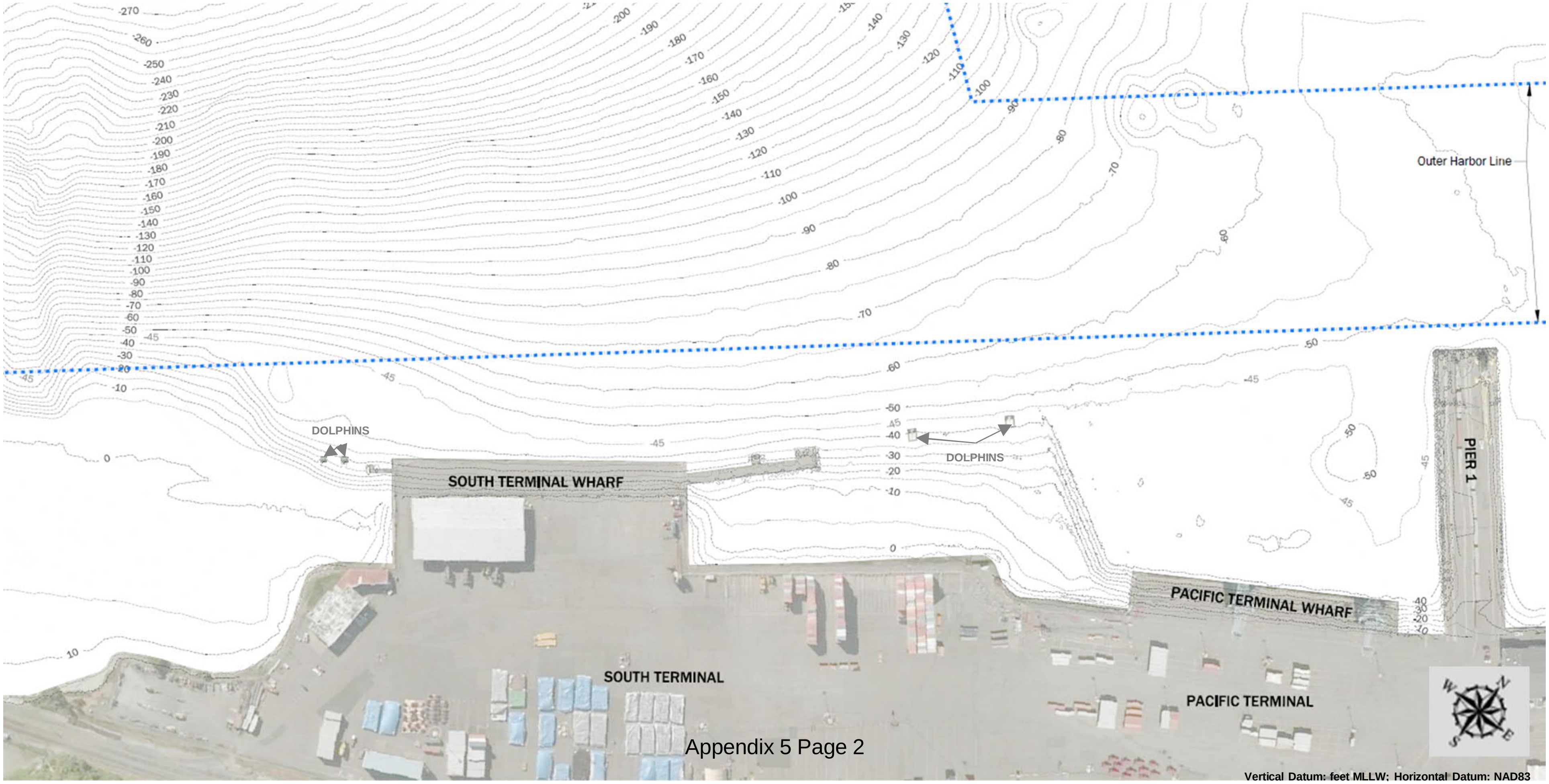
Purpose

- Define the modeling scenarios used in the simulations
- Define inputs and assumptions for the simulations

Referenced Data & Analysis

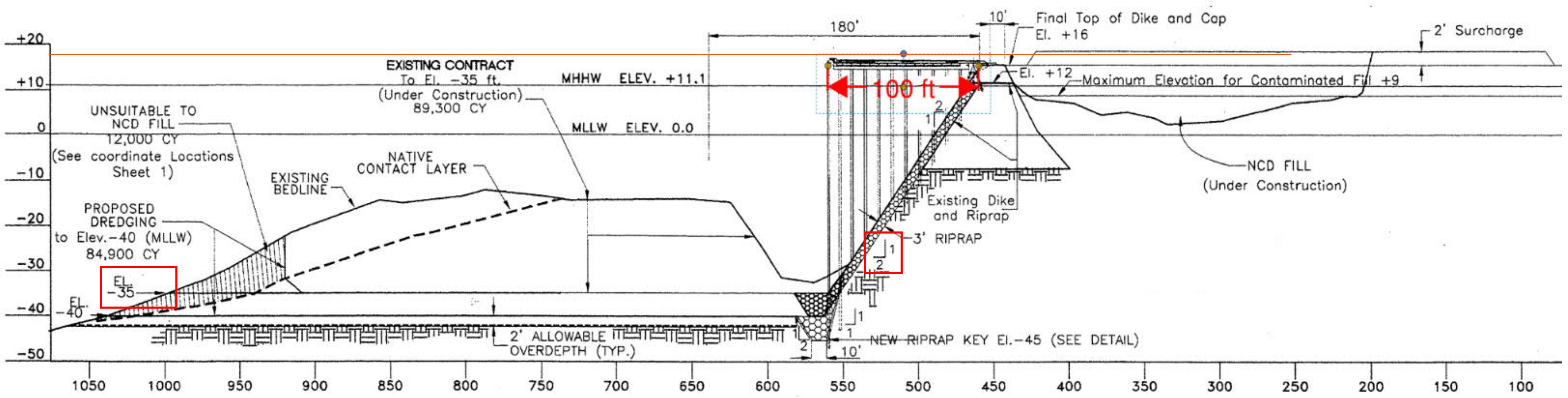
- September 2013 and February 2017 bathymetric surveys
- As-Built Berth Cross-Sections
- Appendix 3: AIS Vessel Tracking Analysis
- Appendix 4: Vessel Maneuvering and Berthing

Existing Site Conditions – Conditions assumed for analysis



Berth As-Builts

Pacific Terminal (1997) - Information used to support model setups in berth area

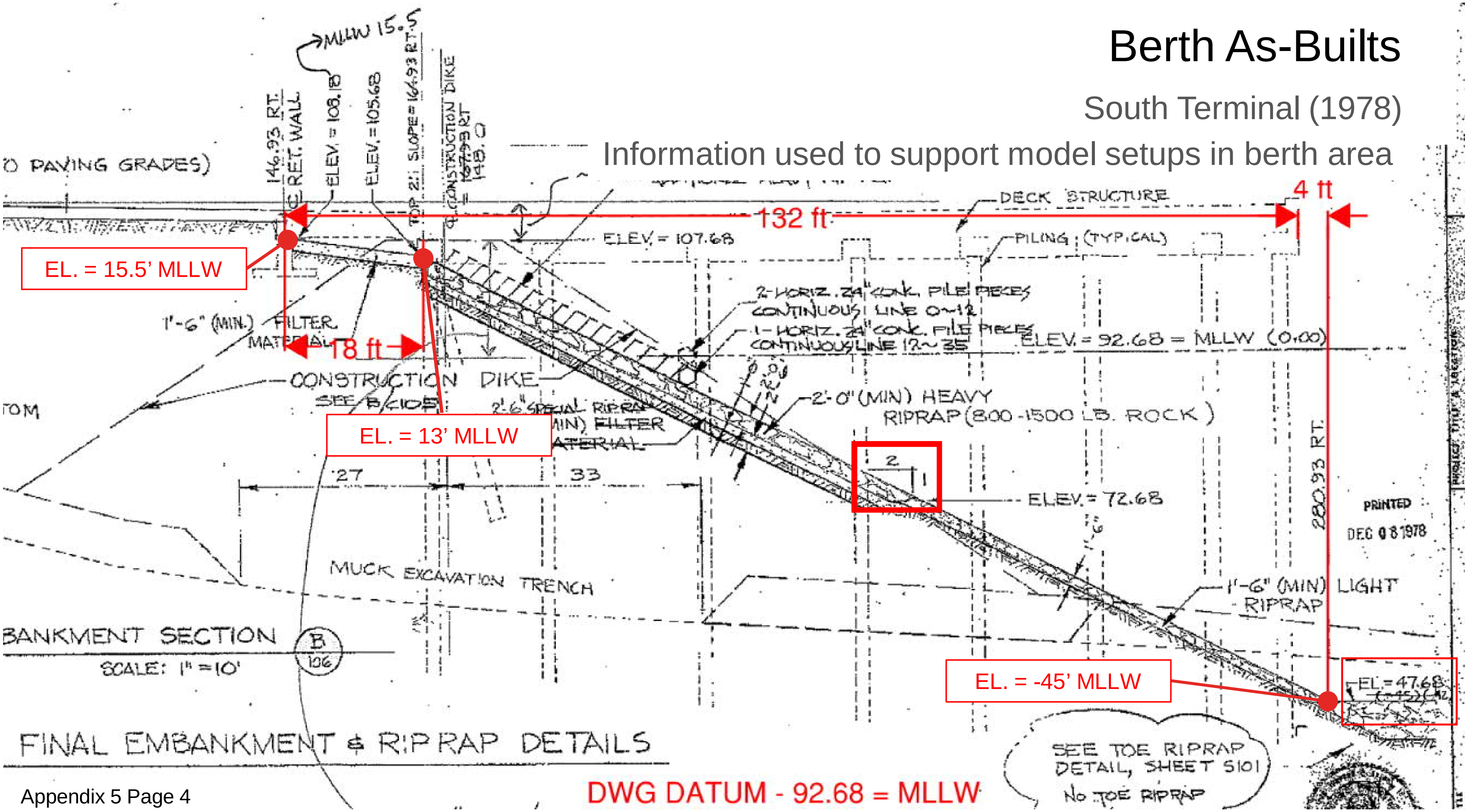


STATION 13+50 SECION A-A

Berth As-Builts

South Terminal (1978)

Information used to support model setups in berth area



Vessels Considered in Analysis

Location	Vessel Name	MMSI	Type	Length (feet)	Beam (feet)	Typical Draft (feet)
Deep Draft Vessels – Existing Use						
Pacific Terminal	Bardu	538005316	Container	685	98	38
South Terminal	Madame Butterfly	563892000	Ro / Ro	649	106	38
South Terminal	POS Oceania	538004706	Bulk Carrier	556	89	29
Tugs and Towing Vessels – Existing and Future Use						
All Terminals	Bo Brusco	367642530	Tug	78	29	9

Vessel Geometry & Power Specifics

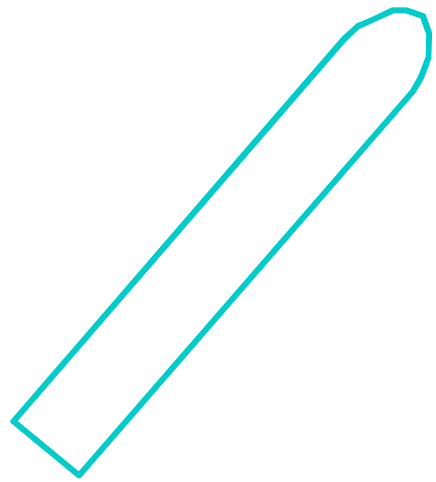
Vessel Name	Vessel Type	Main Prop kW	Main prop. Diameter (m)*	Main Prop Centerline Depth (m)	Thruster kW	Thruster Diameter (m)*	Thruster Centerline Depth (m)*
Bardu	Cont. Ship	21,660	5.7	8.7	1,282	2.0	9.3
Madame Butterfly	Ro-Ro	13,554	6.0	8.6	1,500	2.0	9.3
POS Oceania	Bulk Carrier / Cargo	16,160	5.3	7.1	1,030	1.9	7.9
Tug (Bo Brusco)	Tug	1,764 (each)	2.4	4.1**	N/A	N/A	N/A

* Estimates based on PIANC (2015) formulae
** From similar Tug vessels (e.g., Lexie M)

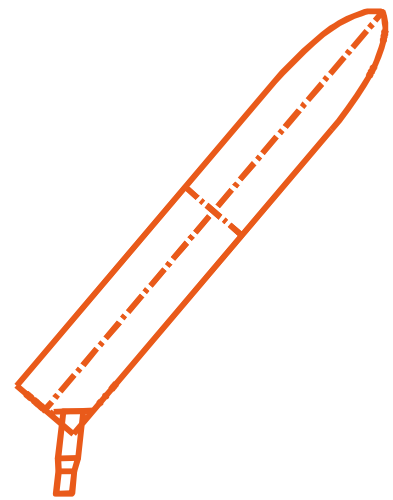
Vessels Considered in Analysis

Legend for Figures

Tug (Bo Brusco)
L = 78 ft
B = 29 ft



Bardu
L = 685 ft
B = 99 ft

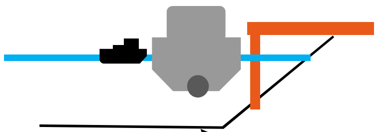


Madame Butterfly
L = 650 ft
B = 106 ft

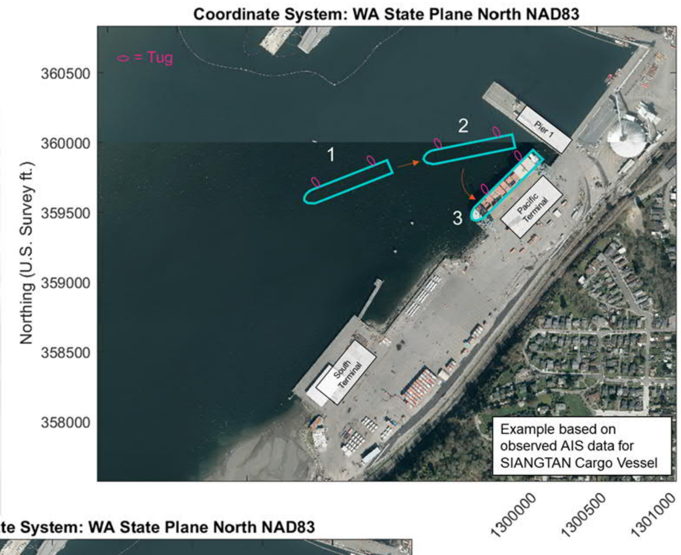
POS Oceania
L = 556 ft
B = 89 ft

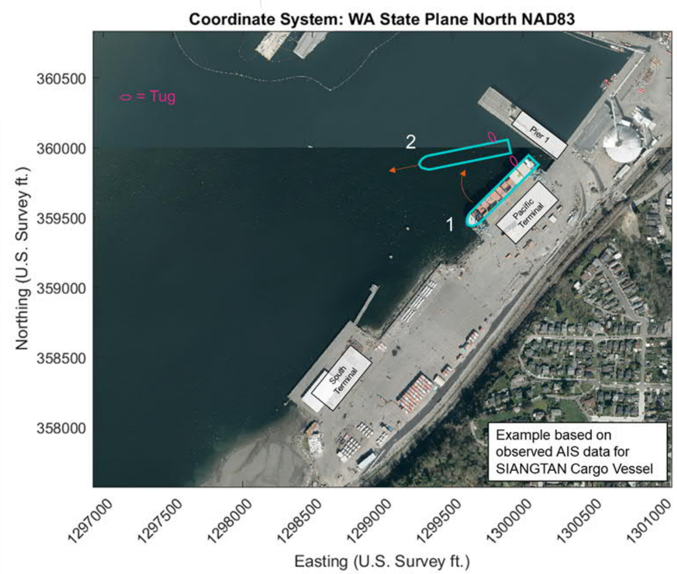
Pacific Terminal – Container Ship Flow 3D Simulations

- Simulations use existing depth



1. Bardu main prop parallel to berth (15% power) (PIANC)
2. Bardu main prop off berth just after tugs have disengaged for departure (28% power) (PIANC)
3. Bardu thruster directed towards berth (100% power)
4. Bardu thruster directed away from berth (100% power)
5. Bo Brusco tug propellers directed towards berth (100% power)
6. Bo Brusco tug propellers directed away from berth (100% power)



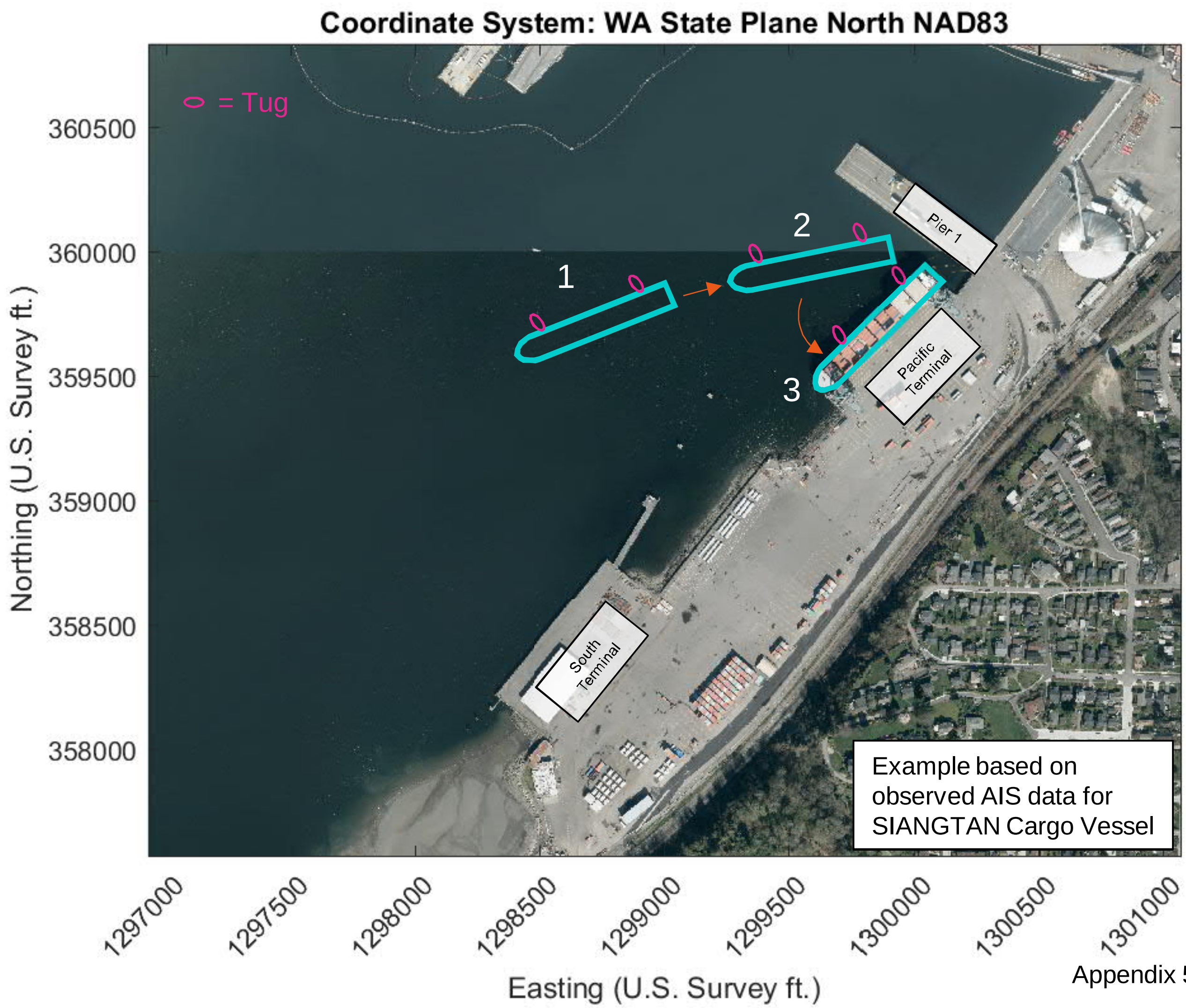


Pacific Terminal

Cargo - Arriving

Operations

- Westwood shipping lines (every Tuesday)
- N-class vessels use 1 tug in, 1 tug out
- Larger Vessels use 2 tugs in, 1 tug out
- Bow thrusters during approach and departure
- Main engine once rotated to face West
- Tractor tug (Bo Brusco) preferred by many captains

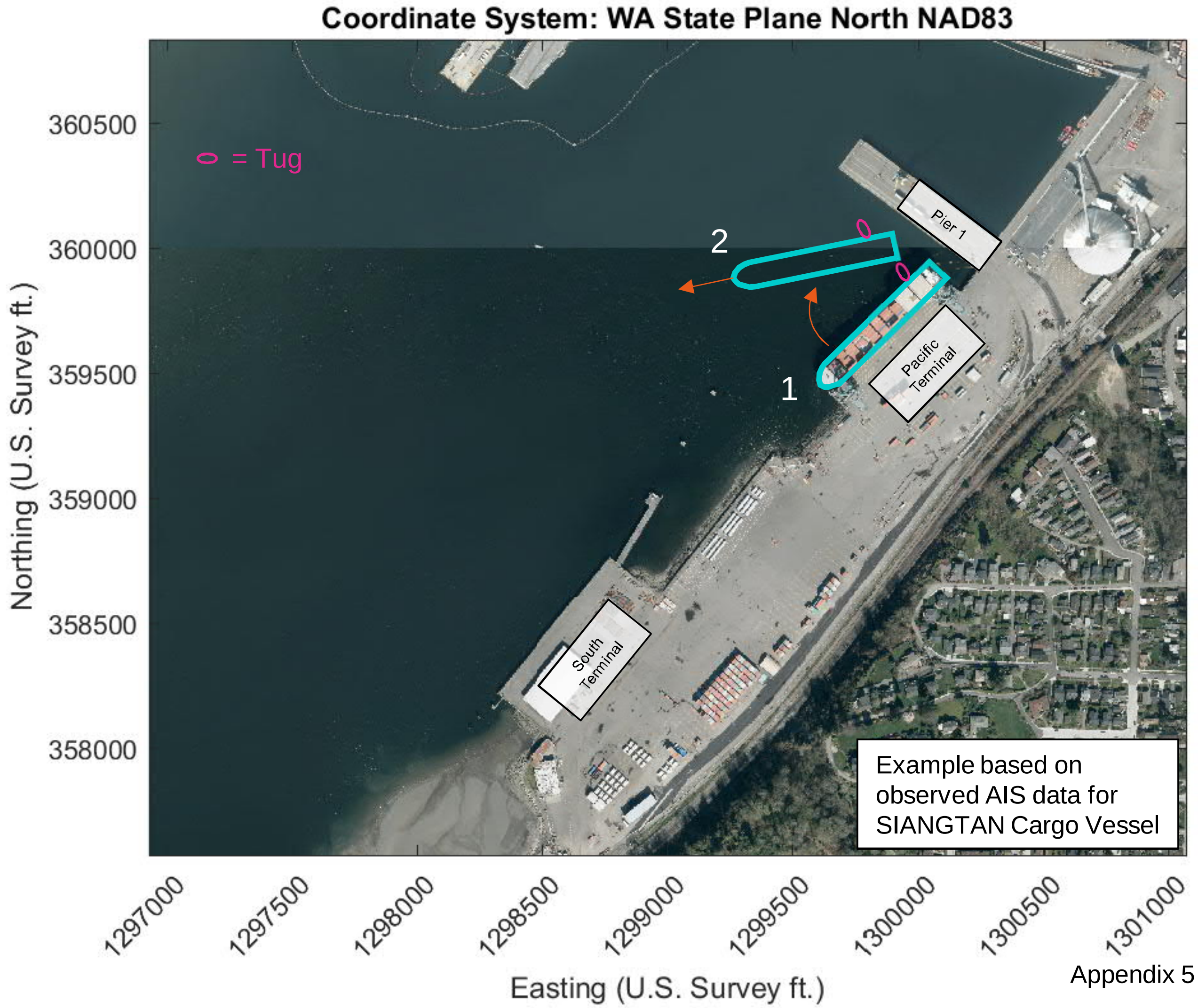


Pacific Terminal

Cargo - Departing

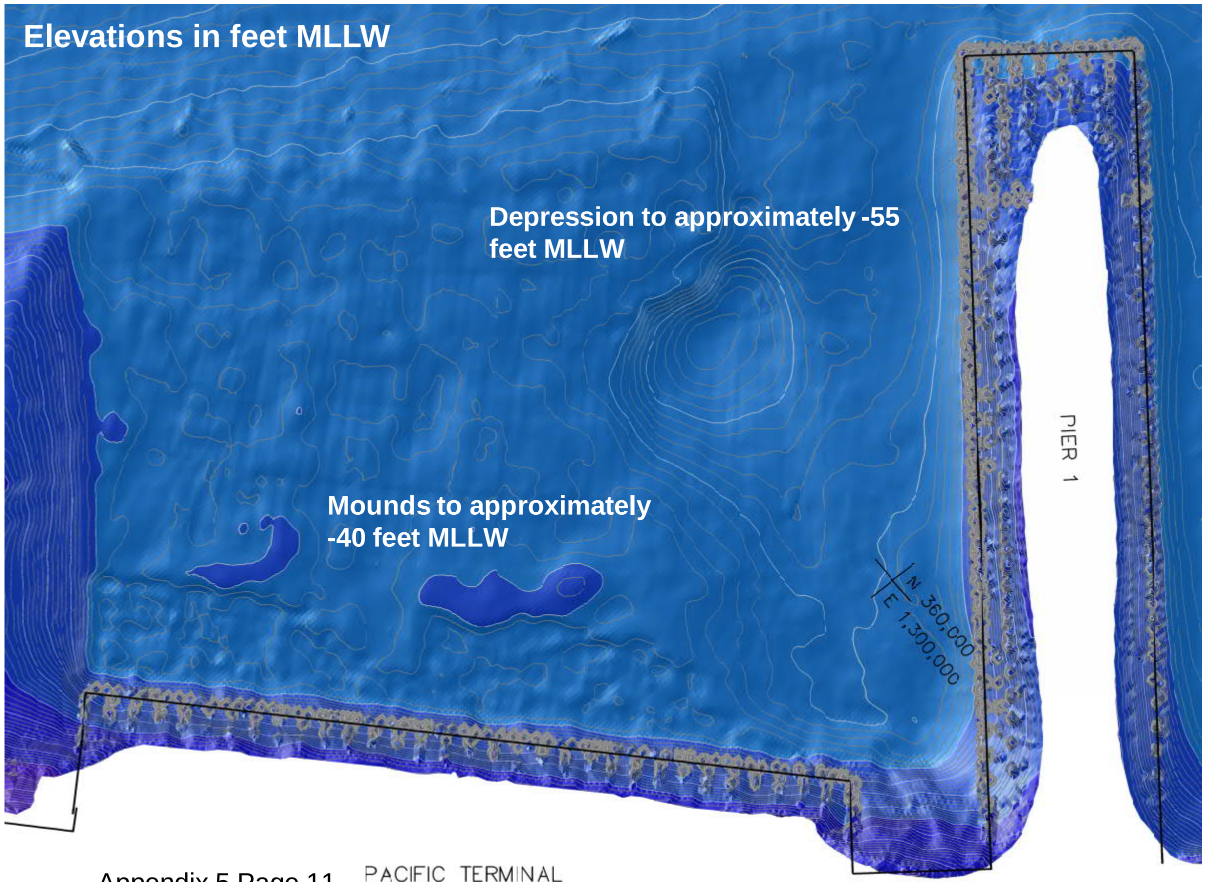
Operations

- Westwood shipping lines (every Tuesday)
- N-class vessels use 1 tug in, 1 tug out
- Larger Vessels use 2 tugs in, 1 tug out
- Bow thrusters during approach and departure
- Main engine once rotated to face West
- Tractor tug (Bo Brusco) preferred by many captains



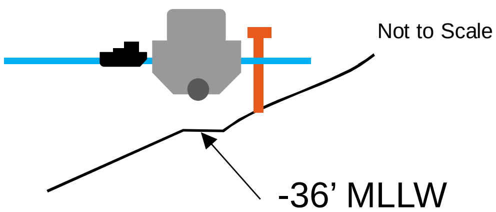
Existing Scour Hole near Pacific Terminal and Pier 1

Elevations Table			
Number	Minimum Elevation	Maximum Elevation	Color
1	−340.000	−320.000	
2	−320.000	−300.000	
3	−300.000	−280.000	
4	−280.000	−260.000	
5	−260.000	−240.000	
6	−240.000	−220.000	
7	−220.000	−200.000	
8	−200.000	−180.000	
9	−180.000	−160.000	
10	−160.000	−140.000	
11	−140.000	−120.000	
12	−120.000	−100.000	
13	−100.000	−80.000	
14	−80.000	−60.000	
15	−60.000	−40.000	
16	−40.000	−20.000	
17	−20.000	0.000	
18	0.000	20.000	
19	20.000	40.000	

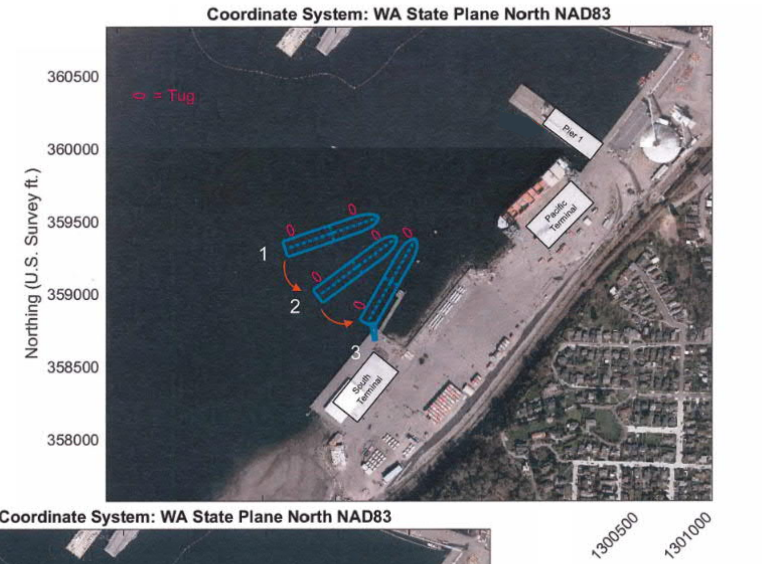


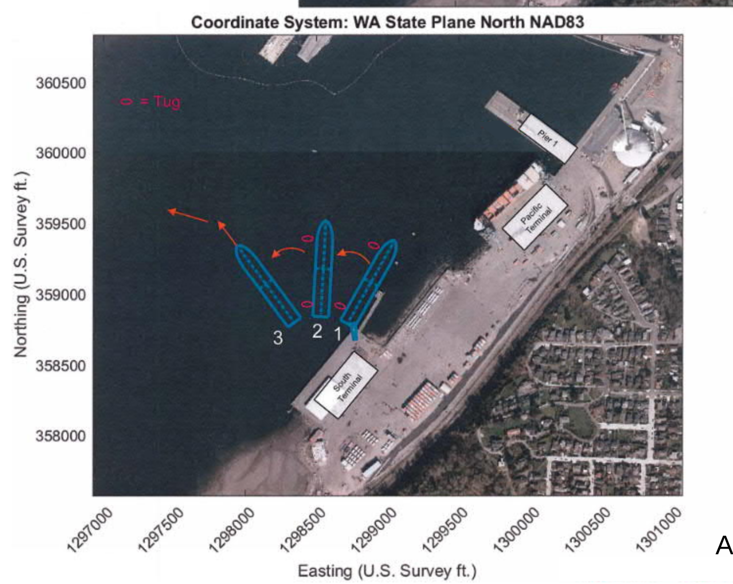
South Terminal – Ro / Ro Carrier Flow 3D Simulations

- Simulations use existing depth



7. Madame Butterfly main prop parallel to berth (15% power) (PIANC)
8. Madame Butterfly thruster directed towards berth (100% power)
9. Madame Butterfly thruster directed away from berth (100% power)
10. Bo Brusco tug propellers directed towards berth (100% power)
11. Bo Brusco tug propellers directed away from berth (100% power)



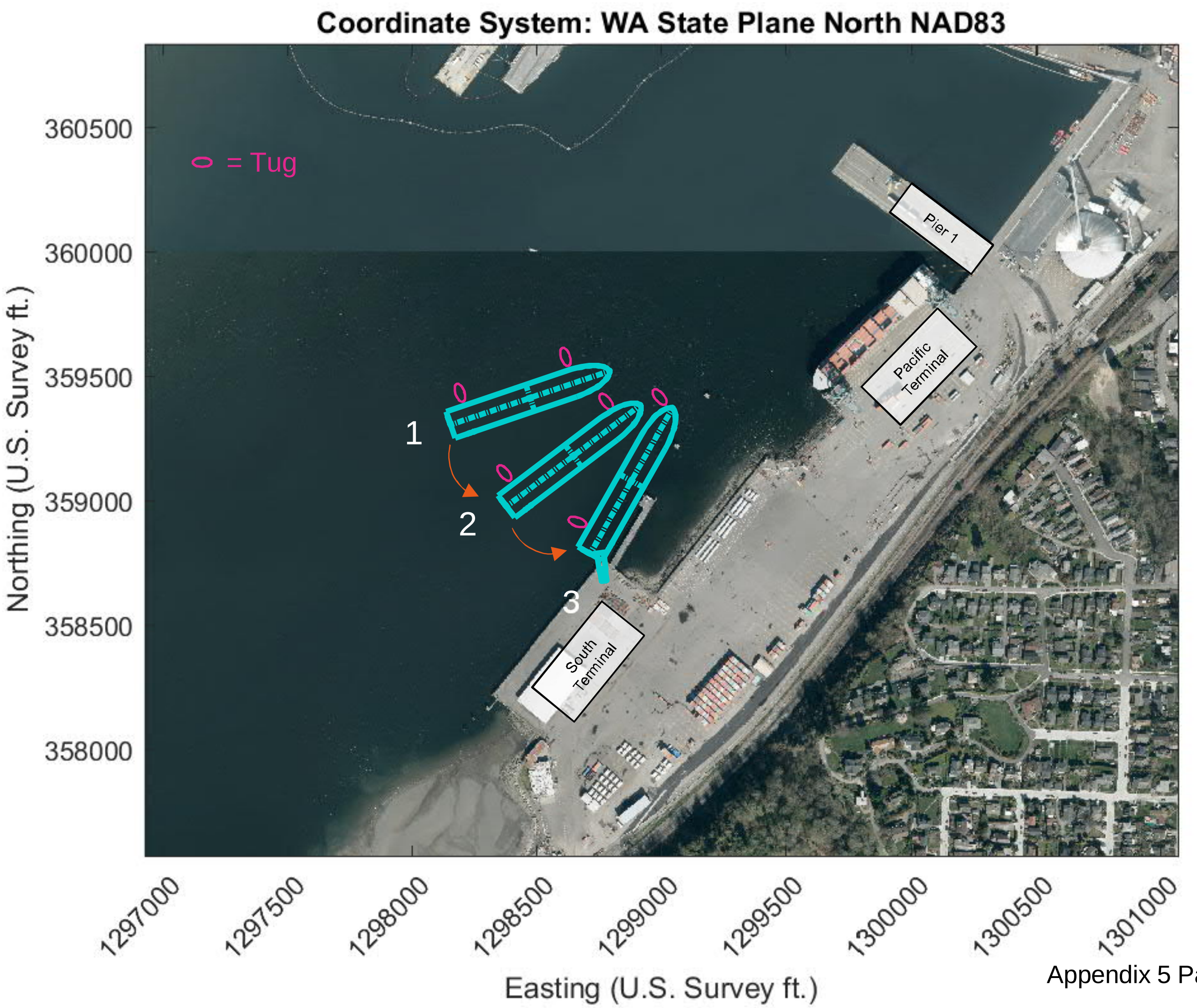


South Terminal

Ro / Ro - Arriving

Operations

- Ro / Ro previously used South Terminal (currently using Pier 1)

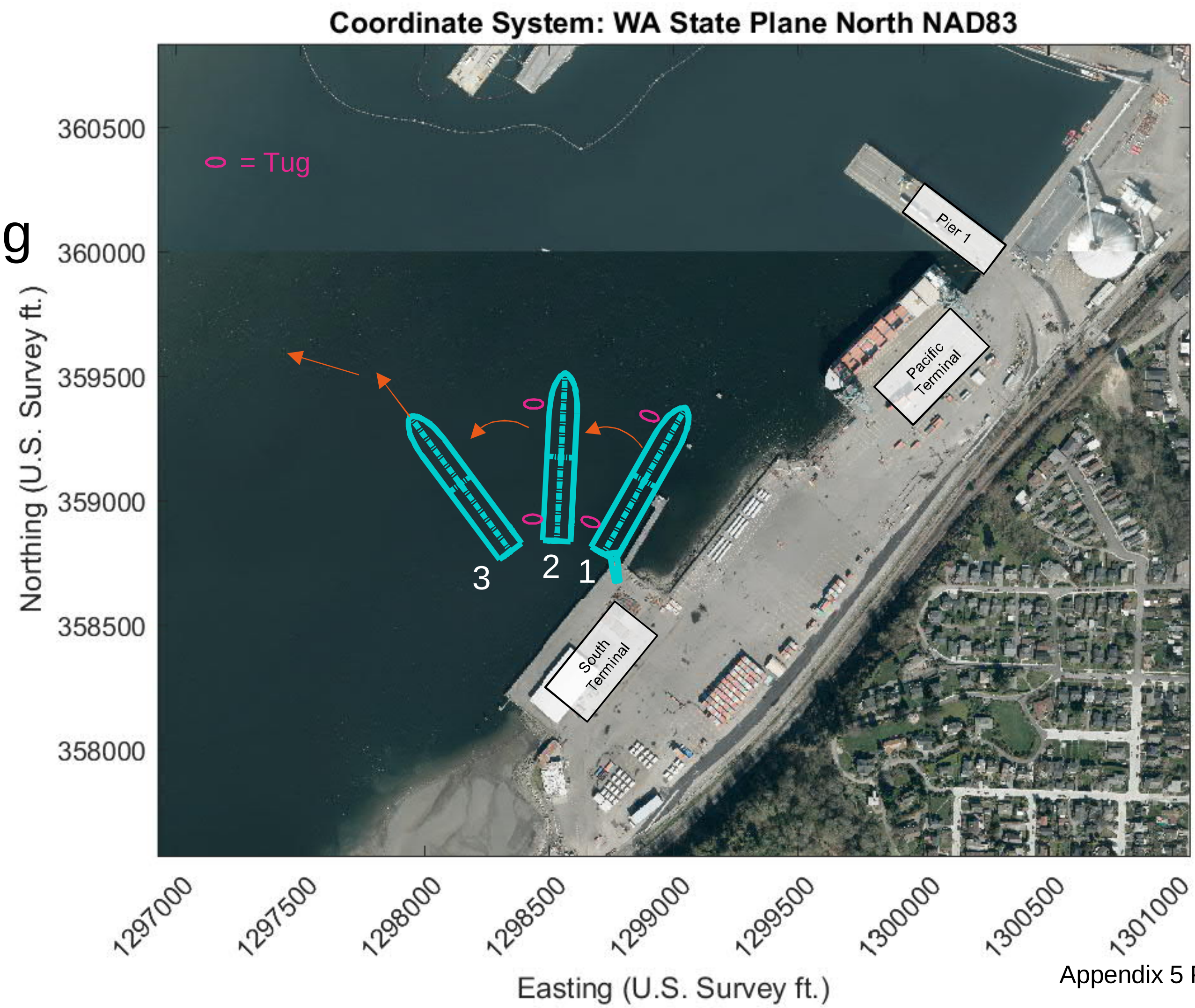


South Terminal

Ro / Ro - Departing

Operations

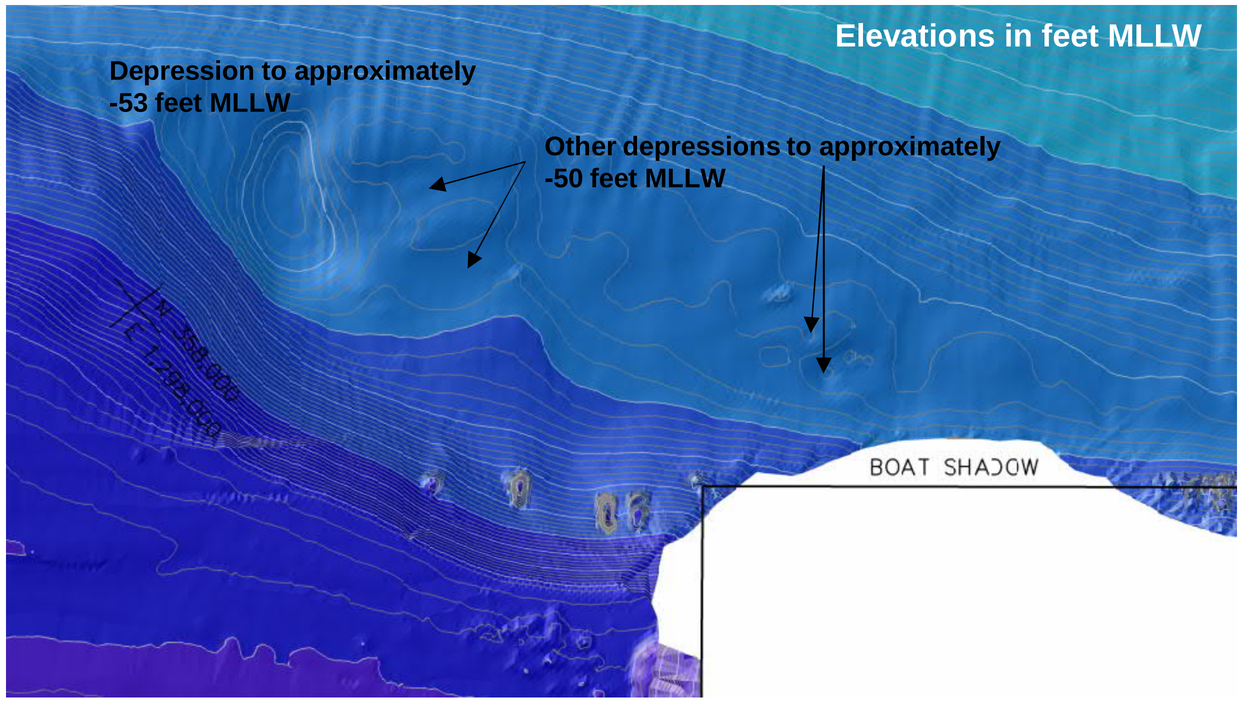
- Ro / Ro previously used South Terminal (currently using Pier 1)



Existing Scour Holes near South Terminal

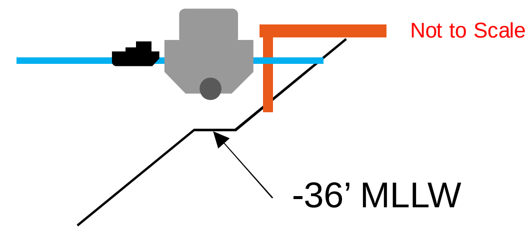
Elevations Table

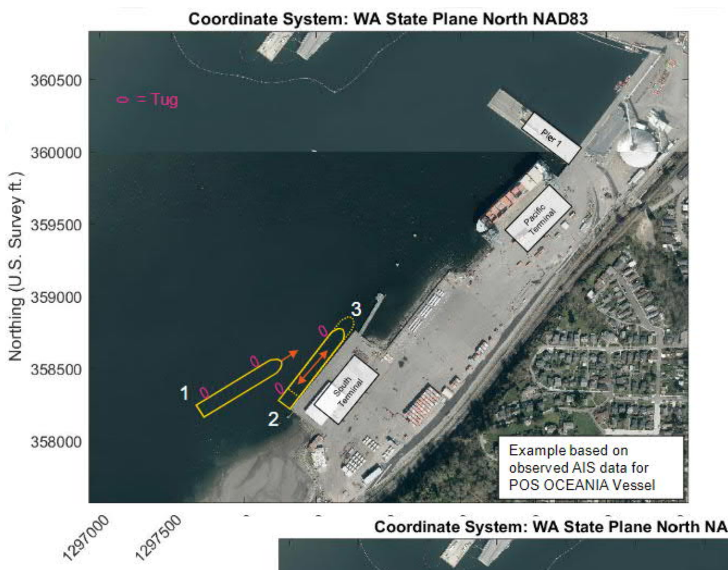
Number	Minimum Elevation	Maximum Elevation	Color
1	−340.000	−320.000	
2	−320.000	−300.000	
3	−300.000	−280.000	
4	−280.000	−260.000	
5	−260.000	−240.000	
6	−240.000	−220.000	
7	−220.000	−200.000	
8	−200.000	−180.000	
9	−180.000	−160.000	
10	−160.000	−140.000	
11	−140.000	−120.000	
12	−120.000	−100.000	
13	−100.000	−80.000	
14	−80.000	−60.000	
15	−60.000	−40.000	
16	−40.000	−20.000	
17	−20.000	0.000	
18	0.000	20.000	
19	20.000	40.000	

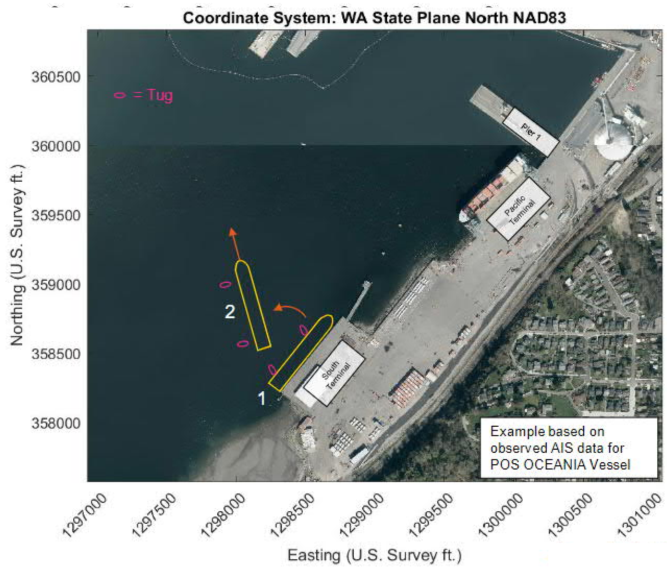


South Terminal Flow 3D Simulations

- Simulations use existing depth







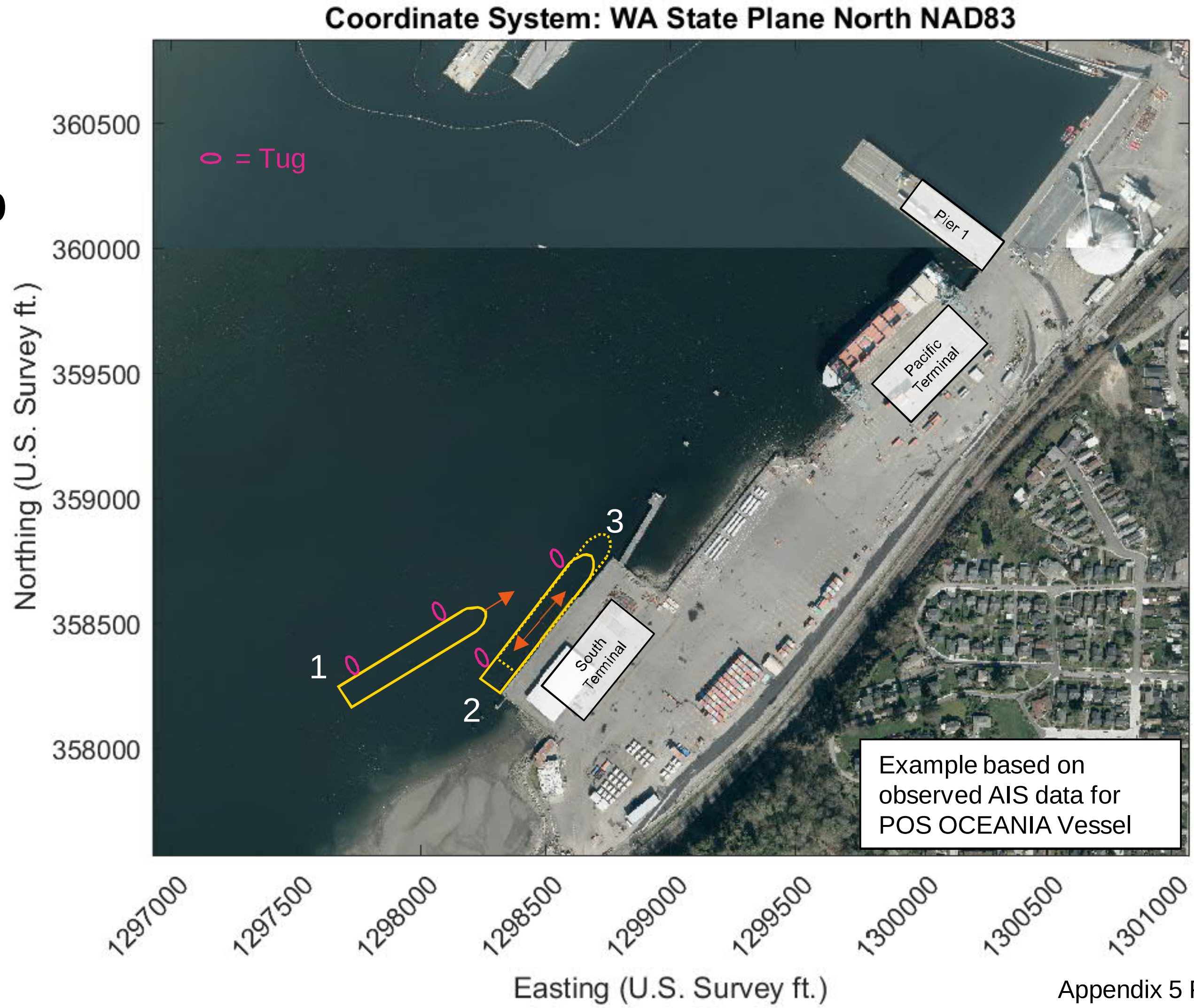
12. POS Oceania main prop parallel to berth (15% power) (PIANC)
13. POS Oceania main prop off berth just after tugs have disengaged for departure (28% power) (PIANC)
14. POS Oceania thruster directed towards berth (100% power)
15. POS Oceania thruster directed away from berth (100% power)
16. Bo Brusco tug propellers directed towards berth (100% power)
17. Bo Brusco tug propellers directed away from berth (100% power)

South Terminal

Cargo – Arriving to Starboard

Operations

- Max vessel size ~850 ft.
- Handy Max vessels typically 400 – 550 ft.
- Typical draft 30 ft.
- Some vessels dock starboard side to berth, others port

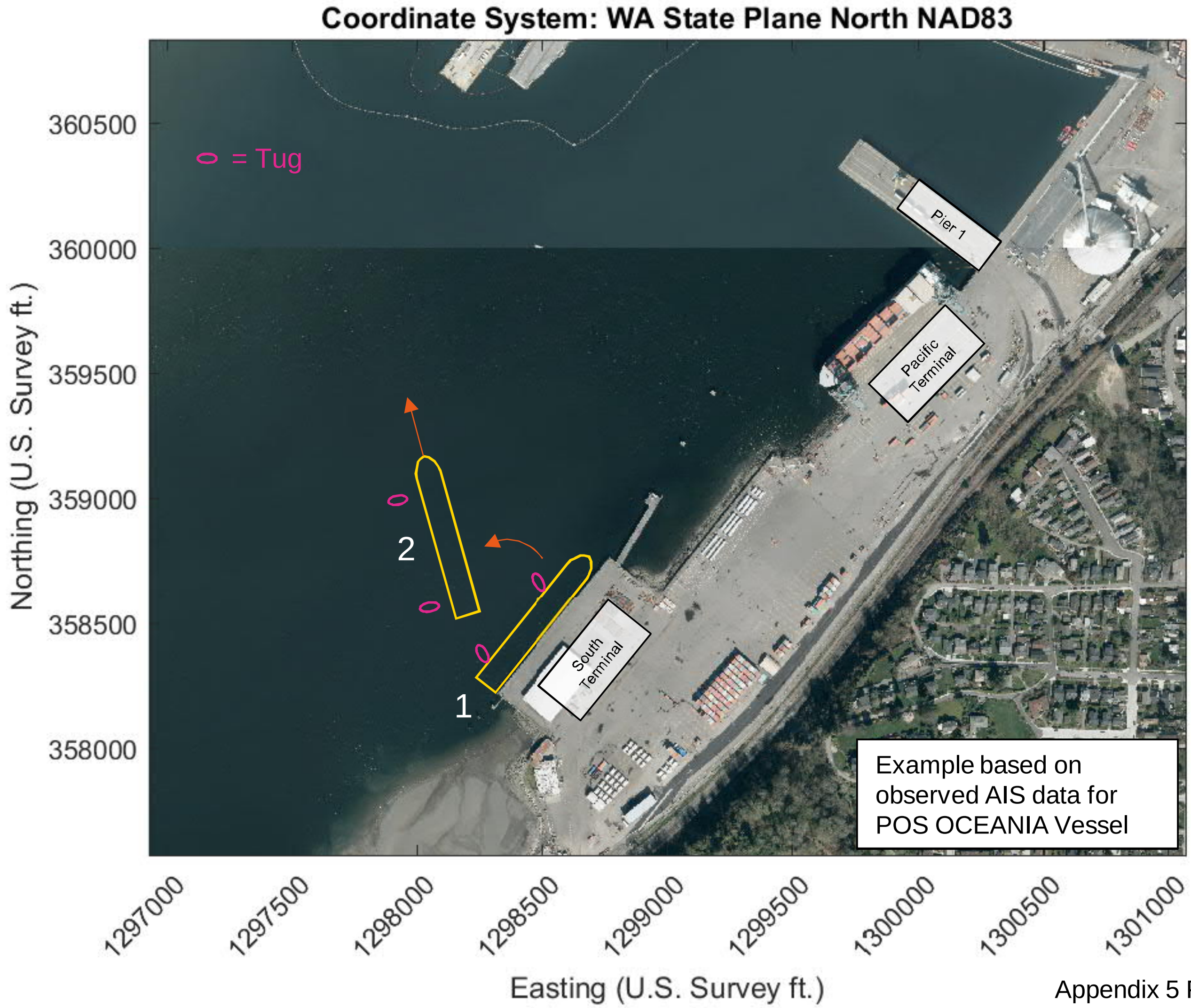


South Terminal

Cargo – Departing to Starboard

Operations

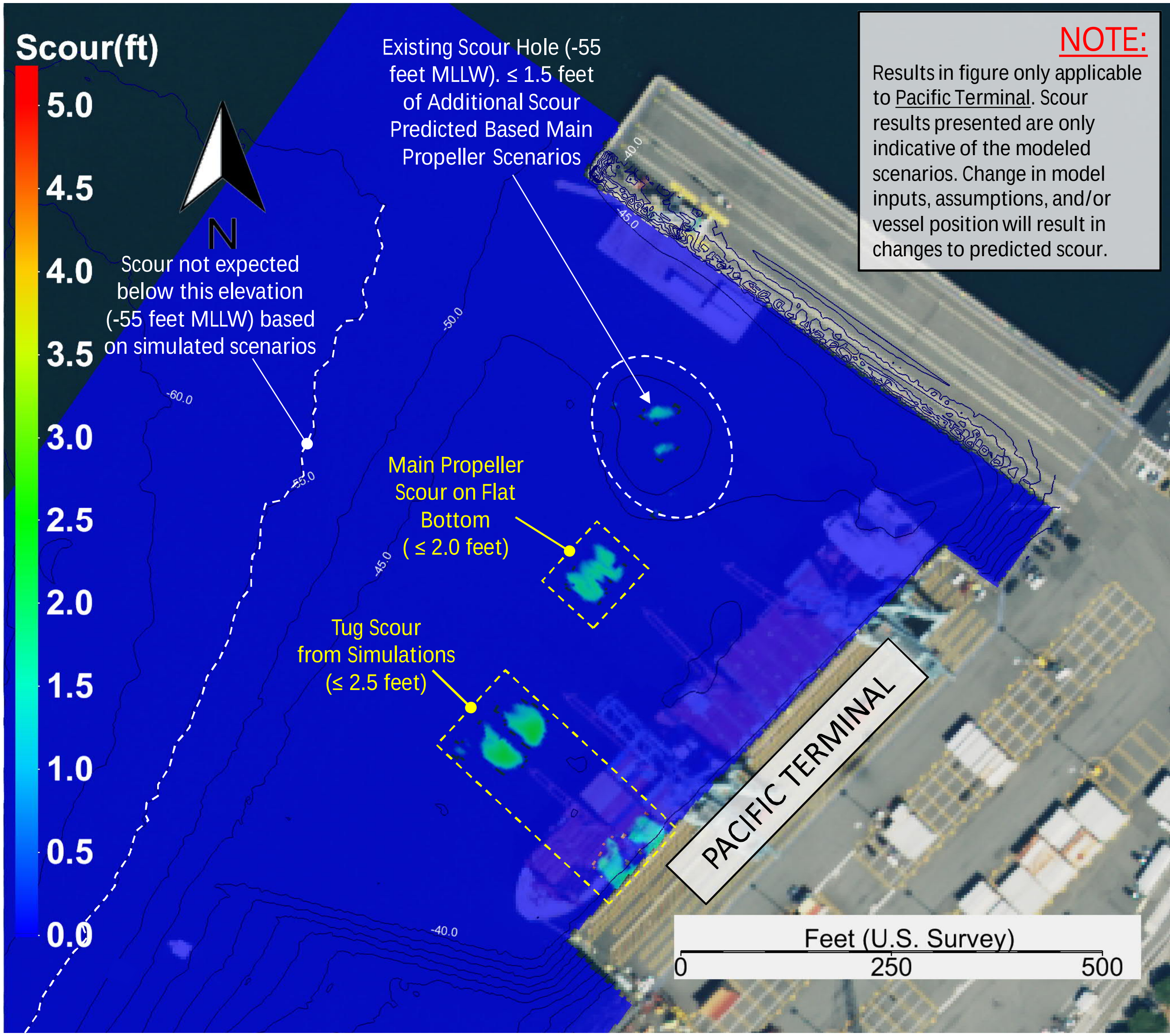
- Max vessel size ~850 ft.
- Handy Max vessels typically 400 – 550 ft.
- Typical draft 30 ft.
- Some vessels dock starboard side to berth, others port



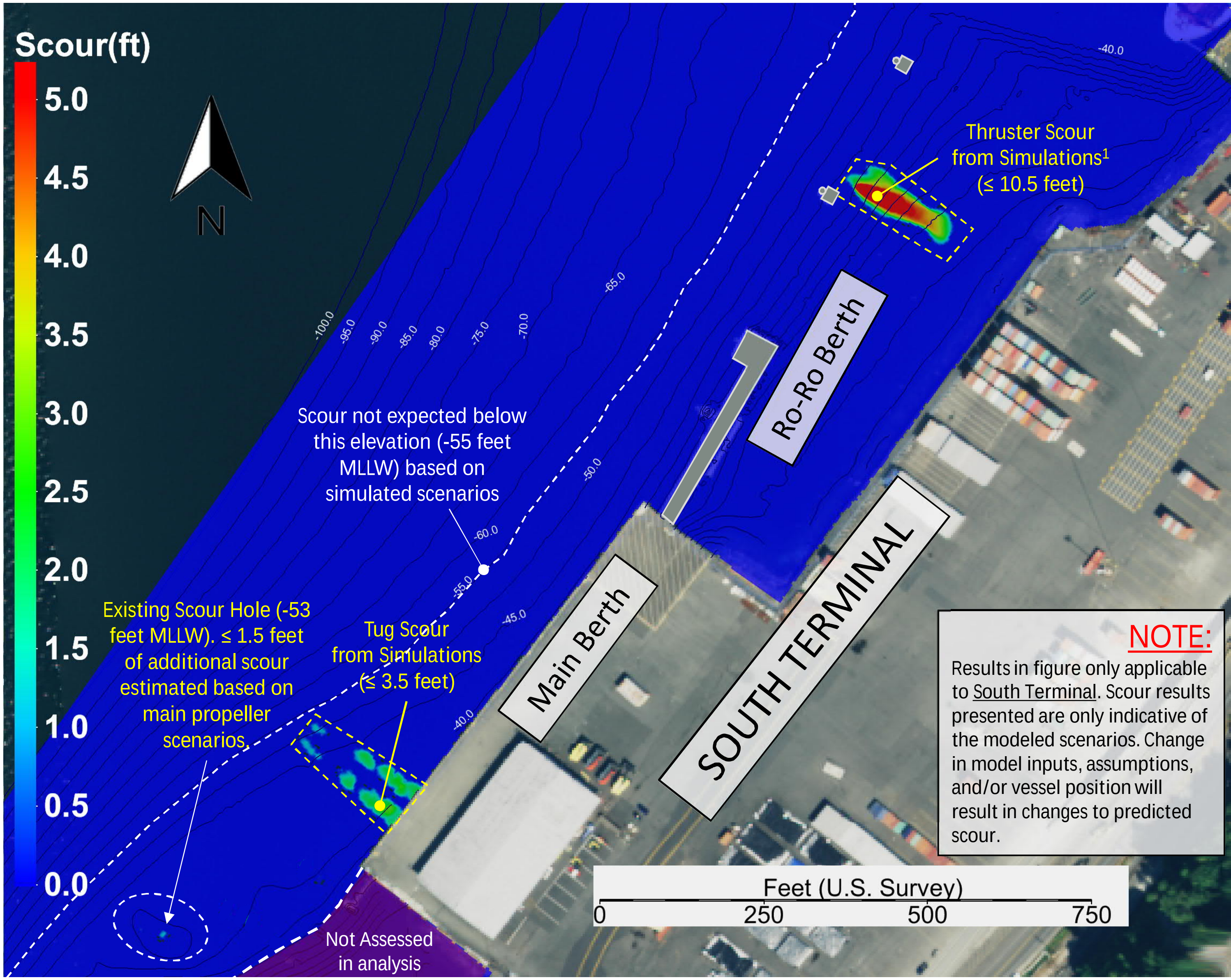
Appendix 6: Propwash Modeling Results

Combined Results Over Study Area

Combined Scour Based on All Simulations at Pacific Terminal



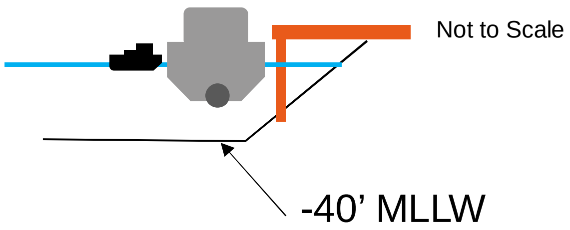
Combined Scour Based on All Simulations at South Terminal



Individual Simulation Results

Pacific Terminal – Container Ship Flow 3D Simulations

- Simulations use existing depth



1. Bardu main prop parallel to berth (15% power) (PIANC)
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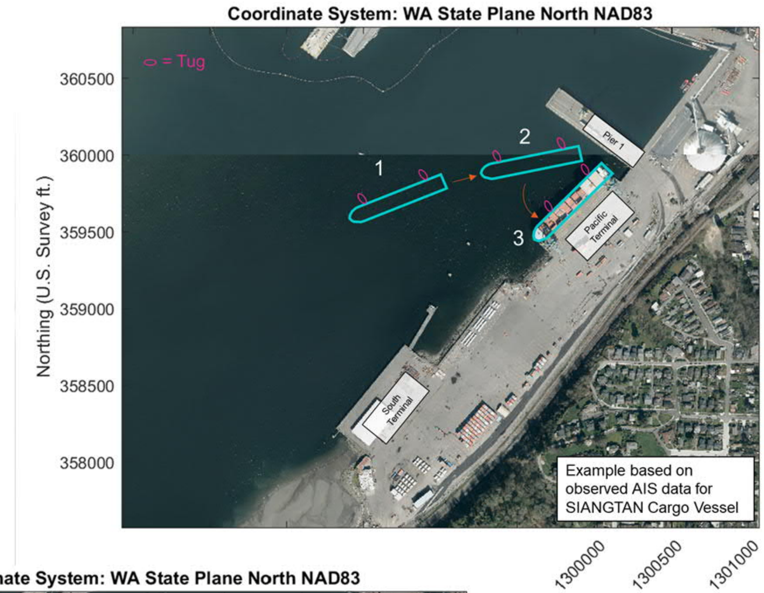
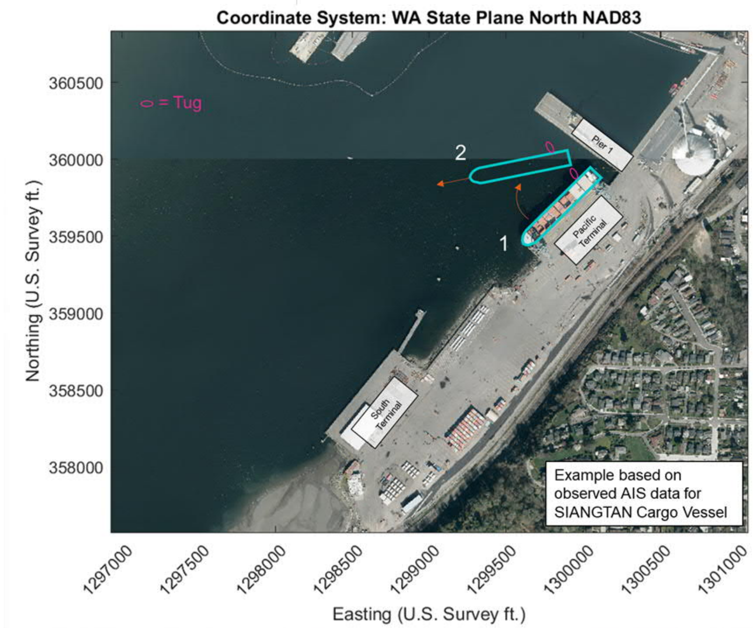
6. Bo Brusco tug propellers directed away from berth (100% power)

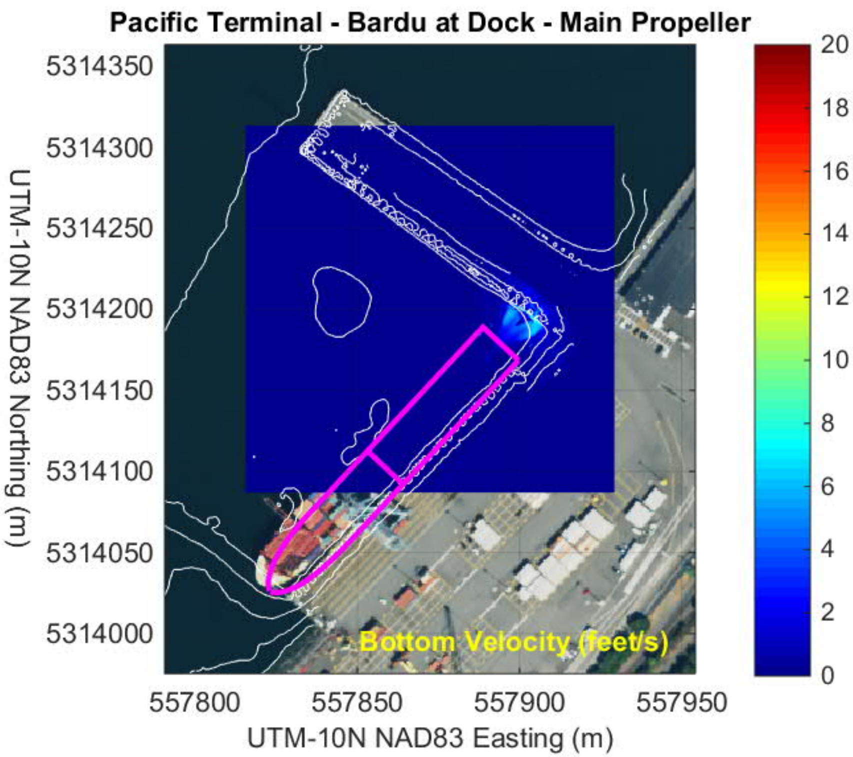




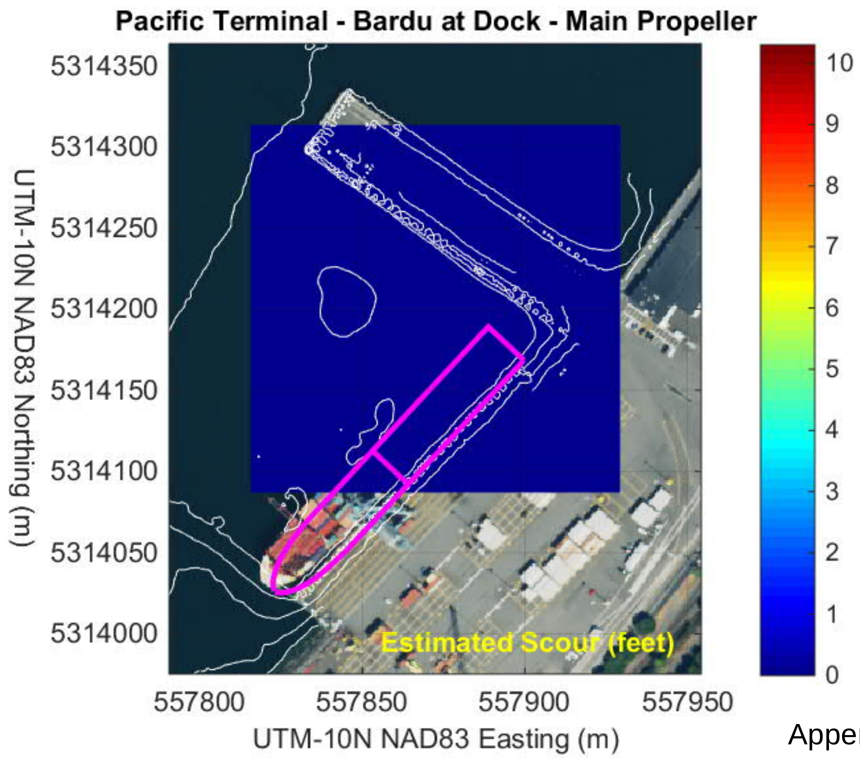
Scenario 1:

Bardu main propeller parallel to berth

Near-Bottom Velocity
(feet/second)



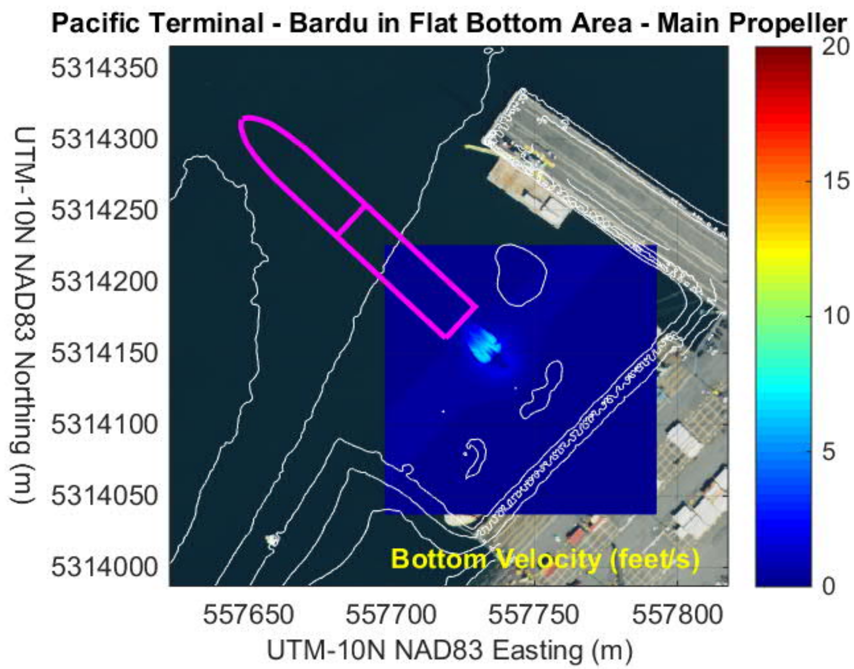
Estimated Scour
(feet)



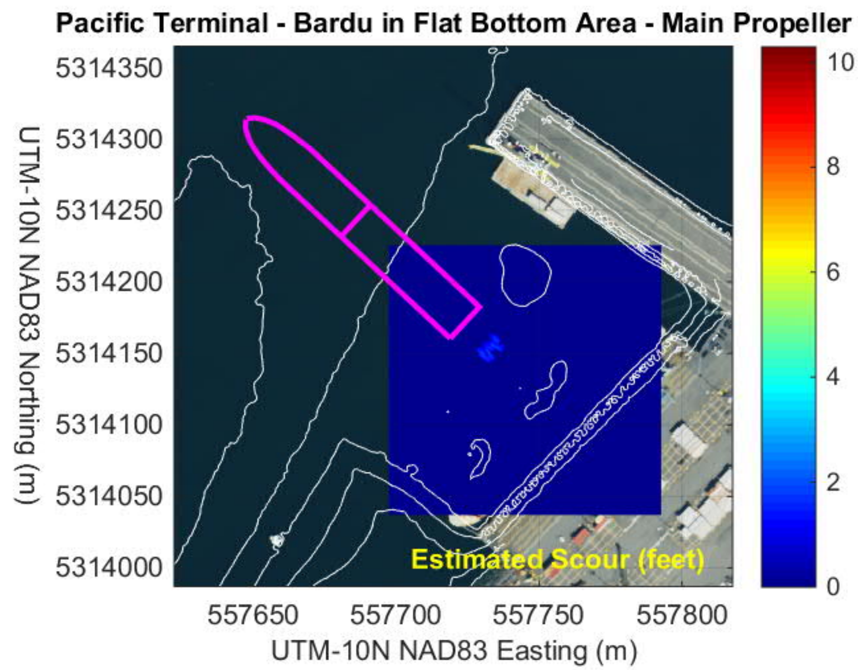
Scenario 2A:

Bardu main propeller off berth just after tugs have disengaged for departure – propeller thrust towards berth

Near-Bottom Velocity
(feet/second)



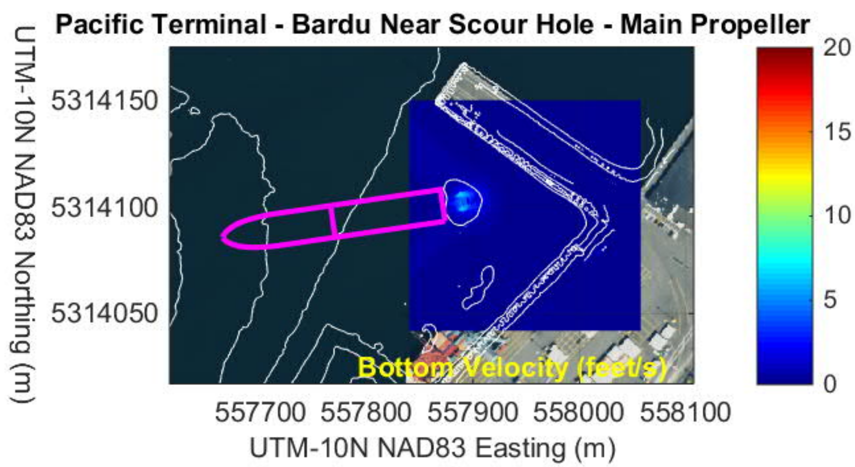
Estimated Scour
(feet)



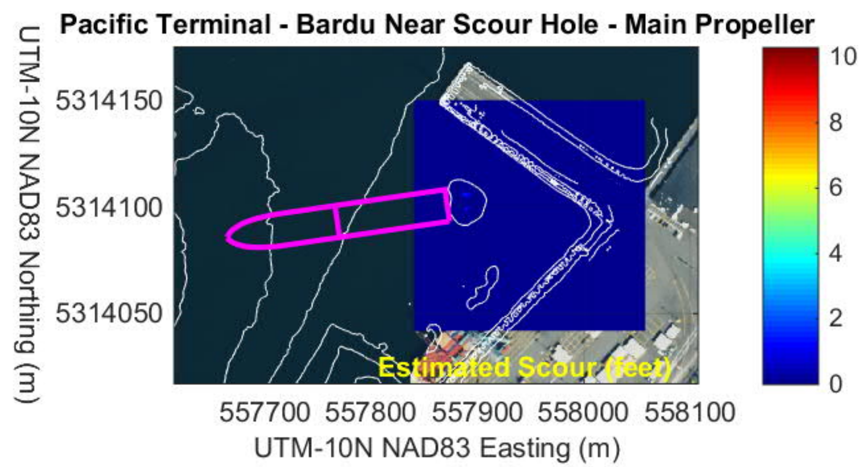
Scenario 2B:

Bardu main propeller off berth just after tugs have disengaged for departure – propeller thrust towards existing scour hole

Near-Bottom Velocity
(feet/second)



Estimated Scour
(feet)

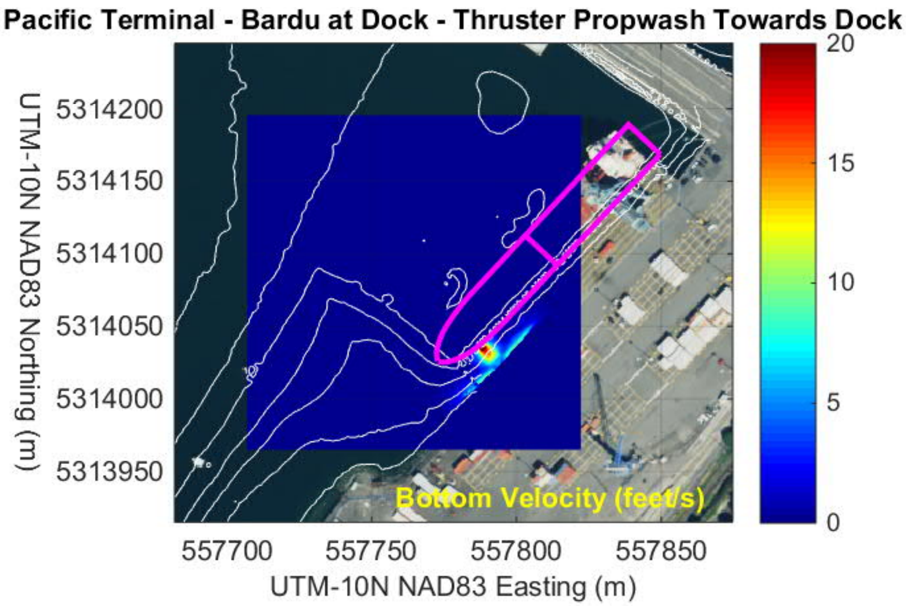


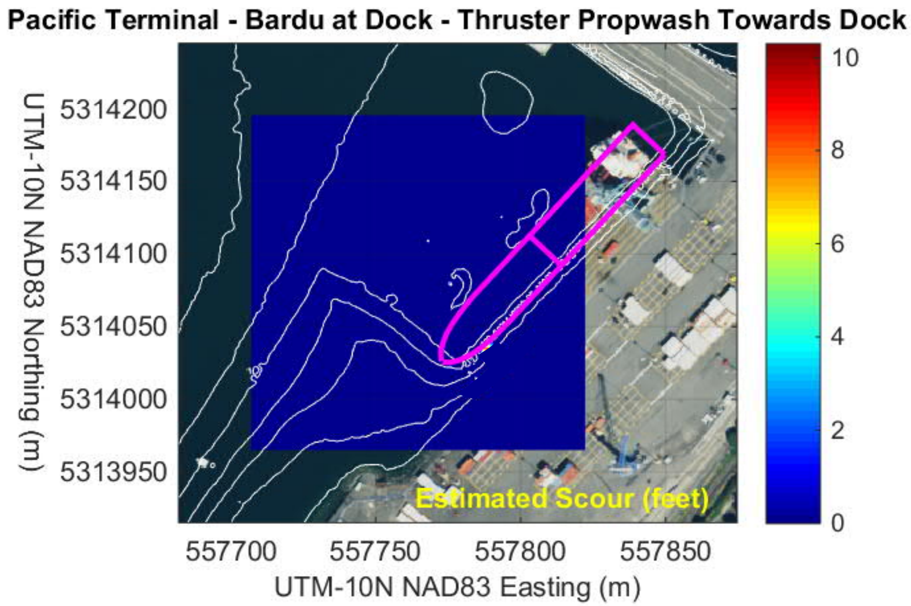
Scenario 3A:

Bardu thruster directed towards berth – Bardu at Dock

Near-Bottom Velocity
(feet/second)

Estimated Scour
(feet)

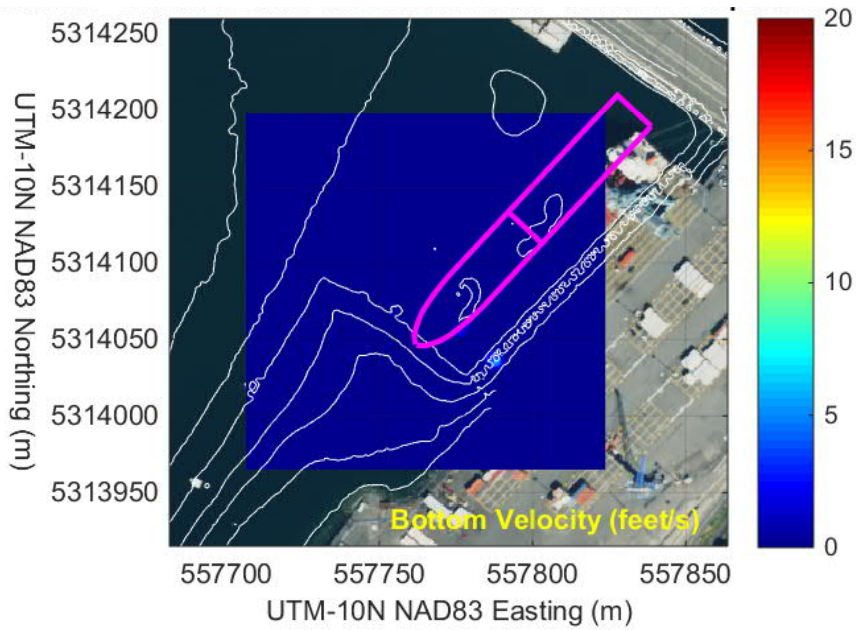




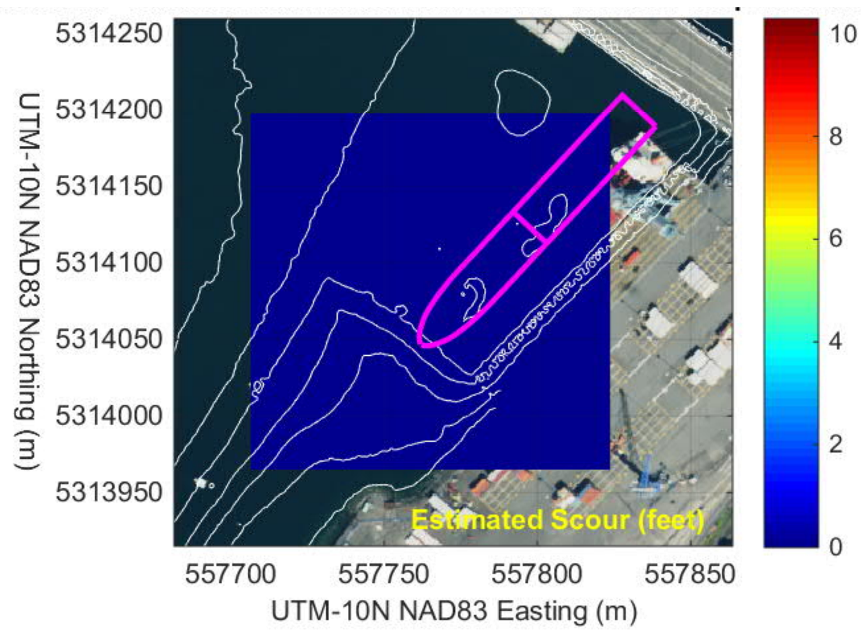
Scenario 3B:

Bardu thruster directed towards berth – Bardu 1 beam width from Dock

Near-Bottom Velocity
(feet/second)



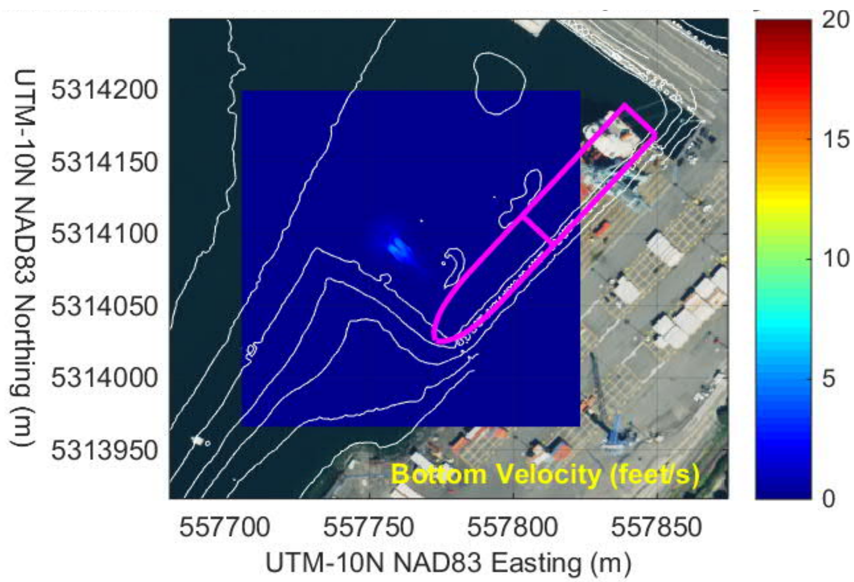
Estimated Scour
(feet)



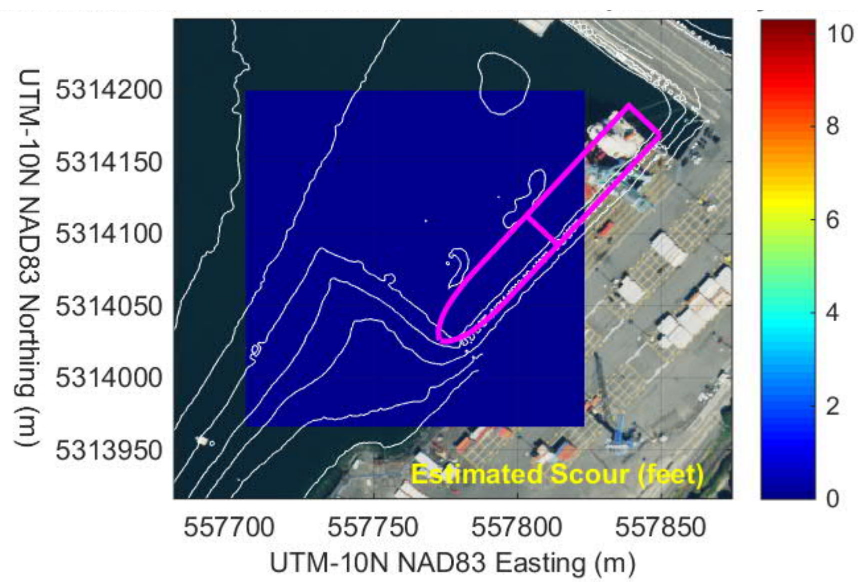
<u>Scenario 4</u>:

Bardu thruster directed away from berth – Bardu near the dock

Near-Bottom Velocity
(feet/second)



Estimated Scour
(feet)

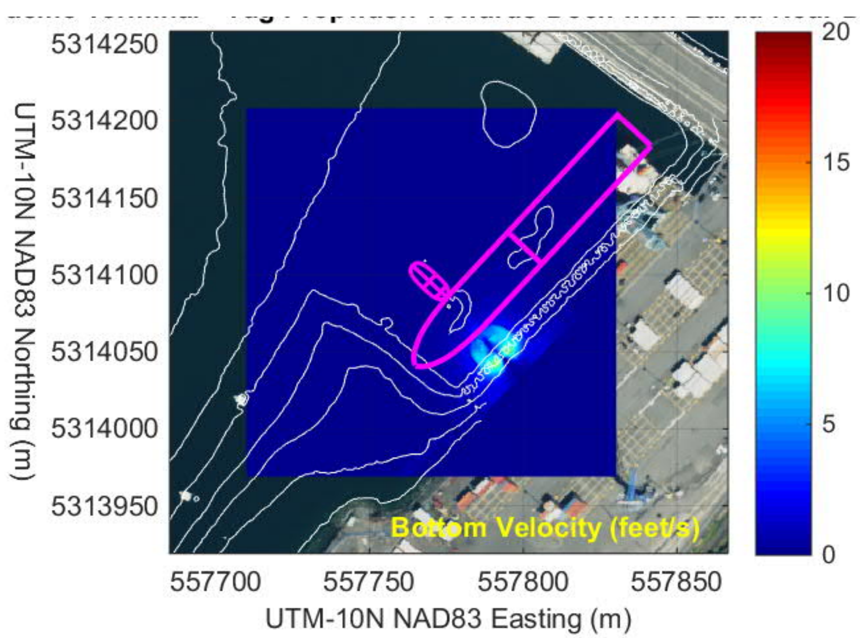


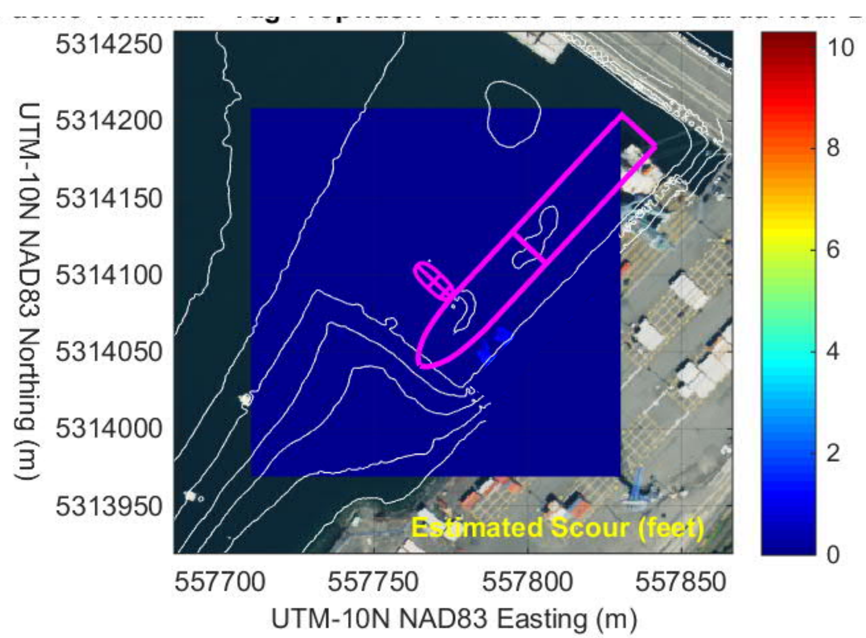
Scenario 5A:

Bo Brusco tug propellers directed towards berth – Bardu near the dock

Near-Bottom Velocity
(feet/second)

Estimated Scour
(feet)

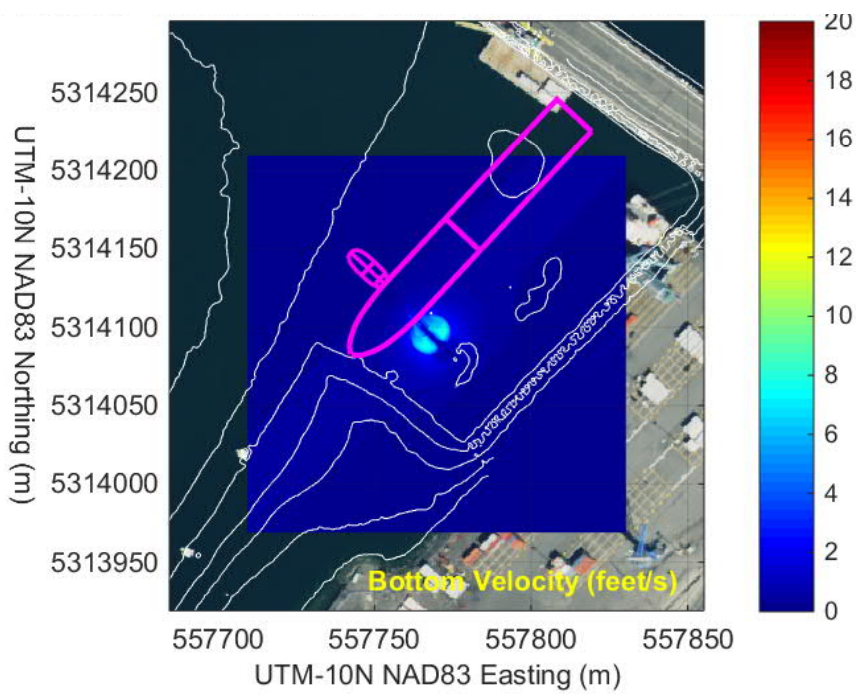




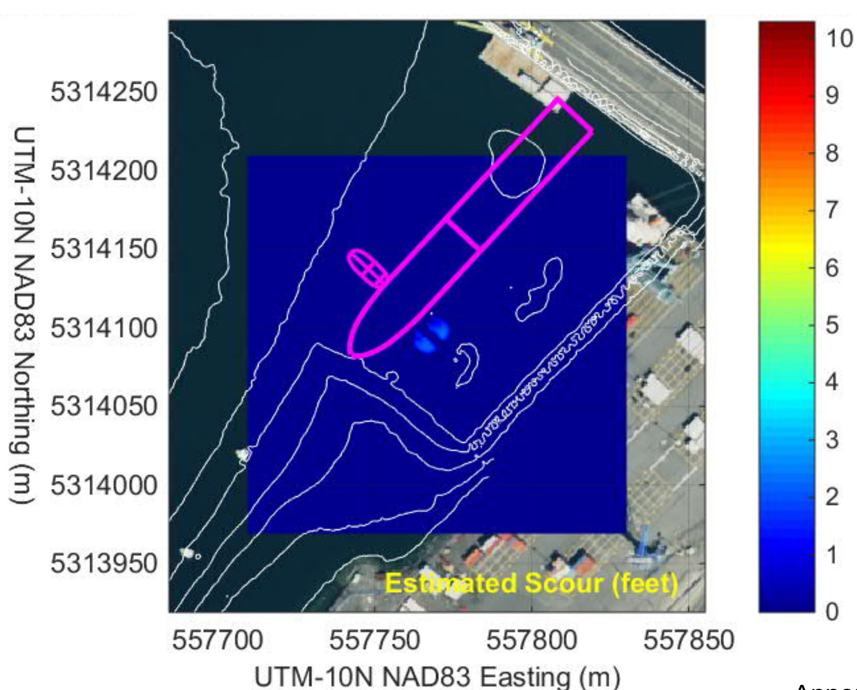
Scenario 5B:

Bo Brusco tug propellers directed towards berth – Bardu in flat-bottom area – tugs getting ready to disengage

Near-Bottom Velocity
(feet/second)



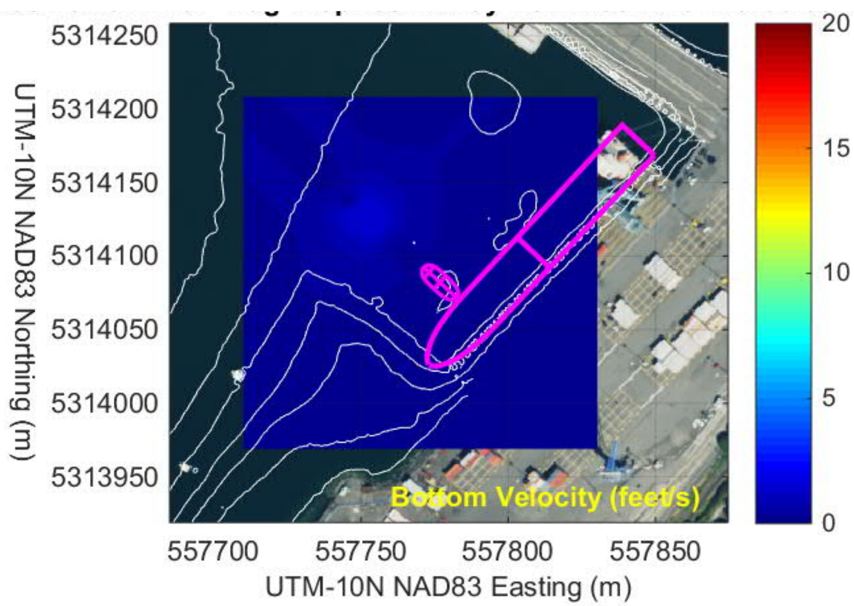
Estimated Scour
(feet)



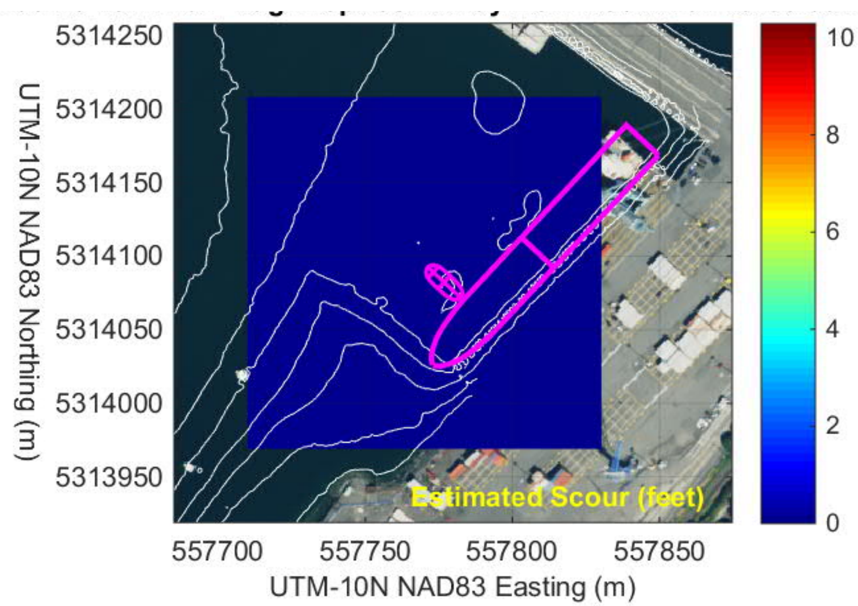
Scenario 6:

Bo Brusco tug propellers directed away from berth – Bardu near the dock

Near-Bottom Velocity
(feet/second)

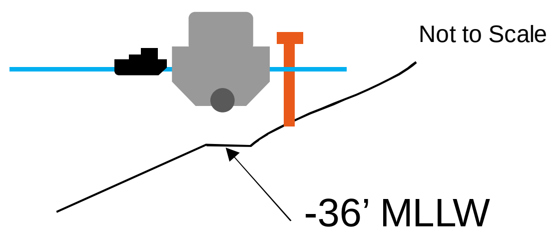


Estimated Scour
(feet)

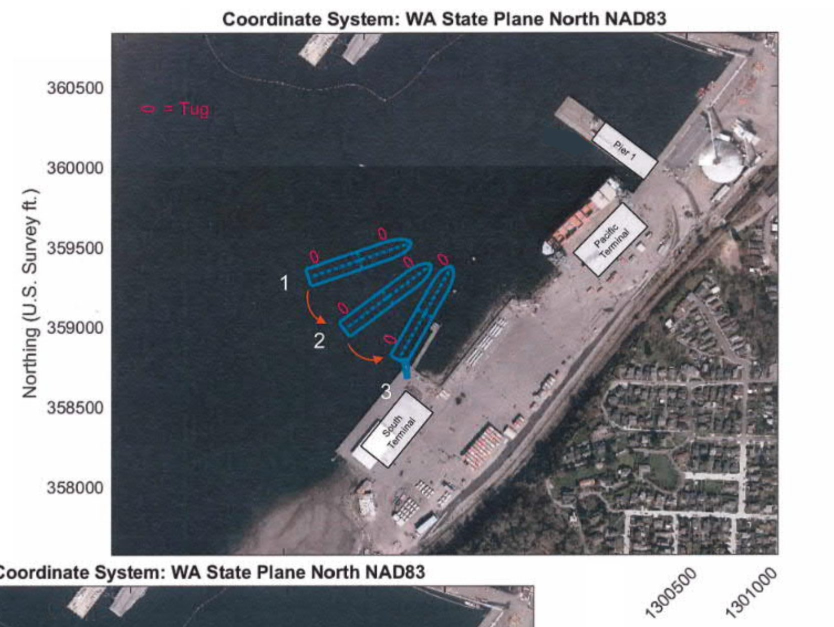


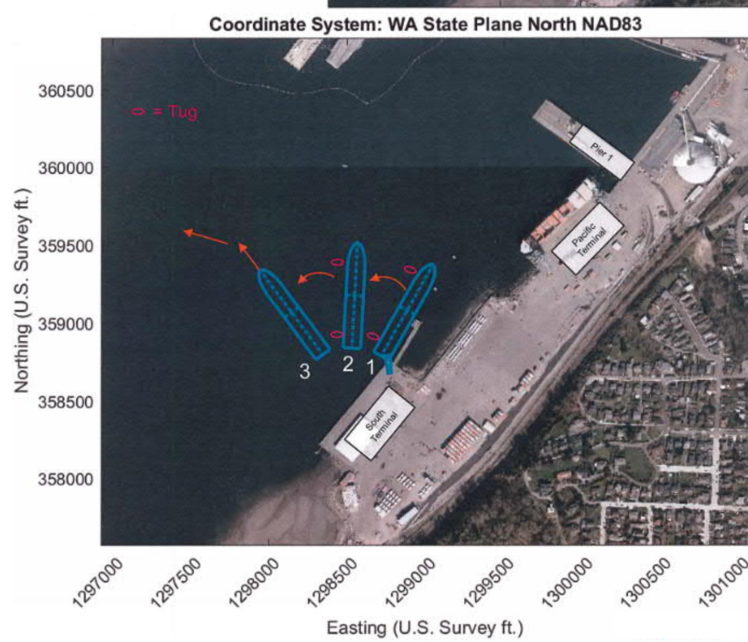
South Terminal – Ro / Ro Carrier Flow 3D Simulations

- Simulations use existing depth



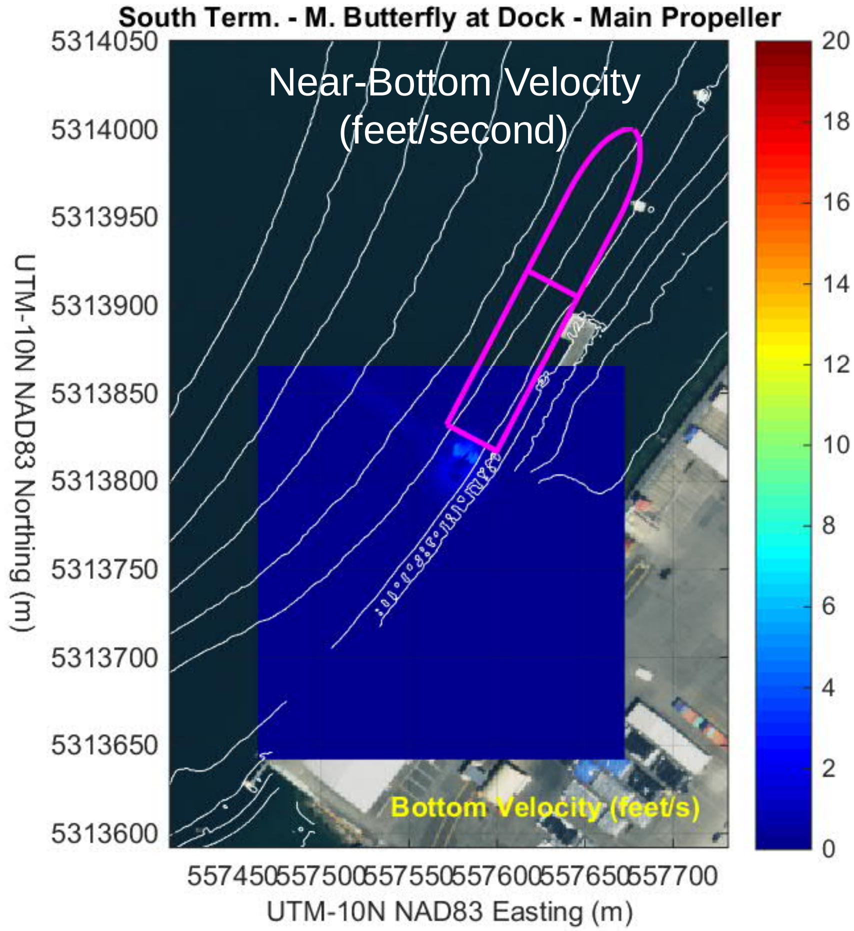
7. Madame Butterfly main prop parallel to berth (15% power) (PIANC)
8. Madame Butterfly thruster directed towards berth (100% power)
9. Madame Butterfly thruster directed away from berth (100% power)
10. Bo Brusco tug propellers directed towards berth (100% power)
11. Bo Brusco tug propellers directed away from berth (100% power)

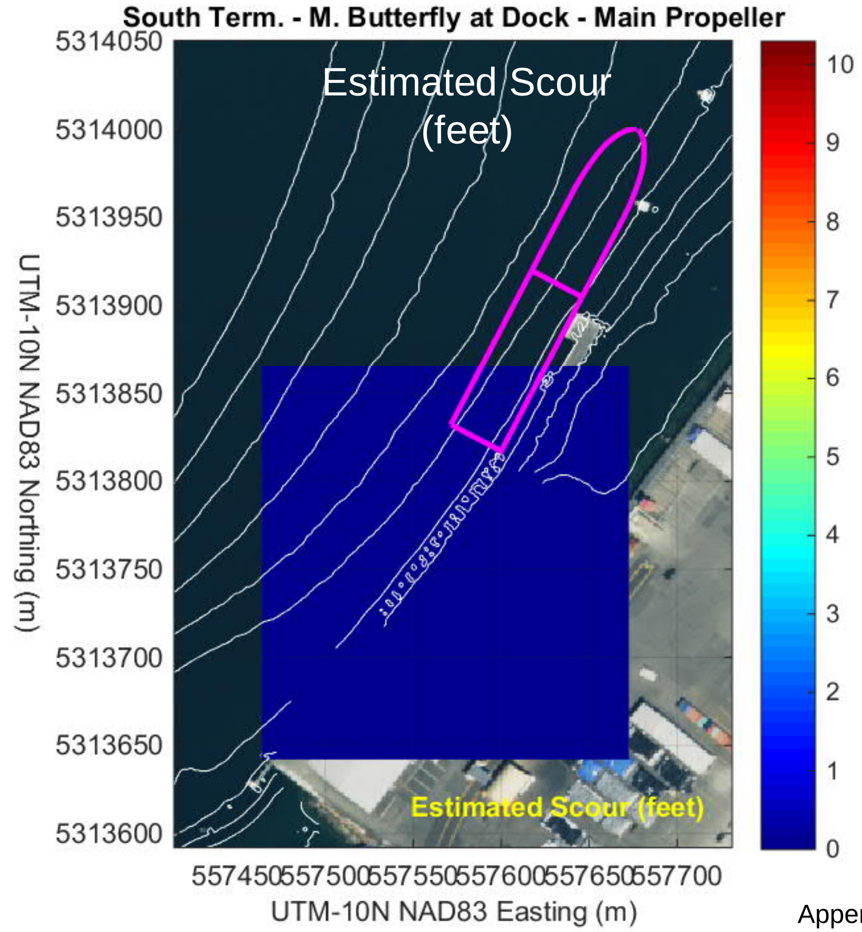




Scenario 7:

Madame Butterfly main propeller parallel to berth – vessel at dock

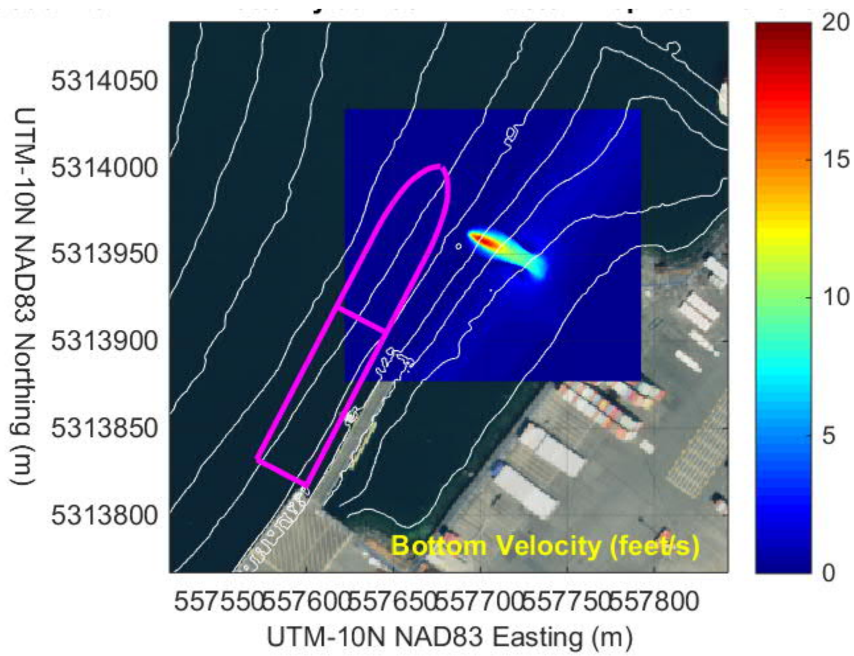




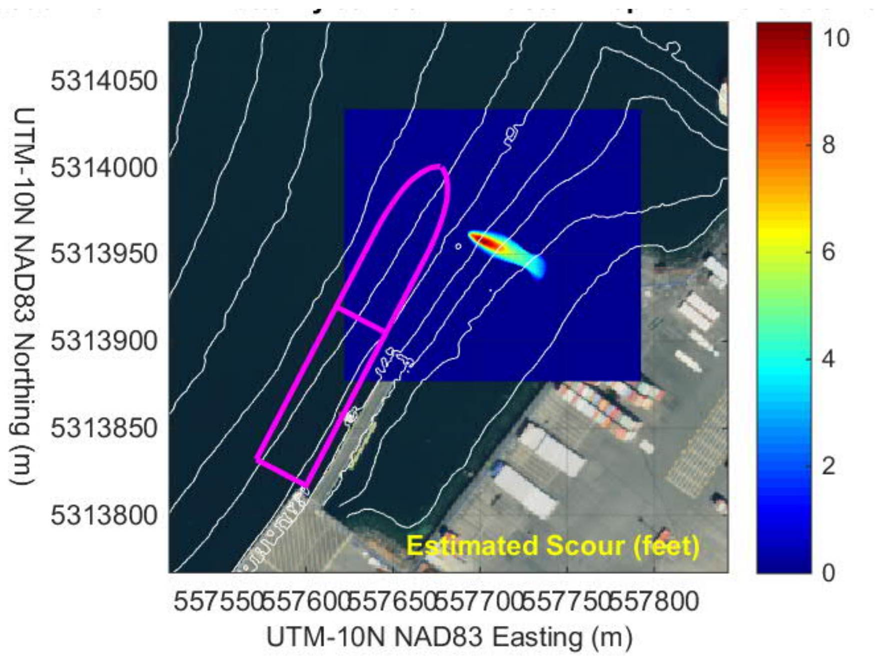
Scenario 8A:

Madame Butterfly thruster directed towards berth – M. Butterfly at the dock

Near-Bottom Velocity
(feet/second)



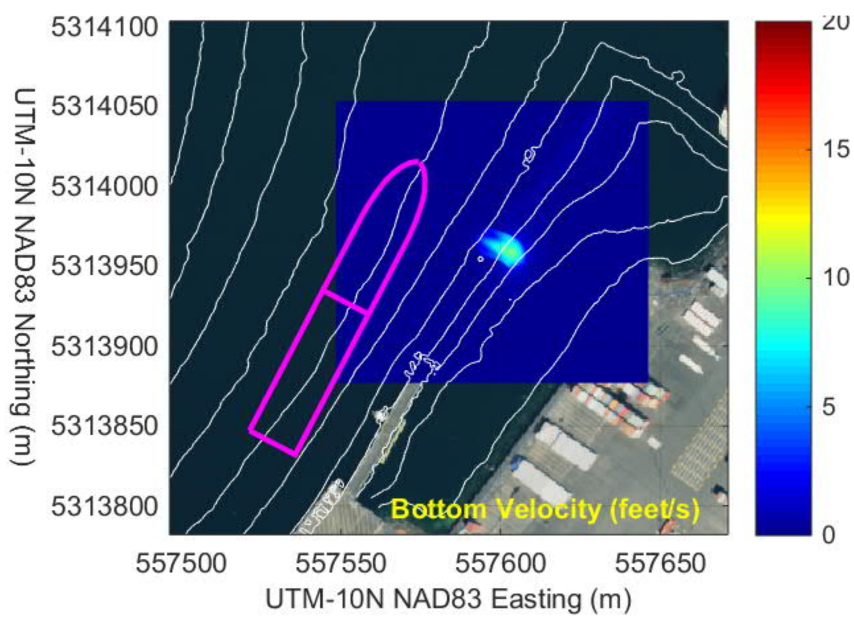
Estimated Scour
(feet)



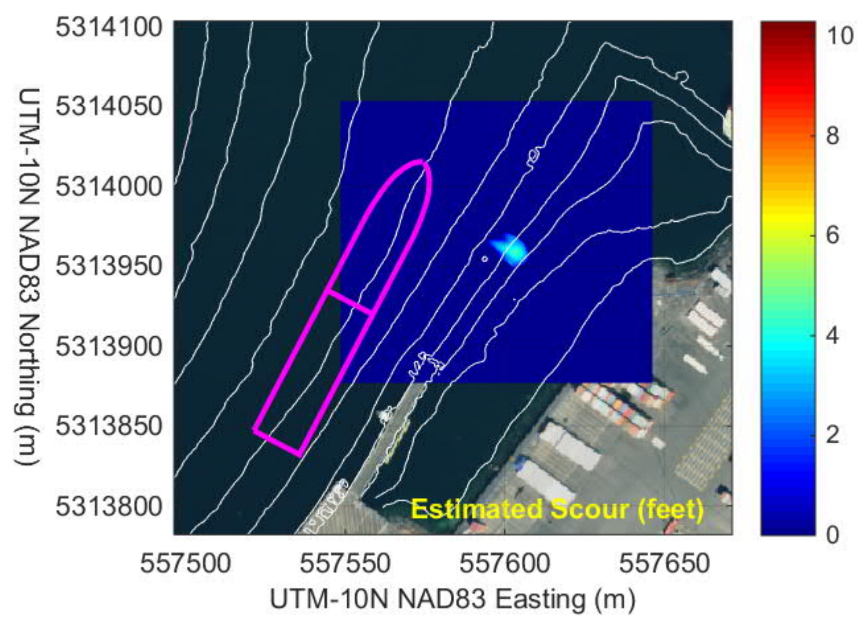
Scenario 8B:

Madame Butterfly thruster directed towards berth – M. Butterfly 1 beam width from dock

Near-Bottom Velocity
(feet/second)



Estimated Scour
(feet)

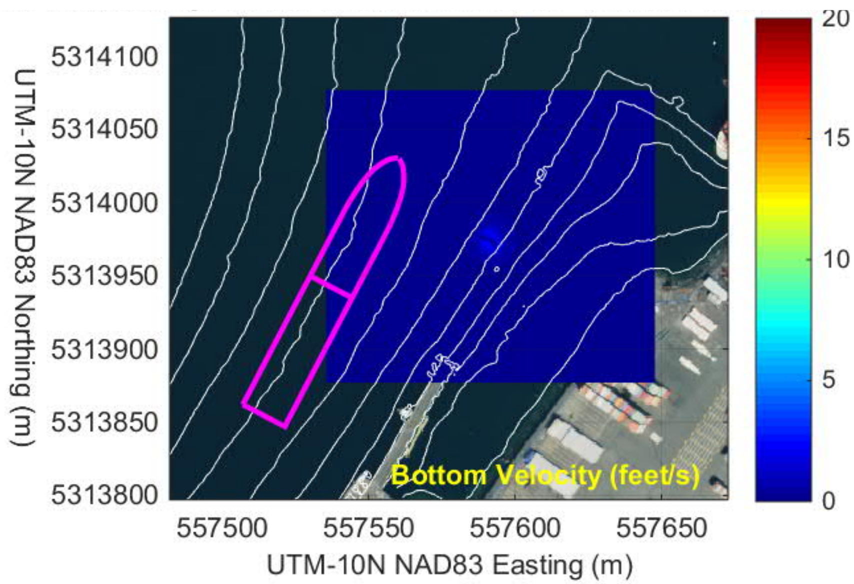


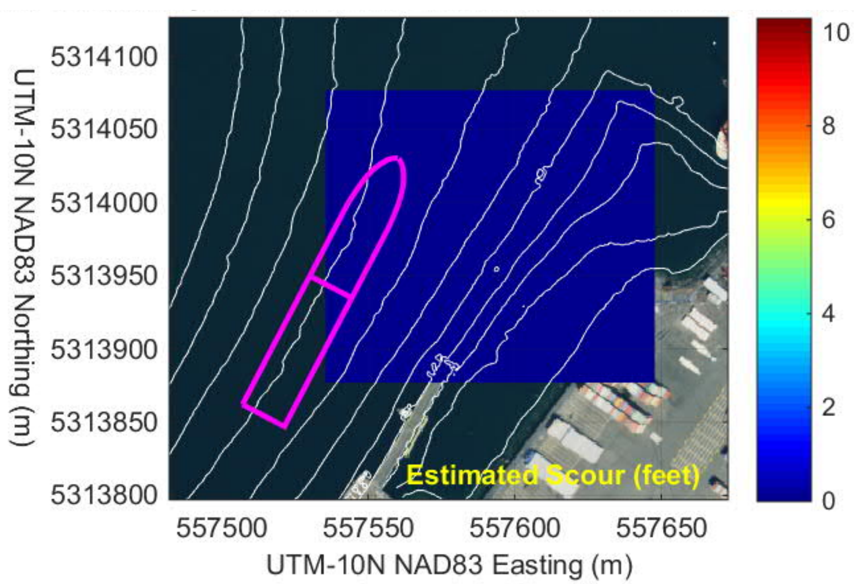
Scenario 8C:

Madame Butterfly thruster directed towards berth – M. Butterfly 2 beam widths from dock

Near-Bottom Velocity
(feet/second)

Estimated Scour
(feet)

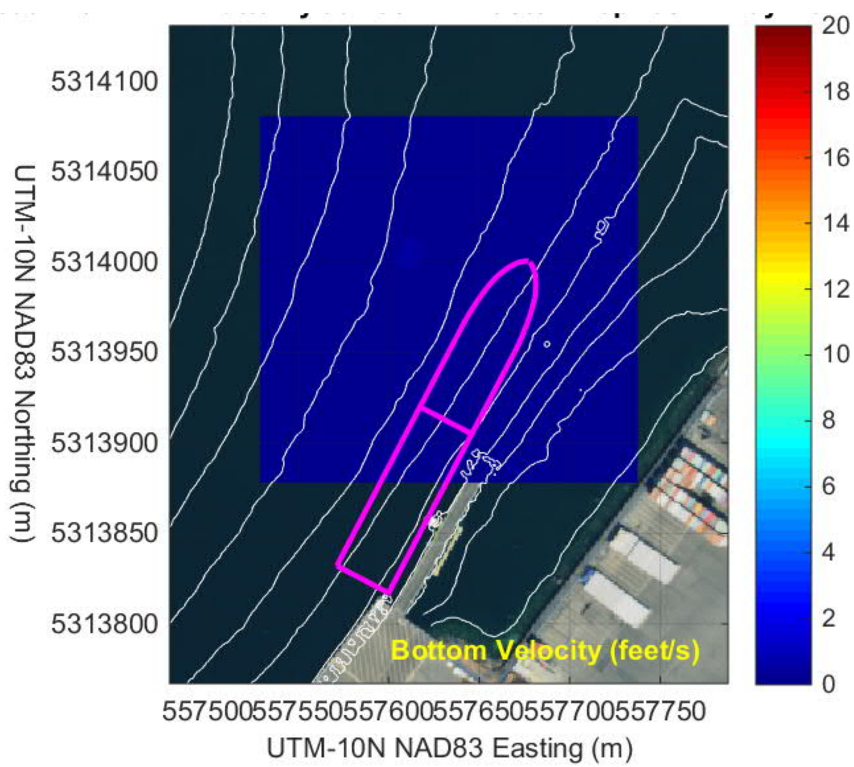




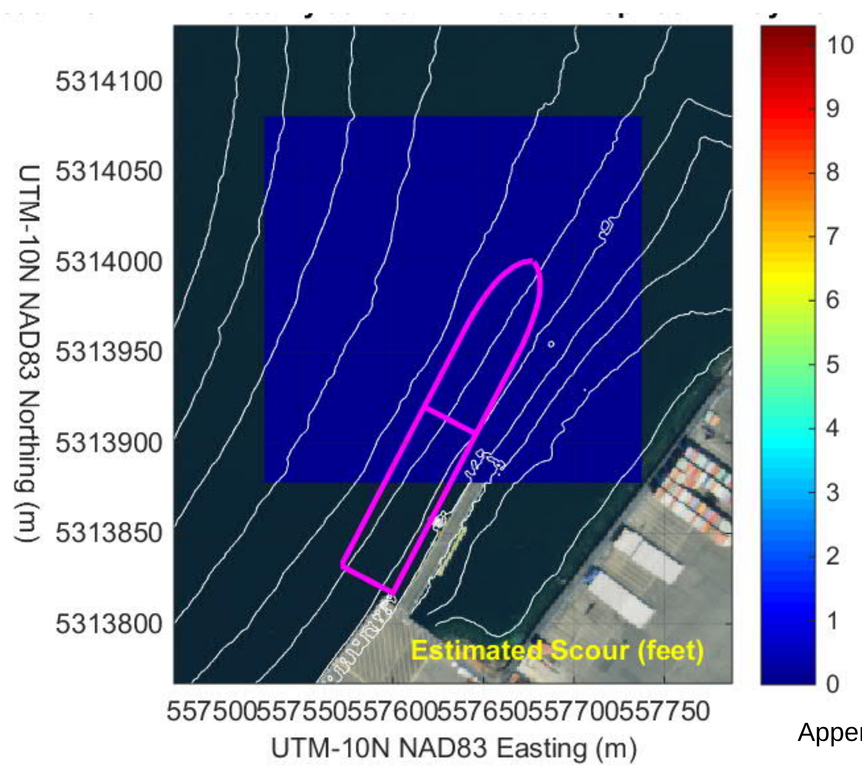
<u>Scenario 9</u>:

Madame Butterfly thruster directed away from berth

Near-Bottom Velocity
(feet/second)



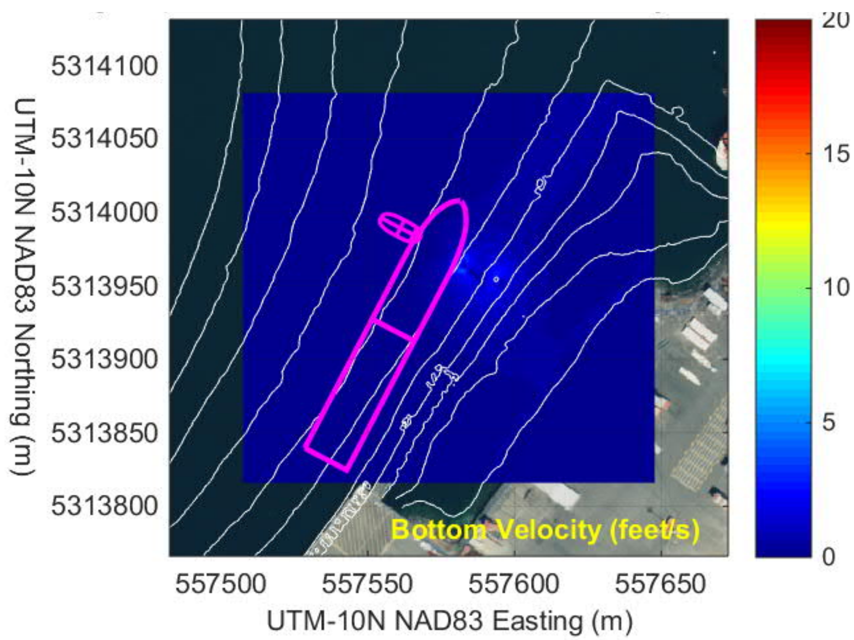
Estimated Scour
(feet)



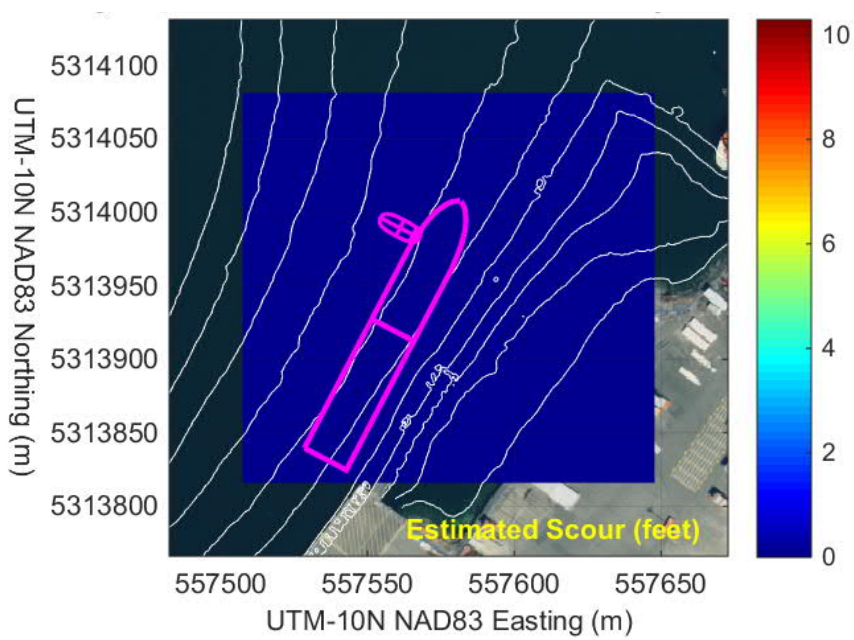
Scenario 10:

Bo Brusco tug propellers directed towards berth – Madame Butterfly near the dock

Near-Bottom Velocity
(feet/second)



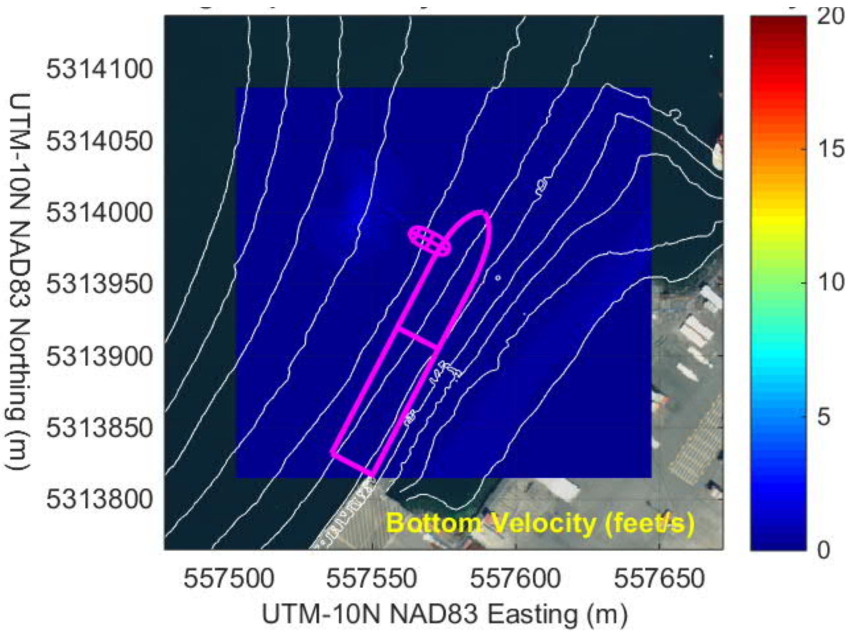
Estimated Scour
(feet)



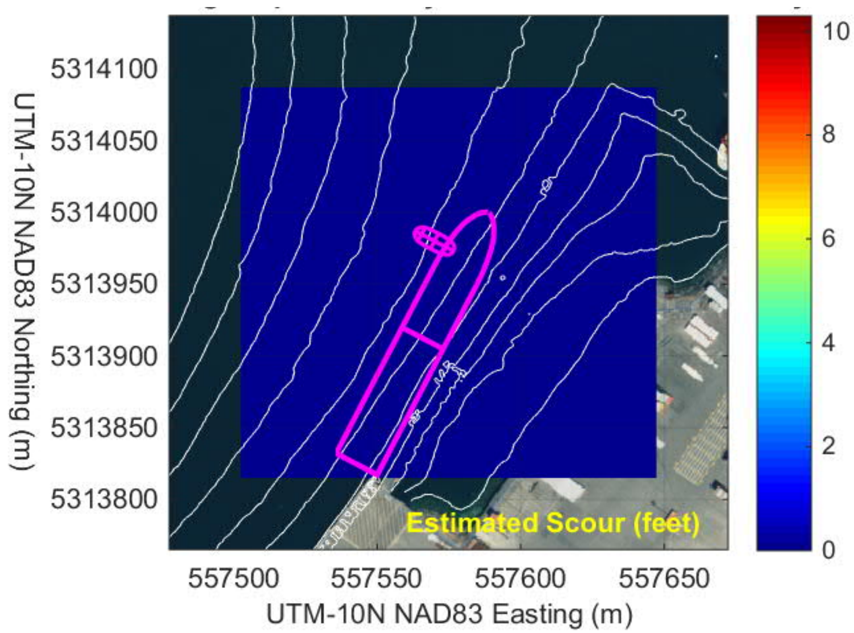
Scenario 11:

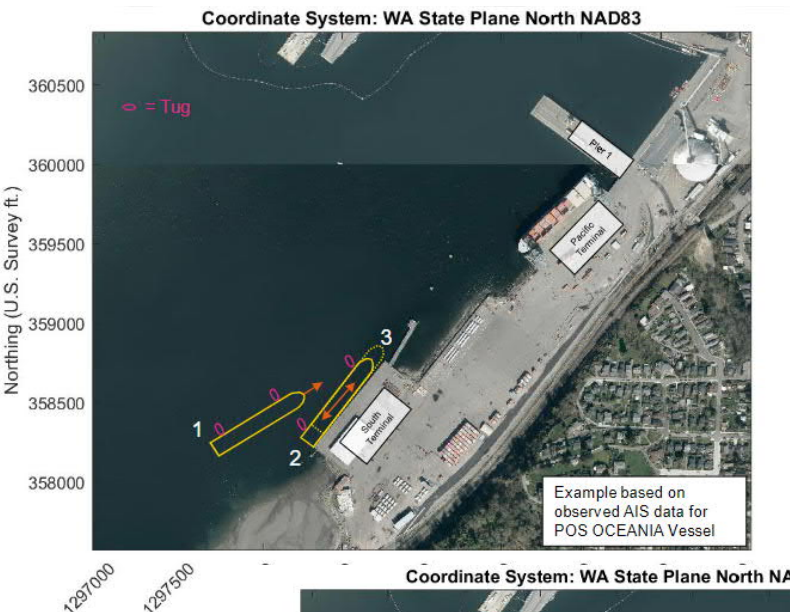
Bo Brusco tug propellers directed away from the berth – Madame Butterfly near the dock

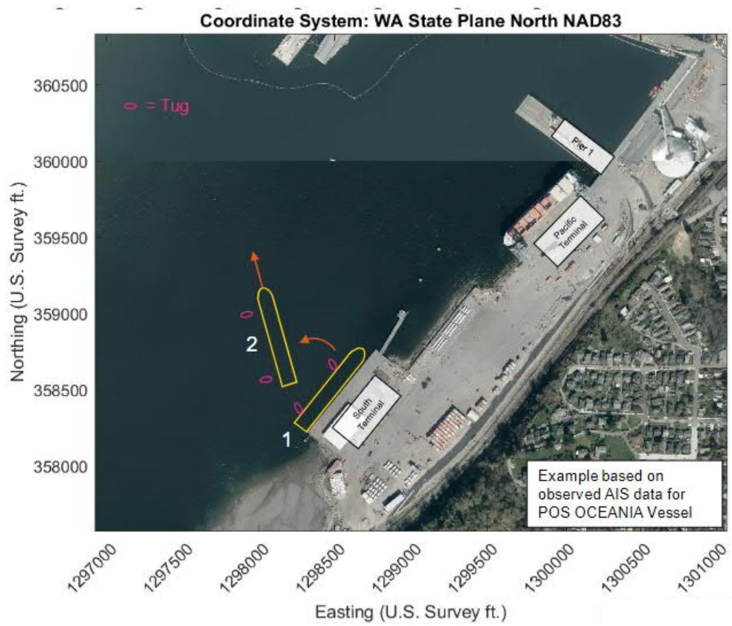
Near-Bottom Velocity (feet/second)



Estimated Scour (feet)

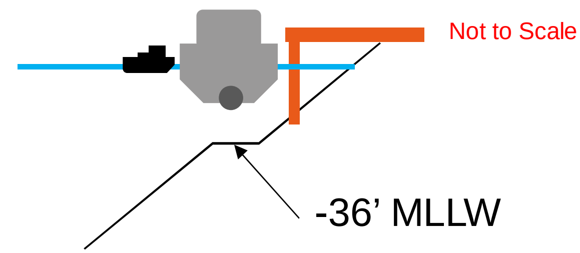






South Terminal Flow 3D Simulations

- Simulations use existing depth

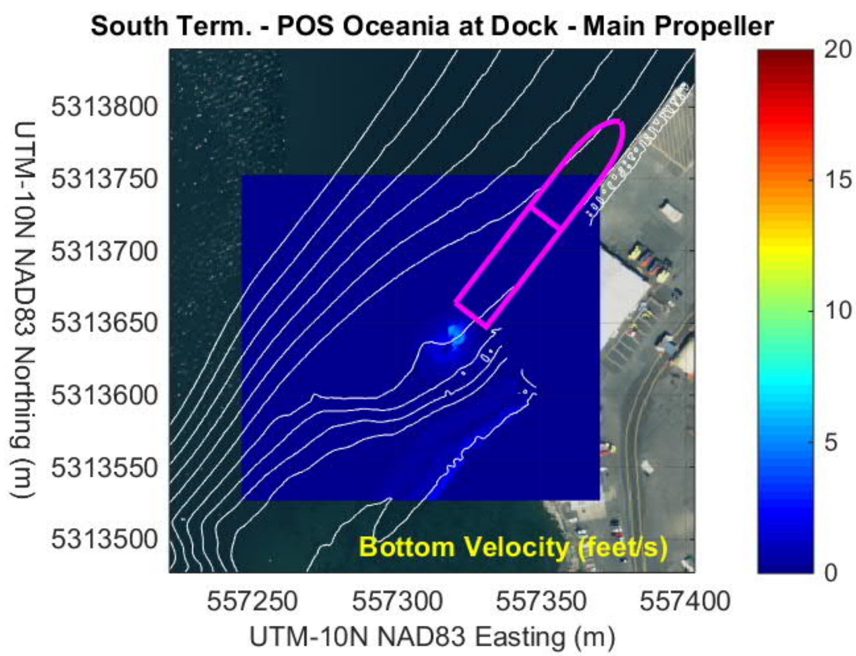


12. POS Oceania main prop parallel to berth (15% power) (PIANC)
13. POS Oceania main prop off berth just after tugs have disengaged for departure (28% power) (PIANC)
14. POS Oceania thruster directed towards berth (100% power)
15. POS Oceania thruster directed away from berth (100% power)
16. Bo Brusco tug propellers directed towards berth (100% power)
17. Bo Brusco tug propellers directed away from berth (100% power)

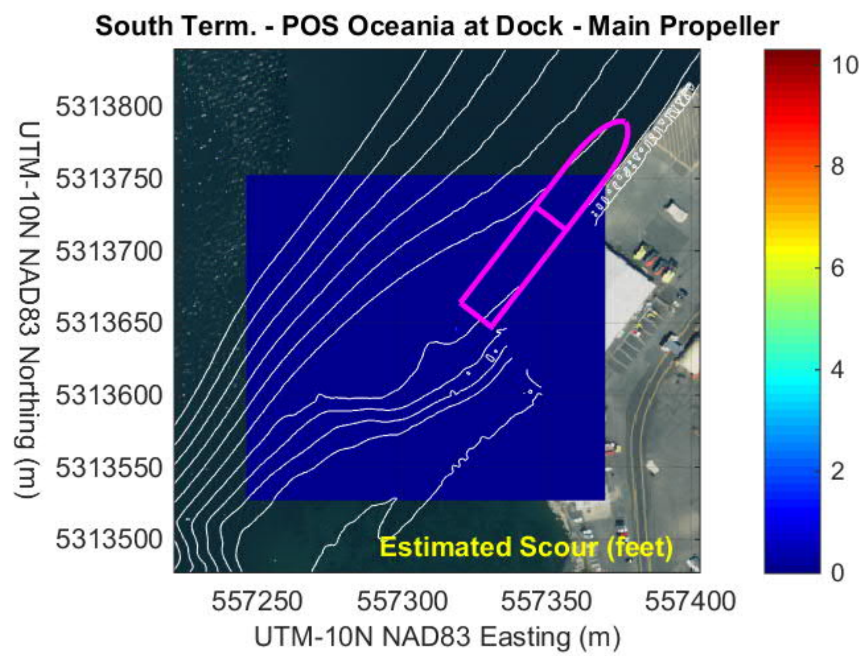
Scenario 12:

POS Oceania main propeller parallel to berth

Near-Bottom Velocity
(feet/second)



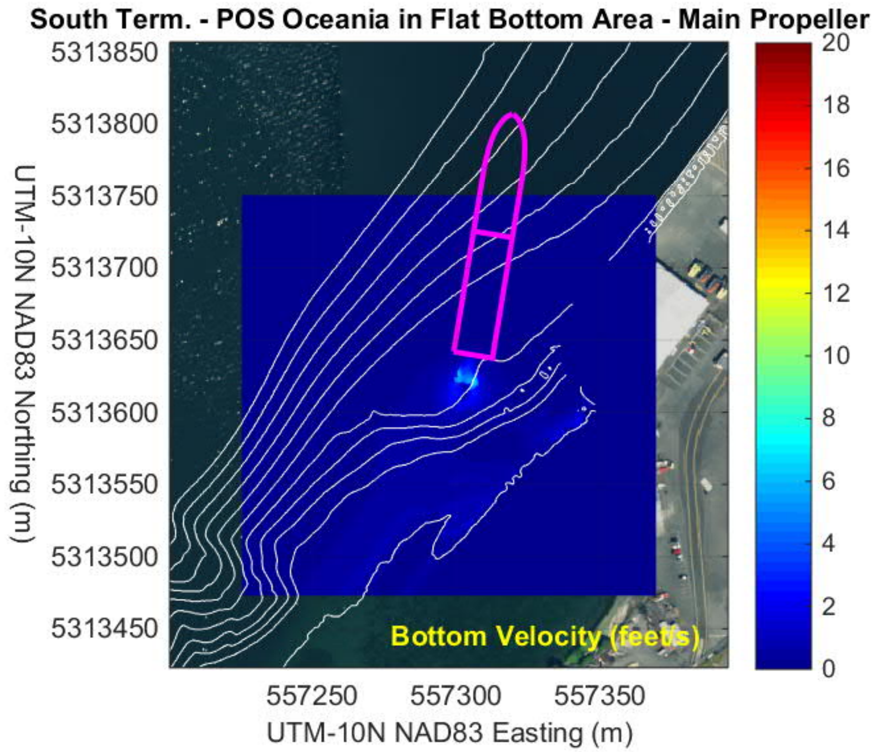
Estimated Scour
(feet)



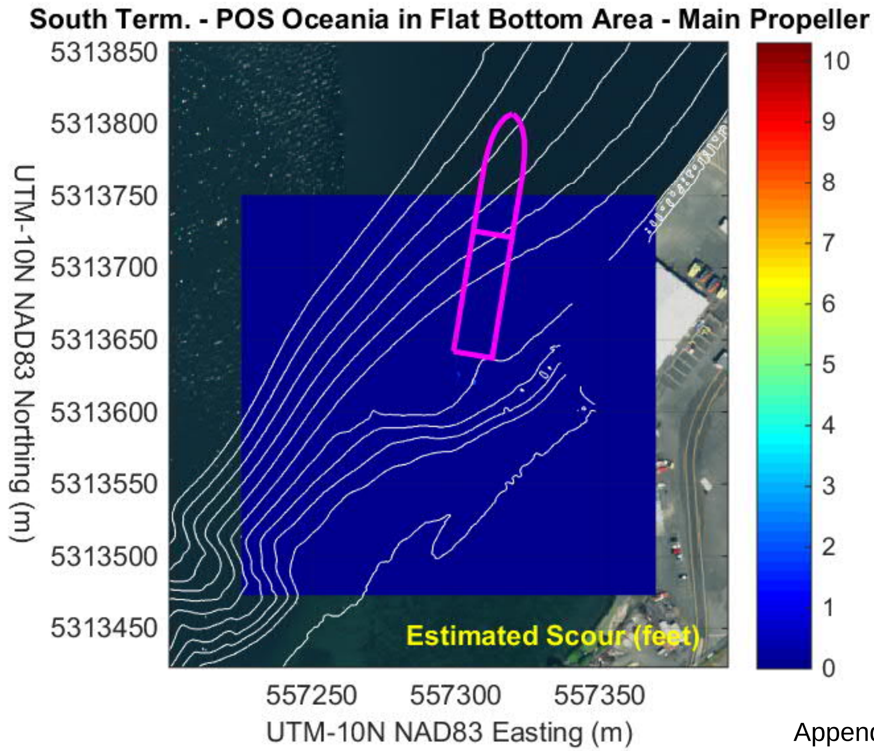
Scenario 13A:

POS Oceania main propeller off berth just after tugs have disengaged for departure – stern of vessel in a flat bottom area

Near-Bottom Velocity
(feet/second)



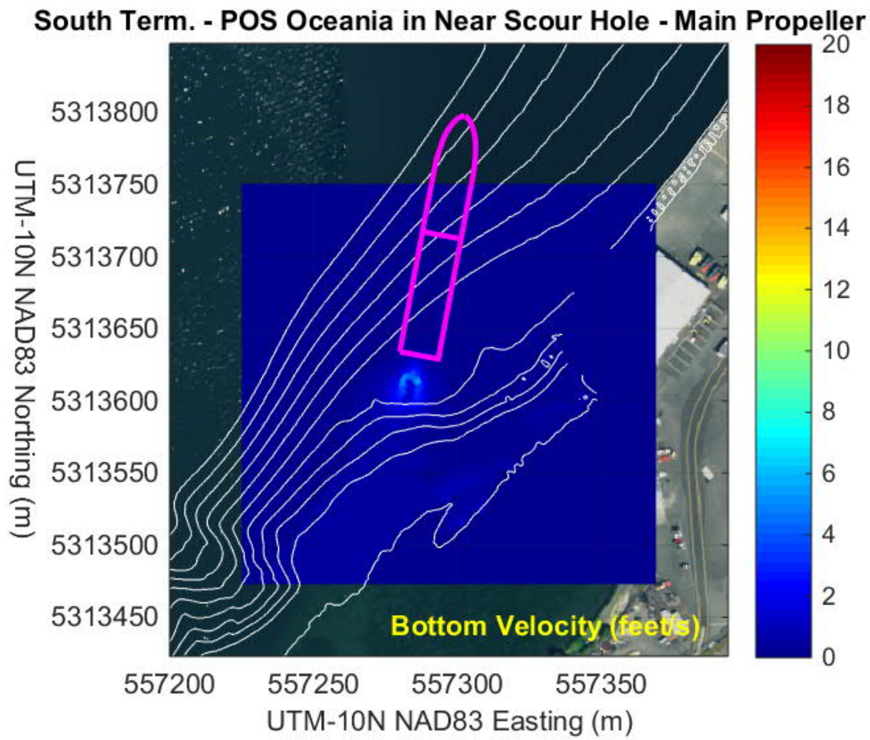
Estimated Scour
(feet)



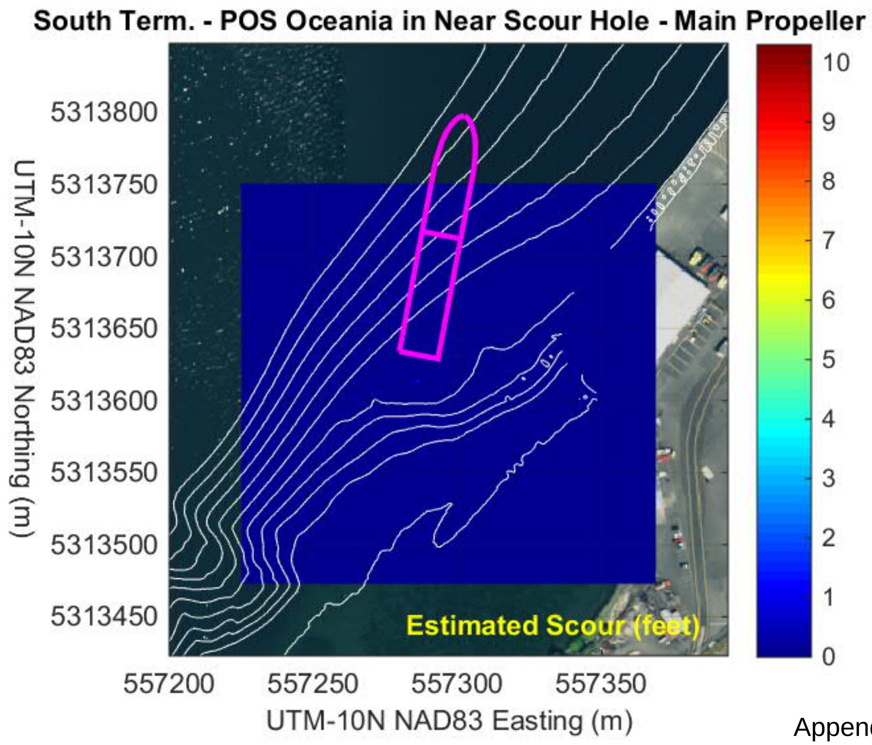
Scenario 13B:

POS Oceania main propeller off berth just after tugs have disengaged for departure – propeller thrust towards existing scour hole

Near-Bottom Velocity
(feet/second)

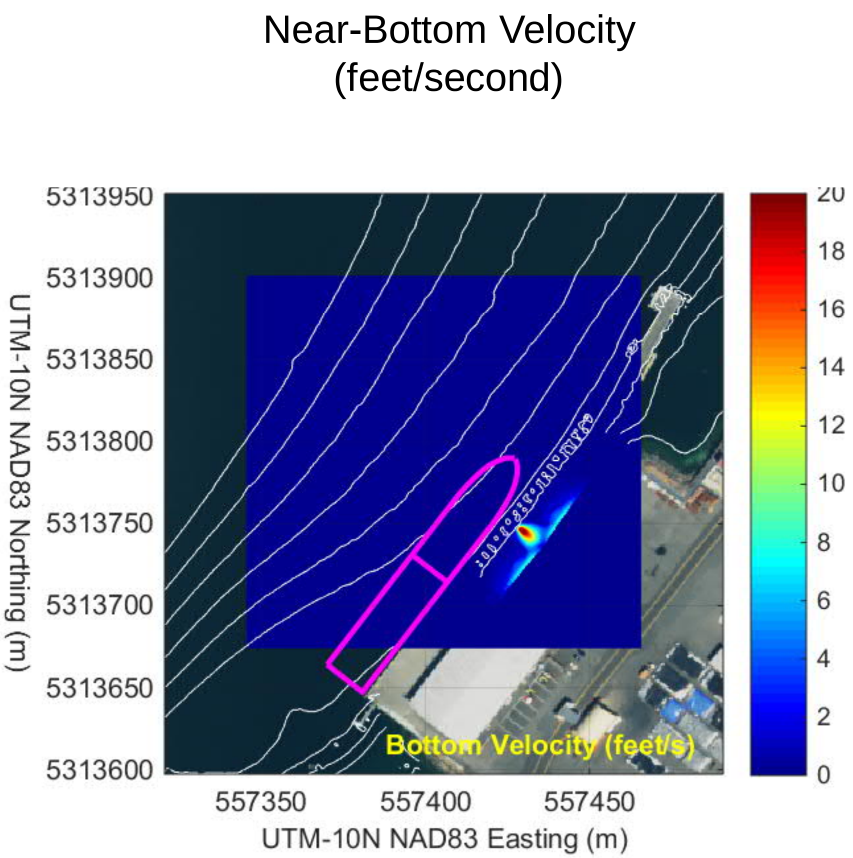


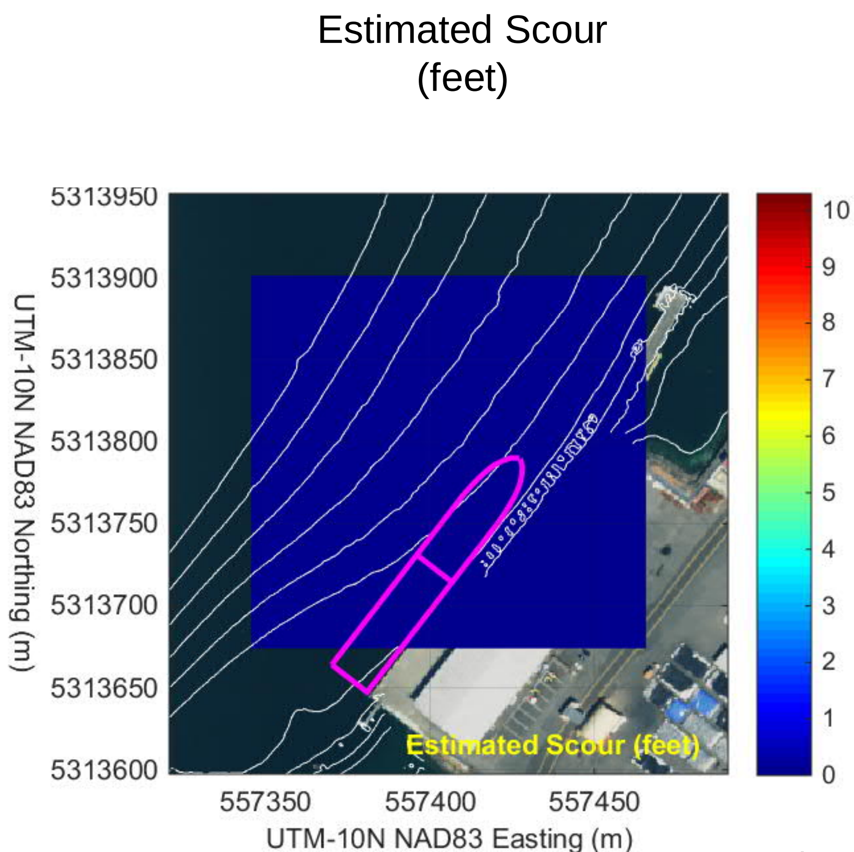
Estimated Scour
(feet)



Scenario 14A:

POS Oceania thruster directed towards berth – POS Oceania at the dock

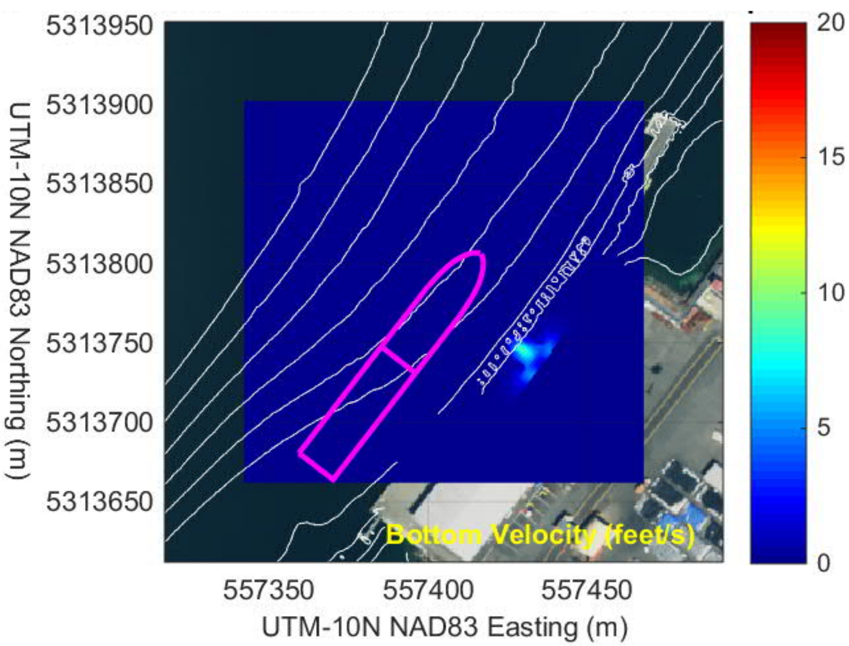




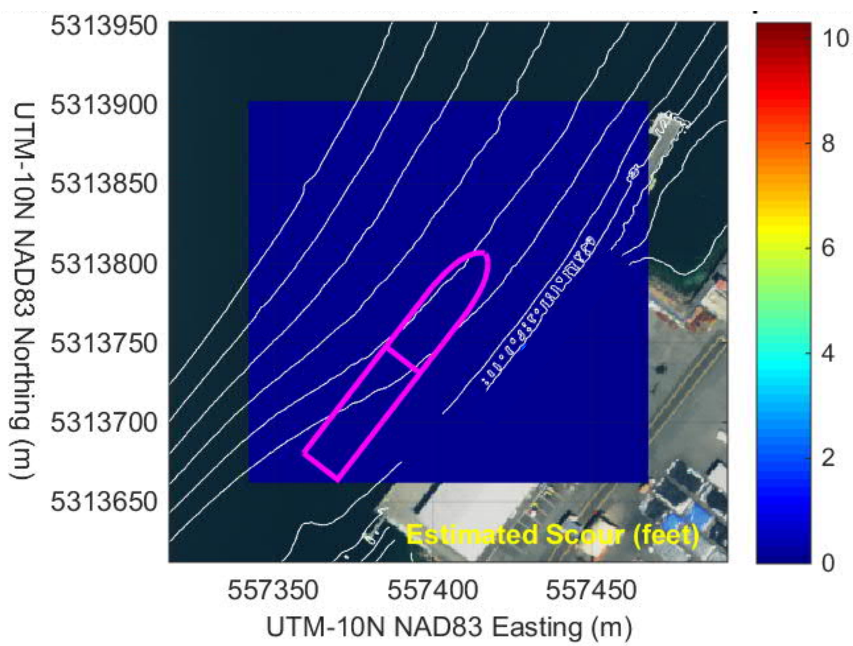
Scenario 14B:

POS Oceania thruster directed towards berth – POS Oceania 1 beam width from dock

Near-Bottom Velocity
(feet/second)

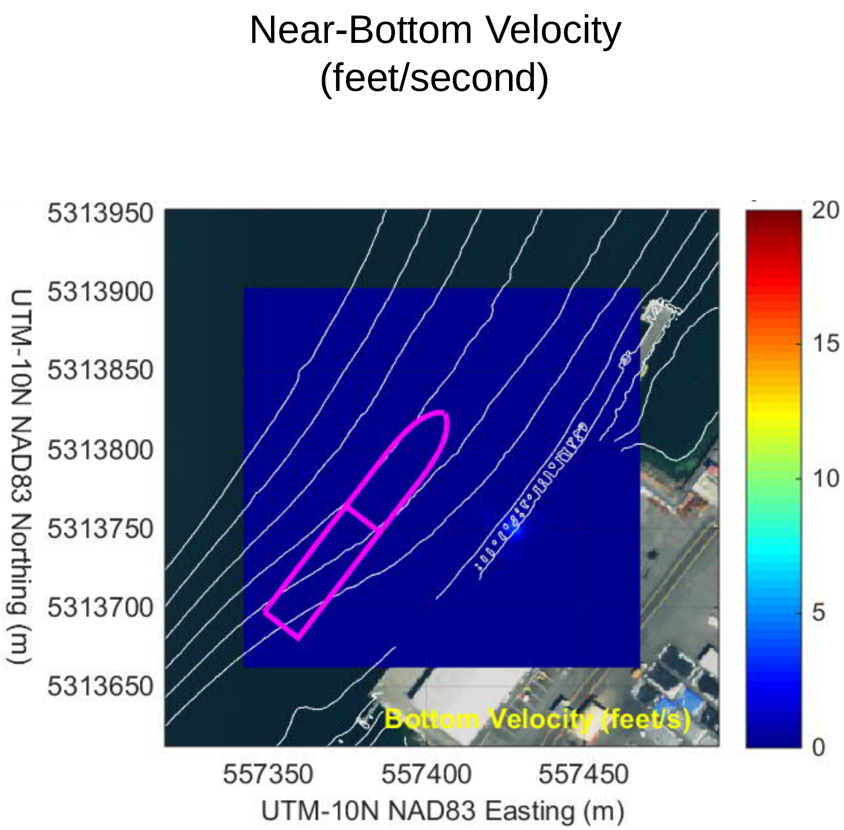


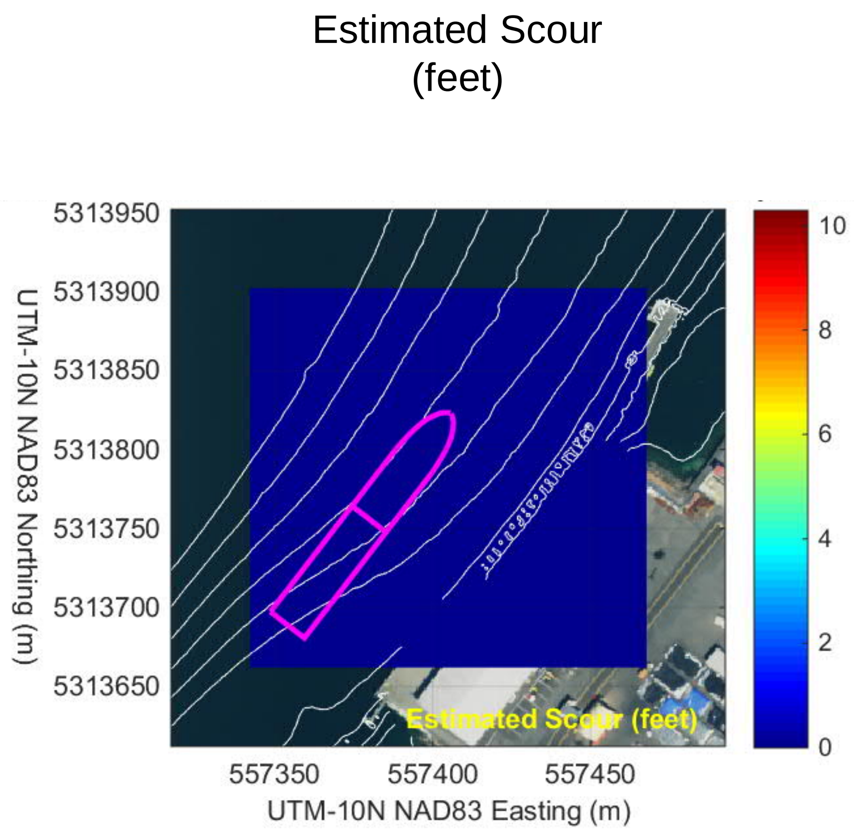
Estimated Scour
(feet)



Scenario 14C:

POS Oceania thruster directed towards berth – POS Oceania 2 beam widths from dock

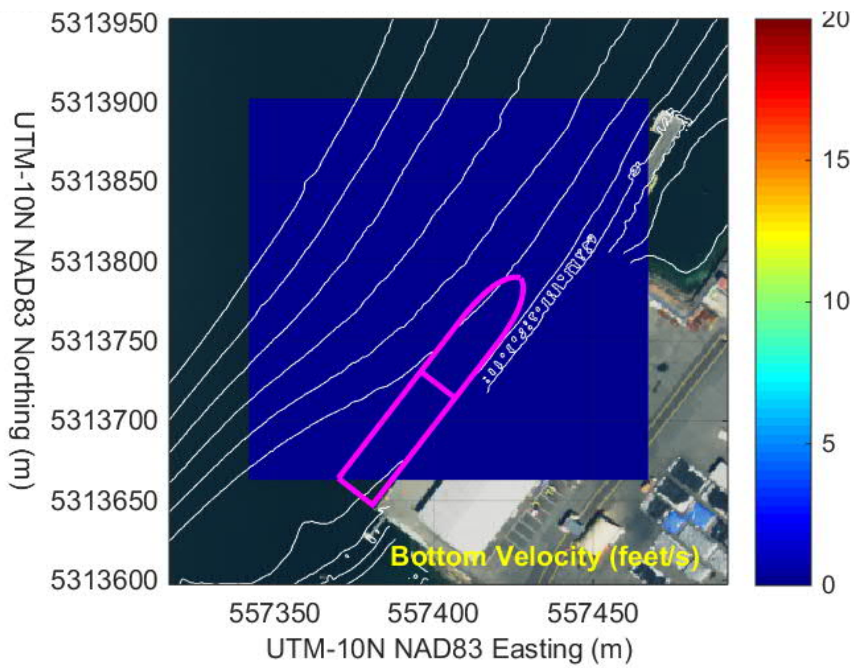




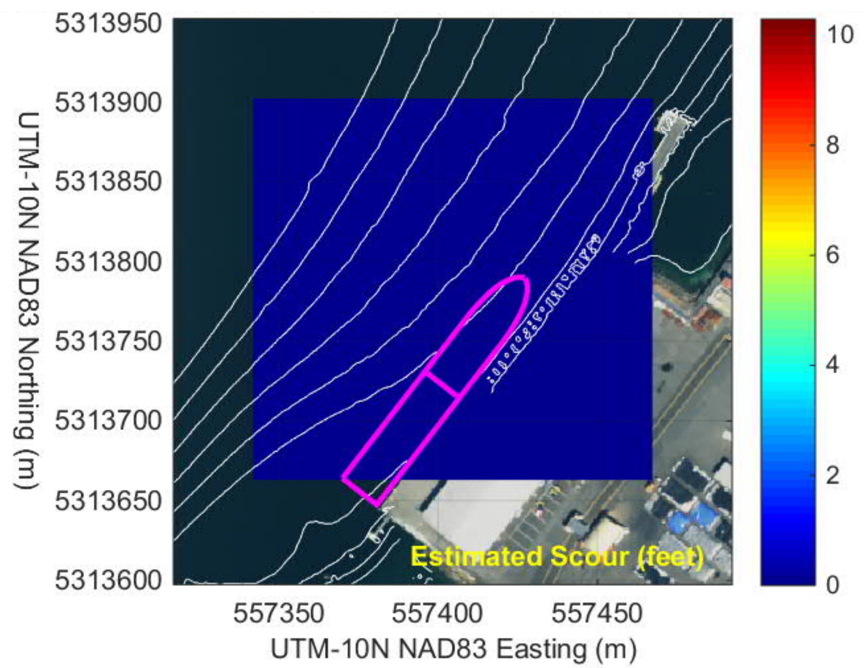
Scenario 15:

POS Oceania thruster directed away from berth

Near-Bottom Velocity
(feet/second)

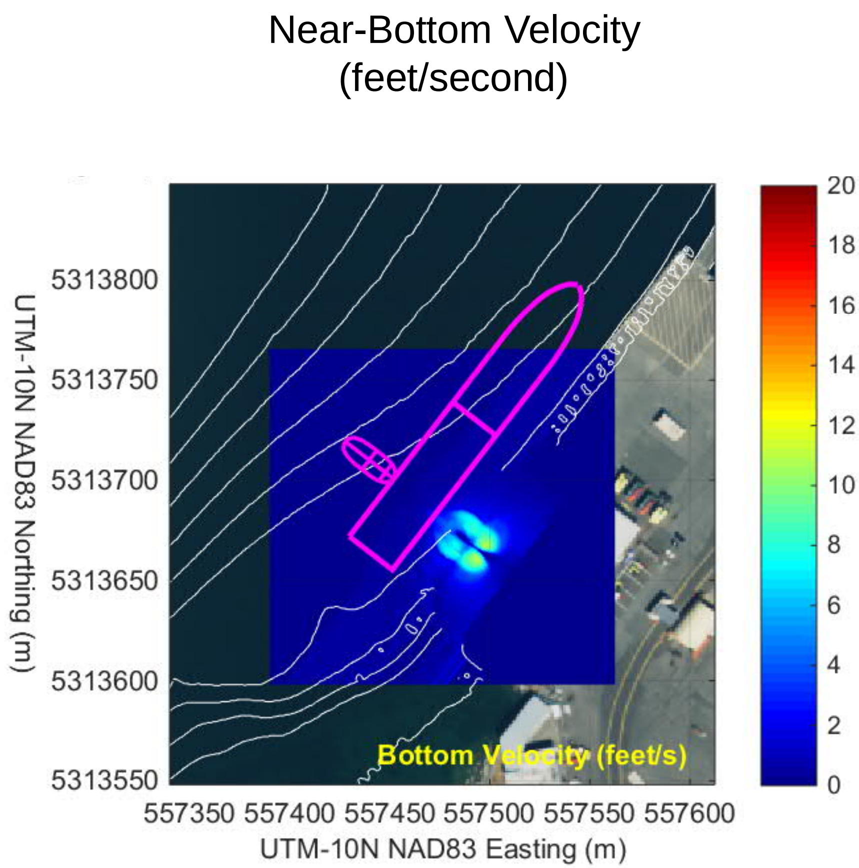


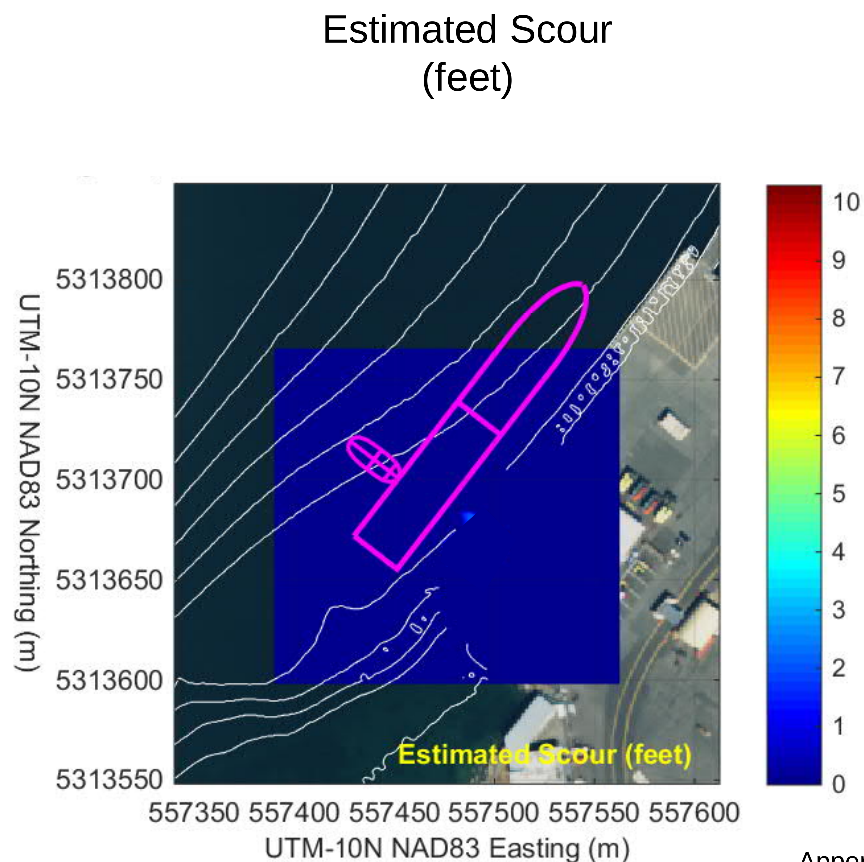
Estimated Scour
(feet)



<u>Scenario 16A</u>:

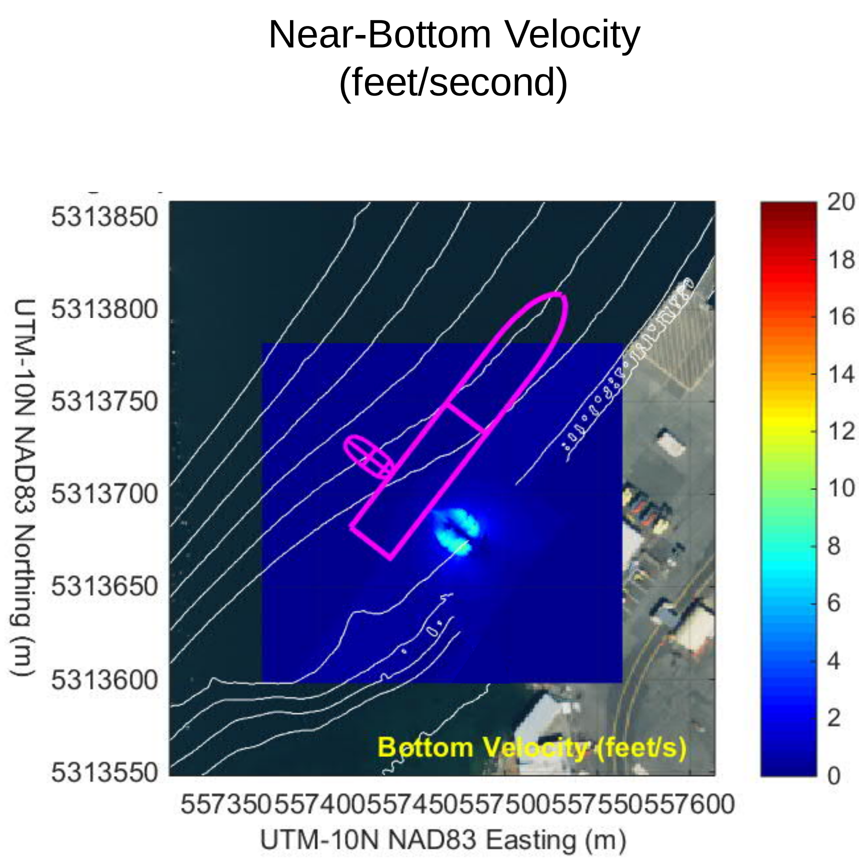
Bo Brusco tug propellers directed towards berth – POS Oceania near dock

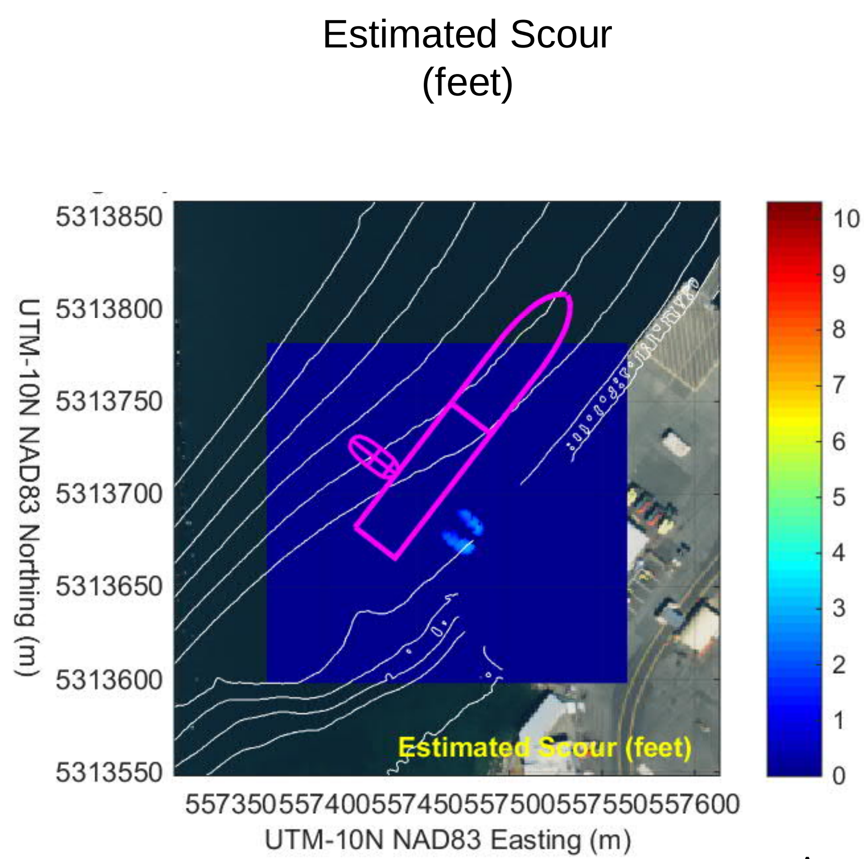




Scenario 16B:

Bo Brusco tug propellers directed towards berth – POS Oceania ½ beam width further from dock

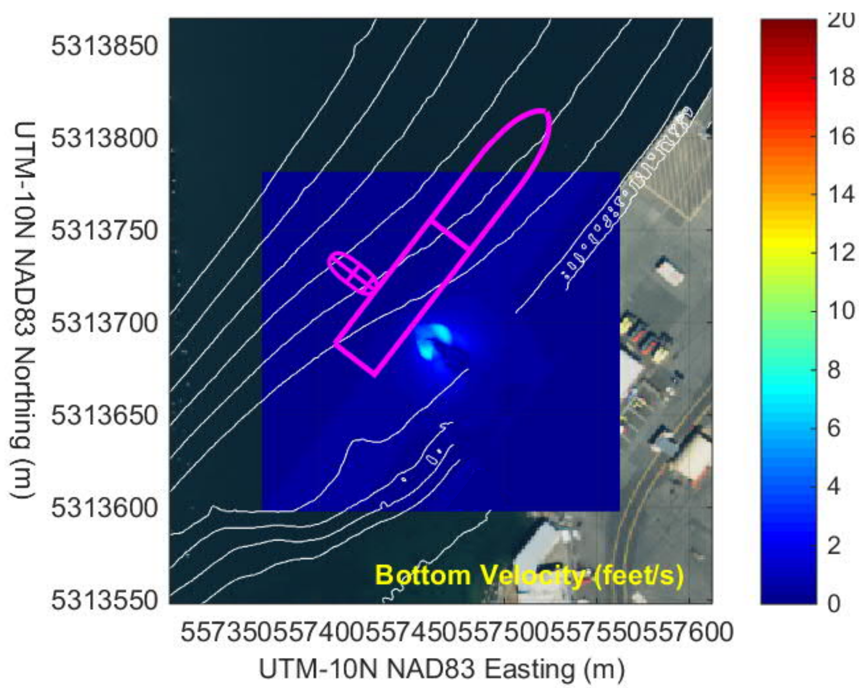




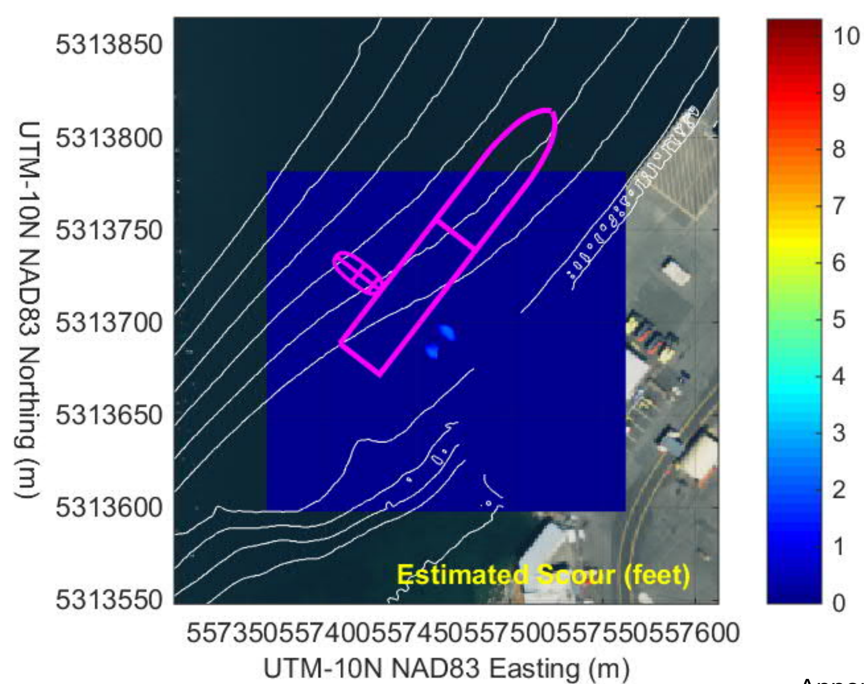
Scenario 16C:

Bo Brusco tug propellers directed towards berth – POS Oceania 1 beam width further from dock

Near-Bottom Velocity
(feet/second)



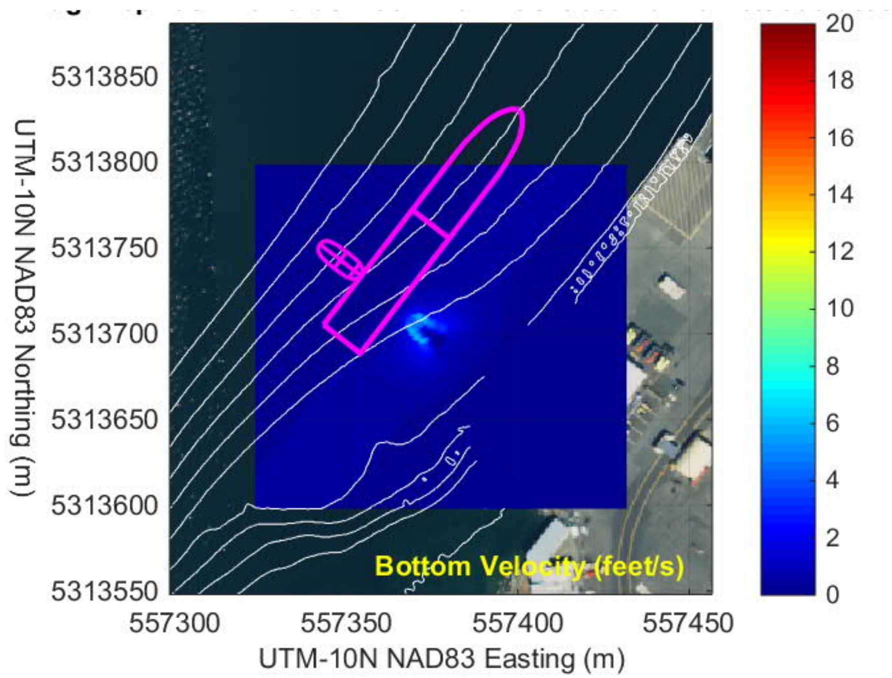
Estimated Scour
(feet)



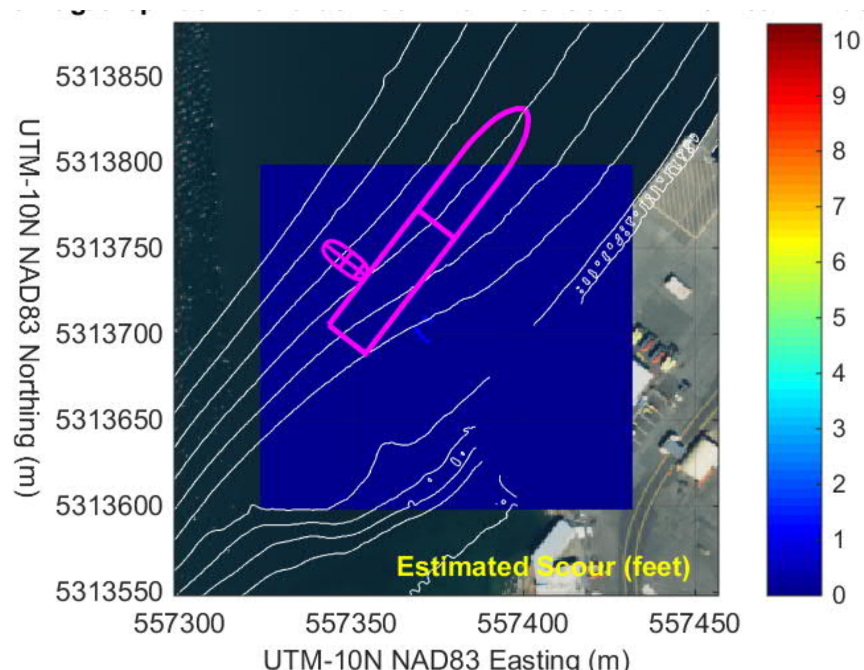
Scenario 16D:

Bo Brusco tug propellers directed towards berth – POS Oceania 2 beam widths further from dock

Near-Bottom Velocity
(feet/second)



Estimated Scour
(feet)



Scenario 17:

Bo Brusco tug propellers directed away from berth

Near-Bottom Velocity
(feet/second)

Estimated Scour
(feet)