90% Remedial Design Basis of Design Report

Appendix J
Engineered Protection Design Analysis for Engineered Caps and Area-Specific Technology

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ABBREVIATIONS

AIS	Automatic Identification System
BODR	*Basis of Design Report*
D_{50}	median particle size
EAA	early action area
ENR	enhanced natural recovery
ENR/AC	Enhanced Natural Recovery/Activated Carbon
EPA	U.S. Environmental Protection Agency
ft/sec	feet per second
FS	Feasibility Study
ft/sec	feet per second
H:V	horizontal to vertical (ratio)
HAT	highest astronomical tide
hp	horsepower
LAT	lowest astronomical tide
LDW	Lower Duwamish Waterway
MHHW	mean higher high water
MLLW	mean lower low water
mph	mile per hour
MSL	mean sea level
NAVD88	North American Vertical Datum of 1988
propwash	propeller wash
RAA	remedial action area
RAL	remedial action level
RD	remedial design
RM	river mile
ROD	*Record of Decision*
SLR	sea level rise
SMA	sediment management area

1 Introduction

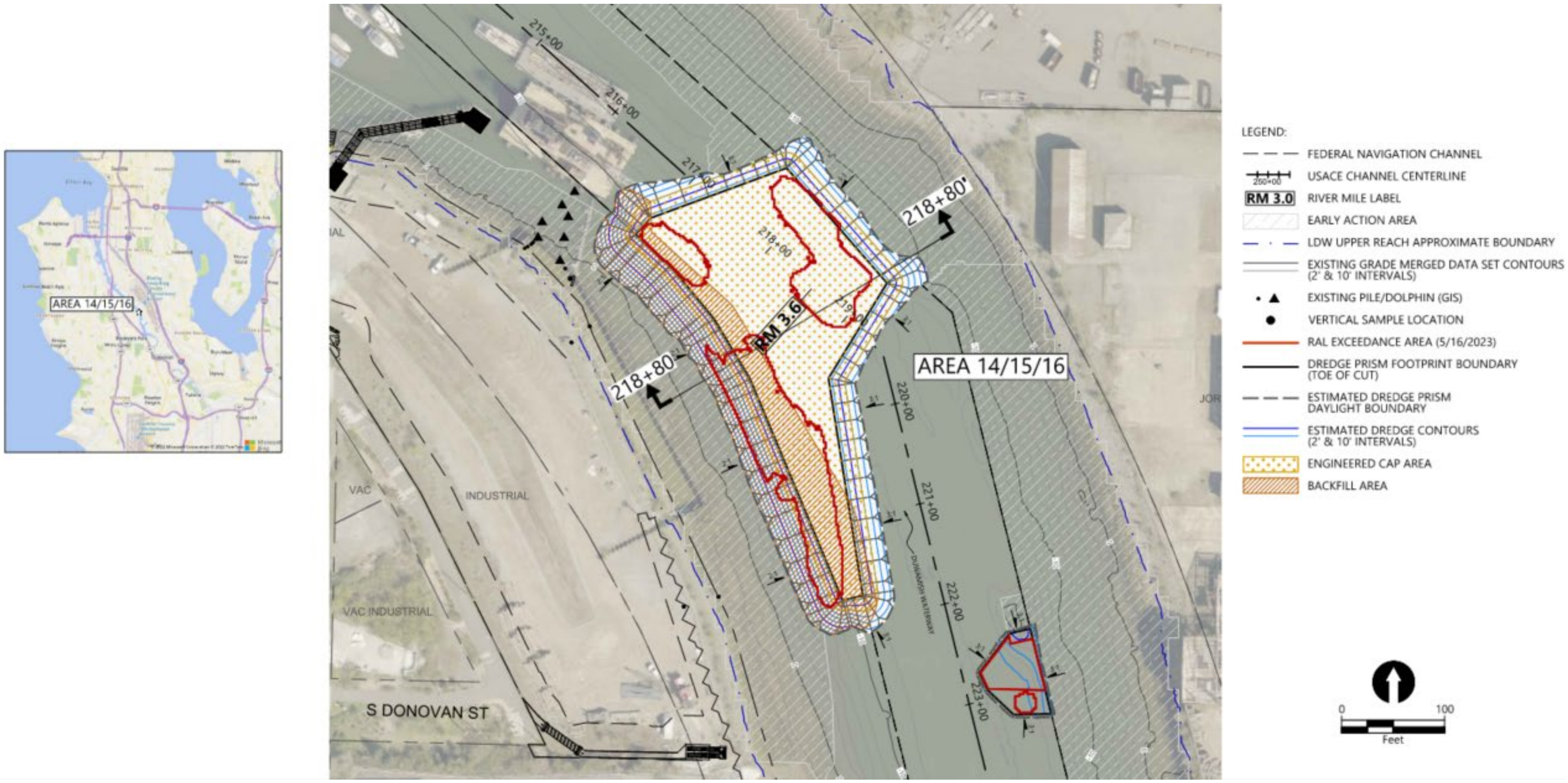
This appendix describes the design of erosion protection for engineered caps at remedial action area (RAA) 14/15/16 (sediment management area [SMA] 12B) and the east bank of RAA 27 (SMA 5). RAA 14/15/16 (SMA 12B) is located in the upper reach of the Lower Duwamish Waterway (LDW) between river miles (RMs) 3.5 and 3.7 spanning the federal navigation channel (FNC) and extending into the west and east intertidal zones outside of the FNC (Figure J1-1). RAA 27 is located in the upper reach of the LDW between RMs 4.0 and 4.2. RAA 27 is split into two SMAs: SMA 5, which is along the upper intertidal bank along the eastern shoreline of the LDW, and SMA 6, which is the offshore portion that does not have an engineered cap (Figure J1-2). Cap contaminant mobility assessments and design are described in Appendix I and summarized in Section 10.3.2.1 of the Pre Final (90%) Remedial Design (RD) *Basis of Design Report* (BODR).

Within the upper reach, capping is a technology that can be assigned in certain areas with deep contamination and compatible final surface elevations, in accordance with the *Record of Decision* (ROD; EPA 2014). The engineered capping erosion protection analysis is presented in this appendix for the intertidal area along the east bank of RAA 27 (SMA 5) and within the FNC at RAA 14/15/16 (SMA 12B). RAA 14/15/16 remedial action will include partial dredging and placing an engineered cap to isolate deep buried contamination that exceeds remedial action levels (RALs) but that cannot be effectively removed due to the depth of contamination and the potential impact of dredging on the adjacent early action areas (EAAs) located immediately to both the east and west intertidal areas outside of the FNC. The methodologies for cap design erosion protection are outlined in Sections 2.1 through 2.7, and the resulting erosion protection cap design for RAA 14/15/16 (SMA 12B) are summarized in Section 2.8.

As discussed in Section 2.2 of the Pre-Final (90%) RD BODR, the sediment cleanup remedy at RAA 27 (Container Properties; RM 4.1E) extends up the adjacent bank. The adjacent bank consists of debris and manufactured materials that help protect the bank slope from potential erosive forces, but the bank at RAA 27 is not an engineered slope. Chemistry data underneath the bank debris and armoring materials could not be collected; however, chemistry data at the toe of the bank slope indicate potential for contaminated sediment underneath at least part of the bank surface. Because there is uncertainty whether sediment underneath the bank debris and armor material at RAA 27 is contaminated, the conservative remedial technology of engineered capping will be applied to the bank portion of this RAA. Therefore, erosion protection design for the bank area at RAA 27 is assumed necessary. The methodologies for cap design erosion protection are outlined in Sections 2.1 through 2.7, and the resulting erosion protection cap design for the bank areas of RAA 27 is summarized in Section 2.9.

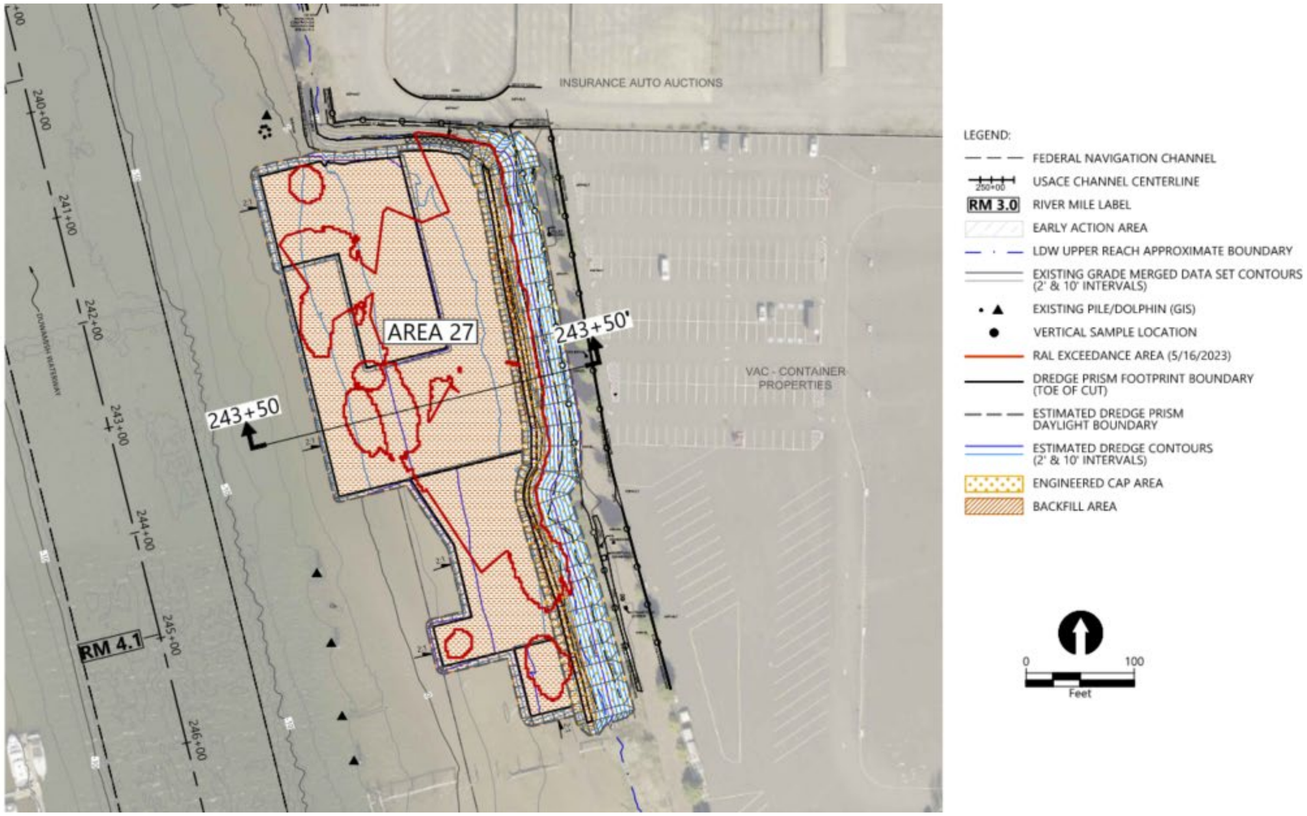
The erosion protection analyses also describe the methods that will be used for erosion protection design for other remedial technology applications (e.g., area-specific technologies). Area-specific technologies consisting of cover material over dredging offset areas are identified for portions of RAA 24/25/26 (Section 3). These are areas adjacent to existing structures or armored slopes and where dredging offsets are required because dredging may cause structural instability of existing structures or armored banks. No dredging will occur within the dredging offset areas, and area-specific technology will be applied to these small, limited areas.

Figure J1-1
Vicinity Map: RAA 14/15/16 (SMA 12B)



Note:
Cross section is presented in Figure J2-3.

Figure J1-2
Vicinity Map: RAA 27 (SMAs 5 and 6)



Note:
Cross section is presented in Figure J2-4.

The primary objective of the erosion protection layer in an engineered cap is to prevent exposure and erosion of the underlying chemical isolation layer. The potential for erosion of the sediment cap depends on the erosive processes likely to occur in the LDW, as well as the materials composing the cap layers. Potential erosive processes that may act on the sediment cap within the upper reach of the LDW include the following:

- Localized propeller wash (propwash) from vessels
- Waves generated by passing vessels (wakes)
- Hydrodynamic flows in the LDW resulting from discharge of tributaries and other discharges, as well as from typical river circulation conditions
- Wind-generated waves due to storm events

Each of these potential erosion processes was evaluated independently to determine the design requirements for the cap erosion protection component. The cap erosion protection layer was then designed to withstand erosion under the range of anticipated conditions for each process. This appendix presents the results of this design analysis.

As described in Palermo et al. (1998):

> The cap component for stabilization/erosion protection has a dual function. On the one hand, this component of the cap is intended to stabilize the contaminated sediments being capped and prevent them from being resuspended and transported offsite. The other function of this component is to make the cap itself resistant to erosion. These functions may be accomplished by a single component, or may require two separate components in an in-situ cap.

Methods for designing cap erosion protection (i.e., armor layer) are presented in Appendix A of Palermo et al. (1998). The cap armor material gradation and thickness must also be designed to stabilize and protect the underlying physical and chemical isolation layers from erosion (based on an evaluation of each potential erosional source). The erosion resistance design must account for the forces along the edge of the cap as well as on the surface of the cap to prevent scour for both typical flows and anticipated flood events.

The armor layer of the cap has been designed to provide stabilization of underlying finer grained cap materials (as well as sediment) to prevent the vertical migration of those materials through the armor layer, termed piping (Palermo et al. 1998). As described in the *Remedial Design Work Plan for the Lower Duwamish Waterway Upper Reach*, the cap design considers the physical, chemical, hydrodynamic, and hydrogeological properties (LDWG 2019).

Climate change is expected to affect the greater Puget Sound region and, relevant to the LDW, includes sea level rise (SLR), changes in precipitation patterns, and overall hydrological changes. Climate change adaptation generally focuses on evaluating a system's vulnerability to climate change and implementing adaptation measures, when warranted, to ensure the remedy continues to remain effective at meeting the ROD objectives (EPA 2014). As such, an evaluation of the long-term effects of SLR and climate change on cap integrity is also discussed in this appendix.

2 Erosion Protection Design for RAA 14/15/16 (SMA 12B) and RAA 27 (SMA 5) Engineered Caps

This section presents an evaluation of the following design criteria as related to erosive forces in the vicinity of RAA 14/15/16 (SMA 12B) and the east bank of RAA 27 (SMA 5):

- Selection of design vessels
- Review of bathymetry, water levels, and potential changes due to SLR
- Predictive modeling to estimate stable particle size for propwash forces, wake forces, hydrodynamic forces, and wind-generated waves

2.1 Selection of Design Vessels

A propwash and vessel wake analysis was conducted to evaluate the stable particle sizes to resist propwash from vessels in the upper reach. Propwash and wake forces are related to specific characteristics of the vessel being considered, including vessel size, vessel power, vessel propeller size, operational speeds, and depth of the propeller beneath the water line. As such, a "design" vessel or vessels must be selected so that propwash and wake forces can be estimated. Vessel traffic data were obtained through the Automatic Identification System (AIS). The AIS vessel data are collected by the U.S. Coast Guard through onboard navigation safety devices that transmit and monitor vessel locations and characteristics of large vessels. These data were downloaded via MarineCadastre.gov (BOEM and NOAA 2021).

The design vessel selection consisted of the following components:

- Vessel activity was evaluated to establish the types and sizes of vessels that utilize the upper reach.
- Vessel characteristics (e.g., draft, propeller type, and dimensions) were obtained for representative vessels, as outlined in this section.
- Vessel operating information and assumptions (e.g., operating horsepower and vessel location and orientation) were selected to correspond with each representative vessel.

The available AIS data for 2020 were plotted. A portion of the data, from October 2020, is presented in Figures J2-1 and J2-2, showing AIS designated vessel types and vessel speeds, respectively. A total of 87 unique vessels were identified that transited in the upper reach during the year. Of those unique vessels, the following three representative design vessels were selected for analysis:

- Capt. Cae Tug
  - The largest tug to transit the area in 2020 (92 feet long)

- Westrac II Tug
  - An average-sized tug (74 feet long), selected to represent the more typical tugs that frequent the area; the average length for tugs that transited the area in 2020 was 72 feet
- Arctic Pride Yacht
  - One of the largest pleasure vessels to transit the area in 2020 at 126 feet long; there were three larger vessels (up to 150 feet long), but Arctic Pride transited more frequently

Table J2-1 outlines the specifications of the three design vessels used in the erosion protection basis of design.

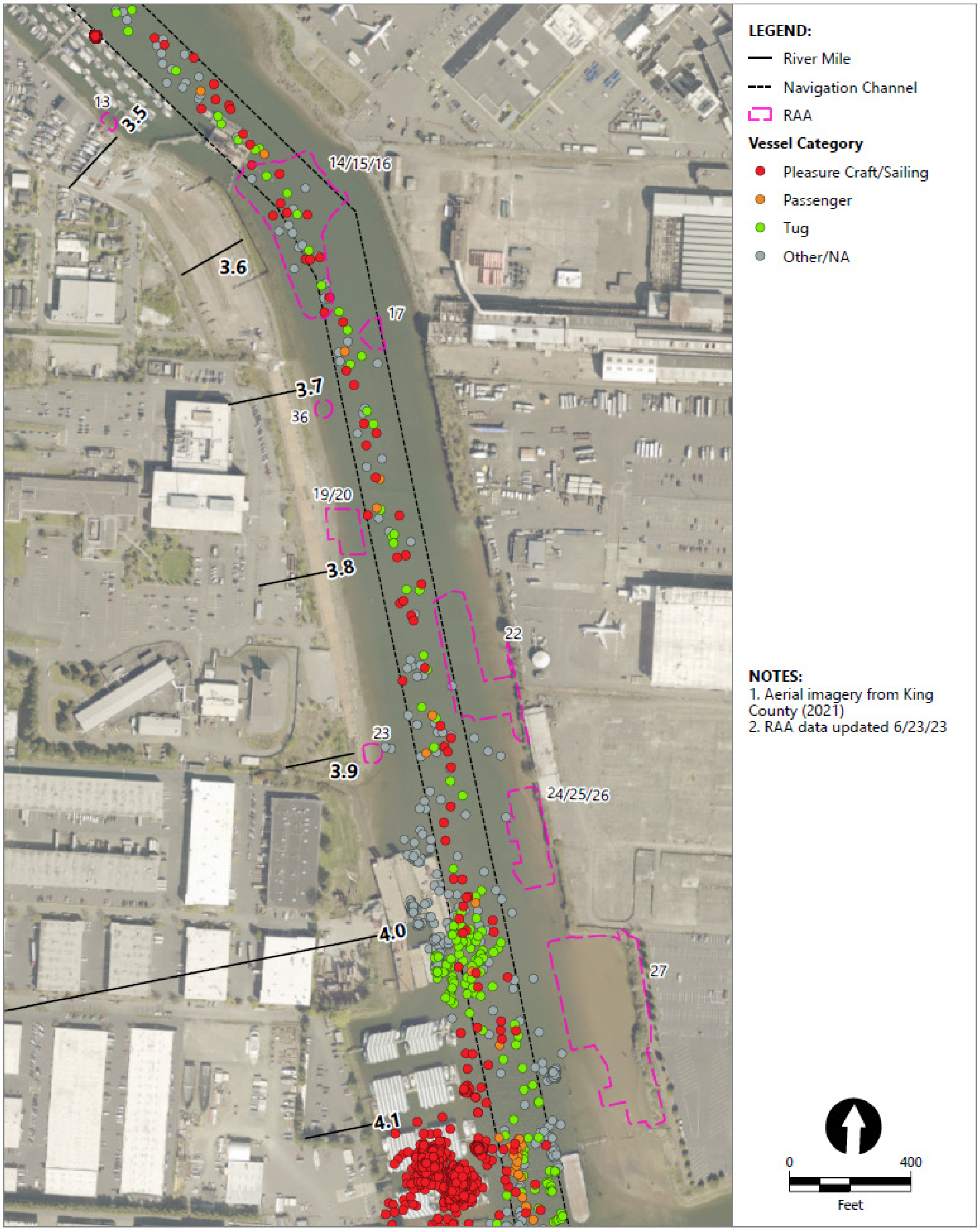
Table J2-1
Design Vessel Specifications

Vessel Characteristic	Capt. Cae Tug	Westrac II Tug	Arctic Pride Yacht
Owner/operator	DeForge Maritime Towing	Western Towboat Company	Private Recreational Vessel
Length	92 feet	74 feet	126 feet
Draft	11 feet	14 feet	6 feet
Propeller diameter	7.25 feet	6.3 feet	4 feet
Horsepower per propeller[1]	1,400 hp	1,250 hp	1,250 hp
Operational speed	4 to 8 knots	4 to 8 knots	4 to 8 knots

Notes:
1. This characteristic is used because the propwash analysis utilizes a single propeller.
hp: horsepower

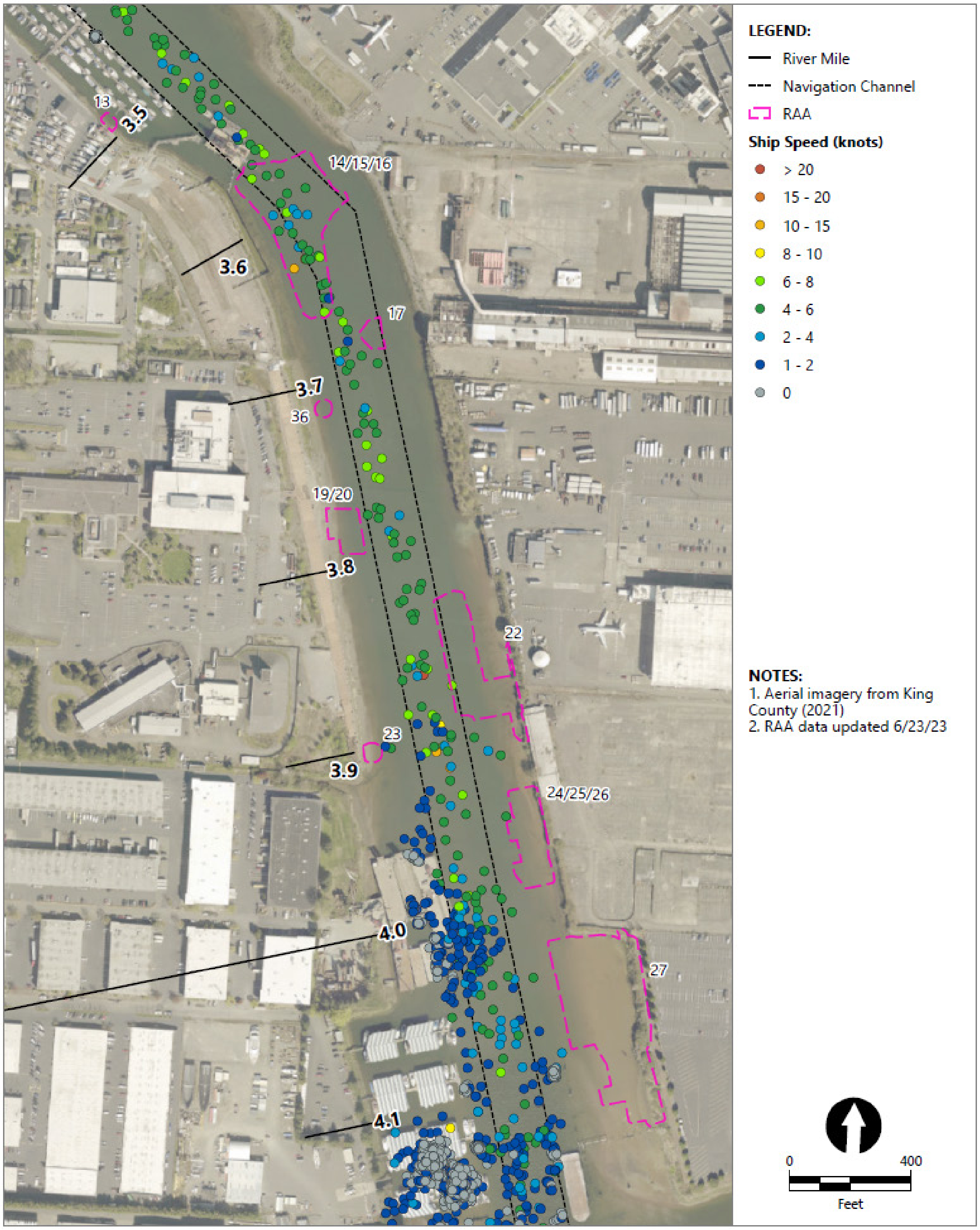
The Feasibility Study (FS) propeller-induced riverbed scour analysis (Appendix C, Part 7 of the FS), used the J. T. Quigg tug, with a length of 100 feet, for the evaluation near the cap design area. This vessel is similar to the Capt. Cae Tug, with similar specifications. Because the FS analysis was performed in 2009, the design vessels were updated to reflect more recent usage data.

Figure J2-1
AIS Vessel Categories: October 2020



Note:
Categories are based on AIS ship types.

Figure J2-2
Vessel Speeds: October 2020



2.2 Bathymetry, Water Levels, and Sea Level Rise Impact

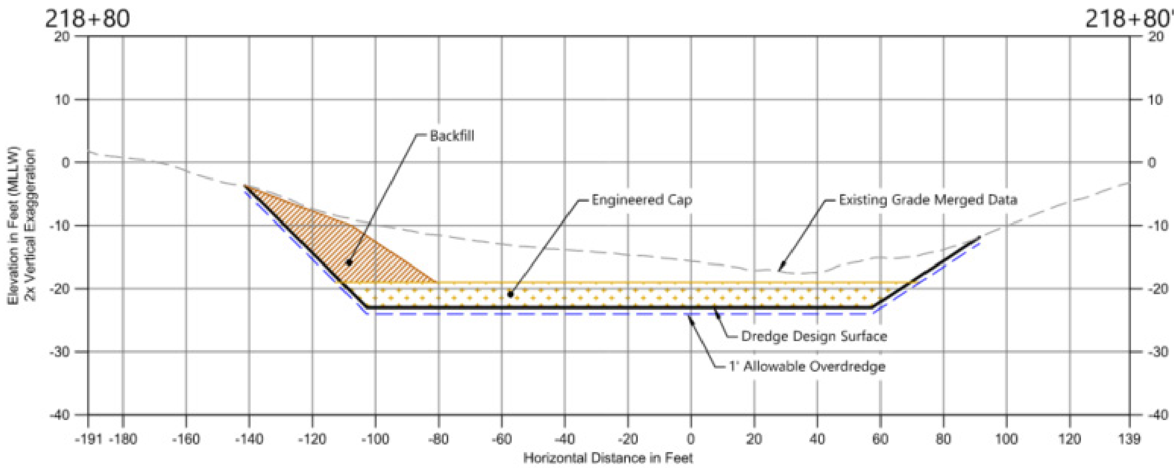
Erosion protection layer stability under vessel propwash and wakes is dependent on the configuration of the navigation channel and the water depths in which the vessels are operating. The upper reach is tidally influenced and experiences a large range of water levels. Table J2-2 outlines the tidal datums for the Seattle, Washington, National Oceanic and Atmospheric Administration Tidal Station (944130).

Table J2-2
Seattle Tidal Datums

Datum	Water Level (feet MLLW)
Highest Astronomical Tide (HAT)	13.3
Mean Higher High Water (MHHW)	11.3
Mean Sea Level (MSL)	6.6
North American Vertical Datum of 1988 (NAVD88)	2.3
Mean Lower Low Water (MLLW)	0
Lowest Astronomical Tide (LAT)	-4.3

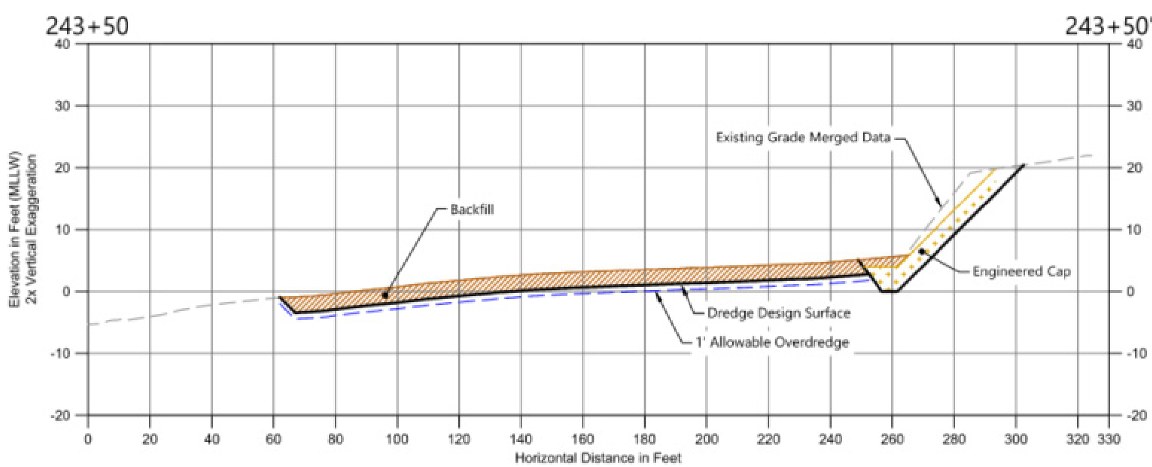
Survey data were used to develop cross sections perpendicular to the FNC through the cap design areas (Figures J2-3 and J2-4). The authorized elevation for the FNC in the upper reach is -15 feet mean lower low water (MLLW).

Figure J2-3
Cross Section A-A′ Through RAA 14/15/16 (SMA 12B)



Notes:
Bathymetric survey by Northwest Hydro performed between April 18, 2019, and May 15, 2019. Additional bathymetric survey by Northwest Hydro performed in June 2020 to fill data gaps. Composite data updated December 23, 2020.
The location of the cross section is shown in Figure J1-1.

Figure J2-4
Cross Section A-A′ Through RAA 27 (SMA 5)



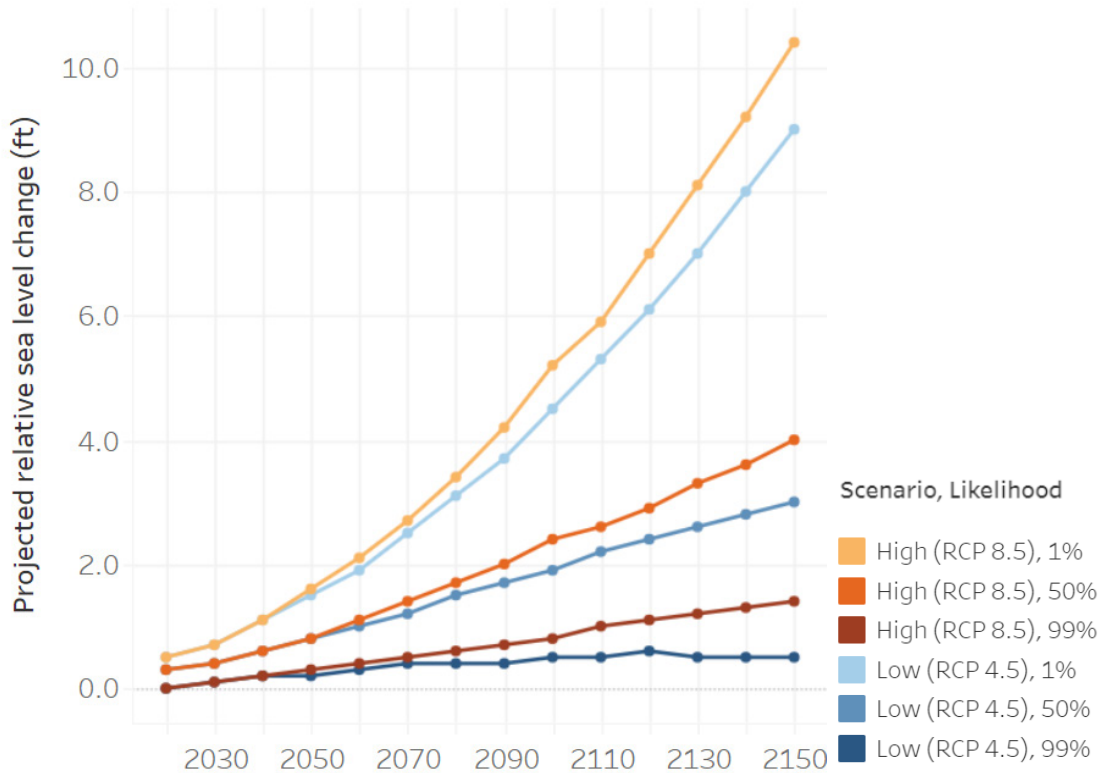
Notes:
Bathymetric survey by Northwest Hydro performed between April 18, 2019, and May 15, 2019. Additional bathymetric survey by Northwest Hydro performed June 2020 to fill data gaps. Composite data updated December 23, 2020.
The location of the cross section is shown in Figure J1-2.

As described in Section 10.9.1 of the Pre-Final (90%) RD BODR, climate change is expected to increase sea levels over time. An increase in mean sea level (MSL) will correspond to an increase in design water levels at the site. In the future, SLR will increase the water depths within the upper reach. The projected changes in sea level have been assessed in accordance with Washington State Department of Ecology guidance.

Figure J2-5 shows the projected SLR for various potential scenarios for the upper reach. The figure presents the projected SLR under the low and high predictions for greenhouse gas scenarios (Representative Concentration Pathways 4.5 and 8.5) for the 1%, 50%, and 99% likelihoods of occurrence. While there is no industry standard for the application of SLR projections, other projects in Puget Sound have incorporated the 50% central estimate for the design of site elevations. Based on the projections and using the 50% central estimate, the relative sea level is predicted to rise between 1.9 and 2.4 feet by 2100 (Miller et al. 2018).

SLR will have different effects on the erosive forces acting on the cap, as discussed in Sections 2.3 through 2.6. Propwash forces are expected to be lower with SLR due to the larger propeller clearance as water depths increase. Wake forces are not expected to change with SLR because wake heights are not expected to change. Hydrodynamic forces are expected to be lower with SLR due to the larger flow area under the same flow volumes because flow is controlled by the upstream restriction at the Interstate 5 crossing of the Green River as described in Section 10.9.2 of the Pre-Final (90%) RD BODR. Wind-generated waves are not expected to be affected by SLR because they are limited by fetch lengths and the narrow shape of the waterway, which would not materially change under SLR.

Figure J2-5
Sea Level Rise Projections for the LDW (Washington Coastal 2022)



2.3 Predictive Modeling to Estimate Stable Particle Size for Propwash Forces

As a vessel or boat moves through the water, the propeller produces an underwater jet. This turbulent jet is known as propwash. Where the jet reaches the mudline, it can contribute to resuspension or movement of bottom particles. Potential propwash effects of representative vessels that operate near and around the cap design area were evaluated in accordance with Appendix A of the U.S. Environmental Protection Agency's (EPA's) *Guidance for In-Situ Subaqueous Capping of Contaminated Sediment* (Palermo et al. 1998) cap armor layer design guidance.

The propwash velocity was calculated using the method developed by Blaauw and van De Kaa (1978). The stable particle size under these velocities was calculated based on a method by Blaauw et al. (1984) and additional research by Maynord (1984); both methods are presented in Appendix A of EPA's *Guidance for In-Situ Subaqueous Capping of Contaminated Sediment* (Palermo et al. 1998): *Armor Layer Design*. The model considers physical vessel characteristics (e.g., propeller diameter, depth of propeller shaft, and total engine horsepower) and operational and site conditions (e.g., applied horsepower and water depth) to estimate propeller-induced bottom velocities at various distances behind the propeller. The model is used to predict the particle size that would be stable when subjected to the steady-state propwash (i.e., the vessel is essentially stationary or maneuvering at a very low speed) from the modeled vessel.

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

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

where:

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

This equation was used to compute propwash velocities for the selected design vessels based on their specifications and operating conditions. For each scenario, bathymetric data were compiled to apply water depths and shoreline orientations (distances and slopes) such that realistic scenarios were analyzed. Propwash velocities at the sediment bed surface were calculated by applying jet velocities to the water depths and local bathymetry data and determining the velocity of the jet where it would meet the sediment bed mudline.

RAA 14/15/16 (SMA 12B) is located within the FNC (Figure J1-1); therefore, vessel traffic is expected to travel directly over the proposed cap, as shown in Figures J2-1 and J2-2. A profile view analysis of the bottom velocities and stable sediments was conducted to estimate how a transiting vessel directly over the cap could affect the proposed cap (see Attachment J.1). The RAA 14/15/16 (SMA 12B) scenarios assume the top of the cap will be conservatively at an elevation of -19 feet MLLW; the ROD (EPA 2014) requires any engineered cap within the FNC to be at least 4 feet below the authorized depth; therefore, in the upper reach, the top of cap elevation must be at or below -19 feet MLLW.

The engineered cap portion of RAA 27 (SMA 5) is located east of the FNC (Figure J1-2), and as Figures J2-1 and J2-2 show, the design vessels are not expected to transit directly over the area. A plan view analysis of the bottom velocities and stable sediments was conducted to estimate how a transiting vessel could affect the proposed cap (see Attachment J.1). The RAA 27 scenarios conservatively assume the design vessels are operating with the propeller located at the eastern boundary of the FNC (mudline elevation of -15 feet MLLW), which is approximately 270 feet from the edge of the engineered cap design area in RAA 27 (lowest point around approximate elevation of +2 feet MLLW).

The scenarios evaluated for both RAA 14/15/16 (SMA 12B) and the east bank of RAA 27 (SMA 5) and results are outlined in Table J2-3. PIANC (2015) suggests using 5% to 15% of the installed power for the main propellers for transiting vessels. Therefore, for this analysis, 15% applied power was conservatively used to calculate the propwash velocities. Although vessels typically operate at some sailing speed, which acts to significantly reduce the duration and magnitude of the propwash acting on the waterway bottom, for purposes of this analysis, static vessel conditions (stationary vessel) were used for evaluating potential propwash forces, which adds an additional conservative factor.

Sailing scenarios for larger vessels at low tidal elevations (i.e., MLLW) were not modeled because the large vessel drafts (drafting greater than 11 feet) would make navigation unsafe due to small propeller clearances, and such a large vessel would not be operating at 15% power.

The largest predicted stable sediment median particle size (D_{50}) for RAA 14/15/16 (SMA 12B) in the FNC is 4.8 inches. For RAA 27 (SMA 5) the required stable sediment is much smaller (less than 0.25 inch) as the area is approximately 270 feet east of the FNC.

Future SLR conditions are not expected to increase the stable particle size required based on propwash. The stable particle size due to propwash forces increases as propeller jet-induced bottom velocities increase. With SLR, the water depths will increase, therefore increasing the propeller clearance and reducing the bottom velocities and ultimately requiring a smaller particle size to be stable.

Table J2-3
Bottom Velocities and Stable Sediment Size

Attachment J.1 Figure No.	RAA	Design Vessel	Water Level (feet MLLW)	Maximum Bottom Velocity in Cap Design Area (ft/sec)	Stable D_{50} in Cap Design Area (inches)
1a	RAA 14/15/16 (SMA 12B)[1]	Capt. Cae Tug	MHHW (11.3)	1.4	0.9
1b			MSL3 (6.6)	1.9	1.7
1c			(3.0)	2.5	2.9
2a		Westrac II Tug	MHHW (11.3)	1.5	1.1
2b			MSL[3] (6.6)	2.2	2.3
2c			(3.0)	3.2	4.8
3a			MHHW (11.3)	0.8	0.3

Attachment J.1 Figure No.	RAA	Design Vessel	Water Level (feet MLLW)	Maximum Bottom Velocity in Cap Design Area (ft/sec)	Stable D_{50} in Cap Design Area (inches)
3b		Arctic Pride Yacht	(3.0)	1.1	0.6
3c			MLLW (0)	1.4	0.9
4a	RAA 27 (SMA 5)[2]	Capt. Cae Tug	MHHW (11.3)	<0.25	0.25
4b			MSL[3] (6.6)	<0.25	0.25
4c			(3.0)	<0.25	0.25
5a		Westrac II Tug	MHHW (11.3)	<0.25	0.25
5b			MSL[3] (6.6)	<0.25	0.25
5c			(3.0)	<0.25	0.25
6a		Arctic Pride Yacht	MHHW (11.3)	<0.25	0.25
6b			(3.0)	<0.25	0.25
6c			MLLW (0)	<0.25	0.25

Notes:
1. RAA 14/15/16 (SMA 12B) scenarios assume the design vessel is operating directly over the cap area (elevation of -19 feet MLLW).
2. RAA 27 (SMA 5) scenarios assume the design vessel is operating with the propeller on the edge of the FNC (elevation of -15 feet MLLW), which is approximately 270 feet from the edge of the cap design area (elevation of +2 feet MLLW).
3. Capt. Cae Tug and Westrac II Tug were not analyzed at MLLW; given their larger drafts, it is unlikely they would operate with such small propeller clearances.

D_{50}: median particle size
ft/sec: feet per second
MHHW: mean higher high water
MLLW: mean lower low water
MSL: mean sea level

2.4 Predictive Modeling to Estimate Stable Particle Size for Wake Forces

Estimates of vessel-induced wake heights were completed through an evaluation of ship traffic patterns within the FNC adjacent to the design area and calculations of vessel wakes based on type of vessel, operational speed, and water depths.

Based on the vessel speed and locations shown in Figure J2-2, the design vessels were assumed to be operating at speeds between 4 and 8 knots (4.6 and 9.2 miles per hour [mph]) within the FNC,[1] as close as 270 feet to the edge of the RAA 27 (SMA 5) cap from the potential sailing line along the eastern edge of the FNC. A wake analysis was not done for RAA 14/15/16 as the top of cap is well below the wake impacted elevations.

The analysis used the Weggel and Sorensen (1986) methodology to predict vessel wakes. The Weggel and Sorensen method is an empirical model (developed from available laboratory and field data on

[1] The Duwamish River has a 7-knot speed limit; AIS data indicate that some vessels exceed this limit.

vessel-generated wakes) to predict maximum wake height as a function of vessel speed, vessel geometry, water depth, and distance from the sailing line. This model is applicable for various vessel types (ranging from tugboats to large tankers), vessel speeds, and water depths. The method calculates the wake height generated at the bow of a vessel as a function of the vessel speed, distance from the sailing line, water depth, vessel displacement volume, and vessel hull geometry (i.e., vessel length, beam, and draft). The method has been widely tested on different vessels and is recommended for use with conditions having a Froude number between 0.2 and 0.8, which was met. The non-dimensional Froude number used in this method is defined as follows:

$$\mathrm{Fr} = \frac{v}{\sqrt{g \times l_w}}$$

where:

Fr	=	Froude number
v	=	vessel velocity (ft/sec)
g	=	acceleration due to gravity foot per second squared
l_w	=	water depth (feet)

Design vessel wake heights were estimated to be up to 0.55 foot with a period up to 2.2 seconds for RAA 27 (see Table J2-4).

Waves (or wakes) break in shallow water when the ratio of wave height to water depth surpasses 0.78 (Dean and Dalrymple 1991). The wide tidal range means the RAA 27 cap design area is sometimes fully inundated, and at lower tidal levels, the cap design area is above the water surface. As the water surface rises and falls over the cap design area, every portion of the proposed cap area will fall within the wave breaking zone. For waves breaking on the cap, the rubble-mound revetment module (USACE 2004) from the Automated Coastal Engineering System developed by the U.S. Army Corps of Engineers (USACE 1992) was used to compute the D_{50} that is stable for the predicted wake height based on the proposed placement slope.

Figure J2-2 shows the cap design cross section for RAA 27, where the cap would be placed at a 2 horizontal to 1 vertical (2H:1V) slope.

Based on these analyses, a stable D_{50} diameter of 2.9 inches would withstand vessel wakes that break on top of a 2H:1V erosion protection layer (summarized in Table J2-4).

Table J2-4
Vessel Wakes and Stable Sediment Sizes

Vessel	Vessel Speed (mph)	Distance from Sailing Line (feet)	Wake Height (feet)	Wake Period (seconds)	Slope	Stable Armor Stone Size D_{50} (inches)
Capt. Cae Tug (MLLW at edge of FNC)	9.2	270	0.50	2.2	2H:1V	2.7
Westrac II Tug (MLLW at edge of FNC)	9.2	270	0.48	2.2	2H:1V	2.6
Arctic Pride Yacht (MLLW at edge of FNC)	9.2	270	0.55	2.2	2H:1V	2.9

Notes:
D_{50}: median particle size
FNC: federal navigation channel
H:V: horizontal to vertical (ratio)
MLLW: mean lower low water
mph: mile per hour

The wake heights do not increase or decrease with the addition of SLR to the waterway, assuming the same vessels and operational criteria. Therefore, required stable sediment sizes for future SLR conditions are not expected to change.

2.5 Predictive Modeling to Estimate Stable Particle Size for Hydrodynamic Forces

Stable particle sizes to resist hydrodynamic flows (i.e., river currents) were assessed for the cap design areas. The 100-year flow event was modeled for the *Lower Duwamish Waterway Sediment Transport Modeling Report* in 2008 (QEA 2008), and the velocity results from the hydrodynamic model cells that includes the cap design areas were used to estimate the stable particle size.

The stable particle size was estimated using a method developed by Maynord (1988) *for Stable Riprap Size for Open Channel Flows*, which is presented in Appendix A of EPA's *Guidance for In-Situ Subaqueous Capping of Contaminated Sediment* (Palermo et al. 1998).

The stable particle size is estimated utilizing the following equation:

$$D_{50} = S_f C_S C_V C_T C_G d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5}$$

where:

D_{50}	=	characteristic riprap size of which 50% is finer by weight
S_f	=	safety factor (1.5)
C_S	=	stability coefficient for incipient failure (0.3 for angular rock)
C_V	=	velocity distribution coefficient (1.0 for straight channels)
C_T	=	blanket thickness coefficient (1.0 for flood flows)
C_G	=	gradation coefficient = $(D_{85}/D_{15})^{1/3}$ (typically 1.2 to 1.5)
d	=	local depth
γ_w	=	unit weight of water
γ_s	=	unit weight of stone
V	=	local depth averaged velocity
K_1	=	side slope correction factor = 0.97 (defined in the following equation)
g	=	gravitational constant

$$K_1 = \sqrt{1 - \frac{\sin^2 \theta}{\sin^2 \Phi}}$$

where:

K_1	=	side slope correction factor
θ	=	angle of side slope with horizontal (2.5H:1V = 21.8 degrees)
Φ	=	angle of repose of riprap material (typically 40 degrees)

The modeled 100-year river velocity of RAA 14/15/16 (SMA 12B) cap area was 5.8 ft/sec, which results in an estimated 2.3-inch stable particle size. The modeled 100-year river velocity over the RAA 27 (SMA 5) cap design area was 1.1 ft/sec, which results in an estimated stable particle size less than 0.1 inch. Note that the resulting stable particle size for river velocity is smaller than that required for propwash, even though the 100-year river velocity was larger than the propwash velocity. This is due to the propwash velocity being a turbulent jet, which results in a larger required grain size to be stable as compared to the same river velocity.

As described in Section 10.9.2 of the Pre-Final (90%) RD BODR, hydrodynamic forces are expected to be lower with SLR due to the larger flow area under the same flow volumes. A larger flow area will reduce the velocities, therefore reducing the required stable sediment size.

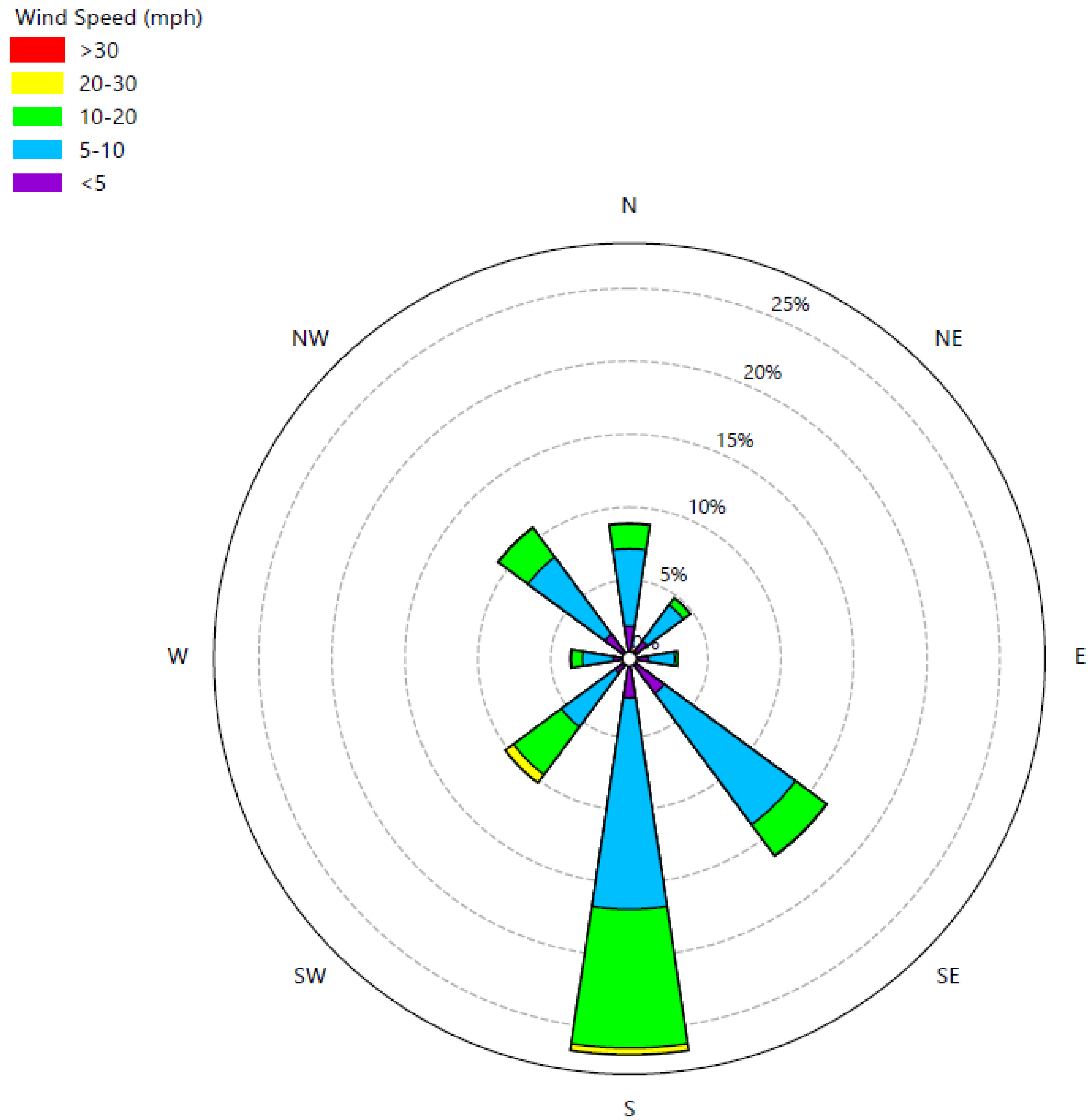
2.6 Predictive Modeling to Estimate Stable Particle Size for Wind-Generated Waves

Wind-generated waves are a result of wind blowing over the water surface. Such waves become larger due to continuous wind in an unobstructed single direction over long distances (fetch[2]). To estimate the wind-generated wave height, the Automated Coastal Engineering System Wave Prediction module was used, which uses wind speed, water depth, and effective fetch distance (Leenknecht et al. 1992).

Measured wind direction and intensity data from King County International Airport, approximately 1.5 miles north of the upper reach, are shown in the wind rose in Figure J2-6.

[2] Fetch refers to the unobstructed over-water distance in the wind direction of interest. Fetch distance can be very long in large open-water locations (e.g., oceans) and is very short where land masses and other wind obstructions (e.g., buildings and bridges) limit the ability of wind shear stress to act for sustained distance on the water surface.

Figure J2-6
Wind Rose: King County International Airport (1943 Through 2022)



Notes:
1. Maximum recorded wind speed: 62 mph
2. Wind data are presented as the "blowing from" direction

Because RAA 14/15/16 (SMA 12B) is below the surf zone (the elevations in which wind-generated waves can impact the sediment bed), and therefore below wave impacts, only RAA 27 (SMA 5) was analyzed.

An extreme analysis was conducted for the 79 years of wind data to find the 100-year wind speeds at various directions. RAA 27 is located at RM 4.0, approximately midway along the upper reach that is oriented NNW to SSE; therefore, two fetches were analyzed. The 100-year wind speeds are 53 mph from the north and 62 mph from the south. The fetch from the north is approximately 0.5 mile and the fetch from the south is approximately 0.6 mile. However, given the waterway is narrow, with a low width to length ratio, effective fetch factors were included to reduce the fetch lengths to 0.2 and 0.3 mile, respectively (Ippen 1966). Utilizing the FNC depth of 26.3 feet at mean higher high water (MHHW), maximum wave heights for the 100-year wind speeds are 0.5 foot from the north and 0.7 foot from the south. SLR, discussed in the Section 2.2, would not materially increase the width of the river and therefore would not change the predicted future wave heights.

Wind-generated wave heights are similar to the predicted possible wake heights caused by transiting vessels (Section 2.4). However, wind-generated waves will be oblique to the cap, and have less force impacting the protection layer, versus the vessel wakes. Therefore, wind-generated waves do not govern the size of the erosion protection layer aggregate.

2.7 Recommended Armor Material Size, Layer Thickness, and Filter Material Size

The cap design areas are expected to be made up of a chemical isolation layer protected by an overlying erosion protection (armor) layer for cap stability for flat areas within the FNC and on slopes up to 2H:1V.

The armor layer material size is driven by the largest particle size that is stable against a range of erosive forces in the upper reach, including hydrodynamic forces, wind-generated waves, vessel-generated propwash, and wakes.

For RAA 14/15/16 (SMA 12B) the primary design criterion for erosion protection is vessel propwash (Section 2.3) and requires a median stable particle size (i.e., D_{50}) of 4.8 inches. The full recommended erosion protection design for RAA 14/15/16 (SMA 12B) is outlined in Section 2.8.

For RAA 27 (SMA 5) the primary design criterion for erosion protection is breaking wakes caused by vessel transit (Section 2.4) and requires a median stable particle size (i.e., D_{50}) of 2.9 inches when placed on the 2H:1V slope. The full recommended erosion protection design for RAA 27 is outlined in Section 2.9

Guidance from Appendix A of Palermo et al. (1998) was used to determine the minimum thickness of the armor layer of the cap, which recommends the armor layer thickness should be two times the D_{50} size; therefore, an armor material with a D_{50} of 2.9 inches would need to be a minimum of 6 inches thick and an armor material with a D_{50} of 4.8 inches would need to be a minimum of 10 inches thick.

Development of gradations of cap materials will consider the design D_{50} values and criteria from the U.S. Army Corps of Engineers Engineering Manual 1110-2-2300 - *General Design and Construction Considerations for Earth and Rock-Fill Dams* (USACE 2004). In addition, the potential for vertical migration of one granular material through another (often referred to as "piping") will also be considered, as recommended by the *Guidance for In-Situ Subaqueous Capping of Contaminated Sediment* (Palermo et al. 1998). The potential for piping can be minimized through the use of well-graded materials for the armor and chemical isolation layers. The compatibility of the two materials in combination is verified below in accordance with geotechnical filter criteria (Terzaghi and Peck 1967) and Palermo et al. (1998).

Standard geotechnical filter criteria presented by Terzaghi and Peck (1967) provide recommended particle size ratios between base and overlying materials (e.g., sand chemical isolation and overlying erosion protection materials). The primary filter criterion particle size relationship primarily applicable to subaqueous capping materials is the ratio of the D_{15} of the armor stone to the D_{85} of the base layer. This relationship relates to the ability of the base layer material (e.g., sand) to pass through the void spaces in the overlying larger material (e.g., erosion protection armor stone). Compliance with the recommended filter criteria minimizes the potential for wash out of the base material by the creation of internal filters in the armor stone voids.

The Terzaghi filter criteria recommend the following relationship to prevent material loss through the armor layer:

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

where:

d_x = particle diameter, such that x percent of the sediment particles are smaller, by weight

A number of factors will be considered in developing the complete material specifications, including the following:

- Local availability of materials
- Material processing effort required to meet specifications
- Cap material placement equipment and limitations

- Required quantities
- Fines content relative to water quality (turbidity)
- Well-graded materials

2.8 RAA 14/15/16 (SMA 12B) Erosion Protection Design

The forces acting on a cap (as outlined in Sections 2.3 through 2.6) within the LDW upper reach are propwash, vessel-generated wake waves, hydrodynamic waves (river currents), and wind-generated waves. To summarize, the modeled design forces acting on the proposed cap for RAA 14/15/16 are as follows:

- **Propwash:** 2.5-ft/sec bottom velocity (turbulent flow), resulting in a stable D_{50} of 4.8 inches (Table J2-3).
- **Vessel-Generated Wake Waves:** RAA 14/15/16 are below the surf zone; no wake forces.
- **Hydrodynamic Currents:** 5.8-ft/sec bottom velocity, resulting in a stable D_{50} of 2.8 inches.
- **Wind-Generated Waves:** RAA 14/15/16 are below the surf zone; no wave forces.

The methodology for determining armor gradation, layer thickness, and filter material considerations is outlined in Section 2.7.

The primary design criterion for erosion protection at RAA 14/15/16 is propwash caused by vessels transiting over RAA 14/15/16 and requires a stable D_{50} of 4.8 inches. An idealized gradation is outlined in Table J2-5. Pre-Final 90% RD specifications will identify the gradation of the armor layer considering locally available source of armor material. Given a D_{50} of 4.8 inches, the armor layer should have a minimum thickness of 10 inches.

Table J2-5
RAA 27 Idealized Armor Gradation

Percent Passing	Size (inches)
100	7.6
85	6.0
50	4.8
15	3.5
0	2.4

Given the size of the armor layer material, a filter material will be required between the armor and isolation sand layer to prevent loss of the isolation sand between the armor material interstices. Based on the criteria outlined in Section 2.7 a filter material with a D_{50} of 0.6 inch will be required for the armor material outlined in Table J2-5. Pre-Final 90% RD specifications will identify the gradation of the filter layer considering locally available source of filter material.

2.9 RAA 27 (SMA 5) Erosion Protection Design

The forces acting on a cap (as outlined in Sections 2.3 through 2.6) within the LDW upper reach are propwash, vessel-generated wake waves, hydrodynamic (river currents), and wind-generated waves. To summarize the forces acting on the proposed cap for RAA 27 are as follows:

- **Propwash:** Less than 0.25 ft/sec bottom velocity (turbulent flow), resulting in a stable D_{50} of 0.25 inch (Table J2-3).
- **Vessel-Generated Wake Waves:** 0.55-foot wave height, 2.2 second wave period, resulting in a stable D_{50} of 2.9 inches on a 2H:1V slope (Table J2-4).
- **Hydrodynamic Currents:** 1.1-ft/sec bottom velocity, resulting in a stable D_{50} of less than 0.1 inch.
- **Wind-Generated Waves:** 0.7-foot oblique wave, resulting in less impact that direct vessel-generated wakes.

The methodology for determining armor gradation, layer thickness, and filter material considerations is outlined in Section 2.7.

The primary design criterion for erosion protection at the bank area of RAA 27 is breaking wakes caused by vessels transiting past RAA 27 and requires a stable D_{50} of 2.9 inches when placed on a 2H:1V slope. An idealized gradation is outlined in Table J2-6. Pre-Final 90% RD specifications will identify the gradation of the armor layer considering locally available source of armor material and will consider other design factors, such as slope stability. Given an idealized D_{50} of 2.9 inches, the armor layer should have a minimum thickness of 6 inches.

Table J2-6
RAA 27 Idealized Armor Gradation

Percent Passing	Size (inches)
100	4.6
85	3.6
50	2.9
15	2.1
0	1.4

Given the size of the armor layer material, a filter material will be required between the armor and isolation sand layer to prevent loss of the isolation sand between the armor material interstices.

Based on the criteria outlined in Section 2.7 a filter material with a D_{50} of 0.4 inch will be required for the armor material outlined in Table J2-6. Pre-Final 90% RD specifications will identify the gradation of the filter layer considering locally available source of armor material. For RAA 27, it is important to note that geotechnical slope stability considerations may end up resulting in a larger design D_{50} size than needed to protect against erosive forces.

3 Area-Specific Technology – Cover Material Design

In addition to engineered caps, an erosion protection design analysis was performed to address stability considerations for area-specific technology application. As described in Section 10.5 of the Pre-Final (90%) RD BODR, use of area-specific technology is proposed to address dredging offset areas. These are areas where dredging next to an existing structure or armored banks may cause structural instability and where enhanced natural recovery (ENR) cannot be used because the surface concentrations exceed the ENR upper limit concentration; no dredging will be conducted in these dredging offset areas, which are very narrow and small areas. The area-specific technology in dredging offset areas (RAA 24/25/26) will consist of placing a clean amended (activated carbon) cover material (Drawing C157 of Volume III). Both dredging offset areas are located above +4 feet MLLW, within the surf zone, and RAA 24/25/26 has an approximate slope of 10H:1V at the north part of the RAA and an approximate slope of 4H:1V along the south end of the RAA.

The clean amended cover material would consist of a gravelly sand. Although ENR remedial technology is not intended to remain stable and is allowed to mix or move around to some degree, area-specific technology is intended to be more stable than the ENR technology and will be used in dredging offset areas that exceed the ENR upper limit concentration.

The four forces evaluated in Sections 2.3 through 2.6 were propwash, vessel-generated wake waves, hydrodynamic currents, and wind-generated waves. Because hydrodynamic and wind-generated waves were determined to be smaller than the vessel wake forces for the cap design areas, and the dredging offset areas are within the surf zone, only vessel forces (i.e., propwash and vessel-generated wakes) were analyzed for the area-specific technology amended cover material design. Both propwash and wake forces were analyzed for RAA 24/25/26.

As discussed in Section 2.2, SLR will have different effects on the erosive forces acting on the amended cover. Propwash forces are expected to be even lower with SLR due to the larger propeller clearance as water depths increase, and wake forces are not expected to change with SLR because there is no expectation for the wake heights to change.

Propwash forces were analyzed utilizing both the Capt. Cae Tug and the Westrac II Tug. The following similar assumptions were made for RAA 24/25/26 analyses as the engineered cap for RAA 27, discussed in Section 2.3:

- The vessels are operating at the edge of the FNC, resulting in the propellers being approximately 140 feet from the edge of the dredging offset areas.
- The vessels are transiting, not turning their propellers toward the shoreline.
- 15% applied power was evaluated.

- MHHW (+11.3 feet MLLW) and MSL (+6.6 feet MLLW) water levels were evaluated, lower water levels were not considered as the proposed cap would not be under enough water for propwash impacts.

Attachment J.2 shows the plan view results at +4 feet MLLW for the two water level scenarios run; both the propwash velocity and stable sediment sizes are shown. Because the area-specific technology site locations are located 140 feet from the edge of the FNC and the depth of the area-specific technology areas are above +4 feet MLLW, propwash velocities are very low. Therefore, all scenarios resulted in a D_{50} stable grain size of less than 0.25 inch at the area-specific technology areas.

The same design methodology as presented in Section 2.4 was used to estimate vessel-generated wakes and stable sediment sizes based on variables for the dredging offset areas. To simplify the analysis, only the Capt. Cae Tug was evaluated because it creates the largest wakes at equal speeds compared to the other vessels analyzed. The wake heights were produced at the lower water levels; therefore, the analysis was run for a water depth of 15 feet (i.e., water surface at 0 feet MLLW). Although the cap would not be underwater, it would experience the breaking wave from a wake produced at MLLW conditions.

Table J3-1 outlines the variables analyzed and resulting sediment size.

Table J3-1
Capt. Cae Tug Wakes and Cover Sediment Sizes for Structural Offset Areas

Vessel Speed (mph)	Sail Line Distance (feet)	Water Depth (feet)	Wake Height (feet)	Wave Period (seconds)	Cover Material D_{50} (inches)	
					Slope: 4H:1V	Slope: 10H:1V
7	140	15	0	0	0.0	0.0
8	140	15	0.3	1.9	**0.6**	0.4
9	140	15	0.7	2.1	1.3	0.8

Notes:
D_{50}: medial particle size
H:V: horizontal to vertical ratio
mph: miles per hour

Compared to RAA 27 (Section 2.4), RAA 24/25/26 has similar wake heights; however, the shallower slopes for amended cover result in smaller amended cover material size requirements. Lower vessel speeds were also analyzed to account for more typical events within the upper reach versus the highest speed recorded in the AIS data. Additionally, a higher allowable damage level was applied compared to the erosion protection cap design; essentially, a lower factor of safety was used to allow for some movement of the amended cover material, but not failure, assuming an amended cover thickness averaging 1 foot. This design approach is considered reasonable because the area-specific technology is not intended to be an engineered cap that typically is designed to prevent any movement of the erosion protection layer.

Vessels operating at 7 mph or lower result in essentially zero wake at the area-specific technology locations; therefore, a stable amended cover is unnecessary, and an amended cover consisting of sand material would be sufficient. For higher velocity and less frequent vessel transit speeds, the amended cover material size increases. Amended cover material size also increases as the placement slope becomes steeper. A vessel operating speed of 8 mph was selected as a conservative design condition because it is the vessel navigation speed limit for the area. For the steepest slope in RAA 24/25/26, this results in a gravel material with D_{50} of 0.6 inch.

Because the stable sediment size (0.6-inch) analysis is a conservative methodology, and the material does not need to meet the erosion protection requirements of an engineered cap, a mix of sand and the stable gravel is proposed to be used. A mixture of approximately 50% sand and 50% gravel is proposed to meet the amended cover (sand) and erosion protection (gravel) needs.

The amended cover material will include sand in the gradation to perform as discussed in Appendix K and allow for blending of granular activated carbon with the sand fraction when needed. To provide erosion protection during larger wake events, a gravel fraction is needed with the sand, creating a gravelly sand mix similar to the material placed at the Enhanced Natural Recovery/Activated Carbon (ENR/AC) Pilot Study intertidal plot but with slightly larger gravel and at a higher fraction to increase the stability of the area-specific technology cover material. The intertidal ENR/AC Pilot Study plot was monitored for 3 years and was found to have remained in place and performed as intended under various physical conditions (e.g., wakes and waves and propwash) over the 3-year study (Wood et al. 2021). The cover material proposed for the structural offset is larger than the ENR/AC Pilot Study ENR material because the wake and sediment size analyses are both conservative evaluations.

The stable gravel gradation and amended cover design gradation blended with 50% sand are outlined in Table J3-2. The gravelly sand mix cover is designed to be placed at a thickness of 1 foot.

Table J3-2
Area-Specific Technology Material Gradations

U.S. Standard Sieve Size	Proposed Percent Passing by Dry Weight	
	Gravel	50% Gravel Mixed with 50% Sand
1-1/2 inch	100	100
3/4 inch	85	90
1/2 inch	50	70 to 75
3/8 inch	15	50 to 60
U.S. No. 4 (0.187 inch)	0	30 to 50
U.S. No. 10 (0.079 inch)	N/A	20 to 50
U.S. No. 200 (0.003 inch)	N/A	0 to 2

Note:
N/A: not applicable

4 References

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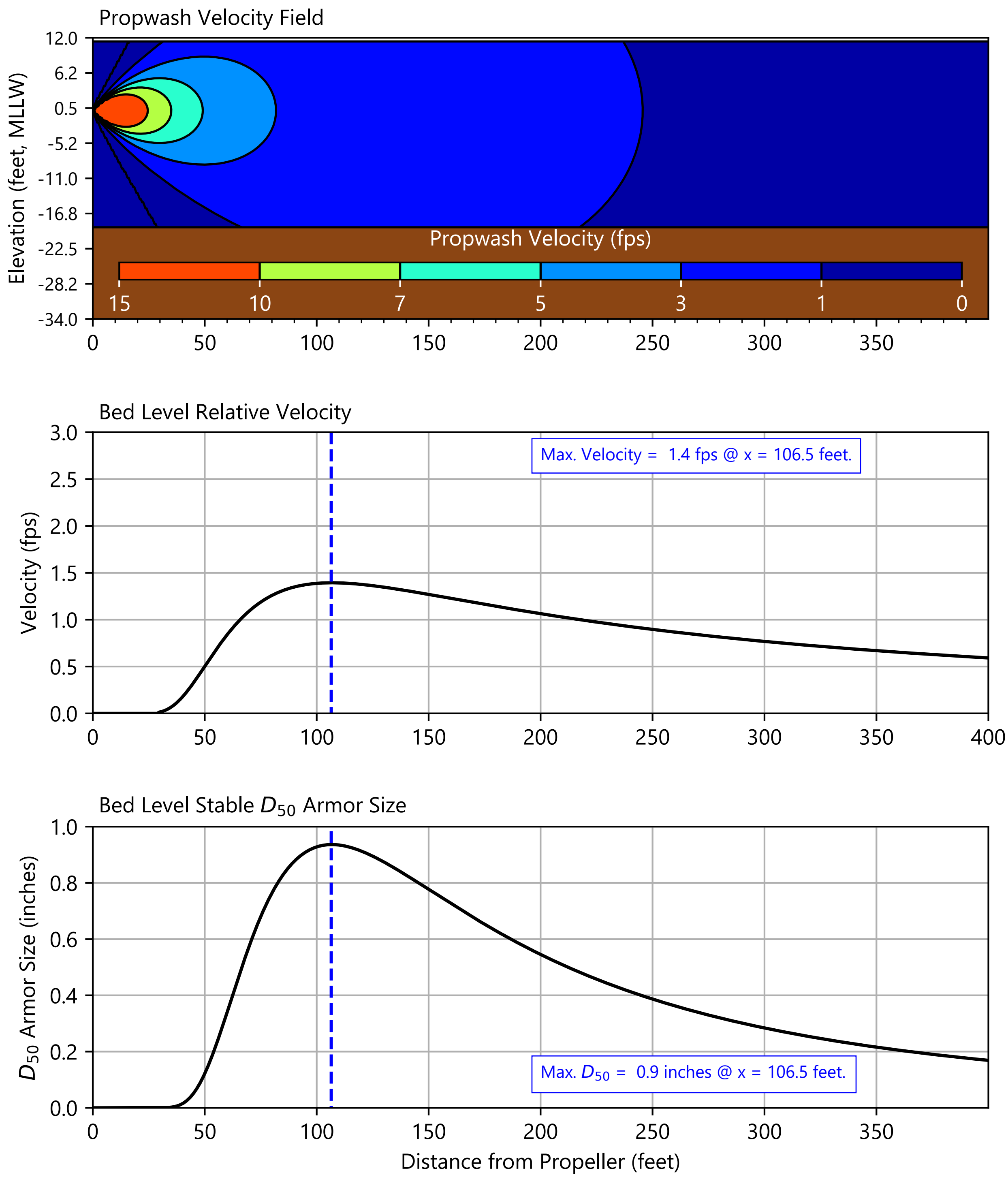
Appendix J – Engineered Protection Design Analysis for Engineered Caps and Area-Specific Technology

Attachment J.1
Bottom Velocity and Sediment Figures
(RAA 14/15/16 and RAA 27)



Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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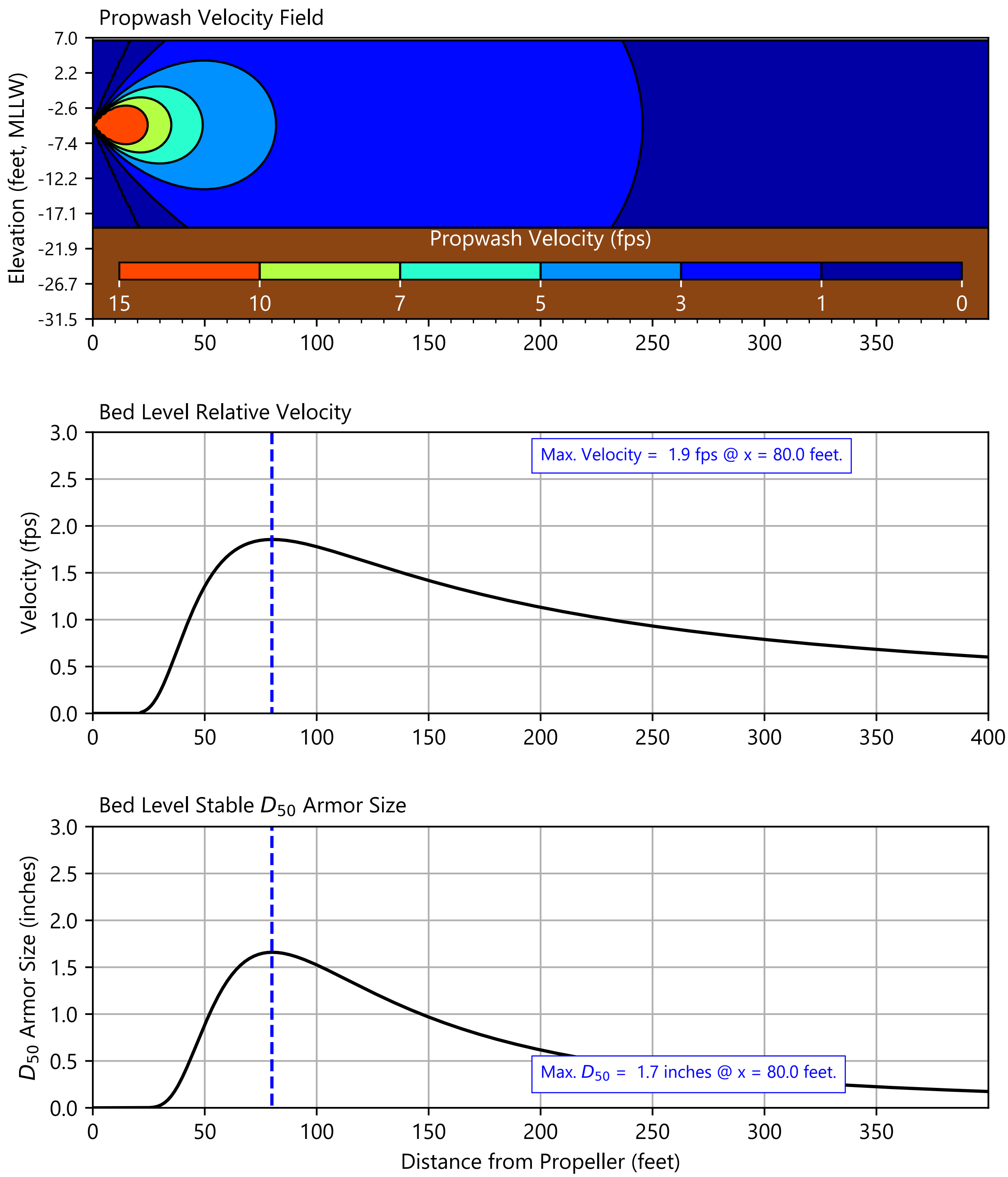
ANCHOR QEA

Figure J.1-1a
Capt Cae Tug at 0 knots, using 15% Applied Power
Transect: RAA 14 15 16 at MHHW



Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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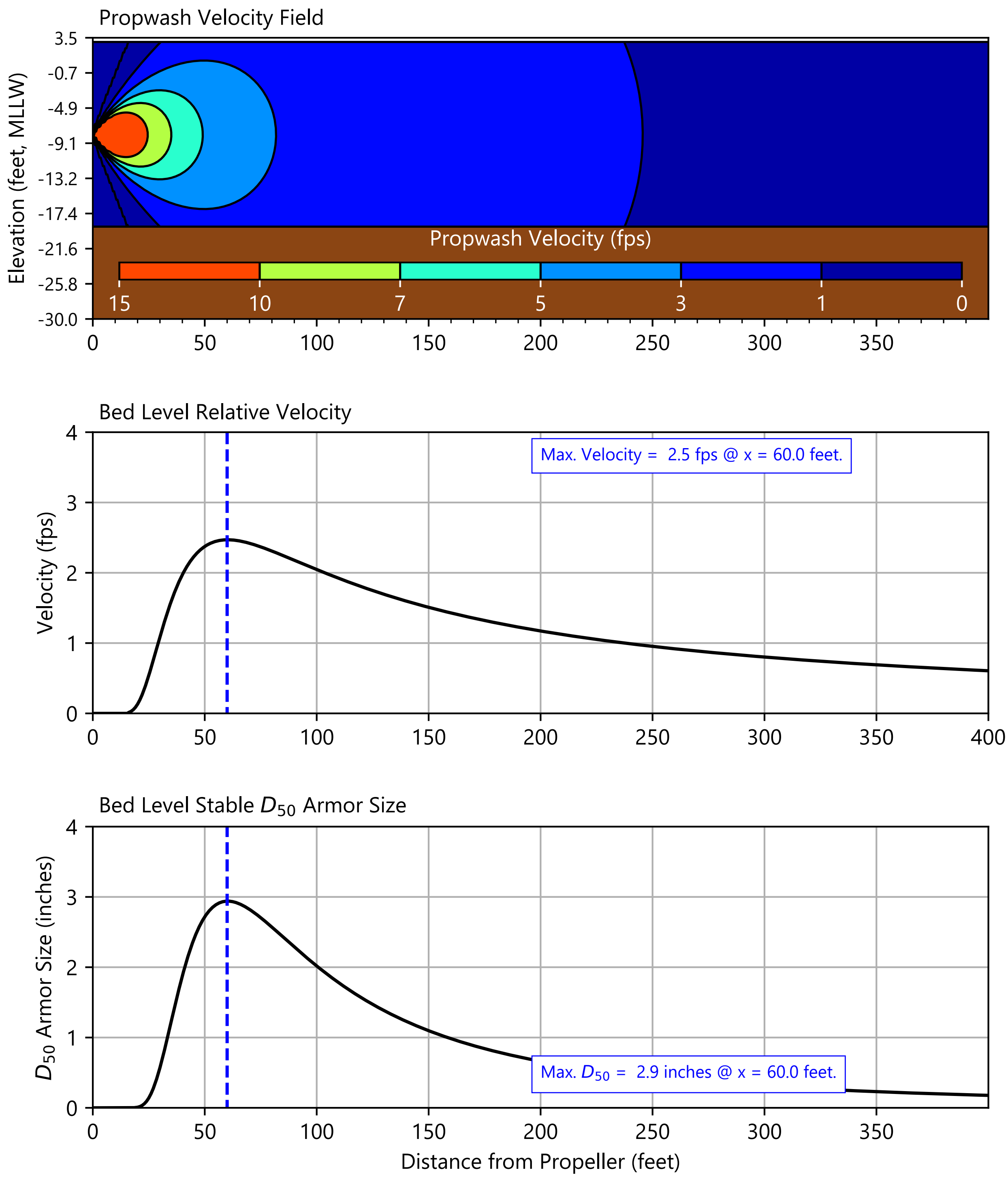
Figure J.1-1b
Capt Cae Tug at 0 knots, using 15% Applied Power
Transect: RAA 14 15 16 at MSL



Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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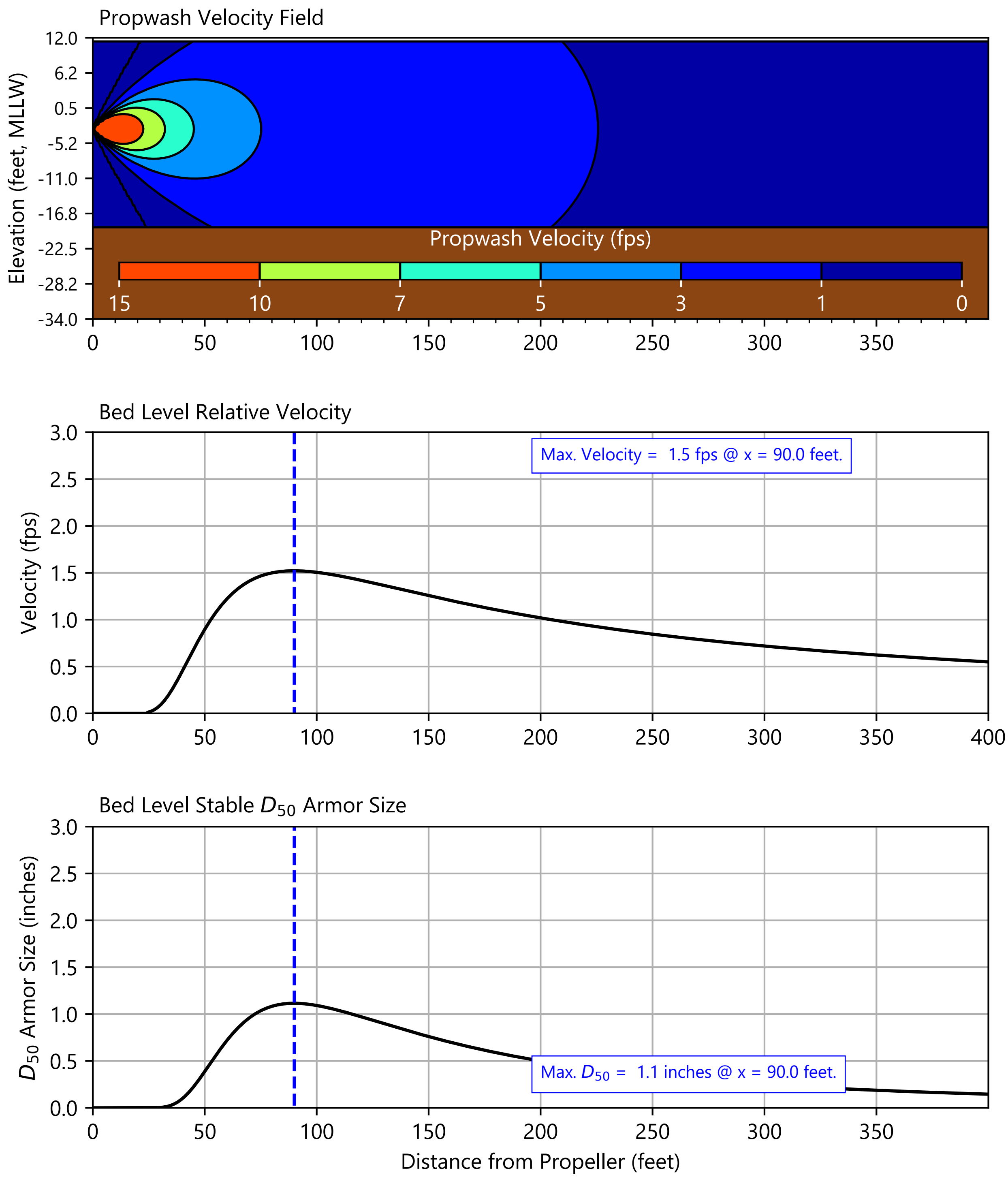

Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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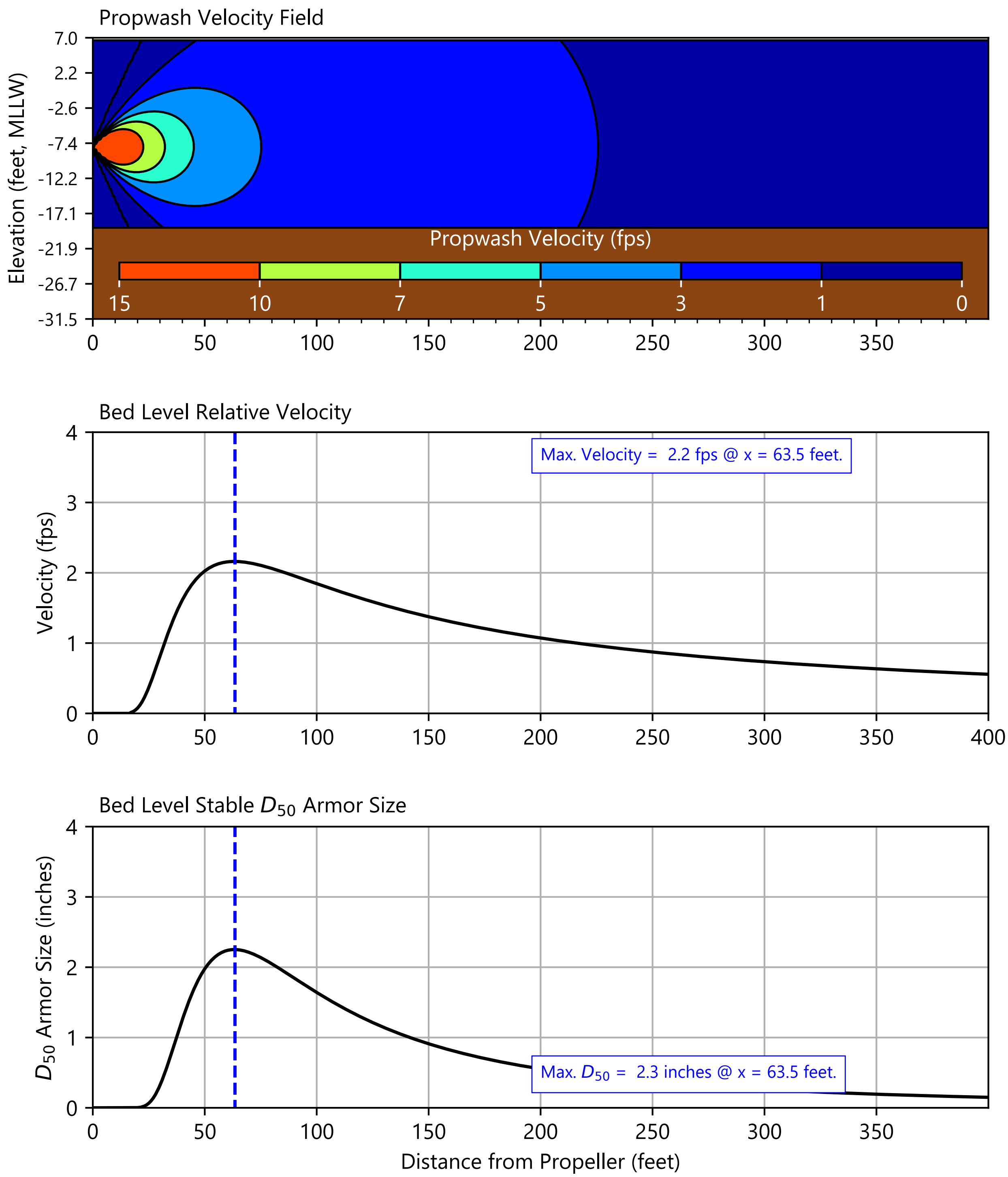
ANCHOR QEA

Figure J.1-2a
Westrac II Tug at 0 knots, using 15% Applied Power
Transect: RAA 14 15 16 at MHHW



Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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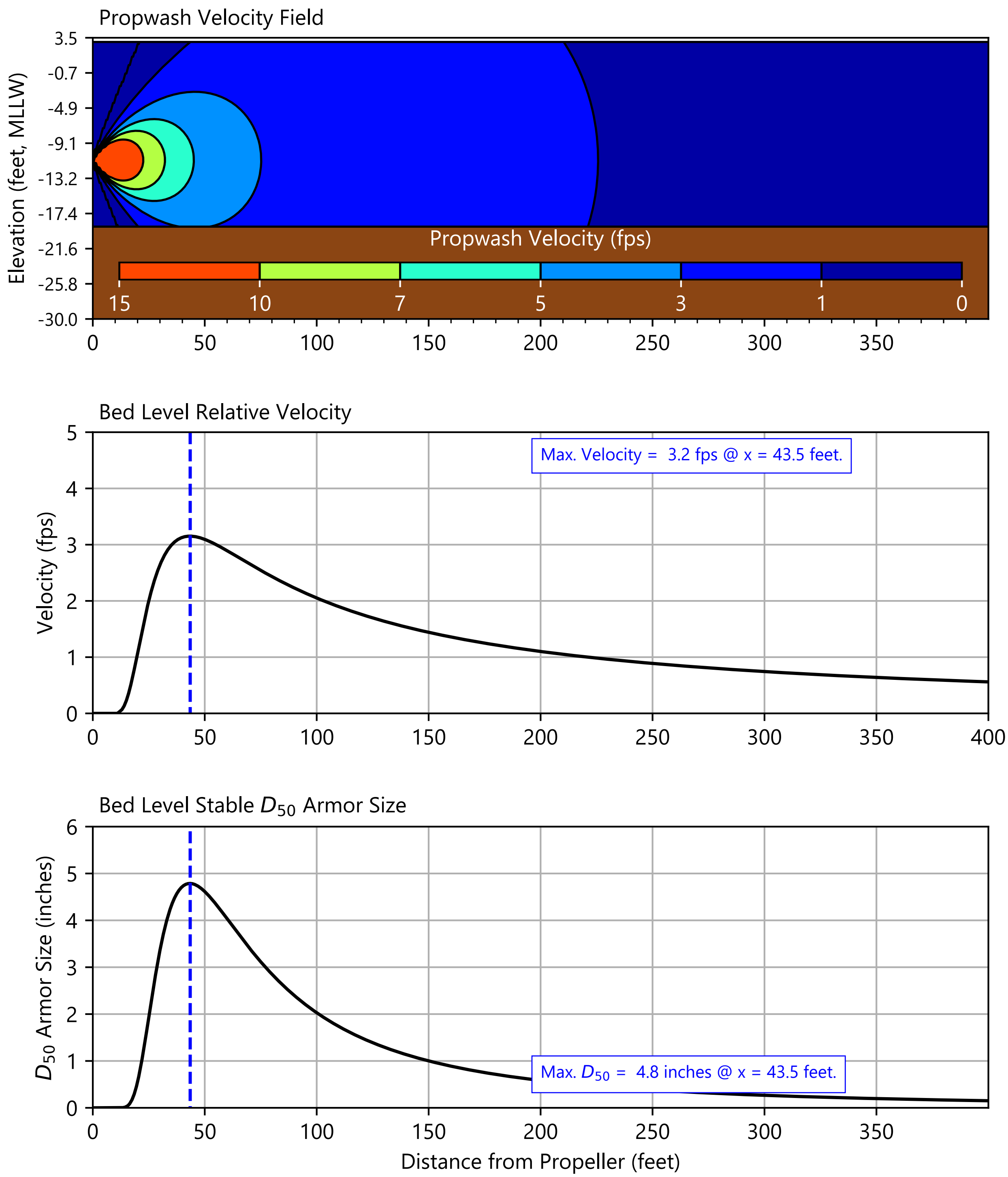
ANCHOR QEA

Figure J.1-2b
Westrac II Tug at 0 knots, using 15% Applied Power
Transect: RAA 14 15 16 at MSL



Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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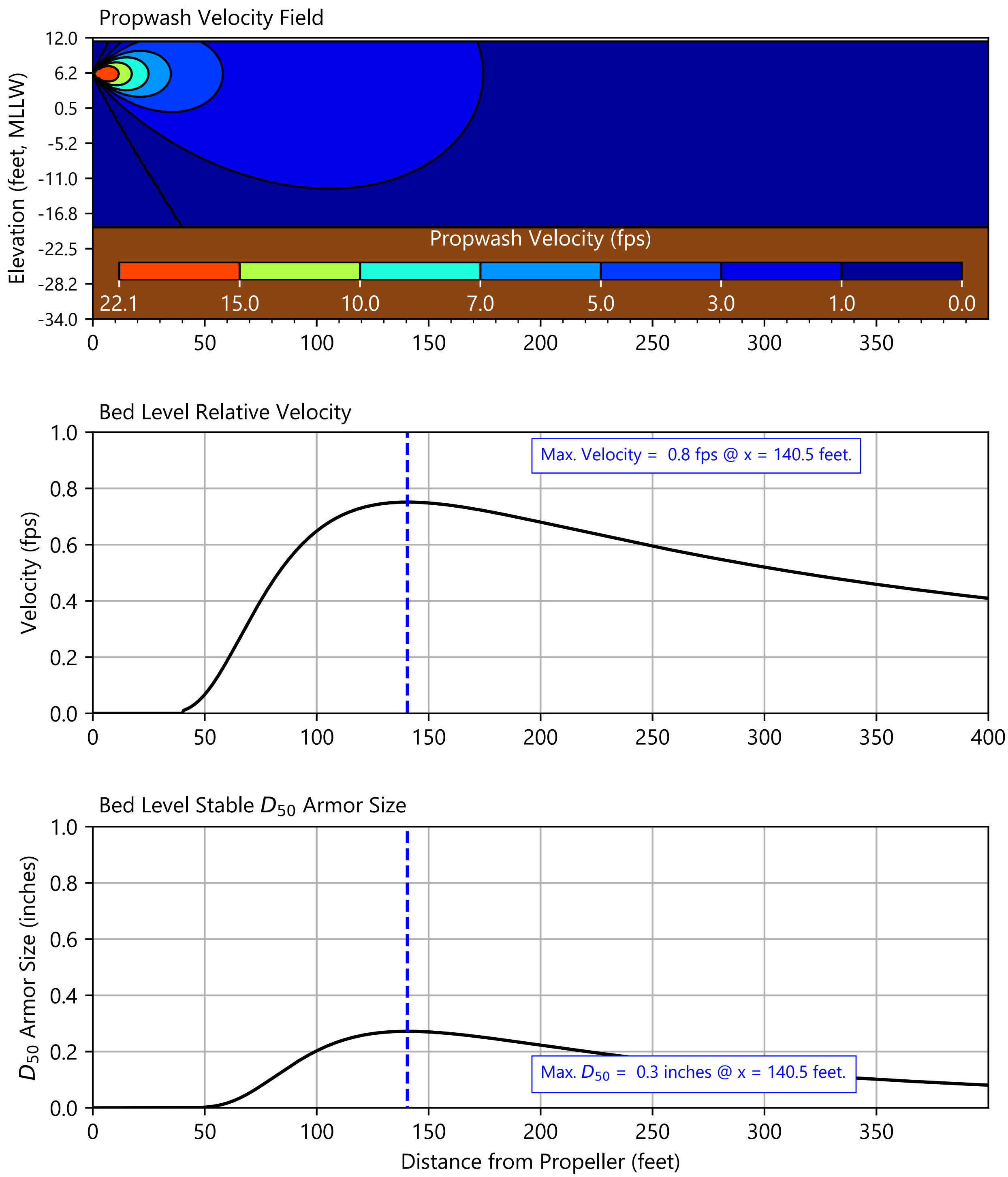
ANCHOR QEA

Figure J.1-2c
Westrac II Tug at 0 knots, using 15% Applied Power
Transect: RAA 14 15 16 at Plus 3 ft MLLW



Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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File Path: C:\Users\acannon\OneDrive - ANCHOR QEA\LDW Propwash\90 pct cap appendix update\LDW-Blaaw_and_Kaa_Propwash_Field_Analysis_v7_0_90pct.py

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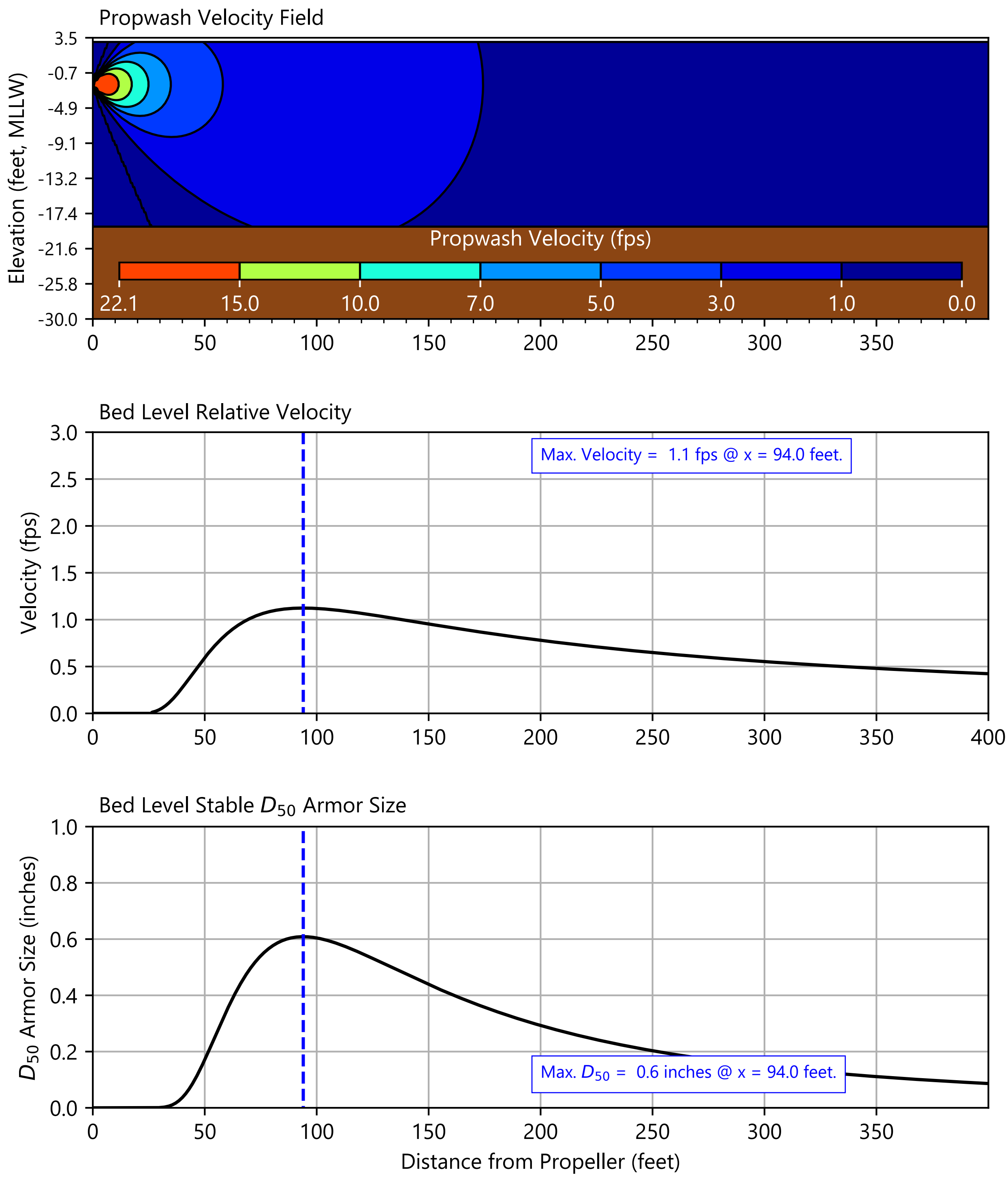
Figure J.1-3a
Arctic Pride Yacht at 0 knots, using 15% Applied Power
Transect: RAA 14 15 16 at MHHW



Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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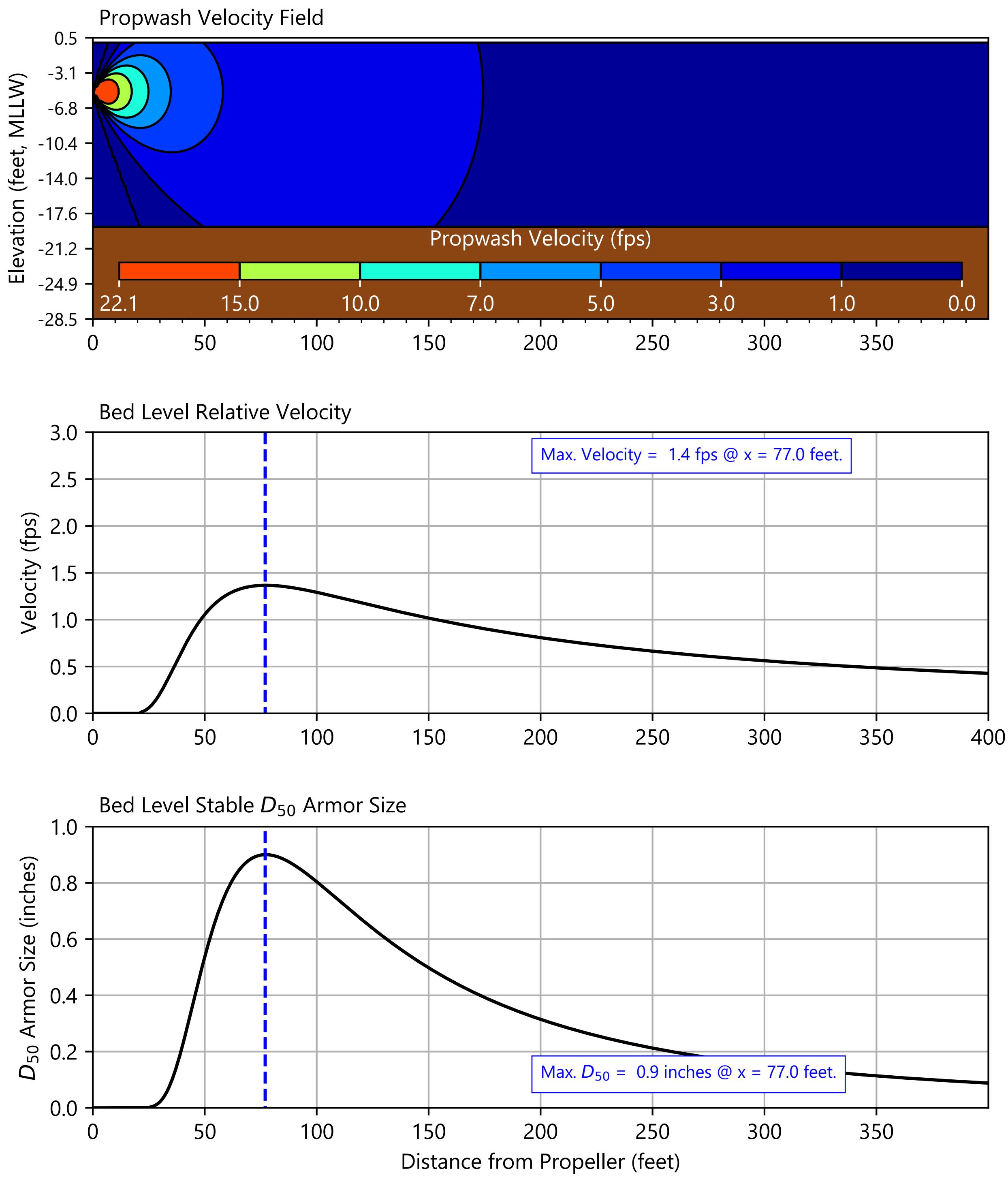
Figure J.1-3b
Arctic Pride Yacht at 0 knots, using 15% Applied Power
Transect: RAA 14 15 16 at Plus 3 ft MLLW



Notes:
While the navigation channel is expected to be -15 ft MLLW, the top of the cap will not be higher than -19 ft MLLW
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.70 for small sediment transport and/or infrequent attack.

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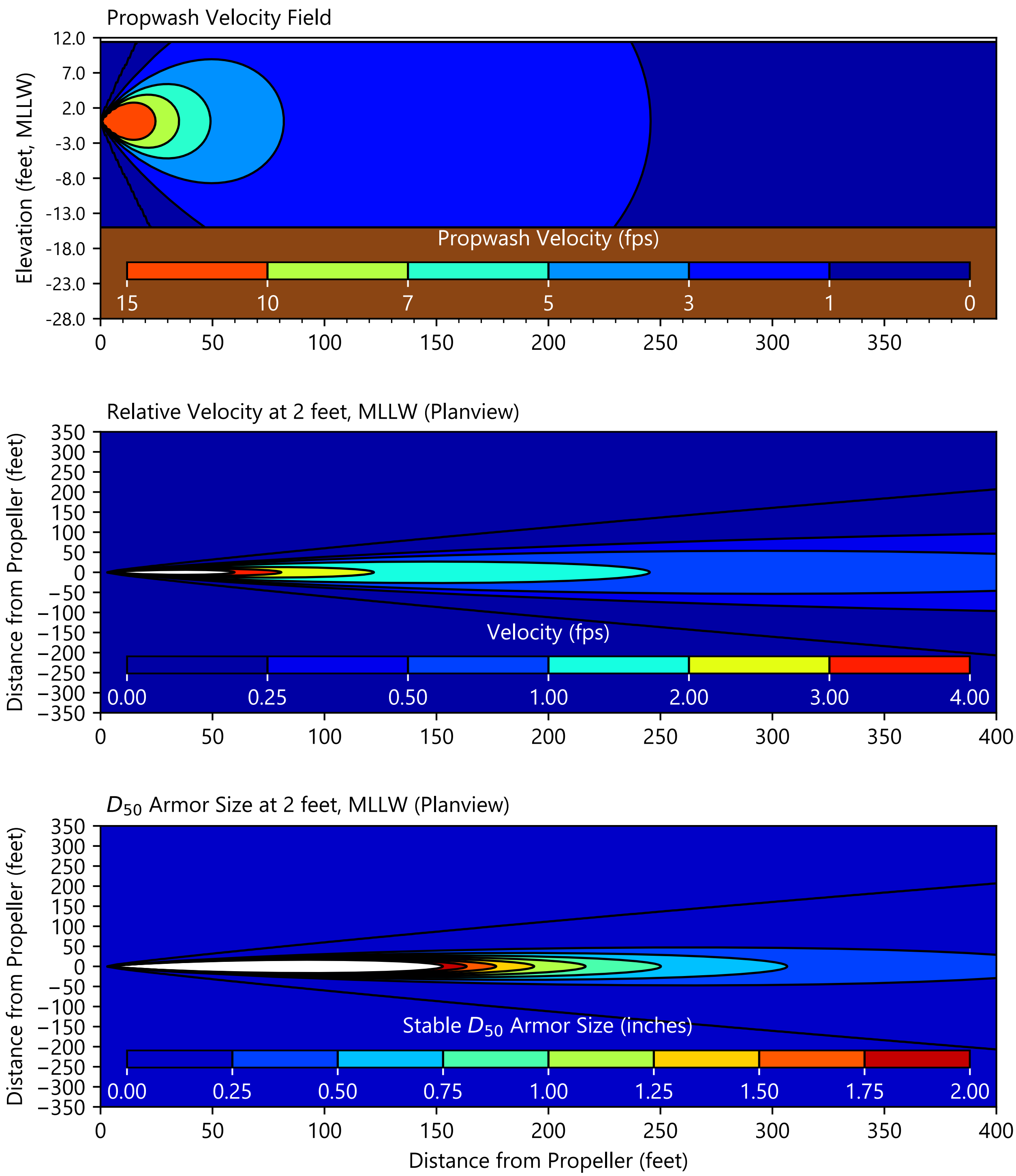
Figure J.1-3c
Arctic Pride Yacht at 0 knots, using 15% Applied Power
Transect: RAA 14 15 16 at MLLW



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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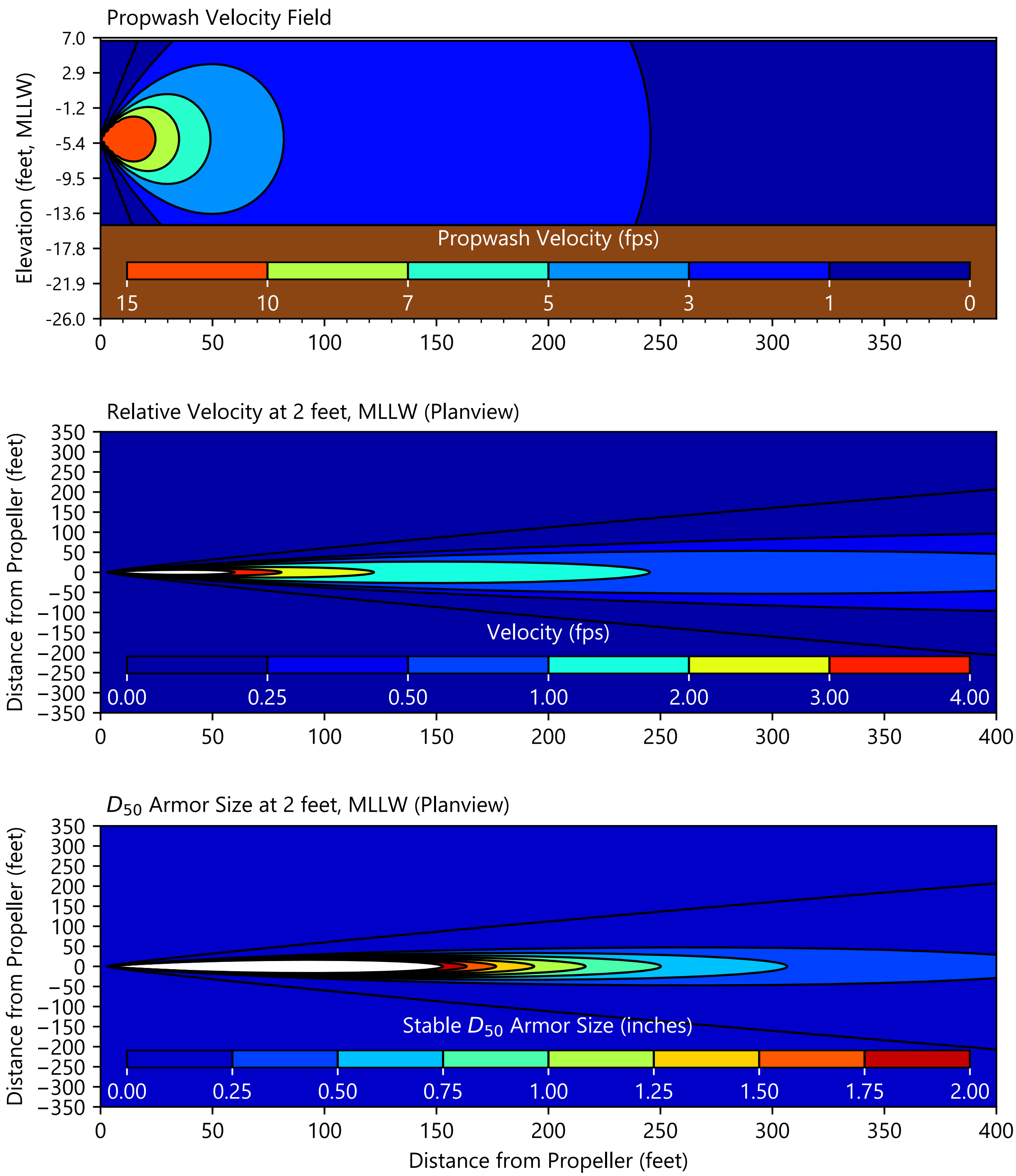
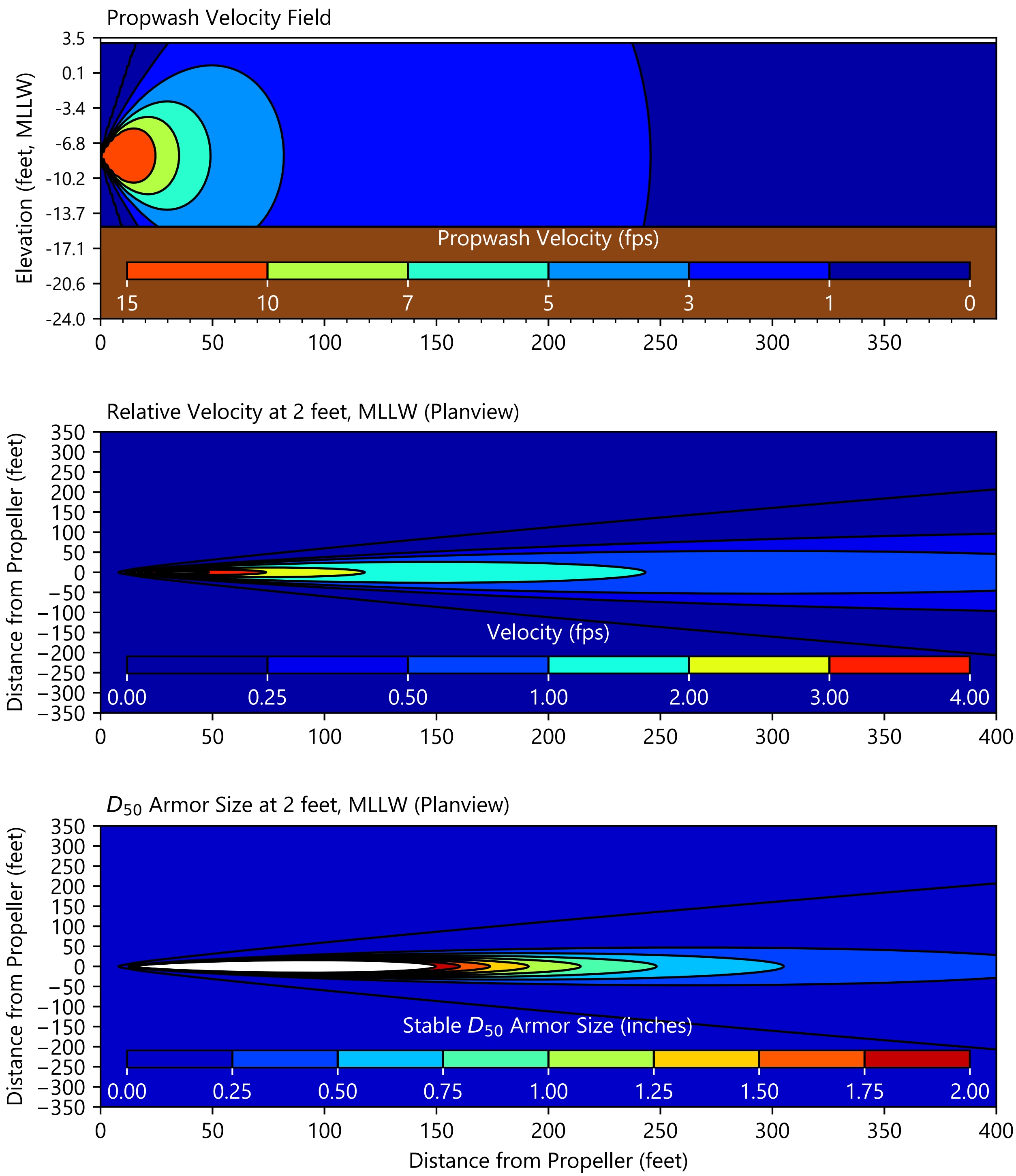
Figure J.1-4a
Capt Cae Tug at 0 knots, using 15% Applied Power
Transect: RAA 27 at MHHW



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

ANCHOR QEA

Figure J.1-4b
Capt Cae Tug at 0 knots, using 15% Applied Power
Transect: RAA 27 at MSL



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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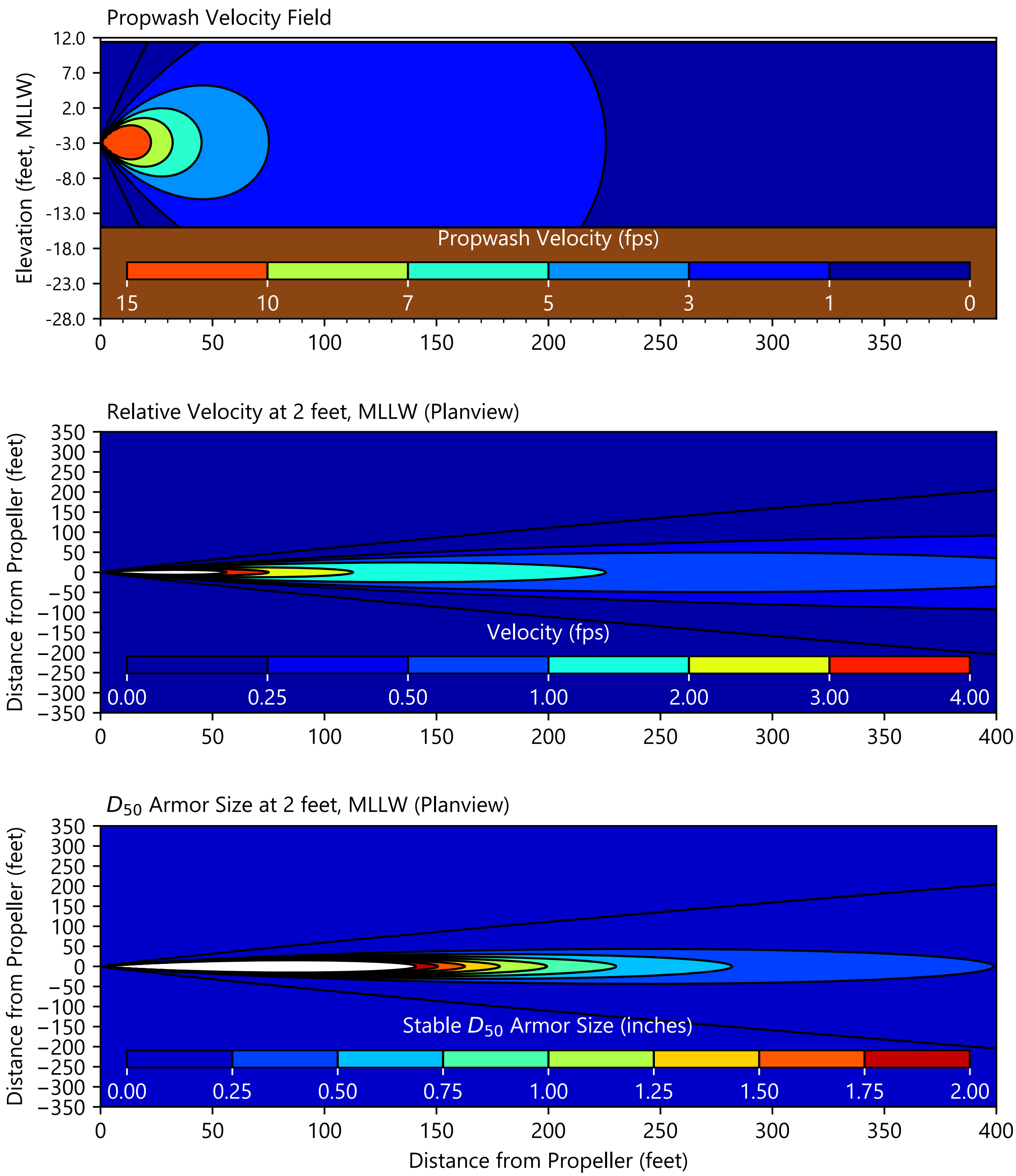
Figure J.1-4c
Capt Cae Tug at 0 knots, using 15% Applied Power
Transect: RAA 27 at Plus 3 ft MLLW



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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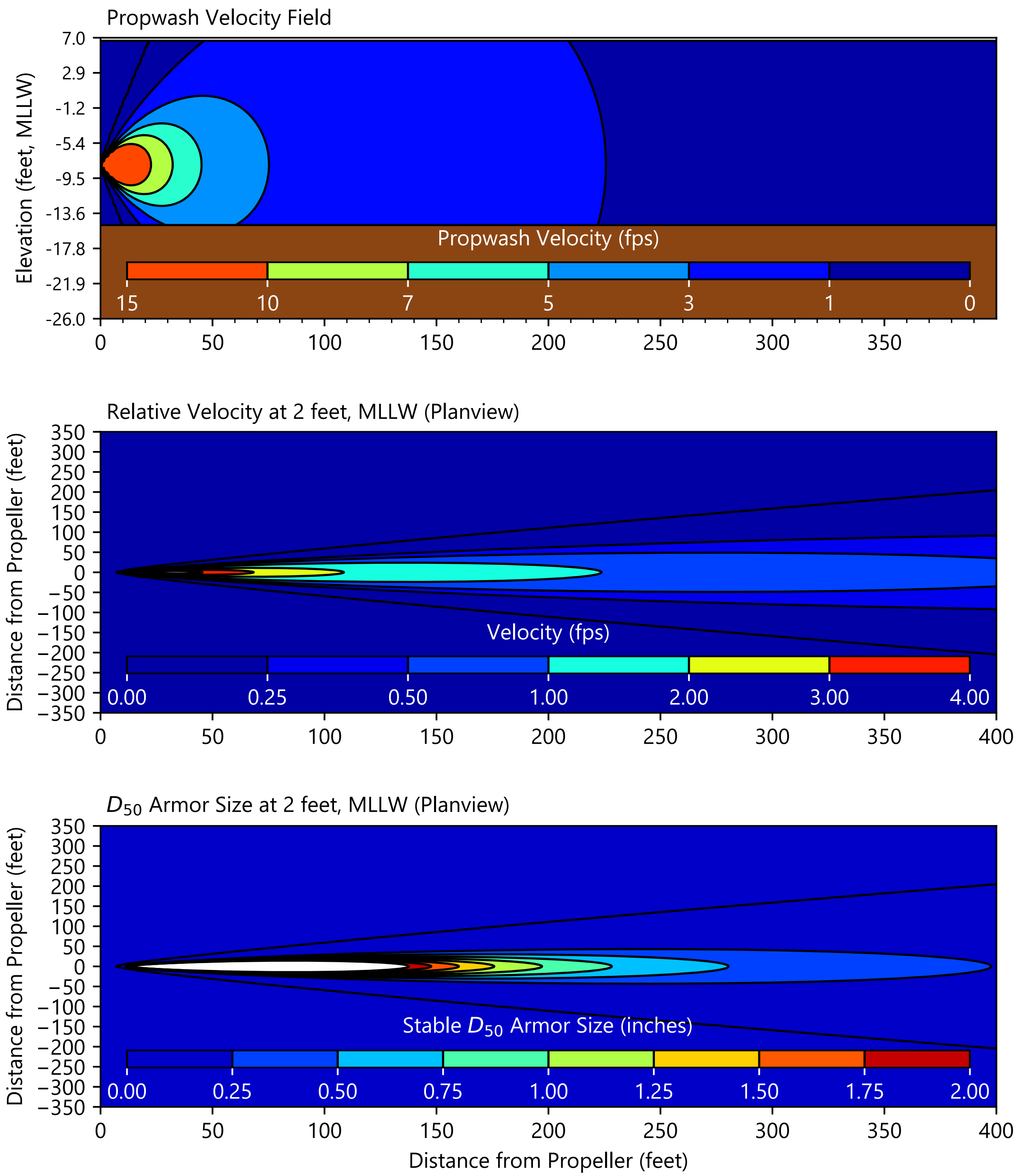
Figure J.1-5a
Westrac II Tug at 0 knots, using 15% Applied Power
Transect: RAA 27 at MHHW



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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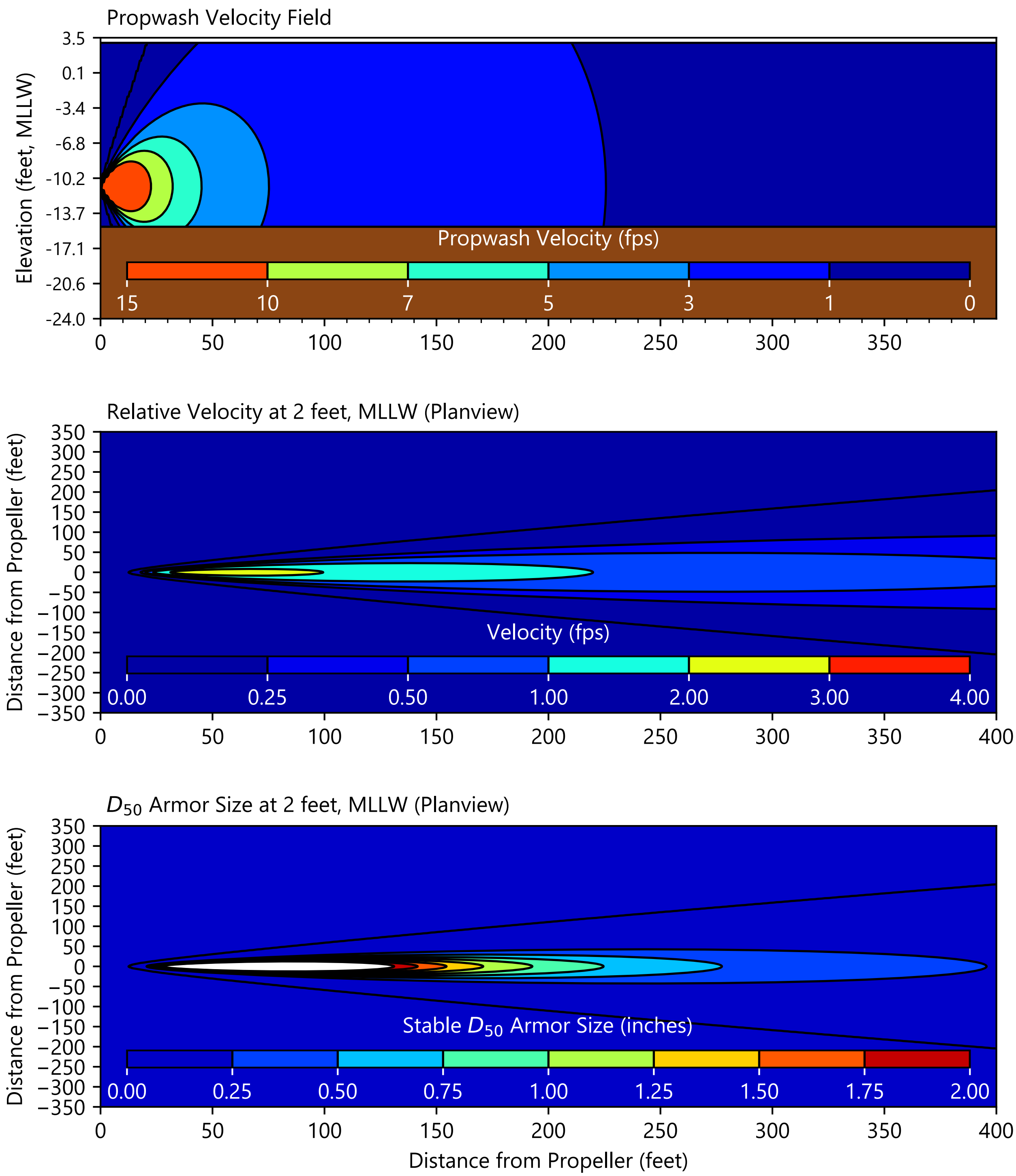
Figure J.1-5b
Westrac II Tug at 0 knots, using 15% Applied Power
Transect: RAA 27 at MSL



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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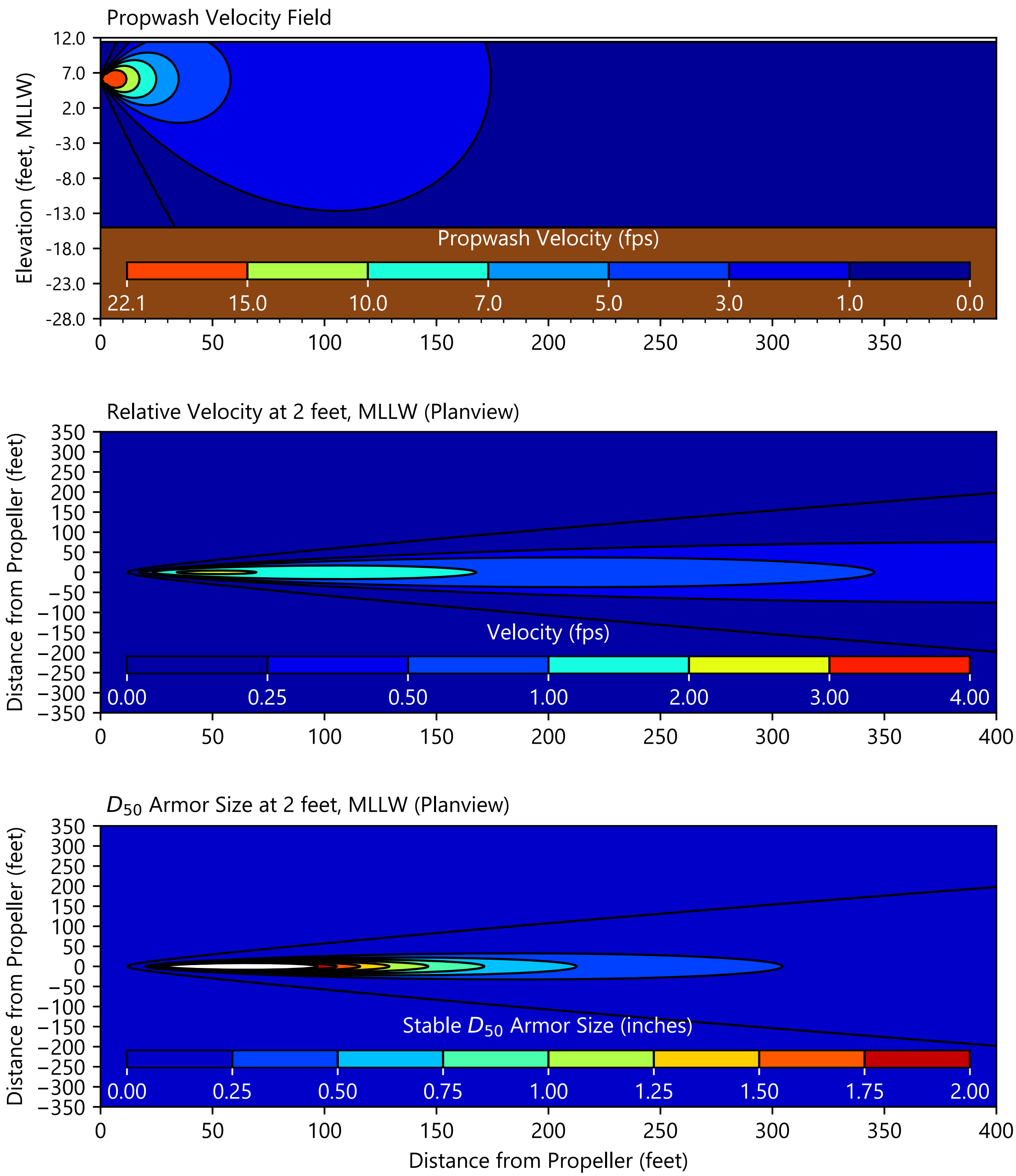
Figure J.1-5c
Westrac II Tug at 0 knots, using 15% Applied Power
Transect: RAA 27 at Plus 3 ft MLLW



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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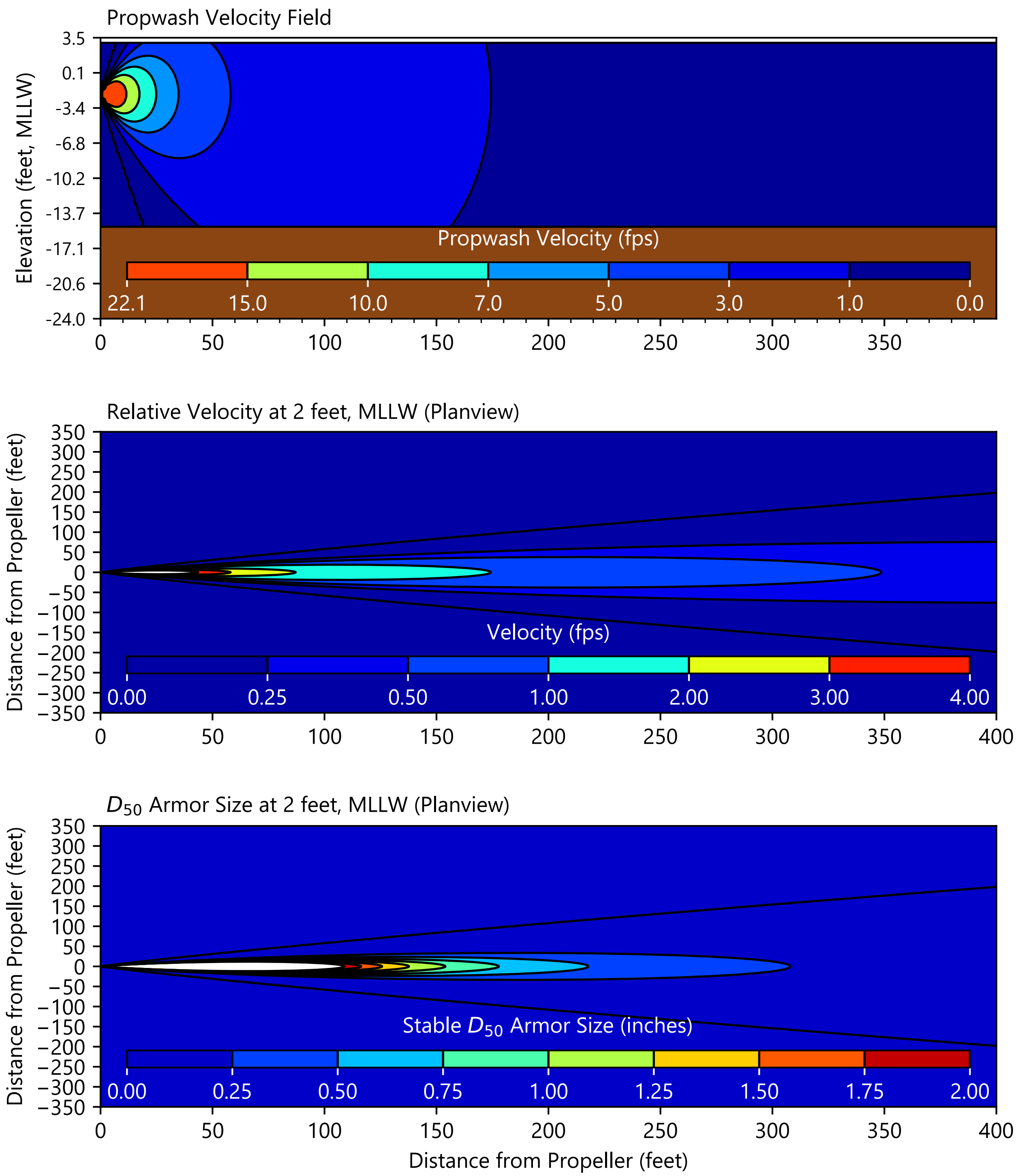
Figure J.1-6a
Arctic Pride Yacht at 0 knots, using 15% Applied Power
Transect: RAA 27 at MHHW



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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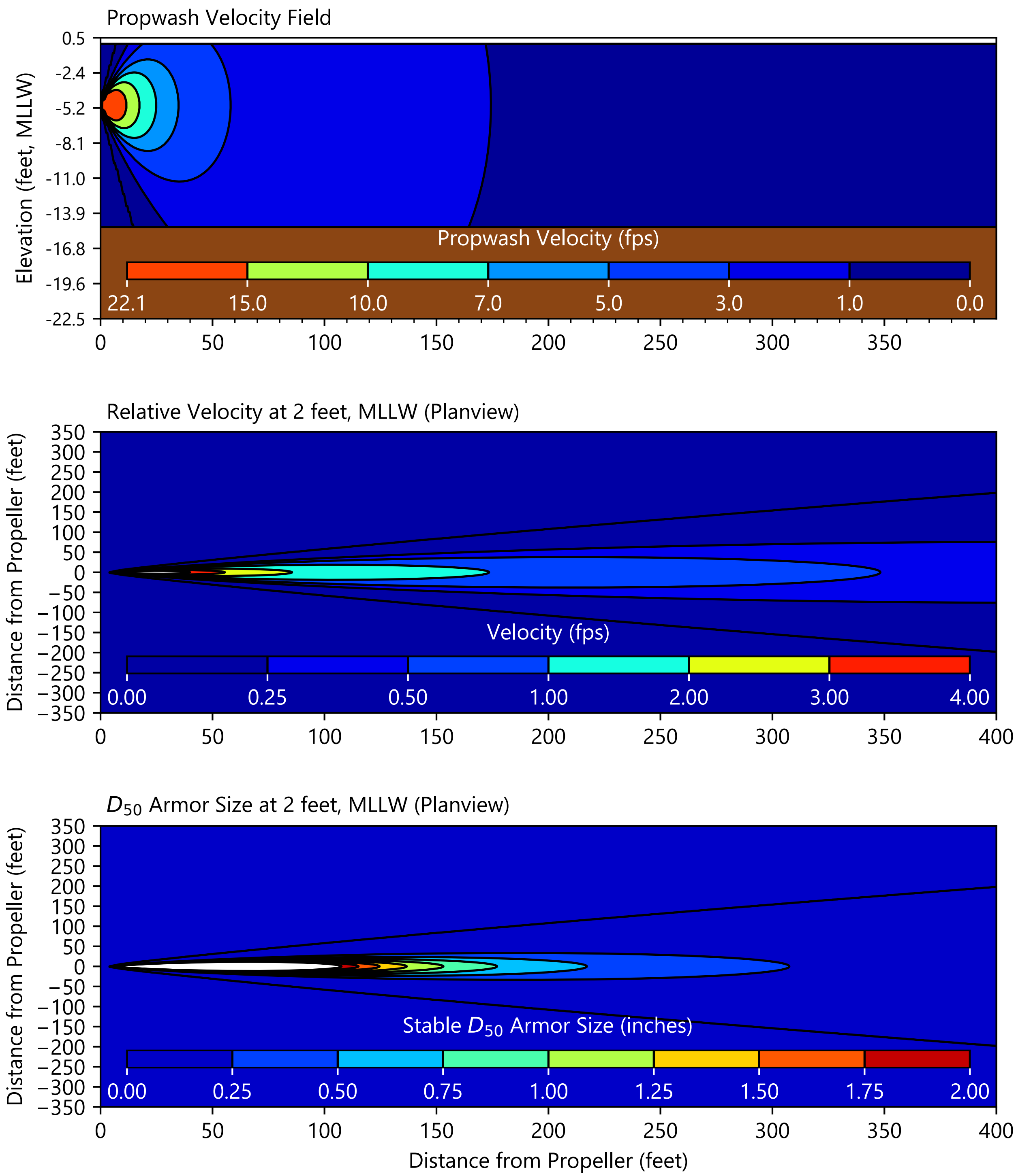
Figure J.1-6b
Arctic Pride Yacht at 0 knots, using 15% Applied Power
Transect: RAA 27 at Plus 3 ft MLLW



Notes:
The +2 ft MLLW elevation is approximately 250 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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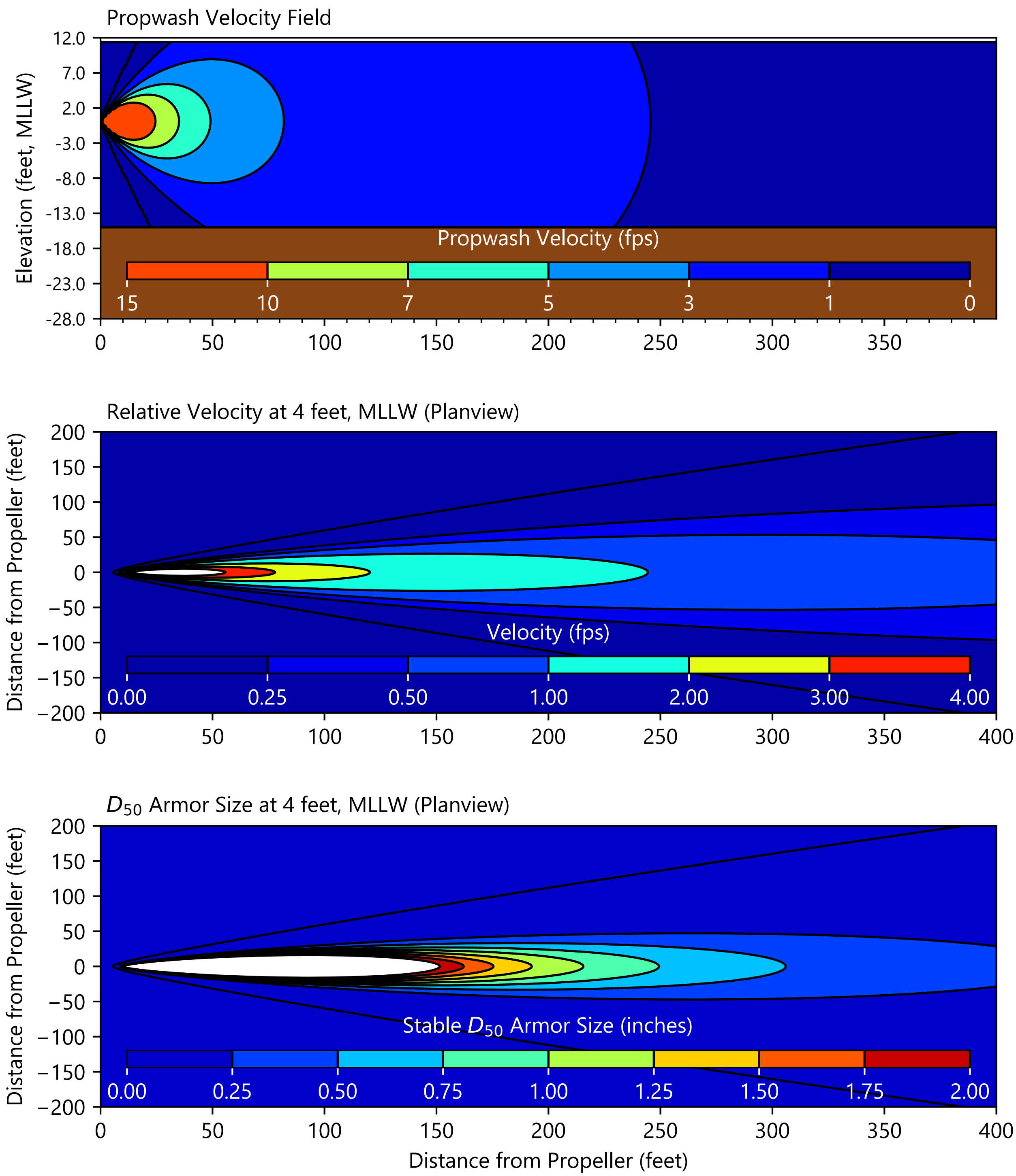
Figure J.1-6c
Arctic Pride Yacht at 0 knots, using 15% Applied Power
Transect: RAA 27 at MLLW

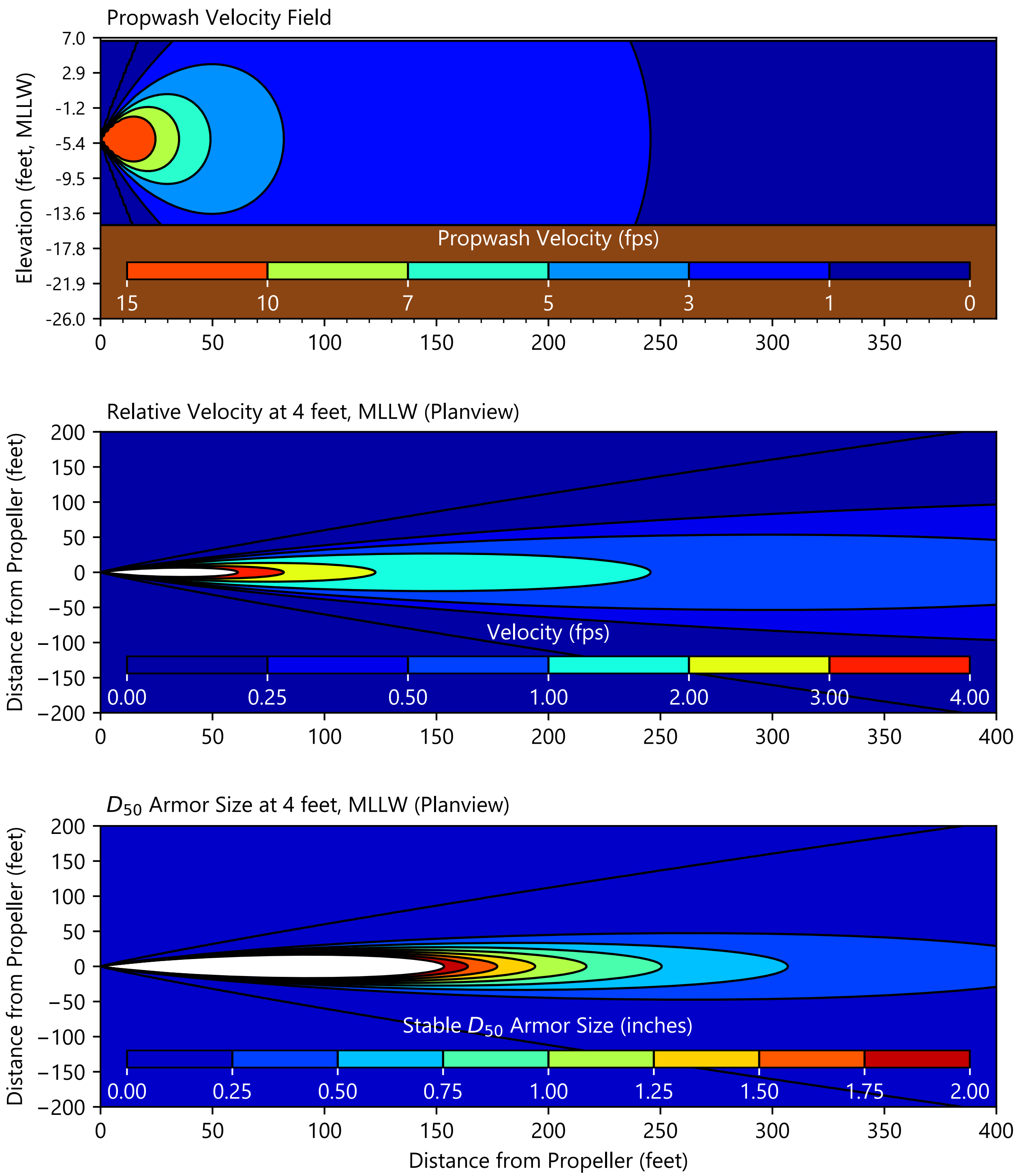
Appendix J – Engineered Protection Design Analysis for Engineered Caps and Area-Specific Technology

Attachment J.2
Bottom Velocity and Sediment Figures
(RAA 24/25/26)

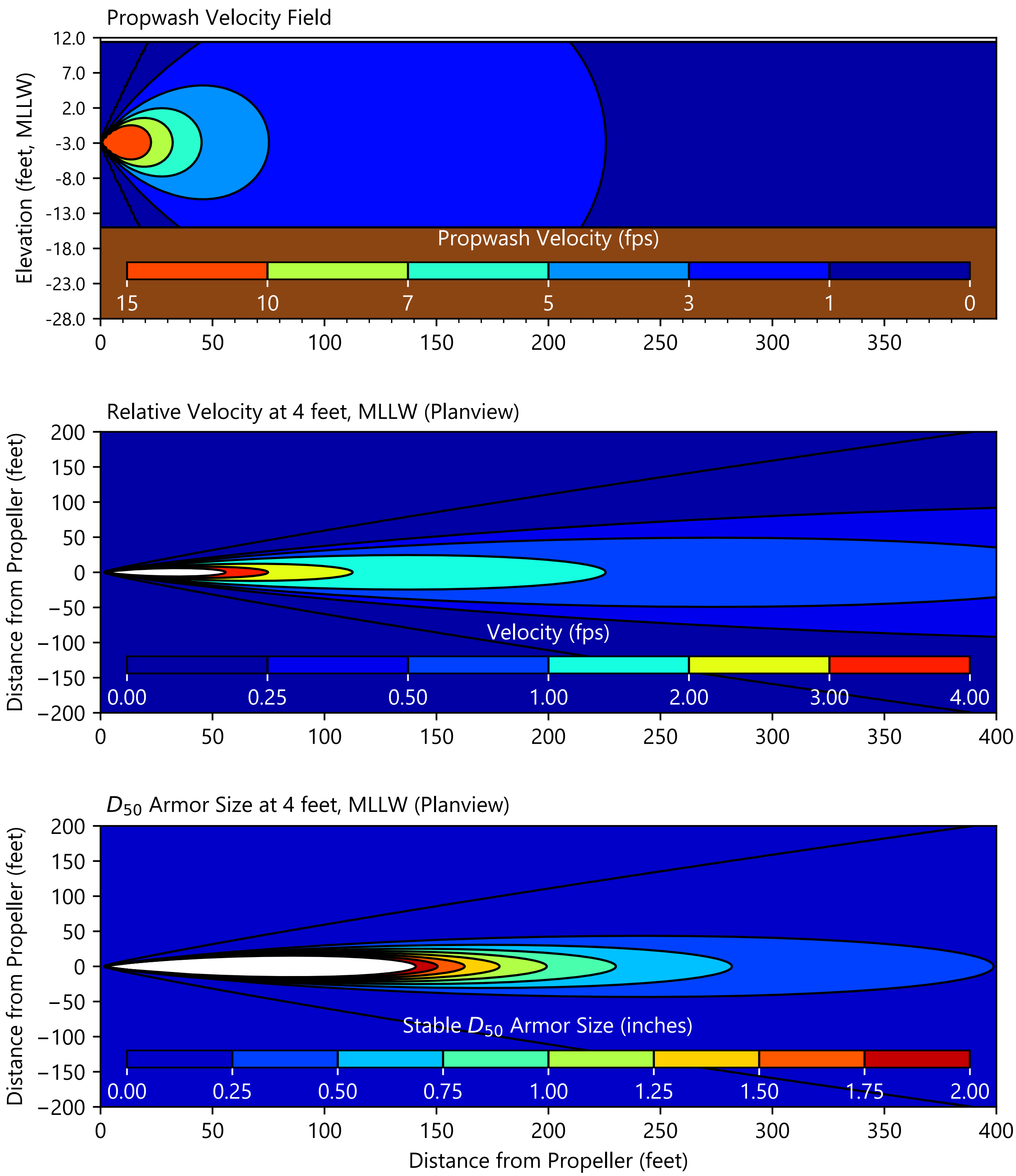


Notes:
The +4 ft MLLW elevation is approximately 140 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

Figure J.2-1a
Capt Cae Tug at 0 knots, using 15% Applied Power
Transect: Nav Channel at MHHW



Notes:
The +4 ft MLLW elevation is approximately 140 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.



Notes:
The +4 ft MLLW elevation is approximately 140 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

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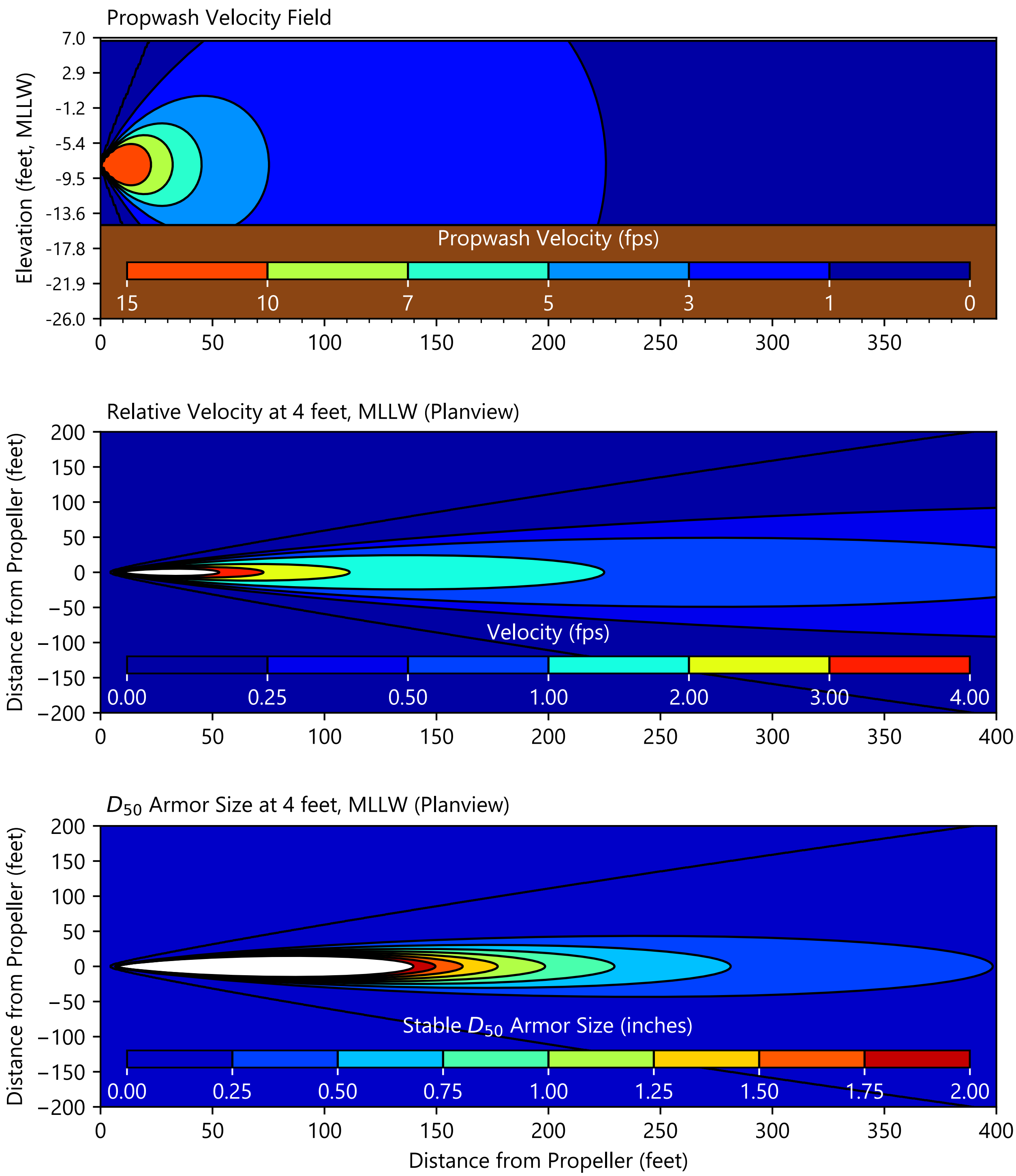
ANCHOR QEA

Figure J.2-2a
Westrac II Tug at 0 knots, using 15% Applied Power
Transect: Nav Channel at MHHW



Notes:
The +4 ft MLLW elevation is approximately 140 feet perpendicular to the sail line.
The propwash analysis is based on the Maynord 1998 capping methodology.
The C_3 coefficient = 0.55 for no sediment movement.

Figure J.2-2b
Westrac II Tug at 0 knots, using 15% Applied Power
Transect: Nav Channel at MSL