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DRAFT MEMORANDUM

To:	Linda Berry-Maraist, Pope Resources/Olympic Property Group	**Date:**	December 6, 2016
From:	Kathy Ketteridge, Ph.D., P.E., and John Laplante, P.E., Anchor QEA, LLC		
Cc:	Clay Patmont, Anchor QEA, LLC		
Re:	Port Gamble Bay Cleanup Project Coastal Engineering Evaluation of Shoreline Erosion		

The Port Gamble Bay Cleanup Project (Project) includes structure removal, excavation, and armored capping of shorelines at the former Mill Site (Site) located in Port Gamble, Washington. The 2 year construction project is currently underway, with the first season of in-water work being completed in February 2016. In March 2016, several significant wind events caused movement of relatively small areas of the shoreline armor rock. In addition to the observed armor movement, areas of the unarmored shorelines where structures were removed during Season 1 have eroded. Subsequent storm events in mid-October 2016 caused localized additional erosion of the unarmored shorelines.

This purpose of this memorandum is to summarize observations and evaluations of the movement of armor rock along the shoreline and erosion of unarmored shoreline areas at the Site that were the result of a series of significant storm events that occurred in March 2016 October 2016. This memorandum also presents design solutions to address erosion issues where necessary. As part of this discussion, wind statistics at the site were revised using updated wind data, which includes wind information through July 2016. This memorandum is divided into two sections: 1) Review of Storm Wind Conditions; and 2) Observed Armor Movement, Shoreline Erosion, and Mitigation Recommendations.

REVIEW OF STORM WIND CONDITIONS

In March 2016, two high wind storm events occurred throughout the Puget Sound area a few days apart, one on March 10 and one on March 13. In October 2016, another significant wind storm event occurred between October 13 and October 15, 2016. Sustained wind speeds during these storm events are available from a buoy owned and maintained by the

University of Washington (NOAA Station #46125) located in Hood Canal, 4 miles northwest of the Site. The height of the anemometer for that buoy is 2.1 meters above sea level. In order to compare the wind speeds measured at the buoy with wind statistics developed in the Port Gamble Bay Cleanup Project Engineering Design Report (Appendix D; Anchor QEA 2015), the buoy wind data were transposed to the equivalent wind speeds at 10 meters above sea level[1]. Wind and tide data for both storms are summarized in Table 1.

Table 1
Summary of Winds during March and October 2016 Storm Events

Date	High Tide Elevations at Port Townsend[1] (MLLW)	Sustained Winds[2]			Maximum Winds[2]		
		Wind Speed (mph)	Wind Duration (hours)	Average Wind Direction	Wind Speed (mph)	Wind Direction	Time and Tide Elevation During Maximum Wind[1] (MLLW)
March 10, 2016	11.1 feet 9.7 feet	≥ 20	17	~140 degrees	46	~130	3:30 pm 7 feet
March 13 to 14, 2016	10.2 feet 9.1 feet	≥ 20	9	~140 degrees	48	~130	11:00 pm 6 feet
October 13 to 15, 2016	10.0 feet 7.1 feet	≥ 20	6	~140 degrees	36	~150	12:00pm 7 feet

Notes:
MLLW = mean lower low water
mph = miles per hour
1. Measured tide data from Port Townsend Station #9444900. Multiple high tides occurred over the duration of the storm event.
2. Wind speeds from NOAA Station #46125, transposed to 10 meters above sea level

To support the Engineering Design Report for the Project (Anchor QEA 2015), a coastal engineering evaluation was completed to evaluate extreme wind speeds and associated wave heights at the Site for use in cap armor design. Long-term wind data used for this evaluation was taken from NOAA station WPOW1 in West Point, Washington, and included hourly wind speeds (2 minute averages) for the years from 1984 to 2009. The West Point station was used for Port Gamble because it is the closest gage location that has a long-term hourly sustained wind speed record (32 years at 10 meters above sea level).

[1] 10 meters is the standard accepted height above the water surface where wind speeds are measured (or estimated) for use in wind-wave prediction. Data from the buoy (measured at 2.1 meters above sea level) was transposed to the equivalent wind speed at 10 meters above mean sea level using a logarithmic wind profile.

Based on the wind statistics shown in Table 2 (from Anchor QEA 2015), the March 10 and March 13 storms were 50-year and 100-year return period events, respectively. The October storm event was not as strong in terms of maximum wind speeds, and was somewhere between a 2-year and a 10-year storm event. In addition to being significant events, each storm event had an unusually long duration. The average duration of high wind events (wind speeds greater than approximately 20 miles per hour) from southerly directions is about 4 hours (Finlayson 2006). The March 10 and 13 storms had durations of 17 hours and 9 hours, respectively. The October storm had a duration of approximately 6 hours. Such a prolonged high wind event would have likely caused a local wind-setup along the Port Gamble shoreline, increasing the water level above the predicted tide height for some portion of the storm events.

Table 2
Return Period Wind Speeds for South-East Storm Directions[1]

Direction (degrees)	2-year (mph)	10-year (mph)	20-year (mph)	50-year (mph)	100-year (mph)
121-150	33	41	44	47	49

Notes:
mph = miles per hour
1. Return period wind speeds are from Table D1-2 from Anchor QEA 2015.

OBSERVED ARMOR MOVEMENT, SHORELINE EROSION, AND MITIGATION RECOMMENDATIONS

On separate occasions in June, July, and August 2016, Anchor QEA, LLC, staff conducted site visits at Port Gamble to observe shoreline conditions and discuss armor movement and shoreline erosion with Pope Resources and Washington Department of Ecology (Ecology) staff. Four areas of interest were identified along the Port Gamble shoreline, as shown in Figure 1. Areas 1 through 3 are areas where structures were removed during Season 1 demolition, but no armored cap was required. Shoreline erosion in these areas has resulted in damage to existing asphalt and/or erosion of bank material. Area 4 was capped with Type 2 armor rock material (d_{50} of 9 inches) during Season 1 in accordance with the Ecology-approved design. Observations in this area noted movement of Type 2 armor rock in the upper inner tidal area. The cap material in this area was sized to balance requirements

for protection of underlying isolation layer and habitat concerns. Therefore, material was sized to allow for some localized movement under the design storm event.

Area 1

Area 1 is located along the north-eastern corner of the Site (see Figure 1).

Observations

The shoreline erosion in this area occurred after creosote-treated piling were removed as part of Site remediation. The shoreline area above mean higher high water has eroded in this area, undermining asphalt paving at the top of the slope, as shown in Photograph 1. Figure 2e shows a pre- and post-storm survey transect that illustrates the erosion that has occurred at this location. In general, the slope of the beach in the upper intertidal area is adjusting to match the milder slope present in the lower intertidal area.

Photograph 1

Shoreline Erosion in Area 1

Recommendations

Design recommendations to address shoreline erosion in this area are shown in Figure 2e. These design recommendations are focused on preventing erosion of the entire slope from top of bank to the lower vertical extent of wave impact (where natural sediments could be eroded during storms). Damaged asphalt at the top of the slope will be removed and the shoreline armored from the top of the bank down to elevation of -5 feet mean lower low water, which is consistent with armoring extent designed for adjacent capping areas (see Port Gamble EDR, Appendix D). The armor will extend horizontally from the existing armored slope to the south of Area 1 (Area 2A) to the west to cover the entire pocket beach area. Armor will consist of a layer of Type 3 material covered with large salvaged armor rock.

Area 2A (work completed)

Area 2A is located along the eastern shoreline that faces the inlet into Port Gamble Bay (see Figure 1), which is armored with large rip rap with asphalt paving along the top of the bank.

Observations

Similar to Area 1, asphalt at the top of the slope was damaged due to wave runup and overtopping, as shown in Photograph 2, which occurred after the structure in this area (the former Eastern Wharf) was removed. Figure 2d shows a pre- and post-storm survey transect that shows no movement of the armor rock on the slope occurred as a result of the storm events.

Photograph 2

Shoreline Erosion in Area 2

Recommendations

The following recommendations to address shoreline erosion (shown in Figure 2d) were carried out prior to publication of this memorandum:

- Damaged asphalt at the top of the armored slope was removed
- Armor rock at the top of the slope was left in place
- The area where asphalt was removed was armored from the top of the remaining armor rock on the slope to the top of the bank
- Placed armor consisted of a layer approximately 1 foot thick of Type 3 material covered with large salvaged armor rock (varied in size from 1 to 3 feet in diameter).

The work described above was completed on August 12, 2016. The completed stabilization work is shown in Photograph 3.

Photograph 3

Completed Shoreline Repair in Area 2

Area 2B

Area 2B is located to the east of the temporary transload facility. Similar to Area 2A, structures and piling were removed from this area as part of demolition for Site remediation. This area is presently armored from about mid-slope down into the water, but does not have any armoring at the upper portion of the slope. This area is the only site that sustained damage due to the October 2016 storm event.

Observations

Erosion of the area during the October storm event was focused along the top of the bank and upper portions of the slope due to a lack of armoring in those areas, as shown in Photograph 4. Photograph 5 shows an image of this area following the October 2016 storm, which illustrates erosion of the top portion of the slope and bank line. Similar to other areas of erosion, the upper shoreline has eroded back to a milder slope to match the existing slope in the lower intertidal area.

Photograph 4

Shoreline Area 2B Prior to October 2016 storm event

Photograph 5

Shoreline Area 2B Following to October 2016 storm event

Recommendations

Recommendations to address erosion in Area 2B (as shown in Photograph 5) should be in-line with slope armoring suggested at Area 2A, which has already been completed:

- Damaged asphalt at the top of the armored slope should be removed
- The bank should be armored from mid-slope where armor currently exists to the top of bank (upper extent of armoring in adjacent area as shown in Photograph 5).
- Placed armor should consist of Type 3 material covered with large salvaged armor rock

Area 3

Area 3 is located between the temporary transload facility and the eastern end of the Type 2 intertidal cap in SMA-2. Structures and piling were removed from this area as part of demolition for Site remediation, and this area is not presently armored.

Observations

Erosion of the area during this storm event was intensified due to the two adjacent armored areas, as seen in Photograph 4. Figure 2c shows a pre- and post-storm survey transect that shows the shoreline erosion in this area. Similarly to Area 1, the upper shoreline has eroded back to a milder slope to match the existing slope in the lower intertidal area.

Photograph 4

Shoreline Erosion in Area 3

Recommendations

Design recommendations to address shoreline erosion in this area are shown in Figure 2c. These design recommendations are focused on preventing erosion of the entire slope from top of bank to the lower vertical extent of wave impact (where natural sediments could be eroded during stomrs). The shoreline in this area will be armored between the end of the

Type 2 cap area and the armored shoreline at the location of the temporary transload area. Armor will consist of a layer of Type 3 material covered with large salvaged armor rock. The armor will extend from the top of the bank down to elevation of -5 feet feet mean lower low water, which is consistent with armoring extent designed for adjacent capping areas (see Port Gamble EDR, Appendix D).

Areas 4 and 5

Areas 4 and 5 are located west of Pier 4, on the south-facing upper intertidal shoreline of SMA-2 as shown in Figure 1.

Observations

The upper intertidal shoreline in Areas 4 and 5 were capped with Type 2 armor rock. Some of the armor rock was displaced in the upper inner tidal zone due to wave impact from the storm events. As stated previously, localized movement of armor rock can occur during a design storm event; this design decision allows for a balance of using a more habitat-friendly armor rock size while still ensuring the protectiveness of the remedy. Specifically, the armor was sized to allow for "start of damage," or movement of some armor rock but not failure of the slope (USACE, 2002). The March 13 storm, as documented in Section 1, was up to a 100-year storm event based on wind velocity data, which was the design storm event for the slope. In addition, the high winds that occurred during that storm event lasted for approximately 32 hours, which is significantly longer than the typical design storm event in the Puget Sound area.

Figure 2b shows a survey transect within Area 4 that illustrates Type 2 rock movement where the majority of the design rock thickness was displaced. However, as seen in Photograph 5, the extent of this level of damage is small, affecting approximately 20 to 30 feet of shoreline.

Figure 2a shows a survey transect in Area 5 that illustrates more typical and expected movement of rock on the slope; this area still has acceptable coverage of armor rock over the filter material.

Photograph 5

Shoreline Erosion in Area 4

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Recommendations

No work is proposed along the majority of the upper shoreline in SMA-2, as characterized by Area 5.

Design recommendations to address movement of the Type 2 cap material localized within Area 4 include adding additional armor rock larger than the Type 2 rock previously placed in that area. As mentioned above, Type 2 rock was sized using design wave conditions (See Port Gamble EDR, Appendix D) assuming movement of some armor rock during the design

storm event (100-year return period) but not failure of the slope (USACE, 2002). Ecology has expressed concerns about this area, and would prefer a more conservative armoring solution for this area. Therefore, a larger armor rock has been sized for placement in Area 4 assuming a "zero damage" factor as opposed to the "start of damage" factor used in the previous calculations to balance stability and habitat goals for the project. Using the same design significant wave height (2.7 feet) the armor rock size assuming "zero damage" (or no movement of the rock at all) is 1.5 feet. Based on this, Anchor QEA recommends placing two-layers of 1 to 1.5 foot rock within Area 4 where significant movement has occurred (the approximate extent of this damage is shown in Figure 1).

CLIMATE CHANGE CONSIDERATIONS

Two considerations related to climate change are applicable to the design of shoreline cap design at Port Gamble, which are discussed in more detail below:

1. Sea level rise
2. Increase in storm wind speeds and/or frequency

Sea Level Rise

The study conducted by National Research Council in 2002 (NRC, 2012) entitled "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future" provides predictions for sea level rise in the Puget Sound region through 2100 and is accepted as the best available estimates of sea level rise for the area[2]. The study provides ranges for sea level rise in the Puget Sound region at several time points into the future.

As illustrated by the ranges of sea level rise predictions provided by the NRC (2012) study, there is a great deal of uncertainty in long-term predictions of sea level rise and the amount of sea level rise that will be realized at Port Gamble Bay over the long term is unknown.

The current (2016) mean higher high water (MHHW) elevation is 10.2 feet relative to mean lower low water (MLLW) from NOAA station 9445016 (Anchor QEA, 2015). King (extreme) tide elevations can reach up to 11.5 feet MLLW, based on review of tidal predications for the same tidal station over a typical year. Using median values for predicted sea level rise for

[2] For example, this study is referenced by Washington Department of Ecology and USACE, Seattle District.

2050, future MHHW elevations could be 11.0 feet MLLW[3]. The elevation of the majority of the upland areas at Port Gamble along the shoreline ranges from 15 to 16 feet MLLW.

If sea levels rise based on current predictions, the location of the surf zone may move landward and there could be increased wave runup and overtopping at the top of bank. As the surf zone moves landward, shear stress on the cap at lower intertidal elevations will be reduced. The potential of increased wave runup and overtopping has already been accounted for in the current design by armoring up to and over the top of bank along the shoreline at the site.

Increased Wind Speeds

Increased "storminess" when discussing coastal processes refers to two things: (1) increased wave heights in the open ocean and (2) changes to wind speeds in the local project area. Port Gamble is not exposed to waves from the Pacific Ocean, and therefore increased "storminess" at the Port Gamble site is limited to consideration of changes to wind speeds in the local area.

While there is general agreement in literature that "storminess" associated with precipitation (i.e. snowfall vs. rain) in the Pacific Northwest (PNW) will likely undergo significant changes due to climate change over the next 50 to 100 years (USGCRP, 2014) there is not as much discussion in literature about changes to wind speeds in the PNW. The effect of climate change on local storm winds is important because if winds increase in the future this would increase locally generated wave heights as well.

An academic study conducted by several researchers at the Climate Impacts Group at the University of Washington evaluated potential changes to wind speeds and frequencies, as well as frequency of lightening, in the PNW (Salathé, et. al. 2015). The study conducted multiple climate model simulations and found (1) "no statistically significant change in the frequency of heavy[4] surface winds" and (2) "no consistent trend toward more extreme wind storms over western Washington in future climate projections." The researches also noted that their results concerning future wind speeds and frequencies does "not conflict with other studies showing more heavy precipitation in future storms. First, heavy precipitation is

[3] Relative to mean lower low water elevation in 2016.
[4] "Heavy" here refers to storm winds.

associated with a different weather pattern (atmospheric rivers) than high wind events. Second, thermodynamic effects associated with warming are sufficient to drive increases in precipitation absent changes in the dynamics of future storms."

Based on the results of this study, we do not anticipate climate change to have significant impacts to storm winds (and therefore storm waves) locally generated in Port Gamble Bay.

REFERENCES

Anchor QEA, 2015. Engineering Design Report, Port Gamble Bay Cleanup Project.

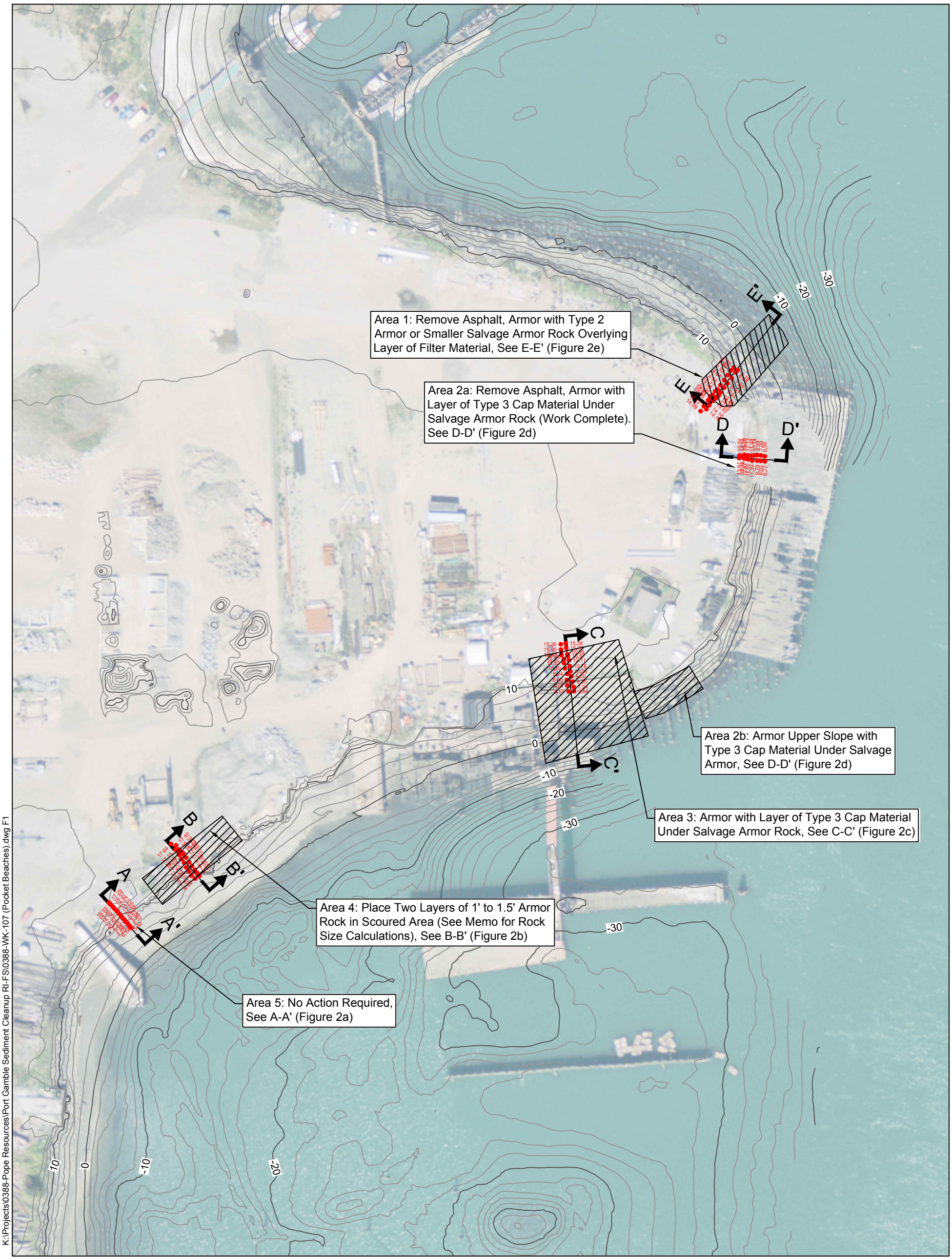
Finlayson, D., 2006. The Geomorphology of Puget Sound Beaches. Technical Report 2006-02. Prepared in support of the Puget Sound Nearshore Partnership. Seattle, Washington: Washington Sea Grant Program, University of Washington. October 2006.

National Research Council (NRC), 2002. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future (2012). NRC, Division on Earth and Life Sciences, Board on Earth Sciences and Resources, Ocean Studies Board. 2012.

Salathé, E.P. Jr., Mauger, G. S., Mass, C. F., Steed R., and B. Dotson. 2015. Final Project Report: Regional Modeling for Windstorms and Lightning. Report prepared for Seattle City Light by the Climate Impacts Group, University of Washington, Seattle.

USGCRP (2014) Mote, P., A. K. Snover, S. Capalbo, S. D. Eigenbrode, P. Glick, J. Littell, R. Raymondi, and S. Reeder, 2014: Ch. 21: Northwest. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 487-513

FIGURES



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Dec 05, 2016 9:25am chewett

SOURCE: Topography from Triad, dated 2012. Bathymetry from eTrac, dated August 17, 2016. Pocket beach sample locations from Orion, dated August 6, 2016.
HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

LEGEND:

Existing Contours (2' and 10' Interval)

Pocket Beach Sample Location and Elevation

0 100
Scale in Feet

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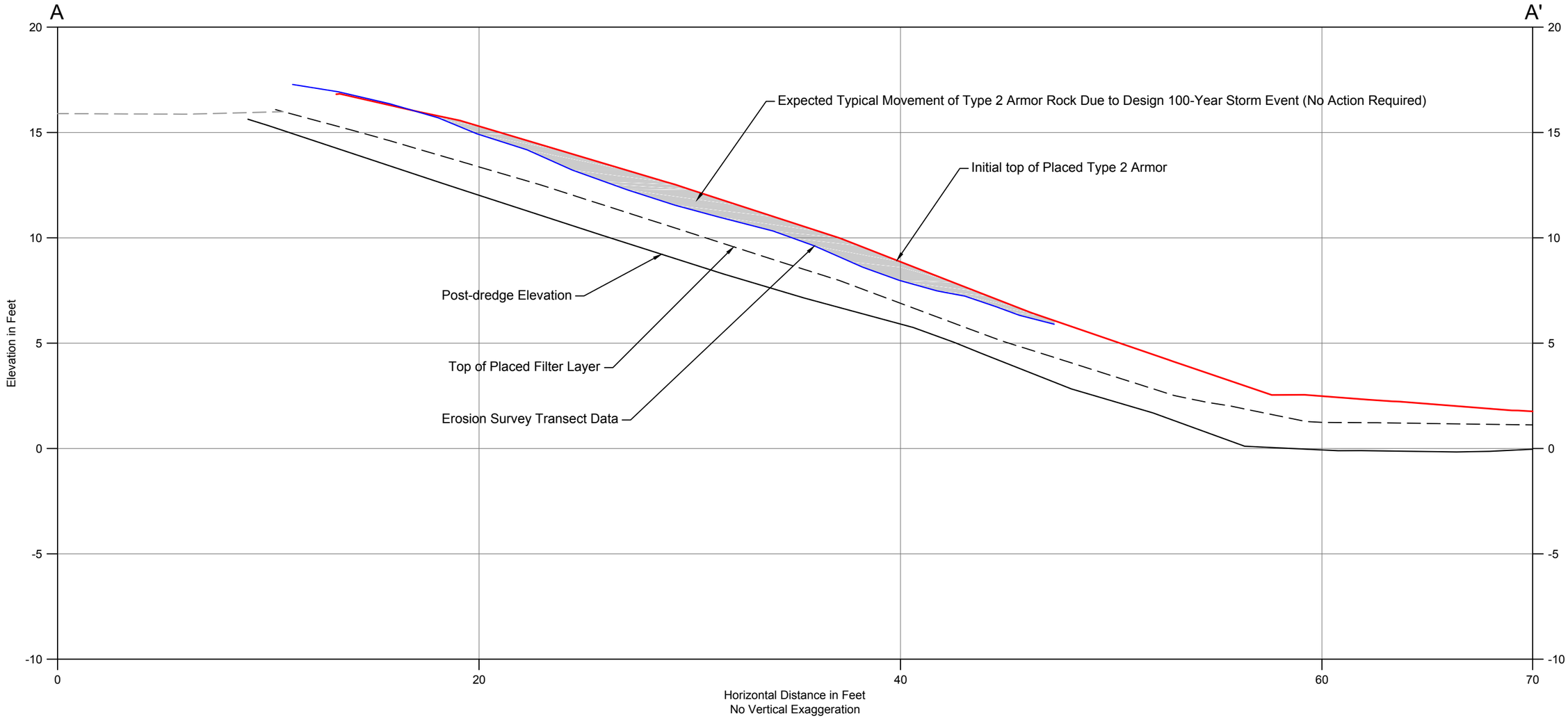
Figure 1
Location of Erosion Areas of Concern
Port Gamble Bay Cleanup Project



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Dec 05, 2016 9:25am chewett

SOURCE: Topography from Triad, dated 2012. Bathymetry from eTrac, dated August 17, 2016. Pocket beach sample locations from Orion, dated August 6, 2016.
HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

LEGEND:

- Existing Grade
- Season 1 Post-dredge Survey
- Season 1 Post-filter Placement Survey
- Season 1 Post-armor Placement Survey
- Erosion Survey Transect Data
- Typical Expected Movement of Type 2 Armor Rock (No Action Required)

0 5
Scale in Feet

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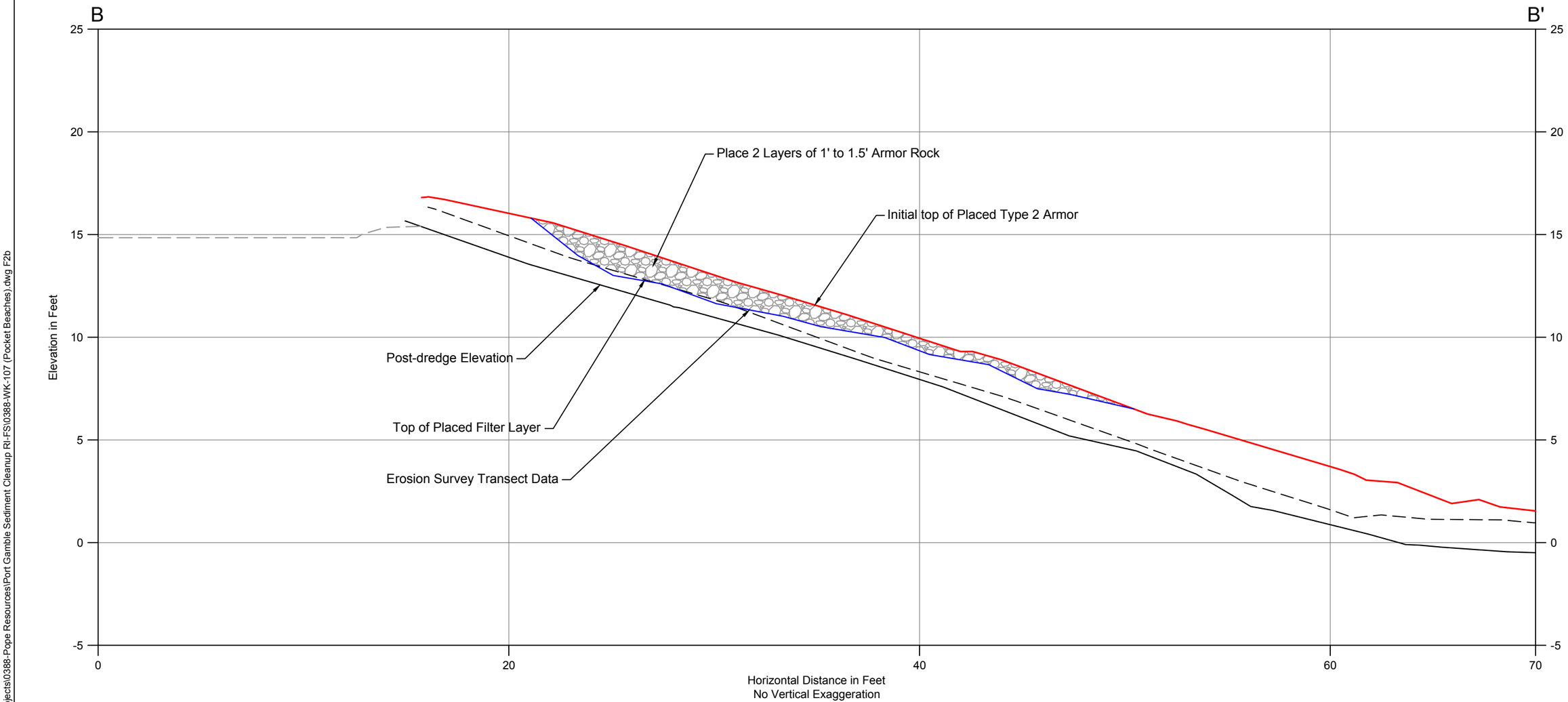
Figure 2a
Cross Section A-A'
Port Gamble Bay Cleanup Project



SOURCE: Topography from Triad, dated 2012. Bathymetry from eTrac, dated August 17, 2016. Pocket beach sample locations from Orion, dated August 6, 2016.
HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

LEGEND:

- Existing Grade
- Season 1 Post-dredge Survey
- Season 1 Post-filter Placement Survey
- Season 1 Post-armor Placement Survey
- Erosion Survey Transect Data
- Place Salvage Riprap

0 5
Scale in Feet

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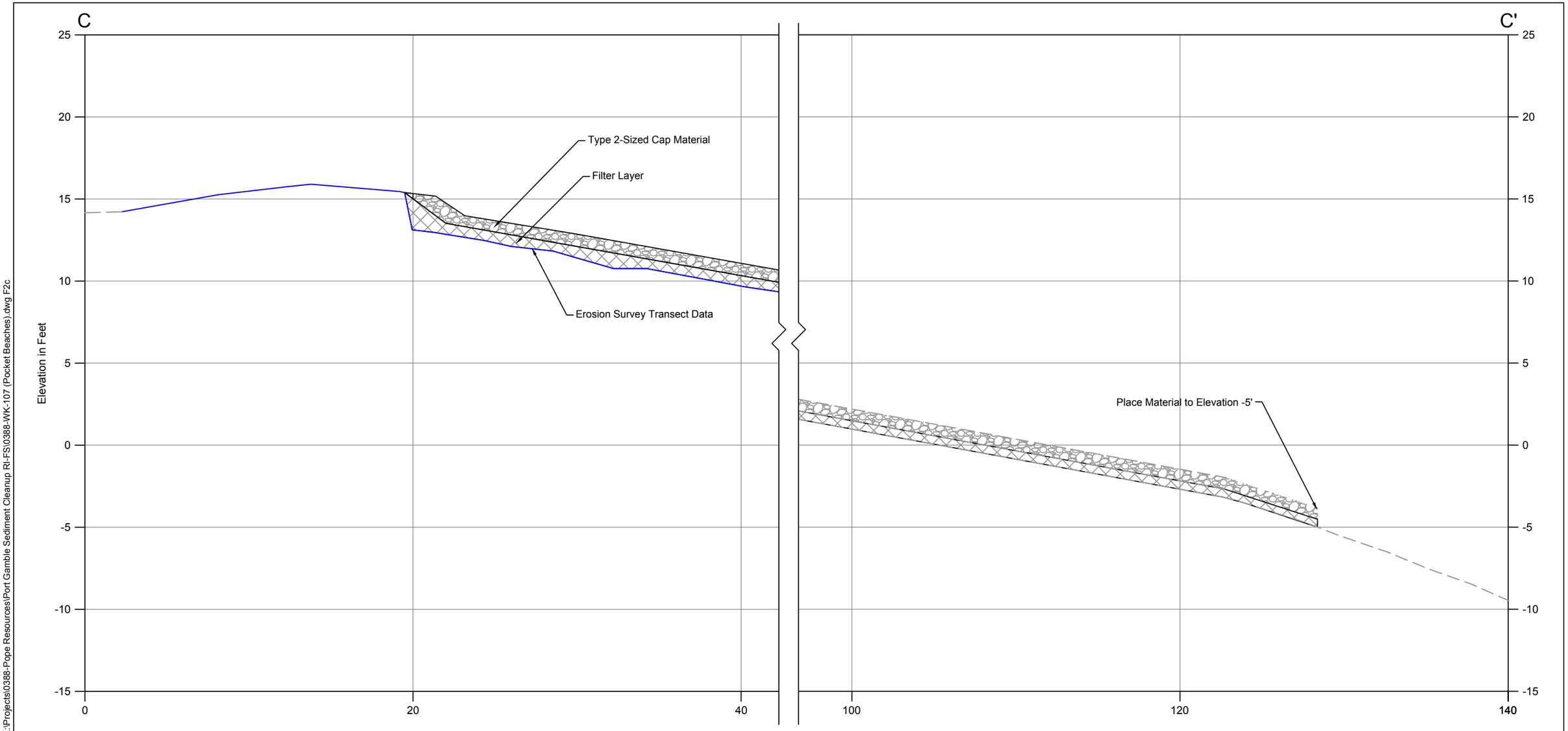
Figure 2b
Cross Section B-B'
Port Gamble Bay Cleanup Project



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Dec 05, 2016 9:25am chewett

SOURCE: Topography from Triad, dated 2012. Bathymetry from eTrac, dated August 17, 2016. Pocket beach sample locations from Orion, dated August 6, 2016.
HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

LEGEND:

- Existing Grade
- Erosion Survey Transect Data
- Place Salvage Riprap over Filter Material

0 6
Scale in Feet

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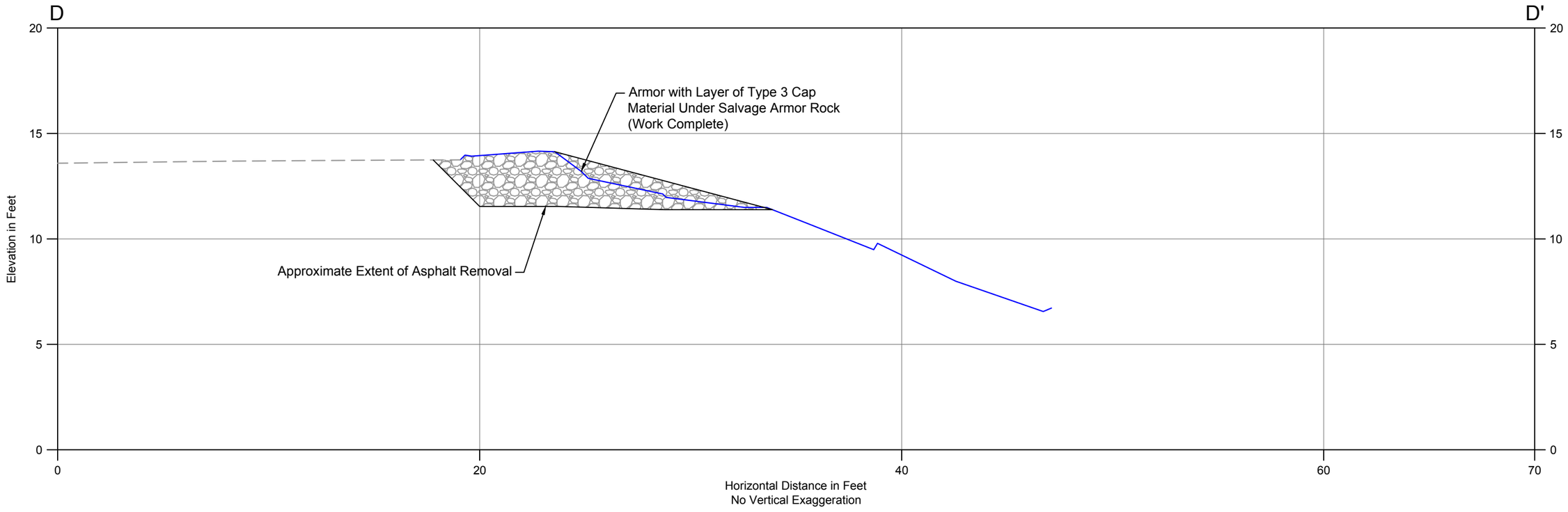
Figure 2c
Cross Section C-C'
Port Gamble Bay Cleanup Project



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Dec 05, 2016 9:25am chewett

SOURCE: Topography from Triad, dated 2012. Bathymetry from eTrac, dated August 17, 2016. Pocket beach sample locations from Orion, dated August 6, 2016.
HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet.
VERTICAL DATUM: Mean Lower Low Water (MLLW).
NOTE: Work shown has been completed.

LEGEND:

- Existing Grade
- Erosion Survey Transect Data
- Salvage Riprap over Type 3 Cap Material (Work Complete)

0 5
Scale in Feet

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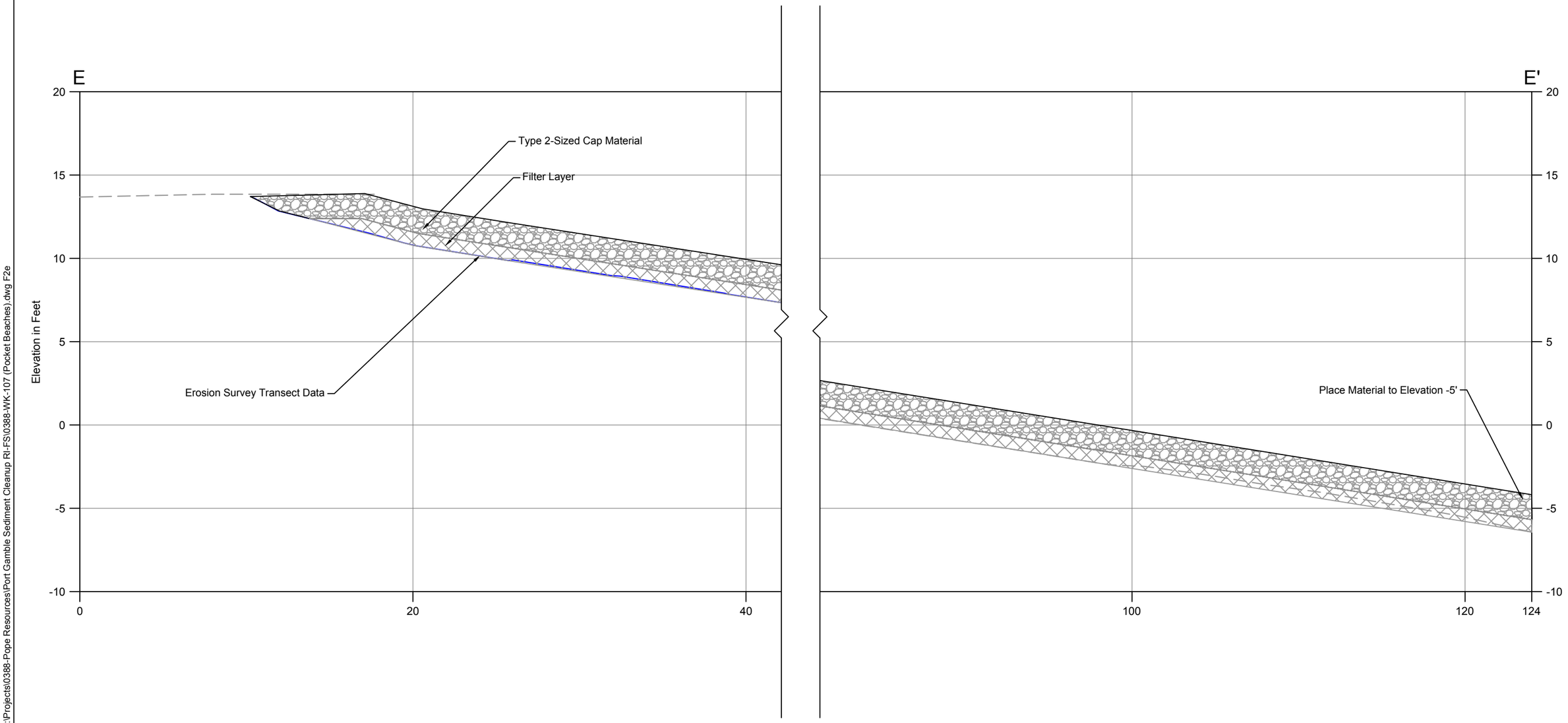
Figure 2d
Cross Section D-D'
Port Gamble Bay Cleanup Project



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SOURCE: Topography from Triad, dated 2012. Bathymetry from eTrac, dated August 17, 2016. Pocket beach sample locations from Orion, dated August 6, 2016.
HORIZONTAL DATUM: Washington State Plane North, NAD83, U.S. Feet.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

LEGEND:

- Existing Grade
- Erosion Survey Transect Data
- Place Salvage Riprap over Filter Material

0 5
Scale in Feet

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Figure 2e
Cross Section E-E'
Port Gamble Bay Cleanup Project